## Revision History
## 16Gb DDR4 AS4C1G16D4 - 96 ball FBGA PACKAGE

| Revision | Details | Date |
|---|---|---|
| Rev 1.0 | Initial Release | October 2022 |
| Rev 2.0 | Added Industrial Grade Part | August 2024 |

## Features

- $V_{DD} = V_{DDQ} = 1.2V \pm 60mV$
- $V_{PP} = 2.5V, -125mV, +250mV$
- On-die, internal, adjustable $V_{REFDQ}$ generation
- 1.2V pseudo open-drain I/O
- Refresh time of 8192-cycle at $T_C$ temperature range:
  - 64ms, at –40°C to 85°C
  - 32ms, at >85°C to 95°C
- 8 internal banks (x16): 2 groups of 4 banks each
- 8*n*-bit prefetch architecture
- Programmable data strobe preambles
- Data strobe preamble training
- Command/Address latency (CAL)
- Multipurpose register READ and WRITE capability
- Write leveling
- Self refresh mode
- Low-power auto self refresh (LPASR)
- Temperature controlled refresh (TCR)
- Fine granularity refresh
- Self refresh abort
- Maximum power saving
- Output driver calibration
- Nominal, park, and dynamic on-die termination (ODT)
- Data bus inversion (DBI) for data bus
- Command/Address (CA) parity
- Databus write cyclic redundancy check (CRC)
- Per-DRAM addressability
- Connectivity test
- JEDEC JESD-79-4 compliant
- sPPR and hPPR capability

## Options[1] / Marking

- Configuration
  - 1 Gig x 16 — 1G16
- 96-ball FBGA package (Pb-free) – x16
  - 9mm x 13mm
- Timing – cycle time
  - 0.625ns @ CL = 22 (DDR4-3200) — -062
- Operating temperature
  - Commercial ($0° \le T_C \le 95°C$)
  - Industrial ($-40° \le TC \le 95°C$)

### Ordering Information

| Product part No | Org | Temperature Tc | Max Clock (MHz) | Package |
|---|---|---|---|---|
| AS4C1G16D4-062BCN | 1G x 16 | Commercial 0°C to 95°C | 1600 | 96-ball FBGA |
| AS4C1G16D4-062BIN | 1G x 16 | Industrial -40°C to 95°C | 1600 | 96-ball FBGA |

### Table 1: Key Timing Parameters

| Speed Grade[1] | Data Rate (MT/s) | Target CL-*n*RCD-*n*RP | $^tAA$ (ns) | $^tRCD$ (ns) | $^tRP$ (ns) |
|---|---|---|---|---|---|
| -062 | 3200 | 22-22-22 | 13.75 | 13.75 | 13.75 |

Note: 1. Refer to the Speed Bin Tables for additional details.

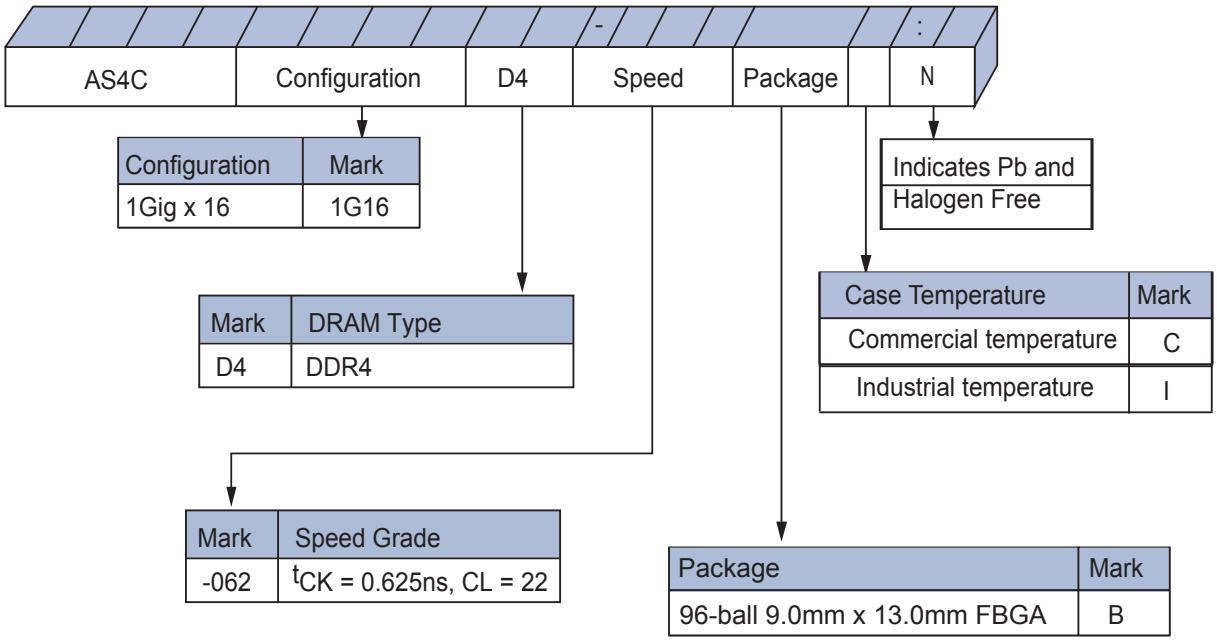
**Table 2: Addressing**

| Parameter | 1024 Meg x 16 |
|---|---|
| Number of bank groups | 2 |
| Bank group address | BG0 |
| Bank count per group | 4 |
| Bank address in bank group | BA[1:0] |
| Row addressing | 128K (A[16:0]) |
| Column addressing | 1K (A[9:0]) |
| Page size[1] | 2KB |

Note: 1. Page size is per bank, calculated as follows:
Page size = $2^{COLBITS}$ × ORG/8, where COLBIT = the number of column address bits and ORG = the number of DQ bits.

**Order Part Number Example**

Example Part Number: AS4C1G16D4-062BCN /AS4C1G16D4-062BIN



## Contents

Important Notes and Warnings ..... 19
General Notes and Description ..... 19
Description ..... 19
Commercial Temperature ..... 20
General Notes ..... 20
Definitions of the Device-Pin Signal Level ..... 21
Definitions of the Bus Signal Level ..... 21
Functional Block Diagrams ..... 22
Ball Assignments ..... 23
Ball Descriptions ..... 24
Package Dimensions ..... 27
State Diagram ..... 28
Functional Description ..... 30
RESET and Initialization Procedure ..... 31
Power-Up and Initialization Sequence ..... 31
RESET Initialization with Stable Power Sequence ..... 34
Uncontrolled Power-Down Sequence ..... 35
Programming Mode Registers ..... 36
Mode Register 0 ..... 39
Burst Length, Type, and Order ..... 40
CAS Latency ..... 41
Test Mode ..... 42
Write Recovery (WR)/READ-to-PRECHARGE ..... 42
DLL RESET ..... 42
Mode Register 1 ..... 43
DLL Enable/DLL Disable ..... 44
Output Driver Impedance Control ..... 45
ODT $R_{TT(NOM)}$ Values ..... 45
Additive Latency ..... 45
Rx CTLE Control ..... 45
Write Leveling ..... 46
Output Disable ..... 46
Mode Register 2 ..... 47
CAS WRITE Latency ..... 49
Low-Power Auto Self Refresh ..... 49
Dynamic ODT ..... 49
Write Cyclic Redundancy Check Data Bus ..... 49
Mode Register 3 ..... 50
Multipurpose Register ..... 51
WRITE Command Latency When CRC/DM is Enabled ..... 52
Fine Granularity Refresh Mode ..... 52
Temperature Sensor Status ..... 52
Per-DRAM Addressability ..... 52
Gear-Down Mode ..... 52
Mode Register 4 ..... 53
Hard Post Package Repair Mode ..... 54
Soft Post Package Repair Mode ..... 54

WRITE Preamble ..... 55
READ Preamble ..... 55
READ Preamble Training ..... 55
Temperature-Controlled Refresh ..... 55
Command Address Latency ..... 55
Internal $V_{REF}$ Monitor ..... 55
Maximum Power Savings Mode ..... 56
Mode Register 5 ..... 57
Data Bus Inversion ..... 58
Data Mask ..... 59
CA Parity Persistent Error Mode ..... 59
ODT Input Buffer for Power-Down ..... 59
CA Parity Error Status ..... 59
CRC Error Status ..... 59
CA Parity Latency Mode ..... 59
Mode Register 6 ..... 60
Data Rate Programming ..... 61
$V_{REFDQ}$ Calibration Enable ..... 61
$V_{REFDQ}$ Calibration Range ..... 61
$V_{REFDQ}$ Calibration Value ..... 61
Truth Tables ..... 62
NOP Command ..... 65
DESELECT Command ..... 65
DLL-Off Mode ..... 65
DLL-On/Off Switching Procedures ..... 67
DLL Switch Sequence from DLL-On to DLL-Off ..... 67
DLL-Off to DLL-On Procedure ..... 69
Input Clock Frequency Change ..... 70
Write Leveling ..... 71
DRAM Setting for Write Leveling and DRAM TERMINATION Function in that Mode ..... 72
Procedure Description ..... 73
Write Leveling Mode Exit ..... 74
Command Address Latency ..... 76
Low-Power Auto Self Refresh Mode ..... 81
Manual Self Refresh Mode ..... 81
Multipurpose Register ..... 83
MPR Reads ..... 84
MPR Readout Format ..... 86
MPR Readout Serial Format ..... 86
MPR Readout Parallel Format ..... 87
MPR Readout Staggered Format ..... 88
MPR READ Waveforms ..... 88
MPR Writes ..... 90
MPR WRITE Waveforms ..... 91
MPR REFRESH Waveforms ..... 92
Gear-Down Mode ..... 94
Maximum Power-Saving Mode ..... 97
Maximum Power-Saving Mode Entry ..... 97
Maximum Power-Saving Mode Entry in PDA ..... 98
CKE Transition During Maximum Power-Saving Mode ..... 98
Maximum Power-Saving Mode Exit ..... 98
Command/Address Parity ..... 100

Per-DRAM Addressability ..... 108
$V_{REFDQ}$ Calibration ..... 111
$V_{REFDQ}$ Range and Levels ..... 112
$V_{REFDQ}$ Step Size ..... 112
$V_{REFDQ}$ Increment and Decrement Timing ..... 113
$V_{REFDQ}$ Target Settings ..... 117
Connectivity Test Mode ..... 119
Pin Mapping ..... 119
Minimum Terms Definition for Logic Equations ..... 120
Logic Equations for a x16 Device ..... 121
CT Input Timing Requirements ..... 121
Excessive Row Activation ..... 123
Post Package Repair ..... 124
Post Package Repair ..... 124
Hard Post Package Repair ..... 125
hPPR Row Repair - Entry ..... 125
hPPR Row Repair – WRA Initiated (REF Commands Allowed) ..... 125
hPPR Row Repair – WR Initiated (REF Commands NOT Allowed) ..... 127
sPPR Row Repair ..... 129
hPPR/sPPR Support Identifier ..... 132
ACTIVATE Command ..... 132
PRECHARGE Command ..... 133
REFRESH Command ..... 133
Temperature-Controlled Refresh Mode ..... 136
Normal Temperature Mode ..... 136
Extended Temperature Mode ..... 136
Fine Granularity Refresh Mode ..... 138
Mode Register and Command Truth Table ..... 138
$^{t}$REFI and $^{t}$RFC Parameters ..... 138
Changing Refresh Rate ..... 141
Usage with TCR Mode ..... 141
Self Refresh Entry and Exit ..... 141
SELF REFRESH Operation ..... 143
Self Refresh Abort ..... 145
Self Refresh Exit with NOP Command ..... 146
Power-Down Mode ..... 148
Power-Down Clarifications – Case 1 ..... 153
Power-Down Entry, Exit Timing with CAL ..... 154
ODT Input Buffer Disable Mode for Power-Down ..... 156
CRC Write Data Feature ..... 158
CRC Write Data ..... 158
WRITE CRC DATA Operation ..... 158
DBI_n and CRC Both Enabled ..... 159
DM_n and CRC Both Enabled ..... 159
DM_n and DBI_n Conflict During Writes with CRC Enabled ..... 159
CRC and Write Preamble Restrictions ..... 159
CRC Simultaneous Operation Restrictions ..... 159
CRC Polynomial ..... 159
CRC Combinatorial Logic Equations ..... 160
Burst Ordering for BL8 ..... 161

CRC Data Bit Mapping ..... 161
CRC Enabled With BC4 ..... 161
CRC with BC4 Data Bit Mapping ..... 162
CRC Equations for x16 Device in BC4 Mode with A2 = 0 and A2 = 1 ..... 163
CRC Error Handling ..... 164
CRC Write Data Flow Diagram ..... 166
Data Bus Inversion ..... 167
DBI During a WRITE Operation ..... 167
DBI During a READ Operation ..... 168
Data Mask ..... 169
Programmable Preamble Modes and DQS Postambles ..... 170
WRITE Preamble Mode ..... 170
READ Preamble Mode ..... 173
READ Preamble Training ..... 173
WRITE Postamble ..... 174
READ Postamble ..... 174
Bank Access Operation ..... 176
READ Operation ..... 180
Read Timing Definitions ..... 180
Read Timing – Clock-to-Data Strobe Relationship ..... 181
Read Timing – Data Strobe-to-Data Relationship ..... 183
$^{t}$LZ(DQS), $^{t}$LZ(DQ), $^{t}$HZ(DQS), and $^{t}$HZ(DQ) Calculations ..... 184
$^{t}$RPRE Calculation ..... 185
$^{t}$RPST Calculation ..... 186
READ Burst Operation ..... 187
READ Operation Followed by Another READ Operation ..... 189
READ Operation Followed by WRITE Operation ..... 194
READ Operation Followed by PRECHARGE Operation ..... 200
READ Operation with Read Data Bus Inversion (DBI) ..... 203
READ Operation with Command/Address Parity (CA Parity) ..... 204
READ Followed by WRITE with CRC Enabled ..... 206
READ Operation with Command/Address Latency (CAL) Enabled ..... 207
WRITE Operation ..... 209
Write Timing Definitions ..... 209
Write Timing – Clock-to-Data Strobe Relationship ..... 209
$^{t}$WPRE Calculation ..... 211
$^{t}$WPST Calculation ..... 212
Write Timing – Data Strobe-to-Data Relationship ..... 212
WRITE Burst Operation ..... 216
WRITE Operation Followed by Another WRITE Operation ..... 218
WRITE Operation Followed by READ Operation ..... 224
WRITE Operation Followed by PRECHARGE Operation ..... 228
WRITE Operation with WRITE DBI Enabled ..... 231
WRITE Operation with CA Parity Enabled ..... 233
WRITE Operation with Write CRC Enabled ..... 234
Write Timing Violations ..... 239
Motivation ..... 239
Data Setup and Hold Violations ..... 239
Strobe-to-Strobe and Strobe-to-Clock Violations ..... 239
ZQ CALIBRATION Commands ..... 240
On-Die Termination ..... 242
ODT Mode Register and ODT State Table ..... 242

ODT Read Disable State Table ..... 243
Synchronous ODT Mode ..... 244
ODT Latency and Posted ODT ..... 244
Timing Parameters ..... 244
ODT During Reads ..... 246
Dynamic ODT ..... 247
Functional Description ..... 247
Asynchronous ODT Mode ..... 250
Electrical Specifications ..... 251
Absolute Ratings ..... 251
DRAM Component Operating Temperature Range ..... 251
Electrical Characteristics – AC and DC Operating Conditions ..... 252
Supply Operating Conditions ..... 252
Leakages ..... 253
$V_{REFCA}$ Supply ..... 253
$V_{REFDQ}$ Supply and Calibration Ranges ..... 254
$V_{REFDQ}$ Ranges ..... 255
Electrical Characteristics – AC and DC Single-Ended Input Measurement Levels ..... 256
RESET_n Input Levels ..... 256
Command/Address Input Levels ..... 256
Command, Control, and Address Setup, Hold, and Derating ..... 258
Data Receiver Input Requirements ..... 260
Connectivity Test (CT) Mode Input Levels ..... 264
Electrical Characteristics – AC and DC Differential Input Measurement Levels ..... 268
Differential Inputs ..... 268
Single-Ended Requirements for CK Differential Signals ..... 269
Slew Rate Definitions for CK Differential Input Signals ..... 270
CK Differential Input Cross Point Voltage ..... 271
DQS Differential Input Signal Definition and Swing Requirements ..... 272
DQS Differential Input Cross Point Voltage ..... 274
Slew Rate Definitions for DQS Differential Input Signals ..... 275
Electrical Characteristics – Overshoot and Undershoot Specifications ..... 277
Address, Command, and Control Overshoot and Undershoot Specifications ..... 277
Clock Overshoot and Undershoot Specifications ..... 278
Data, Strobe, and Mask Overshoot and Undershoot Specifications ..... 279
Electrical Characteristics – AC and DC Output Measurement Levels ..... 279
Single-Ended Outputs ..... 279
Differential Outputs ..... 281
Reference Load for AC Timing and Output Slew Rate ..... 282
Connectivity Test Mode Output Levels ..... 283
Electrical Characteristics – AC and DC Output Driver Characteristics ..... 284
Connectivity Test Mode Output Driver Electrical Characteristics ..... 284
Output Driver Electrical Characteristics ..... 286
Output Driver Temperature and Voltage Sensitivity ..... 289
Alert Driver ..... 289
Electrical Characteristics – On-Die Termination Characteristics ..... 290
ODT Levels and I-V Characteristics ..... 290
ODT Temperature and Voltage Sensitivity ..... 292
ODT Timing DefinitionsODT Timing Definitions and Waveforms ..... 292
DRAM Package Electrical Specifications ..... 296
Thermal Characteristics ..... 299
Current Specifications – Measurement Conditions ..... 300

$I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement Conditions ..... 300
$I_{DD}$ Definitions ..... 301
Current Specifications – Patterns and Test Conditions ..... 305
Current Test Definitions and Patterns ..... 305
$I_{DD}$ Specifications ..... 314
Current Specifications – Limits ..... 315
Speed Bin Tables ..... 318
Backward Compatibility ..... 318
Refresh Parameters By Device Density ..... 337
Electrical Characteristics and AC Timing Parameters ..... 338
Electrical Characteristics and AC Timing Parameters: 2666 Through 3200 ..... 350
Converting Time-Based Specifications to Clock-Based Requirements ..... 361
Options Tables ..... 363

## List of Figures

Figure 1: 1 Gig x 16 Functional Block Diagram ..... 22
Figure 2: 96-Ball x16 Ball Assignments ..... 23
Figure 3: 96-Ball FBGA – x16 ..... 27
Figure 4: Simplified State Diagram ..... 28
Figure 5: RESET and Initialization Sequence at Power-On Ramping ..... 34
Figure 6: RESET Procedure at Power Stable Condition ..... 35
Figure 7: $^{t}$MRD Timing ..... 37
Figure 8: $^{t}$MOD Timing ..... 37
Figure 9: DLL-Off Mode Read Timing Operation ..... 66
Figure 10: DLL Switch Sequence from DLL-On to DLL-Off ..... 68
Figure 11 DLL Switch Sequence from DLL-Off to DLL-On ..... 69
Figure 12 Write Leveling Concept, Example 1 ..... 71
Figure 13: Write Leveling Concept, Example 2 ..... 72
Figure 14: Write Leveling Sequence (DQS Capturing CK LOW at T1 and CK HIGH at T2) ..... 74
Figure 15: Write Leveling Exit ..... 75
Figure 16: CAL Timing Definition ..... 76
Figure 17: CAL Timing Example (Consecutive CS_n = LOW) ..... 76
Figure 18: CAL Enable Timing – $^{t}$MOD_CAL ..... 77
Figure 19: $^{t}$MOD_CAL, MRS to Valid Command Timing with CAL Enabled ..... 77
Figure 20: CAL Enabling MRS to Next MRS Command, $^{t}$MRD_CAL ..... 78
Figure 21: $^{t}$MRD_CAL, Mode Register Cycle Time With CAL Enabled ..... 78
Figure 22: Consecutive READ BL8, CAL3, 1$^{t}$CK Preamble, Different Bank Group ..... 79
Figure 23: Consecutive READ BL8, CAL4, 1$^{t}$CK Preamble, Different Bank Group ..... 79
Figure 24: Auto Self Refresh Ranges ..... 82
Figure 25: MPR Block Diagram ..... 83
Figure 26: MPR READ Timing ..... 88
Figure 27: MPR Back-to-Back READ Timing ..... 89
Figure 28: MPR READ-to-WRITE Timing ..... 90
Figure 29: MPR WRITE and WRITE-to-READ Timing ..... 91
Figure 30: MPR Back-to-Back WRITE Timing ..... 92
Figure 31: REFRESH Timing ..... 92
Figure 32: READ-to-REFRESH Timing ..... 93
Figure 33: WRITE-to-REFRESH Timing ..... 93
Figure 34: Clock Mode Change from 1/2 Rate to 1/4 Rate (Initialization) ..... 95
Figure 35: Clock Mode Change After Exiting Self Refresh ..... 95
Figure 36: Comparison Between Gear-Down Disable and Gear-Down Enable ..... 96
Figure 37: Maximum Power-Saving Mode Entry ..... 97
Figure 38: Maximum Power-Saving Mode Entry with PDA ..... 98
Figure 39: Maintaining Maximum Power-Saving Mode with CKE Transition ..... 98
Figure 40: Maximum Power-Saving Mode Exit ..... 99
Figure 41: Command/Address Parity Operation ..... 100
Figure 42: Command/Address Parity During Normal Operation ..... 102
Figure 43: Persistent CA Parity Error Checking Operation ..... 103
Figure 44: CA Parity Error Checking – SRE Attempt ..... 103
Figure 45: CA Parity Error Checking – SRX Attempt ..... 104
Figure 46: CA Parity Error Checking – PDE/PDX ..... 104

Figure 47: Parity Entry Timing Example – $^{t}$MRD_PAR ..... 105
Figure 48: Parity Entry Timing Example – $^{t}$MOD_PAR ..... 105
Figure 49: Parity Exit Timing Example – $^{t}$MRD_PAR ..... 105
Figure 50: Parity Exit Timing Example – $^{t}$MOD_PAR ..... 106
Figure 51: CA Parity Flow Diagram ..... 107
Figure 52: PDA Operation Enabled, BL8 ..... 109
Figure 53: PDA Operation Enabled, BC4 ..... 109
Figure 54: MRS PDA Exit ..... 110
Figure 55: $V_{REFDQ}$ Voltage Range ..... 111
Figure 56: Example of $V_{REF}$ Set Tolerance and Step Size ..... 113
Figure 57: $V_{REFDQ}$ Timing Diagram for $V_{REF,time}$ Parameter ..... 114
Figure 58: $V_{REFDQ}$ Training Mode Entry and Exit Timing Diagram ..... 115
Figure 59 $V_{REF}$ Step: Single Step Size Increment Case ..... 116
Figure 60: $V_{REF}$ Step: Single Step Size Decrement Case ..... 116
Figure 61: $V_{REF}$ Full Step: From $V_{REF,min}$ to $V_{REF,max}$Case ..... 117
Figure 62: $V_{REF}$ Full Step: From $V_{REF,max}$ to $V_{REF,min}$Case ..... 117
Figure 63: $V_{REFDQ}$ Equivalent Circuit ..... 118
Figure 64: Connectivity Test Mode Entry ..... 122
Figure 65: hPPR WRA – Entry ..... 127
Figure 66: hPPR WRA – Repair and Exit ..... 127
Figure 67: hPPR WR – Entry ..... 128
Figure 68: hPPR WR – Repair and Exit ..... 128
Figure 69: sPPR – Entry ..... 131
Figure 70: sPPR – Repair, and Exit ..... 131
Figure 71: $^{t}$RRD Timing ..... 132
Figure 72: $^{t}$FAW Timing ..... 133
Figure 73: REFRESH Command Timing ..... 134
Figure 74: Postponing REFRESH Commands (Example) ..... 135
Figure 75: Pulling In REFRESH Commands (Example) ..... 135
Figure 76: TCR Mode Example[1] ..... 1137
Figure 77: 4Gb With Fine Granularity Refresh Mode Example ..... 140
Figure 78: OTF REFRESH Command Timing ..... 141
Figure 79: Self Refresh Entry/Exit Timing ..... 144
Figure 80: Self Refresh Entry/Exit Timing with CAL Mode ..... 145
Figure 81: Self Refresh Abort ..... 146
Figure 82: Self Refresh Exit with NOP Command ..... 147
Figure 83: Active Power-Down Entry and Exit ..... 149
Figure 84: Power-Down Entry After Read and Read with Auto Precharge ..... 150
Figure 85: Power-Down Entry After Write and Write with Auto Precharge ..... 150
Figure 86: Power-Down Entry After Write ..... 152
Figure 87: Precharge Power-Down Entry and Exit ..... 151
Figure 88: REFRESH Command to Power-Down Entry ..... 152
Figure 89: Active Command to Power-Down Entry ..... 152
Figure 90: PRECHARGE/PRECHARGE ALL Command to Power-Down Entry ..... 153
Figure 91: MRS Command to Power-Down Entry ..... 153
Figure 92: Power-Down Entry/Exit Clarifications – Case 1 .....154
Figure 93: Active Power-Down Entry and Exit Timing with CAL ..... 154
Figure 94: REFRESH Command to Power-Down Entry with CAL ..... 155
Figure 95: ODT Power-Down Entry with ODT Buffer Disable Mode ..... 156
Figure 96: ODT Power-Down Exit with ODT Buffer Disable Mode ..... 157
Figure 97: CRC Write Data Operation ..... 158
Figure 98: CRC Error Reporting ..... 165

Figure 99: CA Parity Flow Diagram ..... 166
Figure 100: 1tCK vs. 2tCK WRITE Preamble Mode ..... 170
Figure 101: 1tCK vs. 2tCK WRITE Preamble Mode, tCCD = 4 ..... 171
Figure 102: 1tCK vs. 2tCK WRITE Preamble Mode, tCCD = 5 ..... 172
Figure 103: 1tCK vs. 2 tCK WRITE Preamble Mode, tCCD = 6 ..... 172
Figure 104: 1tCK vs. 2tCK READ Preamble Mode ..... 173
Figure 105: READ Preamble Training ..... 174
Figure 106: WRITE Postamble ..... 174
Figure 107: READ Postamble ..... 175
Figure 108: Bank Group x4/x8 Block Diagram ..... 176
Figure 109: READ Burst tCCD_S and tCCD_L Examples ..... 177
Figure 110: Write Burst tCCD_S and tCCD_L Examples ..... 177
Figure 111: tRRD Timing ..... 178
Figure 112: tWTR_S Timing (WRITE-to-READ, Different Bank Group, CRC and DM Disabled) ..... 178
Figure 113: tWTR_L Timing (WRITE-to-READ, Same Bank Group, CRC and DM Disabled) ..... 179
Figure 114: Read Timing Definition ..... 181
Figure 115: Clock-to-Data Strobe Relationship ..... 182
Figure 116: Data Strobe-to-Data Relationship ..... 183
Figure 117: tLZ and tHZ Method for Calculating Transitions and Endpoints ..... 184
Figure 118: tRPRE Method for Calculating Transitions and Endpoints ..... 185
Figure 119: tRPST Method for Calculating Transitions and Endpoints ..... 186
Figure 120: READ Burst Operation, RL = 11 (AL = 0, CL = 11, BL8) ..... 187
Figure 121: READ Burst Operation, RL = 21 (AL = 10, CL = 11, BL8) ..... 188
Figure 122: Consecutive READ (BL8) with 1tCK Preamble in Different Bank Group ..... 189
Figure 123: Consecutive READ (BL8) with 2tCK Preamble in Different Bank Group ..... 189
Figure 124: Nonconsecutive READ (BL8) with 1tCK Preamble in Same or Different Bank Group ..... 190
Figure 125: Nonconsecutive READ (BL8) with 2tCK Preamble in Same or Different Bank Group ..... 190
Figure 126: READ (BC4) to READ (BC4) with 1tCK Preamble in Different Bank Group ..... 191
Figure 127: READ (BC4) to READ (BC4) with 2tCK Preamble in Different Bank Group ..... 191
Figure 128: READ (BL8) to READ (BC4) OTF with 1tCK Preamble in Different Bank Group ..... 192
Figure 129: READ (BL8) to READ (BC4) OTF with 2tCK Preamble in Different Bank Group ..... 192
Figure 130: READ (BC4) to READ (BL8) OTF with 1tCK Preamble in Different Bank Group ..... 193
Figure 131: READ (BC4) to READ (BL8) OTF with 2tCK Preamble in Different Bank Group ..... 193
Figure 132: READ (BL8) to WRITE (BL8) with 1tCK Preamble in Same or Different Bank Group ..... 194
Figure 133: READ (BL8) to WRITE (BL8) with 2tCK Preamble in Same or Different Bank Group ..... 194
Figure 134: READ (BC4) OTF to WRITE (BC4) OTF with 1tCK Preamble in Same or Different Bank Group ..... 195
Figure 135: READ (BC4) OTF to WRITE (BC4) OTF with 2tCK Preamble in Same or Different Bank Group ..... 196
Figure 136: READ (BC4) Fixed to WRITE (BC4) Fixed with 1tCK Preamble in Same or Different Bank Group ..... 196
Figure 137: READ (BC4) Fixed to WRITE (BC4) Fixed with 2tCK Preamble in Same or Different Bank Group ..... 197
Figure 138: READ (BC4) to WRITE (BL8) OTF with 1tCK Preamble in Same or Different Bank Group ..... 198
Figure 139: READ (BC4) to WRITE (BL8) OTF with 2tCK Preamble in Same or Different Bank Group ..... 198
Figure 140: READ (BL8) to WRITE (BC4) OTF with 1tCK Preamble in Same or Different Bank Group ..... 199
Figure 141: READ (BL8) to WRITE (BC4) OTF with 2tCK Preamble in Same or Different Bank Group ..... 199
Figure 142: READ to PRECHARGE with 1tCK Preamble ..... 200
Figure 143: READ to PRECHARGE with 2tCK Preamble ..... 201
Figure 144: READ to PRECHARGE with Additive Latency and 1tCK Preamble ..... 201
Figure 145: READ with Auto Precharge and 1tCK Preamble ..... 202
Figure 146: READ with Auto Precharge, Additive Latency, and 1tCK Preamble ..... 203
Figure 147: Consecutive READ (BL8) with 1tCK Preamble and DBI in Different Bank Group ..... 203
Figure 148: Consecutive READ (BL8) with 1tCK Preamble and CA Parity in Different Bank Group ..... 204
Figure 149: READ (BL8) to WRITE (BL8) with 1tCK Preamble and CA Parity in Same or Different Bank Group ... 205

Figure 150: READ (BL8) to WRITE (BL8 or BC4: OTF) with 1tCK Preamble and Write CRC in Same or Different Bank Group ..... 206
Figure 151: READ (BC4: Fixed) to WRITE (BC4: Fixed) with 1tCK Preamble and Write CRC in Same or Different Bank Group ..... 207
Figure 152: Consecutive READ (BL8) with CAL (3tCK) and 1tCK Preamble in Different Bank Group ..... 207
Figure 153: Consecutive READ (BL8) with CAL (4tCK) and 1tCK Preamble in Different Bank Group ..... 208
Figure 154: Write Timing Definition ..... 210
Figure 155: tWPRE Method for Calculating Transitions and Endpoints ..... 211
Figure 156: tWPST Method for Calculating Transitions and Endpoints ..... 212
Figure 157: Rx Compliance Mask ..... 213
Figure 158: $V_{CENT\_DQ}$ $V_{REFDQ}$ Voltage Variation ..... 213
Figure 159: Rx Mask DQ-to-DQS Timings ..... 214
Figure 160: Rx Mask DQ-to-DQS DRAM-Based Timings ..... 215
Figure 161: Example of Data Input Requirements Without Training ..... 216
Figure 162: WRITE Burst Operation, WL = 9 (AL = 0, CWL = 9, BL8) ..... 217
Figure 163: WRITE Burst Operation, WL = 19 (AL = 10, CWL = 9, BL8) ..... 218
Figure 164: Consecutive WRITE (BL8) with 1tCK Preamble in Different Bank Group ..... 218
Figure 165: Consecutive WRITE (BL8) with 2tCK Preamble in Different Bank Group ..... 219
Figure 166: Nonconsecutive WRITE (BL8) with 1tCK Preamble in Same or Different Bank Group ..... 220
Figure 167: Nonconsecutive WRITE (BL8) with 2tCK Preamble in Same or Different Bank Group ..... 220
Figure 168: WRITE (BC4) OTF to WRITE (BC4) OTF with 1 tCK Preamble in Different Bank Group ..... 221
Figure 169: WRITE (BC4) OTF to WRITE (BC4) OTF with 2 tCK Preamble in Different Bank Group ..... 222
Figure 170: WRITE (BC4) Fixed to WRITE (BC4) Fixed with 1 tCK Preamble in Different Bank Group ..... 222
Figure 171: WRITE (BL8) to WRITE (BC4) OTF with 1 tCK Preamble in Different Bank Group ..... 223
Figure 172: WRITE (BC4) OTF to WRITE (BL8) with 1 tCK Preamble in Different Bank Group ..... 224
Figure 173: WRITE (BL8) to READ (BL8) with 1tCK Preamble in Different Bank Group ..... 224
Figure 174: WRITE (BL8) to READ (BL8) with 1tCK Preamble in Same Bank Group ..... 225
Figure 175: WRITE (BC4) OTF to READ (BC4) OTF with 1tCK Preamble in Different Bank Group ..... 226
Figure 176: WRITE (BC4) OTF to READ (BC4) OTF with 1tCK Preamble in Same Bank Group ..... 226
Figure 177: WRITE (BC4) Fixed to READ (BC4) Fixed with 1 tCK Preamble in Different Bank Group ..... 227
Figure 178: WRITE (BC4) Fixed to READ (BC4) Fixed with 1tCK Preamble in Same Bank Group ..... 227
Figure 179: WRITE (BL8/BC4-OTF) to PRECHARGE with 1tCK Preamble ..... 228
Figure 180: WRITE (BC4-Fixed) to PRECHARGE with 1tCK Preamble ..... 229
Figure 181: WRITE (BL8/BC4-OTF) to Auto PRECHARGE with 1tCK Preamble ..... 229
Figure 182: WRITE (BC4-Fixed) to Auto PRECHARGE with 1tCK Preamble ..... 230
Figure 183: WRITE (BL8/BC4-OTF) with 1tCK Preamble and DBI ..... 231
Figure 184: WRITE (BC4-Fixed) with 1tCK Preamble and DBI ..... 232
Figure 185: Consecutive Write (BL8) with 1tCK Preamble and CA Parity in Different Bank Group ..... 233
Figure 186: Consecutive WRITE (BL8/BC4-OTF) with 1tCK Preamble and Write CRC in Same or Different Bank Group ..... 234
Figure 187: Consecutive WRITE (BC4-Fixed) with 1tCK Preamble and Write CRC in Same or Different Bank Group ..... 235
Figure 188: Nonconsecutive WRITE (BL8/BC4-OTF) with 1tCK Preamble and Write CRC in Same or Different Bank Group ..... 236
Figure 189: Nonconsecutive WRITE (BL8/BC4-OTF) with 2tCK Preamble and Write CRC in Same or Different Bank Group ..... 237
Figure 190: WRITE (BL8/BC4-OTF/Fixed) with 1tCK Preamble and Write CRC in Same or Different Bank Group .238
Figure 191: ZQ Calibration Timing ..... 241
Figure 192: Functional Representation of ODT ..... 242
Figure 193: Synchronous ODT Timing with BL8 ..... 245
Figure 194: Synchronous ODT with BC4 ..... 245
Figure 195: ODT During Reads ..... 246

Figure 196: Dynamic ODT (1$^{t}$ CK Preamble; CL = 14, CWL = 11, BL = 8, AL = 0, CRC Disabled) ..... 248
Figure 197: Dynamic ODT Overlapped with $R_{TT(NOM)}$ (CL = 14, CWL = 11, BL = 8, AL = 0, CRC Disabled) ..... 249
Figure 198: Asynchronous ODT Timings with DLL Off ..... 250
Figure 199: $V_{REFDQ}$ Voltage Range ..... 253
Figure 200: RESET_n Input Slew Rate Definition ..... 256
Figure 201: Single-Ended Input Slew Rate Definition ..... 258
Figure 202: DQ Slew Rate Definitions ..... 261
Figure 203: Rx Mask Relative to $^{t}$DS/$^{t}$DH ..... 263
Figure 204: Rx Mask Without Write Training ..... 264
Figure 205: TEN Input Slew Rate Definition ..... 265
Figure 206: CT Type-A Input Slew Rate Definition ..... 265
Figure 207: CT Type-B Input Slew Rate Definition ..... 266
Figure 208: CT Type-C Input Slew Rate Definition ..... 267
Figure 209: CT Type-D Input Slew Rate Definition ..... 267
Figure 210: Differential AC Swing and “Time Exceeding AC-Level” $^{t}$DVAC ..... 268
Figure 211: Single-Ended Requirements for CK ..... 270
Figure 212: Differential Input Slew Rate Definition for CK_t, CK_c ..... 271
Figure 213: $V_{IX(CK)}$ Definition ..... 271
Figure 214: Differential Input Signal Definition for DQS_t, DQS_c ..... 272
Figure 215: DQS_t, DQS_c Input Peak Voltage Calculation and Range of Exempt non-Monotonic Signaling ..... 273
Figure 216: $V_{IXDQS}$ Definition ..... 274
Figure 217: Differential Input Slew Rate and Input Level Definition for DQS_t, DQS_c ..... 275
Figure 218: ADDR, CMD, CNTL Overshoot and Undershoot Definition ..... 277
Figure 219: CK Overshoot and Undershoot Definition ..... 278
Figure 220: Data, Strobe, and Mask Overshoot and Undershoot Definition ..... 279
Figure 221: Single-ended Output Slew Rate Definition ..... 280
Figure 222: Differential Output Slew Rate Definition ..... 282
Figure 223: Reference Load For AC Timing and Output Slew Rate ..... 283
Figure 224: Connectivity Test Mode Reference Test Load ..... 283
Figure 225: Connectivity Test Mode Output Slew Rate Definition ..... 284
Figure 226: Output Driver During Connectivity Test Mode ..... 285
Figure 227: Output Driver: Definition of Voltages and Currents ..... 286
Figure 228: Alert Driver ..... 290
Figure 229: ODT Definition of Voltages and Currents ..... 291
Figure 230: ODT Timing Reference Load ..... 292
Figure 231: $^{t}$ADC Definition with Direct ODT Control ..... 294
Figure 232: $^{t}$ADC Definition with Dynamic ODT Control ..... 294
Figure 233: $^{t}$AOFAS and $^{t}$AONAS Definitions ..... 295
Figure 234: Thermal Measurement Point ..... 299
Figure 235: Measurement Setup and Test Load for $I_{DDx}$, $I_{PPx}$, and $I_{DDQx}$ ..... 301
Figure 236: Correlation: Simulated Channel I/O Power to Actual Channel I/O Power ..... 301

## List of Tables

Table 1: Key Timing Parameters ..... 2
Table 2: Addressing ..... 3
Table 3: Ball Descriptions ..... 24
Table 4: State Diagram Command Definitions ..... 29
Table 5: Supply Power-up Slew Rate ..... 31
Table 6: Address Pin Mapping ..... 39
Table 7: MR0 Register Definition ..... 39
Table 8: Burst Type and Burst Order ..... 41
Table 9: Address Pin Mapping ..... 43
Table 10: MR1 Register Definition ..... 43
Table 11: Additive Latency (AL) Settings ..... 45
Table 12: Address Pin Mapping ..... 47
Table 13: MR2 Register Definition ..... 48
Table 14: Address Pin Mapping ..... 50
Table 15: MR3 Register Definition ..... 50
Table 16: Address Pin Mapping ..... 53
Table 17: MR4 Register Definition ..... 53
Table 18: Address Pin Mapping ..... 57
Table 19: MR5 Register Definition ..... 57
Table 20: Address Pin Mapping ..... 60
Table 21: MR6 Register Definition ..... 60
Table 22: Truth Table – Command ..... 62
Table 23: Truth Table – CKE ..... 64
Table 24: MR Settings for Leveling Procedures ..... 72
Table 25 DRAM TERMINATION Function in Leveling Mode ..... 72
Table 26: Auto Self Refresh Mode ..... 81
Table 27: MR3 Setting for the MPR Access Mode ..... 83
Table 28: DRAM Address to MPR UI Translation ..... 83
Table 29: MPR Page and MPR*x* Definitions ..... 84
Table 30: MPR Readout Serial Format ..... 86
Table 31: MPR Readout – Parallel Format ..... 87
Table 32: MPR Readout Staggered Format, x8 and x16 ..... 88
Table 33: Mode Register Setting for CA Parity ..... 102
Table 34: $V_{REFDQ}$ Range and Levels ..... 112
Table 35: $V_{REFDQ}$ Settings ($V_{DDQ}$ = 1.2V) ..... 118
Table 36: Connectivity Mode Pin Description and Switching Levels ..... 120
Table 37: MAC Encoding of MPR Page 3 MPR3 ..... 123
Table 38: PPR MR0 Guard Key Settings ..... 125
Table 39: DDR4 hPPR Timing Parameters DDR4-1600 through DDR4-3200 ..... 129
Table 40: sPPR Associated Rows ..... 129
Table 41: PPR MR0 Guard Key Settings ..... 130
Table 42: DDR4 sPPR Timing Parameters DDR4-1600 through DDR4-3200 ..... 131
Table 43: DDR4 Repair Mode Support Identifier ..... 132
Table 44: Normal $^{t}$REFI Refresh (TCR Enabled) ..... 136
Table 45: MRS Definition ..... 138
Table 46: REFRESH Command Truth Table ..... 138
Table 47: $^{t}$REFI and $^{t}$RFC Parameters ..... 139

Table 48: Power-Down Entry Definitions ..... 148
Table 49: CRC Error Detection Coverage ..... 159
Table 50: CRC Data Mapping for x16 Devices, BL8 ..... 161
Table 51: CRC Data Mapping for x16 Devices, BC4 ..... 162
Table 52: DBI vs. DM Function Matrix ..... 167
Table 53: DBI Write, DQ Frame Format (x16) ..... 167
Table 54: DBI Read, DQ Frame Format (x16) ..... 168
Table 55: DM vs. DBI Function Matrix ..... 169
Table 56: Data Mask, DQ Frame Format (x16) ..... 169
Table 57: CWL Selection ..... 171
Table 58: DDR4 Bank Group Timing Examples ..... 176
Table 59: Read-to-Write and Write-to-Read Command Intervals ..... 181
Table 60: Termination State Table ..... 243
Table 61: Read Termination Disable Window ..... 243
Table 62: ODT Latency at DDR4-1600/-1866/-2133/-2400/-2666/-3200 ..... 244
Table 63: Dynamic ODT Latencies and Timing (1$^{t}$CK Preamble Mode and CRC Disabled) ..... 247
Table 64: Dynamic ODT Latencies and Timing with Preamble Mode and CRC Mode Matrix ..... 248
Table 65: Absolute Maximum Ratings ..... 251
Table 66: Temperature Range ..... 251
Table 67: Recommended Supply Operating Conditions ..... 252
Table 68: $V_{DD}$ Slew Rate ..... 252
Table 69: Leakages ..... 253
Table 70: $V_{REFDQ}$ Specification ..... 254
Table 71: $V_{REFDQ}$ Range and Levels ..... 255
Table 72: RESET_n Input Levels (CMOS) ..... 256
Table 73: Command and Address Input Levels: DDR4-1600 Through DDR4-2400 ..... 256
Table 74: Command and Address Input Levels: DDR4-2666 ..... 257
Table 75: Command and Address Input Levels: DDR4-2933 and DDR4-3200 ..... 257
Table 76: Single-Ended Input Slew Rates ..... 258
Table 77: Command and Address Setup and Hold Values Referenced – AC/DC-Based ..... 259
Table 78: Derating Values for $^{t}$IS/$^{t}$IH – AC100DC75-Based ..... 259
Table 79: Derating Values for $^{t}$IS/$^{t}$IH – AC90/DC65-Based ..... 260
Table 80: DQ Input Receiver Specifications ..... 261
Table 81: Rx Mask and $^{t}$DS/$^{t}$DH without Write Training ..... 264
Table 82: TEN Input Levels (CMOS) ..... 264
Table 83: CT Type-A Input Levels ..... 265
Table 84: CT Type-B Input Levels ..... 266
Table 85: CT Type-C Input Levels (CMOS) ..... 266
Table 86: CT Type-D Input Levels ..... 267
Table 87: Differential Input Swing Requirements for CK_t, CK_c ..... 268
Table 88: Minimum Time AC Time $^{t}$DVAC for CK ..... 269
Table 89: Single-Ended Requirements for CK ..... 270
Table 90: CK Differential Input Slew Rate Definition ..... 270
Table 91: Cross Point Voltage For CK Differential Input Signals at DDR4-1600 through DDR4-2400 ..... 272
Table 92: Cross Point Voltage For CK Differential Input Signals at DDR4-2666 through DDR4-3200 ..... 272

Table 93: DDR4-1600 through DDR4-2400 Differential Input Swing Requirements for DQS_t, DQS_c ..... 272
Table 94: DDR4-2633 through DDR4-3200 Differential Input Swing Requirements for DQS_t, DQS_c ..... 273
Table 95: Cross Point Voltage For Differential Input Signals DQS ..... 274
Table 96: DQS Differential Input Slew Rate Definition ..... 275
Table 97: DDR4-1600 through DDR4-2400 Differential Input Slew Rate and Input Levels for DQS_t, DQS_c ... 275
Table 98: DDR4-2666 through DDR4-3200 Differential Input Slew Rate and Input Levels for DQS_t, DQS_c ... 276
Table 99: ADDR, CMD, CNTL Overshoot and Undershoot/Specifications ..... 277
Table 100: CK Overshoot and Undershoot/ Specifications ..... 278
Table 101: Data, Strobe, and Mask Overshoot and Undershoot/ Specifications ..... 279
Table 102: Single-Ended Output Levels ..... 279
Table 103: Single-Ended Output Slew Rate Definition ..... 280
Table 104: Single-Ended Output Slew Rate ..... 281
Table 105: Differential Output Levels ..... 281
Table 106: Differential Output Slew Rate Definition ..... 281
Table 107: Differential Output Slew Rate ..... 282
Table 108: Connectivity Test Mode Output Levels ..... 283
Table 109: Connectivity Test Mode Output Slew Rate ..... 284
Table 110: Output Driver Electrical Characteristics During Connectivity Test Mode ..... 286
Table 111: Strong Mode (34Ω) Output Driver Electrical Characteristics ..... 287
Table 112: Weak Mode (48Ω) Output Driver Electrical Characteristics ..... 288
Table 113: Output Driver Sensitivity Definitions ..... 289
Table 114: Output Driver Voltage and Temperature Sensitivity ..... 289
Table 115: Alert Driver Voltage ..... 290
Table 116: ODT DC Characteristics ..... 291
Table 117: ODT Sensitivity Definitions ..... 292
Table 118: ODT Voltage and Temperature Sensitivity ..... 292
Table 119: ODT Timing Definitions ..... 293
Table 120: Reference Settings for ODT Timing Measurements ..... 293
Table 121: DRAM Package Electrical Specifications for x16 Devices ..... 297
Table 122: Pad Input/Output Capacitance ..... 298
Table 123: Thermal Characteristics ..... 299
Table 124: Basic $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement Conditions ..... 302
Table 125: $I_{DD0}$ and $I_{PP0}$ Measurement-Loop Pattern[1] ..... 305
Table 126: $I_{DD1}$ Measurement – Loop Pattern[1] ..... 306
Table 127: $I_{DD2N}$, $I_{DD3N}$, and $I_{PP3P}$ Measurement – Loop Pattern[1] ..... 307
Table 128: $I_{DD2NT}$ Measurement – Loop Pattern[1] ..... 308
Table 129: $I_{DD4R}$ Measurement – Loop Pattern[1] ..... 309
Table 130: $I_{DD4W}$ Measurement – Loop Pattern[1] ..... 310
Table 131: $I_{DD4Wc}$ Measurement – Loop Pattern[1] ..... 311
Table 132: $I_{DD5R}$ Measurement – Loop Pattern[1] ..... 312
Table 133: $I_{DD7}$ Measurement – Loop Pattern[1] ..... 313
Table 134: Timings used for $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement – Loop Patterns ..... 314
Table 135: $I_{DD}$ and $I_{PP}$ Current Limits; Die Rev. E (-40°C ≤ $T_C$ ≤ 85°C) ..... 315
Table 136: Backward Compatibility ..... 319
Table 137: DDR4-1600 Speed Bins and Operating Conditions ..... 321
Table 138: DDR4-1866 Speed Bins and Operating Conditions ..... 323
Table 139: DDR4-2133 Speed Bins and Operating Conditions ..... 325
Table 140: DDR4-2400 Speed Bins and Operating Conditions ..... 327
Table 141: DDR4-2666 Speed Bins and Operating Conditions ..... 329

Table 142: DDR4-2933 Speed Bins and Operating Conditions ..... 332
Table 143: DDR4-3200 Speed Bins and Operating Conditions ..... 335
Table 144: Refresh Parameters by Device Density ..... 337
Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 ..... 338
Table 146: Electrical Characteristics and AC Timing Parameters ..... 350
Table 147: Options – Speed Based ..... 363
Table 148: Options – Width Based ..... 364

## Important Notes and Warnings

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## General Notes and Description

### Description

The DDR4 SDRAM is a high-speed dynamic random-access memory internally configured as an eight-bank DRAM for the x16 configuration.

The DDR4 SDRAM uses an 8*n*-prefetch architecture to achieve high-speed operation. The 8*n*-prefetch architecture is combined with an interface designed to transfer two data words per clock cycle at the I/O pins.

A single READ or WRITE operation for the DDR4 SDRAM consists of a single 8*n*-bit wide, four-clock data transfer at the internal DRAM core and two corresponding *n*-bit wide, one-half-clock-cycle data transfers at the I/O pins.

## Commercial Temperature

A Commercial temperature device option requires that the case temperature not exceed below 0°C or above 95°C. JEDEC specifications require the refresh rate to double when $T_C$ exceeds 85°C; this also requires use of the high-temperature self refresh option.

## Industrial Temperature

An Industrial temperature device option requires that the case temperature not exceed below -40°C or above 95°C. JEDEC specifications require the refresh rate to double when $T_C$ exceeds 85°C; this also requires use of the high-temperature self refresh option.

## General Notes

- The functionality and the timing specifications discussed in this data sheet are for the DLL enable mode of operation (normal operation), unless specifically stated otherwise.
- Throughout the data sheet, the various figures and text refer to DQs as "DQ." The DQ term is to be interpreted as any and all DQ collectively, unless specifically stated otherwise.
- The terms "_t" and "_c" are used to represent the true and complement of a differential signal pair. These terms replace the previously used notation of "#" and/or over-bar characters. For example, differential data strobe pair DQS, DQS# is now referred to as DQS_t, DQS_c.
- The term "_n" is used to represent a signal that is active LOW and replaces the previously used "#" and/or overbar characters. For example: CS# is now referred to as CS_n.
- The terms "DQS" and "CK" found throughout the data sheet are to be interpreted as DQS_t and DQS_c, and CK_t and CK_c respectively, unless specifically stated otherwise.
- Complete functionality may be described throughout the entire document; any page or diagram may have been simplified to convey a topic and may not be inclusive of all requirements.

- Any specific requirement takes precedence over a general statement.
- Any functionality not specifically stated here within is considered undefined, illegal, and not supported, and can result in unknown operation.
- Addressing is denoted as BG[*n*] for bank group, BA[*n*] for bank address, and A[*n*] for row/column address.
- The NOP command is not allowed, except when exiting maximum power savings mode or when entering gear-down mode, and only a DES command should be used.
- Not all features described within this document may be available on the rev. A (first) version.
- Not all specifications listed are finalized industry standards; best conservative estimates have been provided when an industry standard has not been finalized.
- Although it is implied throughout the specification, the DRAM must be used after $V_{DD}$ has reached the stable power-on level, which is achieved by toggling CKE at least once every 8192 × $^{t}$REFI. However, in the event CKE is fixed HIGH, toggling CS_n at least once every 8192 × $^{t}$REFI is an acceptable alternative. Placing the DRAM into self refresh mode also alleviates the need to toggle CKE.
- Not all features designated in the data sheet may be supported by earlier die revisions due to late definition by JEDEC.
- A x16 device's DQ bus is comprised of two bytes. If only one of the bytes is used, use the lower byte for data transfers and terminate the upper byte as noted:
  - Connect UDQS_t to $V_{DDQ}$ or $V_{SS}$/ $V_{SSQ}$ via a resistor in the 200Ω range.
  - Connect UDQS_c to the opposite rail via a resistor in the same 200Ω range.
  - Connect UDM to $V_{DDQ}$ via a large (10,000Ω) pull-up resistor.
  - Connect UDBI to $V_{DDQ}$ via a large (10,000Ω) pull-up resistor.
  - Connect DQ[15:8] individually to $V_{DDQ}$ via a large (10,000Ω) resistors or float DQ[15:8].

## Definitions of the Device-Pin Signal Level

- HIGH: A device pin is driving the logic 1 state.
- LOW: A device pin is driving the logic 0 state.
- High-Z: A device pin is tri-state.
- ODT: A device pin terminates with the ODT setting, which could be terminating or tri-state depending on the mode register setting.

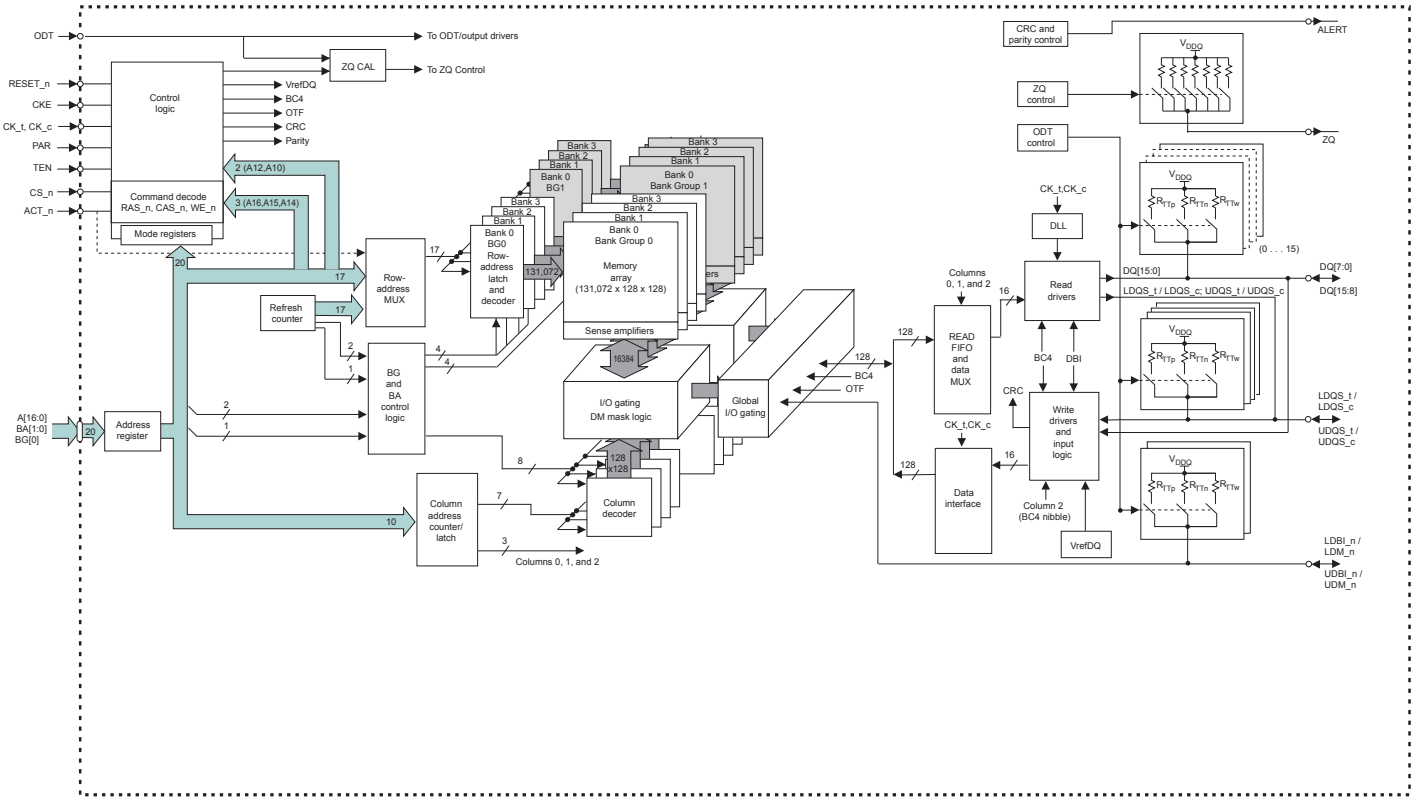
## Definitions of the Bus Signal Level

- HIGH: One device on the bus is HIGH, and all other devices on the bus are either ODT or High-Z. The voltage level on the bus is nominally $V_{DDQ}$.
- LOW: One device on the bus is LOW, and all other devices on the bus are either ODT or High-Z. The voltage level on the bus is nominally $V_{OL(DC)}$ if ODT was enabled, or $V_{SSQ}$ if High-Z.
- High-Z: All devices on the bus are High-Z. The voltage level on the bus is undefined as the bus is floating.
- ODT: At least one device on the bus is ODT, and all others are High-Z. The voltage level on the bus is nominally $V_{DDQ}$.

## Functional Block Diagrams

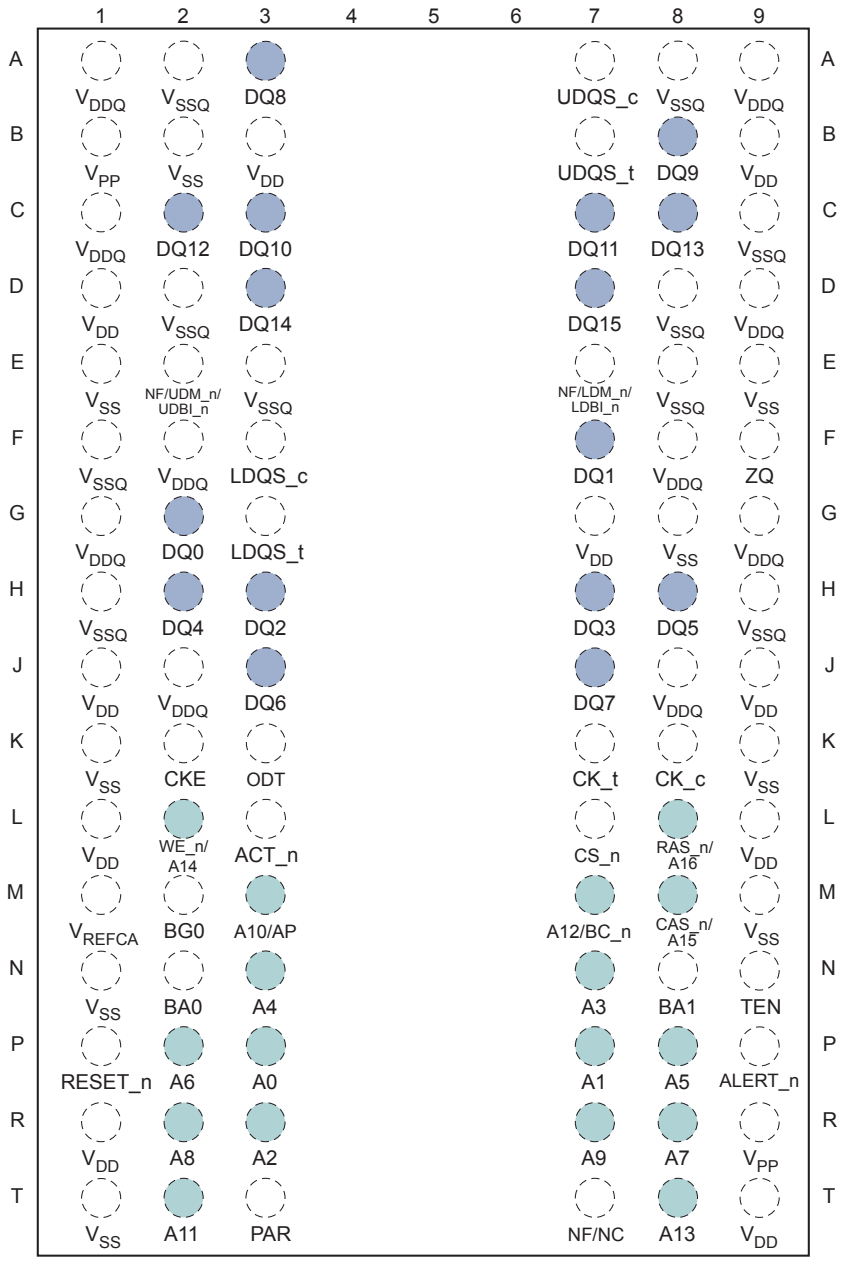
DDR4 SDRAM is a high-speed, CMOS dynamic random access memory. It is internally configured as an 16-bank (4-banks per Bank Group) DRAM.

**Figure 1: 1 Gig x 16 Functional Block Diagram**



## Ball Assignments

**Figure 2: 96-Ball x16 Ball Assignments**




Notes:
1. See Ball Descriptions.
2. A slash "/" defines a mode register selectable function, command/address function, density, or package dependence.
3. Address bits (including bank groups) are density and configuration-dependent (see Addressing).

## Ball Descriptions

The pin description table below is a comprehensive list of all possible pins for DDR4 devices. All pins listed may not be supported on the device defined in this data sheet. See the Ball Assignments section to review all pins used on this device.

**Table 3: Ball Descriptions**

| Symbol | Type | Description |
|---|---|---|
| A[16:0] | Input | **Address inputs:** Provide the row address for ACTIVATE commands and the column address for READ/WRITE commands to select one location out of the memory array in the respective bank. (A10/AP, A12/BC_n, WE_n/A14, CAS_n/A15, RAS_n/A16 have additional functions, see individual entries in this table.) The address inputs also provide the op-code during the MODE REGISTER SET command. A16 is used on some 8Gb and 16Gb parts. |
| A10/AP | Input | **Auto precharge:** A10 is sampled during READ and WRITE commands to determine whether auto precharge should be performed to the accessed bank after a READ or WRITE operation. (HIGH = auto precharge; LOW = no auto precharge.) A10 is sampled during a PRECHARGE command to determine whether the PRECHARGE applies to one bank (A10 LOW) or all banks (A10 HIGH). If only one bank is to be precharged, the bank is selected by the bank group and bank addresses. |
| A12/BC_n | Input | **Burst chop:** A12/BC_n is sampled during READ and WRITE commands to determine if burst chop (on-the-fly) will be performed. (HIGH = no burst chop; LOW = burst chopped). See the Command Truth Table. |
| ACT_n | Input | **Command input:** ACT_n indicates an ACTIVATE command. When ACT_n (along with CS_n) is LOW, the input pins RAS_n/A16, CAS_n/A15, and WE_n/A14 are treated as row address inputs for the ACTIVATE command. When ACT_n is HIGH (along with CS_n LOW), the input pins RAS_n/ A16, CAS_n/A15, and WE_n/A14 are treated as normal commands that use the RAS_n, CAS_n, and WE_n signals. See the Command Truth Table. |
| BA[1:0] | Input | **Bank address inputs:** Define the bank (within a bank group) to which an ACTIVATE, READ, WRITE, or PRECHARGE command is being applied. Also determines which mode register is to be accessed during a MODE REGISTER SET command. |
| BG[0] | Input | **Bank group address inputs:** Define the bank group to which an ACTIVATE, READ, WRITE, or PRECHARGE command is being applied. Also determines which mode register is to be accessed during a MODE REGISTER SET command. |
| CK_t, CK_c | Input | **Clock:** Differential clock inputs. All address, command, and control input signals are sampled on the crossing of the positive edge of CK_t and the negative edge of CK_c. |

**Table 3: Ball Descriptions (Continued)**

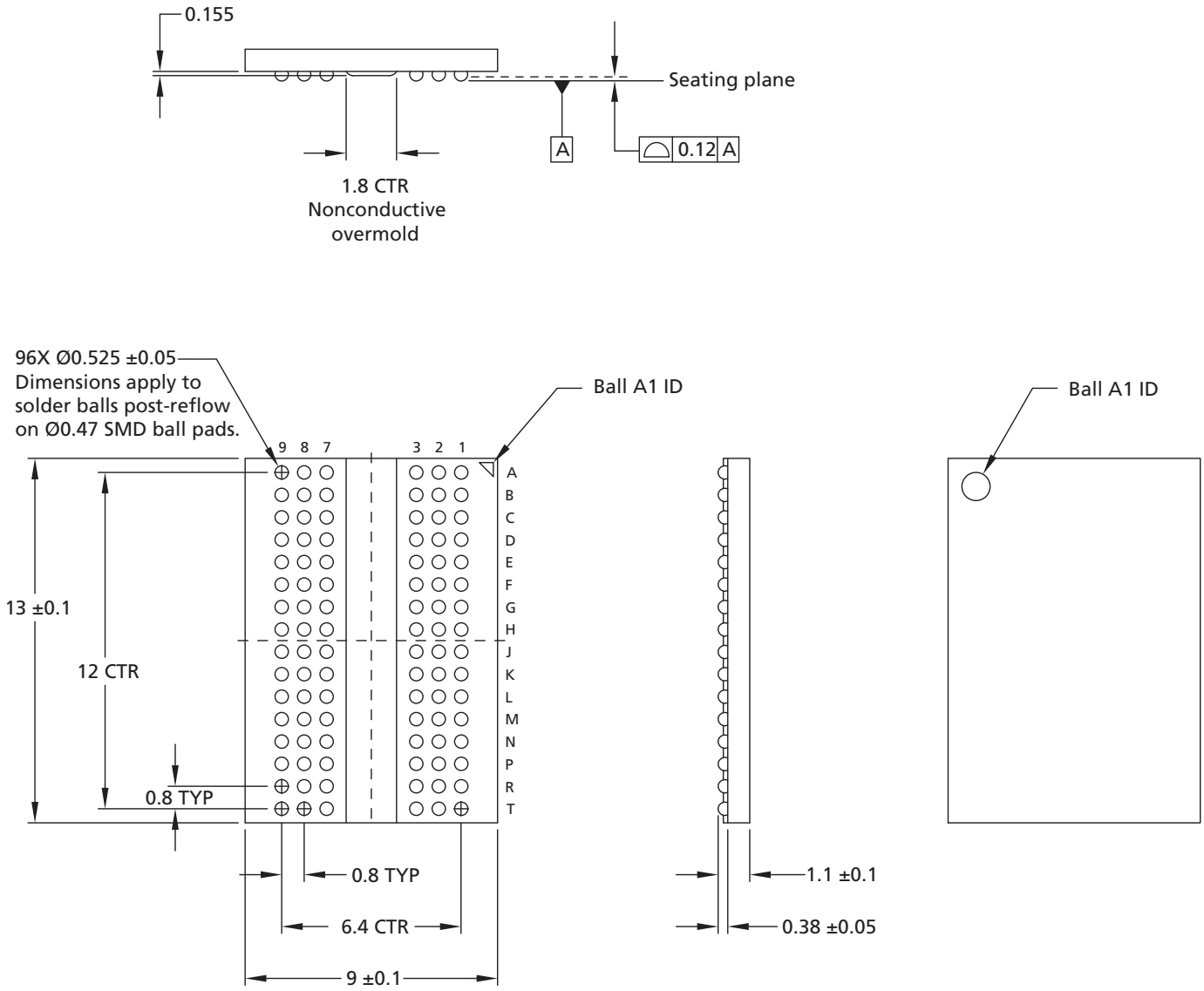
| Symbol | Type | Description |
|---|---|---|
| CKE | Input | **Clock enable:** CKE HIGH activates and CKE LOW deactivates the internal clock signals, device input buffers, and output drivers. Taking CKE LOW provides PRE-CHARGE POWER-DOWN and SELF REFRESH operations (all banks idle), or active power-down (row active in any bank). CKE is asynchronous for self refresh exit, however, timing parameters such as $^{t}$XS are still calculated from the first rising clock edge where CKE HIGH satisfies $^{t}$IS. After $V_{REFCA}$ has become stable during the power-on and initialization sequence, it must be maintained during all operations (including SELF REFRESH). CKE must be maintained HIGH throughout read and write accesses. Input buffers (ex-cluding CK_t, CK_c, ODT, RESET_n, and CKE) are disabled during power-down. Input buffers (excluding CKE and RESET_n) are disabled during self refresh. |
| CS_n | Input | **Chip select:** All commands are masked when CS_n is registered HIGH. CS_n provides for external rank selection on systems with multiple ranks. CS_n is considered part of the command code. |
| UDM_n<br>LDM_n | Input | **Input data mask:** DM_n is an input mask signal for write data. Input data is masked when DM is sampled LOW coincident with that input data during a write access. DM is sampled on both edges of DQS. The UDM_n and LDM_n pins are used in the x16 configuration: UDM_n is associated with DQ[15:8]; LDM_n is associated with DQ[7:0]. The DM, DBI, and TDQS functions are en-abled by mode register settings. See the Data Mask section. |
| ODT | Input | **On-die termination:** ODT (registered HIGH) enables termination resistance internal to the DDR4 SDRAM. For the x16 configuration, $R_{TT}$ is applied to each DQ, UDQS_t, UDQS_c, LDQS_t, LDQS_c, UDM_n, and LDM_n signal.<br>The ODT pin will be ignored if the mode registers are programmed to disable $R_{TT}$. |
| PAR | Input | **Parity for command and address:** This function can be enabled or disabled via the mode register. When enabled, the parity signal covers all command and address inputs, including ACT_n, RAS_n/A16, CAS_n/A15, WE_n/A14, A[16:0], A10/AP, A12/BC_n, BA[1:0], and BG[0] with C0, C1, and C2 on 3DS only devices. Control pins NOT covered by the parity signal are CS_n, CKE, and ODT. Unused address pins that are density and configuration-specific should be treated internally as 0s by the DRAM parity logic. Command and address inputs will have parity check performed when commands are latched via the rising edge of CK_t and when CS_n is LOW. |
| RAS_n/A16,<br>CAS_n/A15,<br>WE_n/A14 | Input | **Command inputs:** RAS_n/A16, CAS_n/A15, and WE_n/A14 (along with CS_n and ACT_n) define the command and/or address being entered. See the ACT_n description in this table. |
| RESET_n | Input | **Active LOW asynchronous reset:** Reset is active when RESET_n is LOW, and inactive when RESET_n is HIGH. RESET_n must be HIGH during normal operation. RESET_n is a CMOS rail-to-rail signal with DC HIGH and LOW at 80% and 20% of $V_{DD}$ (960 mV for DC HIGH and 240 mV for DC LOW). |
| TEN | Input | **Connectivity test mode:** TEN is active when HIGH and inactive when LOW. TEN must be LOW during normal operation. TEN is a CMOS rail-to-rail signal with DC HIGH and LOW at 80% and 20% of $V_{DD}$ (960mV for DC HIGH and 240mV for DC LOW). On Alliance 3DS devices, connectivity test mode is not supported and the TEN pin should be considered NF maintained LOW at all times. |

**Table 3: Ball Descriptions (Continued)**

| Symbol | Type | Description |
|---|---|---|
| DQ | I/O | **Data input/output:** Bidirectional data bus. DQ represents DQ[15:0] for the x16 configurations, respectively. If write CRC is enabled via mode register, the write CRC code is added at the end of data burst. Any one or all of DQ0, DQ1, DQ2, and DQ3 may be used to monitor the internal $V_{REF}$ level during test via mode register setting MR[4] A[4] = HIGH, training times change when enabled. During this mode, the $R_{TT}$ value should be set to High-Z. This measurement is for verification purposes and is NOT an external voltage supply pin. |
| UDBI_n, LDBI_n | I/O | **DBI input/output:** Data bus inversion. UDBI_n and LDBI_n are used in the x16 configuration; UDBI_n is associated with DQ[15:8], and LDBI_n is associated with DQ[7:0]. The DBI feature is not supported on the x4 configuration. DBI is not supported for 3DS devices and should be disabled in MR5. DBI can be configured for both READ (out-put) and WRITE (input) operations depending on the mode register settings. The DM, DBI functions are enabled by mode register settings. See the Data Bus In-version section. |
| DQS_t, DQS_c, UDQS_t, UDQS_c, LDQS_t, LDQS_c | I/O | **Data strobe:** Output with READ data, input with WRITE data. Edge-aligned with READ data, centered-aligned with WRITE data. For the x16, LDQS corresponds to the data on DQ[7:0]; UDQS corresponds to the data on DQ[15:8]. DDR4 SDRAM supports a differential data strobe only and does not support a single-ended data strobe. |
| ALERT_n | Output | **Alert output:** This signal allows the DRAM to indicate to the system's memory controller that a specific alert or event has occurred. Alerts will include the command/address parity error and the CRC data error when either of these functions is enabled in the mode register. |
| TDQS_t, TDQS_c | Output | **Termination data strobe:** TDQS_t and TDQS_c are used by x8 DRAMs only. When enabled via the mode register, the DRAM will enable the same $R_{TT}$ termination resistance on TDQS_t and TDQS_c that is applied to DQS_t and DQS_c. When the TDQS function is disabled via the mode register, the DM/TDQS_t pin will provide the DATA MASK (DM) function, and the TDQS_c pin is not used. The TDQS function must be disabled in the mode register for both the x4 and x16 configurations. The DM function is supported only in x8 and x16 configurations. |
| $V_{DD}$ | Supply | **Power supply:** 1.2V ±0.060V. |
| $V_{DDQ}$ | Supply | **DQ power supply:** 1.2V ±0.060V. |
| $V_{PP}$ | Supply | **DRAM activating power supply:** 2.5V –0.125V/+0.250V. |
| $V_{REFCA}$ | Supply | Reference voltage for control, command, and address pins. |
| $V_{SS}$ | Supply | Ground. |
| $V_{SSQ}$ | Supply | DQ ground. |
| ZQ | Reference | **Reference ball for ZQ calibration:** This ball is tied to an external 240Ω resistor (RZQ), which is tied to $V_{SSQ}$. |
| RFU | – | Reserved for future use. |
| NC | – | **No connect:** No internal electrical connection is present. |
| NF | – | **No function:** Internal connection is present but has no function. |

## Package Dimensions

**Figure 3: 96-Ball FBGA – x16**




Notes: 1. All dimensions are in millimeters.
2. Solder ball material: SACQ (92.45% Sn, 4% Ag, 0.5% Cu, 3% Bi, 0.05%Ni).

## State Diagram

This simplified state diagram provides an overview of the possible state transitions and the commands to control them. Situations involving more than one bank, the enabling or disabling of on-die termination, and some other events are not captured in full detail.

**Figure 4: Simplified State Diagram**

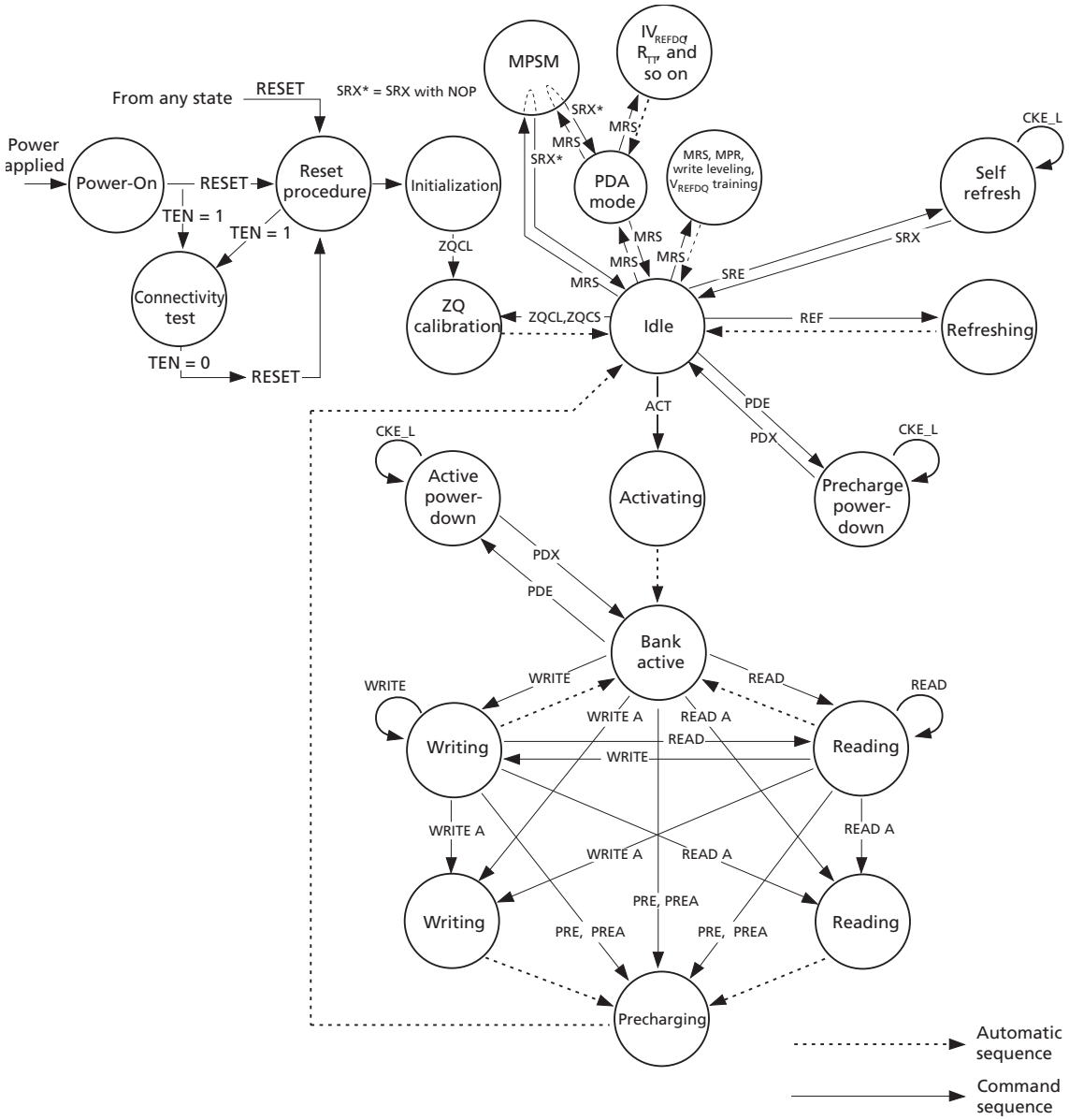


**Table 4: State Diagram Command Definitions**

| Command | Description |
|---|---|
| ACT | Active |
| MPR | Multipurpose register |
| MRS | Mode register set |
| PDE | Enter power-down |
| PDX | Exit power-down |
| PRE | Precharge |
| PREA | Precharge all |
| READ | RD, RDS4, RDS8 |
| READ A | RDA, RDAS4, RDAS8 |
| REF | Refresh, fine granularity refresh |
| RESET | Start reset procedure |
| SRE | Self refresh entry |
| SRX | Self refresh exit |
| TEN | Boundary scan mode enable |
| WRITE | WR, WRS4, WRS8 with/without CRC |
| WRITE A | WRA, WRAS4, WRAS8 with/without CRC |
| ZQCL | ZQ calibration long |
| ZQCS | ZQ calibration short |

Note: 1. See the Command Truth Table for more details.

## Functional Description

The DDR4 SDRAM is a high-speed dynamic random-access memory internally configured as eight banks for each bank group (2 bank groups with 4 banks each) for x16 devices. The device uses double data rate (DDR) architecture to achieve high-speed operation. DDR4 architecture is essentially an 8*n*-prefetch architecture with an interface designed to transfer two data words per clock cycle at the I/O pins. A single read or write access for a device module effectively consists of a single 8*n*-bit-wide, four-clock-cycle-data transfer at the internal DRAM core and eight corresponding *n*-bit-wide, one-half-clock-cycle data transfers at the I/O pins.

Read and write accesses to the device are burst-oriented. Accesses start at a selected location and continue for a burst length of eight or a chopped burst of four in a programmed sequence. Operation begins with the registration of an ACTIVE command, which is then followed by a READ or WRITE command. The address bits registered coincident with the ACTIVE command are used to select the bank and row to be accessed  BG0 selects the bank group for x16; BA[1:0] select the bank, and A[16:0] select the row. See the Addressing section for more details). The address bits registered coincident with the READ or WRITE command are used to select the starting column location for the burst operation, determine if the auto PRECHARGE command is to be issued (via A10), and select BC4 or BL8 mode on-the-fly (OTF) (via A12) if enabled in the mode register.

Prior to normal operation, the device must be powered up and initialized in a predefined manner. The following sections provide detailed information covering device reset and initialization, register definition, command descriptions, and device operation.

NOTE: The use of the NOP command is allowed only when exiting maximum power saving mode or when entering gear-down mode.

## RESET and Initialization Procedure

To ensure proper device function, the power-up and reset initialization default values for the following mode register (MR) settings are defined as:

- Gear-down mode (MR3 A[3]): 0 = 1/2 rate
- Per-DRAM addressability (MR3 A[4]): 0 = disable
- Maximum power-saving mode (MR4 A[1]): 0 = disable
- CS to command/address latency (MR4 A[8:6]): 000 = disable
- CA parity latency mode (MR5 A[2:0]): 000 = disable
- Hard post package repair mode (MR4 A[13]): 0 = disable
- Soft post package repair mode (MR4 A[5]): 0 = disable

### Power-Up and Initialization Sequence

The following sequence is required for power-up and initialization:

1. Apply power (RESET_n and TEN should be maintained below $0.2 \times V_{DD}$ while supplies ramp up; all other inputs may be undefined). When supplies have ramped to a valid stable level, RESET_n must be maintained below $0.2 \times V_{DD}$ for a minimum of $^{t}$PW_RESET_L and TEN must be maintained below $0.2 \times V_{DD}$ for a minimum of 700µs. CKE is pulled LOW anytime before RESET_n is de-asserted (minimum time of 10ns). The power voltage ramp time between 300mV to $V_{DD,min}$ must be no greater than 200ms, and during the ramp, $V_{DD}$ must be greater than or equal to $V_{DDQ}$ and ($V_{DD}$ - $V_{DDQ}$) < 0.3V. $V_{PP}$ must ramp at the same time or up to 10 minutes prior to $V_{DD}$, and $V_{PP}$ must be equal to or higher than $V_{DD}$ at all times. The total time for which $V_{PP}$ is powered and $V_{DD}$ is unpowered should not exceed 360 cumulative hours. After $V_{DD}$ has ramped and reached a stable level, RESET_n must go high within 10 minutes. After RESET_n goes high, the initialization sequence must be started within 3 seconds. For debug purposes, the 10 minute and 3 second delay limits may be extended to 60 minutes each provided the DRAM is operated in this debug mode for no more than 360 cumulative hours.

   During power-up, the supply slew rate is governed by the limits stated in the table below and either condition A or condition B listed below must be met.

**Table 5: Supply Power-up Slew Rate**

| Symbol | Min | Max | Unit | Comment |
|---|---|---|---|---|
| $V_{DD}$_SL, $V_{DDQ}$_SL, $V_{PP}$_SL | 0.004 | 600 | V/ms | Measured between 300mV and 80% of supply minimum |
| $V_{DD}$_ona | N/A | 200 | ms | $V_{DD}$ maximum ramp time from 300mV to $V_{DD}$ minimum |
| $V_{DDQ}$_ona | N/A | 200 | ms | $V_{DDQ}$ maximum ramp time from 300mV to $V_{DDQ}$ minimum |

Note: 1. 20 MHz band-limited measurement.

- Condition A:
  – Apply $V_{PP}$ without any slope reversal before or at the same time as $V_{DD}$ and $V_{DDQ}$.

  - $V_{DD}$ and $V_{DDQ}$ are driven from a single-power converter output and apply $V_{DD}/V_{DDQ}$ without any slope reversal before or at the same time as $V_{TT}$ and $V_{REFCA}$.
  - The voltage levels on all balls other than $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ must be less than or equal to $V_{DDQ}$ and $V_{DD}$ on one side and must be greater than or equal to $V_{SSQ}$ and $V_{SS}$ on the other side.
  - $V_{TT}$ is limited to 0.76V MAX when the power ramp is complete.
  - $V_{REFCA}$ tracks $V_{DD}/2$.
- Condition B:
  - Apply $V_{PP}$ without any slope reversal before or at the same time as $V_{DD}$.
  - Apply $V_{DD}$ without any slope reversal before or at the same time as $V_{DDQ}$.
  - Apply $V_{DDQ}$ without any slope reversal before or at the same time as $V_{TT}$ and $V_{REFCA}$.
  - The voltage levels on all pins other than $V_{PP}$, $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ must be less than or equal to $V_{DDQ}$ and $V_{DD}$ on one side and must be larger than or equal to $V_{SSQ}$ and $V_{SS}$ on the other side.

2. After RESET_n is de-asserted, wait for a minimum of 500us, but no longer than 3 seconds, before allowing CKE to be registered HIGH at clock edge Td. During this time, the device will start internal state initialization; this will be done independently of external clocks. A reasonable attempt was made in the design to power up with the following default MR settings: gear-down mode (MR3 A[3]): 0 = 1/2 rate; per-DRAM addressability (MR3 A[4]): 0 = disable; maximum power-down (MR4 A[1]): 0 = disable; CS to command/address latency (MR4 A[8:6]): 000 = disable; CA parity latency mode (MR5 A[2:0]): 000 = disable. However, it should be assumed that at power up the MR settings are undefined and should be programmed as shown below.
3. Clocks (CK_t, CK_c) need to be started and stabilized for at least 10ns or 5 $^{t}$CK (whichever is larger) before CKE is registered HIGH at clock edge Td. Because CKE is a synchronous signal, the corresponding setup time to clock ($^{t}$IS) must be met. Also, a DESELECT command must be registered (with $^{t}$IS setup time to clock) at clock edge Td. After the CKE is registered HIGH after RESET, CKE needs to be continuously registered HIGH until the initialization sequence is finished, including expiration of $^{t}$DLLK and $^{t}$ZQinit.
4. The device keeps its ODT in High-Z state as long as RESET_n is asserted. Further, the SDRAM keeps its ODT in High-Z state after RESET_n de-assertion until CKE is registered HIGH. The ODT input signal may be in an undefined state until $^{t}$IS before CKE is registered HIGH. When CKE is registered HIGH, the ODT input signal may be statically held either LOW or HIGH. If $R_{TT(NOM)}$ is to be enabled in MR1, the ODT input signal must be statically held LOW. In all cases, the ODT input sig-nal remains static until the power-up initialization sequence is finished, including the expiration of $^{t}$DLLK and $^{t}$ZQinit.
5. After CKE is registered HIGH, wait a minimum of RESET CKE EXIT time, $^{t}$XPR, before issuing the first MRS command to load mode register ($^{t}$XPR = MAX ($^{t}$XS, 5 × $^{t}$CK).
6. Issue MRS command to load MR3 with all application settings, wait $^{t}$MRD.
7. Issue MRS command to load MR6 with all application settings, wait $^{t}$MRD.
8. Issue MRS command to load MR5 with all application settings, wait $^{t}$MRD.
9. Issue MRS command to load MR4 with all application settings, wait $^{t}$MRD.
10. Issue MRS command to load MR2 with all application settings, wait $^{t}$MRD.
11. Issue MRS command to load MR1 with all application settings, wait $^{t}$MRD.

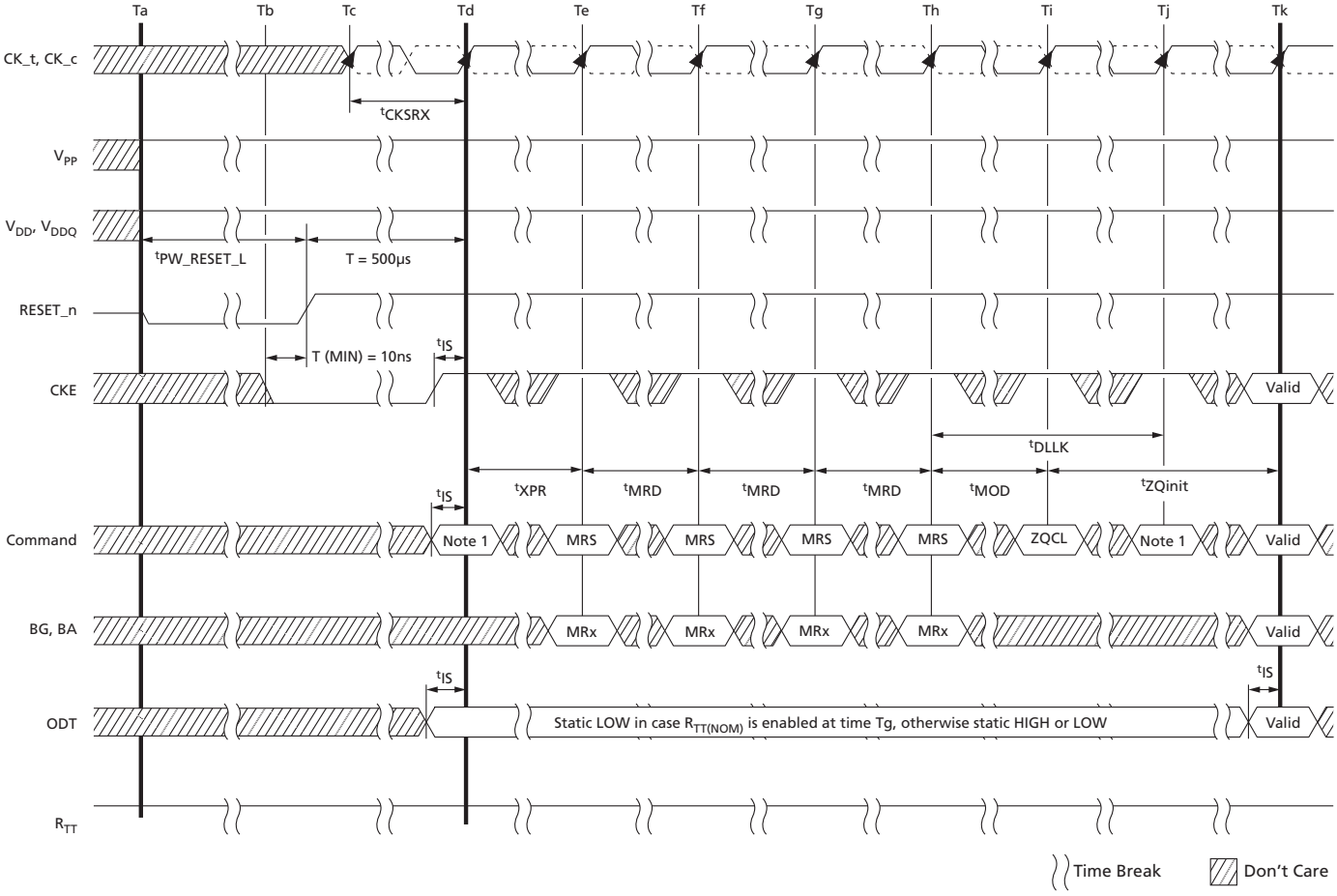
12. Issue MRS command to load MR0 with all application settings, wait $^{t}$MOD.
13. Issue a ZQCL command to start ZQ calibration.
14. Wait for $^{t}$DLLK and $^{t}$ZQinit to complete.
15. The device will be ready for normal operation. Once the DRAM has been initialized, if the DRAM is in an idle state longer than 960ms, then either (a) REF commands must be issued within $^{t}$REFI constraints (specification for posting allowed) or (b) CKE or CS_n must toggle once within every 960ms interval of idle time. For debug purposes, the 960ms delay limit maybe extended to 60 minutes provided the DRAM is operated in this debug mode for no more than 360 cumulative hours.

A stable valid $V_{DD}$ level is a set DC level (0Hz to 250 KHz) and must be no less than $V_{DD,min}$ and no greater than $V_{DD,max}$. If the set DC level is altered anytime after initialization, the DLL reset and calibrations must be performed again after the new set DC level is stable. AC noise of ±60mV (greater than 250 KHz) is allowed on $V_{DD}$ provided the noise doesn't alter $V_{DD}$ to less than $V_{DD,min}$ or greater than $V_{DD,max}$.

A stable valid $V_{DDQ}$ level is a set DC level (0Hz to 250 KHz) and must be no less than $V_{DDQ,min}$ and no greater than $V_{DDQ,max}$. If the set DC level is altered anytime after initialization, the DLL reset and calibrations must be performed again after the new set DC level is stable. AC noise of ±60mV (greater than 250 KHz) is allowed on $V_{DDQ}$ provided the noise doesn't alter $V_{DDQ}$ to less than $V_{DDQ,min}$ or greater than $V_{DDQ,max}$.

A stable valid $V_{PP}$ level is a set DC level (0Hz to 250 KHz) and must be no less than $V_{PP,min}$ and no greater than $V_{PP,max}$. If the set DC level is altered anytime after initialization, the DLL reset and calibrations must be performed again after the new set DC level is stable. AC noise of ±120mV (greater than 250KHz) is allowed on $V_{PP}$ provided the noise doesn't alter $V_{PP}$ to less than $V_{PP,min}$ or greater than $V_{PP,max}$.

**Figure 5: RESET and Initialization Sequence at Power-On Ramping**




Notes:
1. From time point Td until Tk, a DES command must be applied between MRS and ZQCL commands.
2. MRS commands must be issued to all mode registers that have defined settings.
3. In general, there is no specific sequence for setting the MRS locations (except for dependent or co-related features, such as ENABLE DLL in MR1 prior to RESET DLL in MR0, for example).
4. TEN is not shown; however, it is assumed to be held LOW.

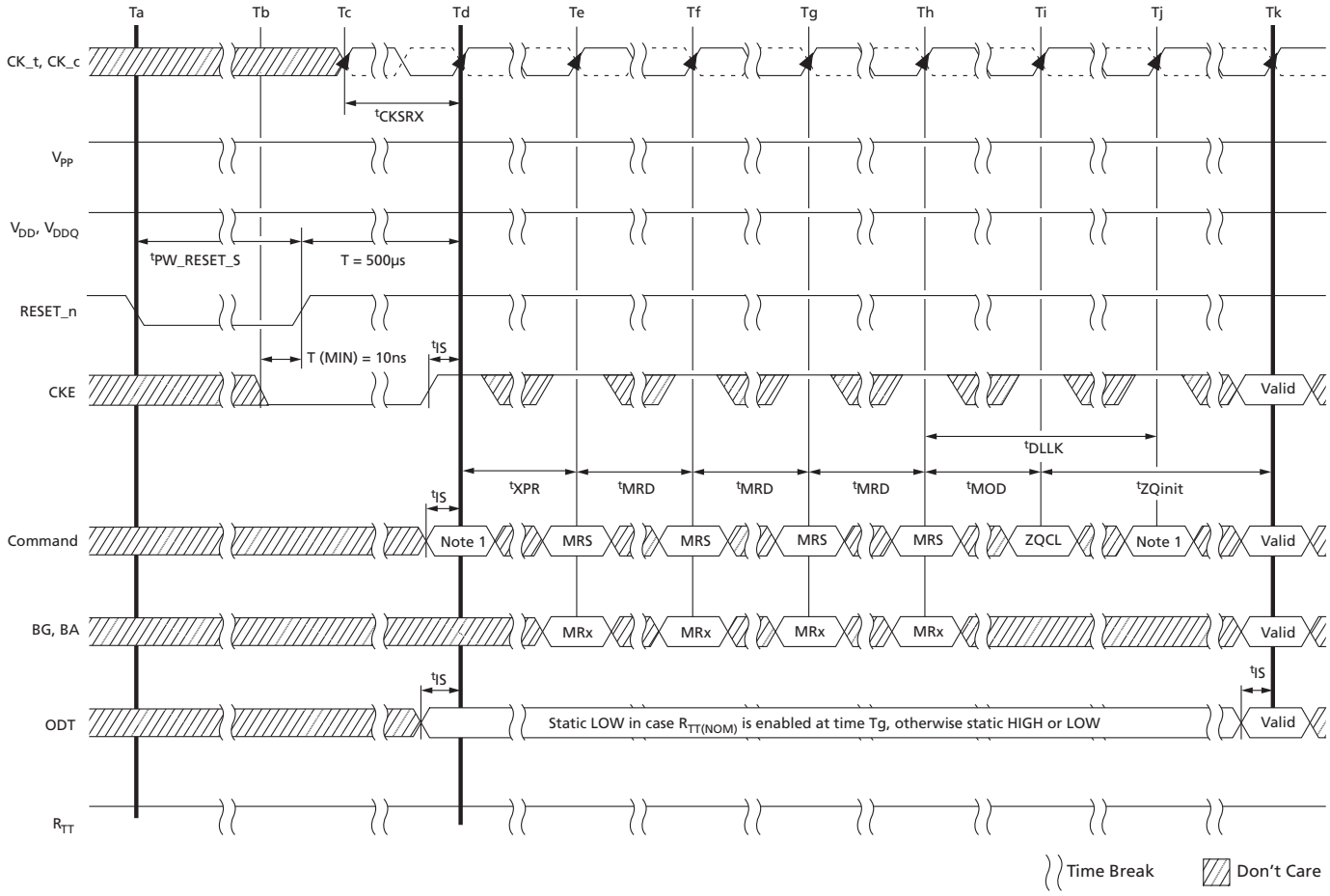
## RESET Initialization with Stable Power Sequence

The following sequence is required for RESET at no power interruption initialization:

1. Assert RESET_n below $0.2 \times V_{DD}$ any time when reset is needed (all other inputs may be undefined). RESET_n needs to be maintained for minimum $^{t}$PW_RESET. CKE is pulled LOW before RESET_n being de-asserted (minimum time 10ns).
2. Follow Steps 2 through 10 in the Reset and Initialization Sequence at Power-On Ramping procedure.

When the reset sequence is complete, all counters except the refresh counters have been reset and the device is ready for normal operation.

**Figure 6: RESET Procedure at Power Stable Condition**




Notes:
1. From time point Td until Tk, a DES command must be applied between MRS and ZQCL commands.
2. MRS commands must be issued to all mode registers that have defined settings.
3. In general, there is no specific sequence for setting the MRS locations (except for dependent or co-related features, such as ENABLE DLL in MR1 prior to RESET DLL in MR0, for example).
4. TEN is not shown; however, it is assumed to be held LOW.

## Uncontrolled Power-Down Sequence

In the event of an uncontrolled ramping down of $V_{PP}$ supply, $V_{PP}$ is allowed to be less than $V_{DD}$ provided the following conditions are met:

- Condition A: $V_{PP}$ and $V_{DD}/V_{DDQ}$ are ramping down (as part of turning off) from normal operating levels.
- Condition B: The amount that $V_{PP}$ may be less than $V_{DD}/V_{DDQ}$ is less than or equal to 500mV.
- Condition C: The time $V_{PP}$ may be less than $V_{DD}$ is ≤10ms per occurrence with a total accumulated time in this state ≤100ms.

- Condition D: The time $V_{PP}$ may be less than 2.0V and above $V_{SS}$ while turning off is ≤15ms per occurrence with a total accumulated time in this state ≤150ms.

## Programming Mode Registers

For application flexibility, various functions, features, and modes are programmable in seven mode registers (MR*n*) provided by the device as user defined variables that must be programmed via a MODE REGISTER SET (MRS) command. Because the default values of the mode registers are not defined, contents of mode registers must be fully initialized and/or re-initialized; that is, they must be written after power-up and/or reset for proper operation. The contents of the mode registers can be altered by re-executing the MRS command during normal operation. When programming the mode registers, even if the user chooses to modify only a sub-set of the MRS fields, all address fields within the accessed mode register must be redefined when the MRS command is issued. MRS and DLL RESET commands do not affect array contents, which means these commands can be executed any time after power-up without affecting the array contents.

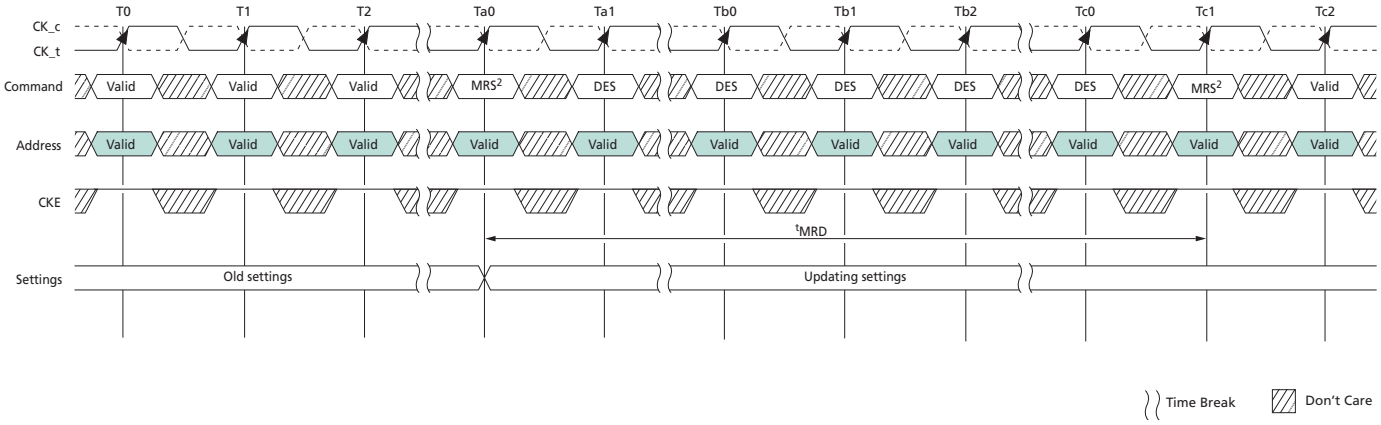
The MRS command cycle time, $^{t}$MRD, is required to complete the WRITE operation to the mode register and is the minimum time required between the two MRS commands shown in the $^{t}$MRD Timing figure.

Some of the mode register settings affect address/command/control input functionality. In these cases, the next MRS command can be allowed when the function being up-dated by the current MRS command is completed. These MRS commands don't apply $^{t}$MRD timing to the next MRS command; however, the input cases have unique MR setting procedures, so refer to individual function descriptons:

- Gear-down mode
- Per-DRAM addressability
- CMD address latency
- CA parity latency mode
- $V_{REFDQ}$ training value
- $V_{REFDQ}$ training mode
- $V_{REFDQ}$ training range

Some mode register settings may not be supported because they are not required by certain speed bins.

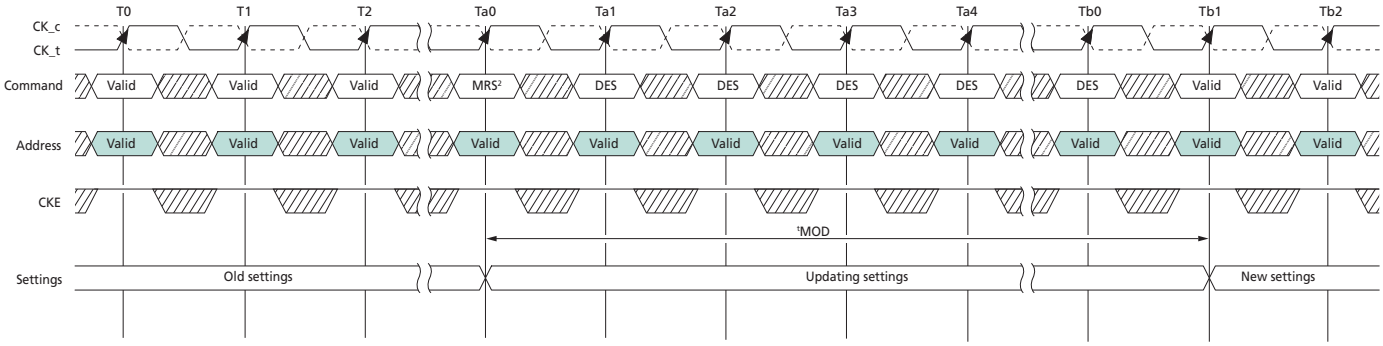
**Figure 7: $^{t}$MRD Timing**




Notes:
1. This timing diagram depicts CA parity mode "disabled" case.
2. $^{t}$MRD applies to all MRS commands with the following exceptions:
   Gear-down mode
   CA parity latency mode
   CMD address latency
   Per-DRAM addressability mode
   $V_{REFDQ}$ training value, $V_{REFDQ}$ training mode, and $V_{REFDQ}$ training range

The MRS command to nonMRS command delay, $^{t}$MOD, is required for the DRAM to update features, except for those noted in note 2 in figure below where the individual function descriptions may specify a different requirement. $^{t}$MOD is the minimum time required from an MRS command to a nonMRS command, excluding DES, as shown in the $^{t}$MOD Timing figure.

**Figure 8: $^{t}$MOD Timing**




Notes:
1. This timing diagram depicts CA parity mode "disabled" case.
2. $^{t}$MOD applies to all MRS commands with the following exceptions:
   DLL enable, DLL RESET, Gear-down mode
   $V_{REFDQ}$ training value, internal $V_{REF}$ training monitor, $V_{REFDQ}$ training mode, and $V_{REFDQ}$ training range

   Maximum power savings mode , Per-DRAM addressability mode, and CA parity latency mode

The mode register contents can be changed using the same command and timing requirements during normal operation as long as the device is in idle state; that is, all banks are in the pre-charged state with $^{t}$RP satisfied, all data bursts are completed, and CKE is HIGH prior to writing into the mode register. If the $R_{TT(NOM)}$ feature is enabled in the mode register prior to and/or after an MRS command, the ODT signal must continuously be registered LOW, ensuring $R_{TT}$ is in an off state prior to the MRS command. The ODT signal may be registered HIGH after $^{t}$MOD has expired. If the $R_{TT(NOM)}$ feature is disabled in the mode register prior to and after an MRS command, the ODT signal can be registered either LOW or HIGH before, during, and after the MRS command. The mode registers are divided into various fields depending on functionality and modes.
In some mode register setting cases, function updating takes longer than $^{t}$MOD. This type of MRS does not apply $^{t}$MOD timing to the next valid command, excluding DES. These MRS command input cases have unique MR setting procedures, so refer to individual function descriptions.

## Mode Register 0

Mode register 0 (MR0) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR0 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR0 Register Definition table.

**Table 6: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET command.

**Table 7: MR0 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>**000 = MR0**<br>001 = MR1<br>010 = MR2<br>011 = MR3<br>100 = MR4<br>101 = MR5<br>110 = MR6<br>111 = DNU |
| 17 | **N/A on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 13,11:9 | **WR (WRITE recovery)/RTP (READ-to-PRECHARGE)**<br>0000 = 10 / 5 clocks[1]<br>0001 = 12 / 6 clocks<br>0010 = 14 / 7 clocks[1]<br>0011 = 16 / 8 / clocks<br>0100 = 18 / 9 clocks[1]<br>0101 = 20 /10 clocks<br>0110 = 24 / 12 clocks<br>0111 = 22 / 11 clocks[1]<br>1000 = 26 / 13 clocks[1]<br>1001 = 28 / 14 clocks[2]<br>1010 through 1111 = Reserved |

**Table 7: MR0 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 8 | **DLL reset**<br>0 = No<br>1 = Yes |
| 7 | **Test mode (TM) – Manufacturer use only**<br>0 = Normal operating mode, must be programmed to 0 |
| 12, 6:4, 2 | **CAS latency (CL) – Delay in clock cycles from the internal READ command to first data-out**<br>00000 = 9 clocks[1]<br>00001 = 10 clocks<br>00010 = 11 clocks[1]<br>00011 = 12 clocks<br>00100 = 13 clocks[1]<br>00101 = 14 clocks<br>00110 = 15 clocks[1]<br>00111 = 16 clocks<br>01000 = 18 clocks<br>01001 = 20 clocks<br>01010 = 22 clocks<br>01011 = 24 clocks<br>01100 = 23 clocks[1]<br>01101 = 17 clocks[1]<br>01110 = 19 clocks[1]<br>01111 = 21 clocks [1]<br>10000 = 25 clocks<br>10001 = 26 clocks<br>10011 = 28 clocks<br>10100 = 29 clocks[1]<br>10101 = 30 clocks<br>10110 = 31 clocks[1]<br>10111 = 32 clocks |
| 3 | **Burst type (BT) – Data burst ordering within a READ or WRITE burst access**<br>0 = Nibble sequential<br>1 = Interleave |
| 1:0 | **Burst length (BL) – Data burst size associated with each read or write access**<br>00 = BL8 (fixed)<br>01 = BC4 or BL8 (on-the-fly)<br>10 = BC4 (fixed)<br>11 = Reserved |

Notes: 1. Not allowed when 1/4 rate gear-down mode is enabled.
2. If WR requirement exceeds 28 clocks or RTP exceeds 14 clocks, WR should be set to 28 clocks and RTP should be set to 14 clocks.

## Burst Length, Type, and Order

Accesses within a given burst may be programmed to sequential or interleaved order. The ordering of accesses within a burst is determined by the burst length, burst type,

and the starting column address as shown in the following table. Burst length options include fixed BC4, fixed BL8, and on-the-fly (OTF), which allows BC4 or BL8 to be selected coincidentally with the registration of a READ or WRITE command via A12/BC_n.

**Table 8: Burst Type and Burst Order**

Note 1 applies to the entire table

| Burst Length | READ/ WRITE | Starting Column Address (A[2, 1, 0]) | Burst Type = Sequential (Decimal) | Burst Type = Interleaved (Decimal) | Notes |
|---|---|---|---|---|---|
| BC4 | READ | 0 0 0 | 0, 1, 2, 3, T, T, T, T | 0, 1, 2, 3, T, T, T, T | 2, 3 |
| | | 0 0 1 | 1, 2, 3, 0, T, T, T, T | 1, 0, 3, 2, T, T, T, T | 2, 3 |
| | | 0 1 0 | 2, 3, 0, 1, T, T, T, T | 2, 3, 0, 1, T, T, T, T | 2, 3 |
| | | 0 1 1 | 3, 0, 1, 2, T, T, T, T | 3, 2, 1, 0, T, T, T, T | 2, 3 |
| | | 1 0 0 | 4, 5, 6, 7, T, T, T, T | 4, 5, 6, 7, T, T, T, T | 2, 3 |
| | | 1 0 1 | 5, 6, 7, 4, T, T, T, T | 5, 4, 7, 6, T, T, T, T | 2, 3 |
| | | 1 1 0 | 6, 7, 4, 5, T, T, T, T | 6, 7, 4, 5, T, T, T, T | 2, 3 |
| | | 1 1 1 | 7, 4, 5, 6, T, T, T, T | 7, 6, 5, 4, T, T, T, T | 2, 3 |
| | WRITE | 0, V, V | 0, 1, 2, 3, X, X, X, X | 0, 1, 2, 3, X, X, X, X | 2, 3 |
| | | 1, V, V | 4, 5, 6, 7, X, X, X, X | 4, 5, 6, 7, X, X, X, X | 2, 3 |
| BL8 | READ | 0 0 0 | 0, 1, 2, 3, 4, 5, 6, 7 | 0, 1, 2, 3, 4, 5, 6, 7 | |
| | | 0 0 1 | 1, 2, 3, 0, 5, 6, 7, 4 | 1, 0, 3, 2, 5, 4, 7, 6 | |
| | | 0 1 0 | 2, 3, 0, 1, 6, 7, 4, 5 | 2, 3, 0, 1, 6, 7, 4, 5 | |
| | | 0 1 1 | 3, 0, 1, 2, 7, 4, 5, 6 | 3, 2, 1, 0, 7, 6, 5, 4 | |
| | | 1 0 0 | 4, 5, 6, 7, 0, 1, 2, 3 | 4, 5, 6, 7, 0, 1, 2, 3 | |
| | | 1 0 1 | 5, 6, 7, 4, 1, 2, 3, 0 | 5, 4, 7, 6, 1, 0, 3, 2 | |
| | | 1 1 0 | 6, 7, 4, 5, 2, 3, 0, 1 | 6, 7, 4, 5, 2, 3, 0, 1 | |
| | | 1 1 1 | 7, 4, 5, 6, 3, 0, 1, 2 | 7, 6, 5, 4, 3, 2, 1, 0 | |
| | WRITE | V, V, V | 0, 1, 2, 3, 4, 5, 6, 7 | 0, 1, 2, 3, 4, 5, 6, 7 | 3 |

Notes:
1. 0...7 bit number is the value of CA[2:0] that causes this bit to be the first read during a burst.
2. When setting burst length to BC4 (fixed) in MR0, the internal WRITE operation starts two clock cycles earlier than for the BL8 mode, meaning the starting point for $^{t}$WR and $^{t}$WTR will be pulled in by two clocks. When setting burst length to OTF in MR0, the internal WRITE operation starts at the same time as a BL8 (even if BC4 was selected during column time using A12/BC4_n) meaning that if the OTF MR0 setting is used, the starting point for $^{t}$WR and $^{t}$WTR will not be pulled in by two clocks as described in the BC4 (fixed) case.
3. T = Output driver for data and strobes are in High-Z.
   V = Valid logic level (0 or 1), but respective buffer input ignores level on input pins.
   X = "Don't Care."

## CAS Latency

The CAS latency (CL) setting is defined in the MR0 Register Definition table. CAS latency is the delay, in clock cycles, between the internal READ command and the availability of the first bit of output data. The device does not support half-clock latencies. The

overall read latency (RL) is defined as additive latency (AL) + CAS latency (CL): RL = AL + CL.

## Test Mode

The normal operating mode is selected by MR0[7] and all other bits set to the desired values shown in the MR0 Register Definition table. Programming MR0[7] to a value of 1 places the device into a DRAM manufacturer-defined test mode to be used only by the manufacturer, not by the end user. No operations or functionality is specified if MR0[7] = 1.

## Write Recovery (WR)/READ-to-PRECHARGE

The programmed write recovery (WR) value is used for the auto pre-charge feature along with $^{t}$RP to determine $^{t}$DAL. WR for auto pre-charge (MIN) in clock cycles is calculated by dividing $^{t}$WR (in ns) by $^{t}$CK (in ns) and rounding to the next integer using the rounding algorithms found in the Converting Time-Based Specifications to Clock-Based Requirements section. The WR value must be programmed to be equal to or larger than $^{t}$WR (MIN). When both DM and write CRC are enabled in the mode register, the device calculates CRC before sending the write data into the array; $^{t}$WR values will change when enabled. If there is a CRC error, the device blocks the WRITE operation and discards the data.

Internal READ-to-PRE-CHARGE (RTP) command delay for auto pre-charge (MIN) in clock cycles is calculated by dividing $^{t}$RTP (in ns) by $^{t}$CK (in ns) and rounding to the next integer using the rounding algorithms found in the Converting Time-Based Specifications to Clock-Based Requirements section. The RTP value in the mode register must be programmed to be equal to or larger than RTP (MIN). The programmed RTP value is used with $^{t}$RP to determine the ACT timing to the same bank.

## DLL RESET

The DLL reset bit is self-clearing, meaning that it returns to the value of 0 after the DLL RESET function has been issued. After the DLL is enabled, a subsequent DLL RESET should be applied. Any time the DLL RESET function is used, $^{t}$DLLK must be met before functions requiring the DLL can be used. Such as READ commands or synchronous ODT operations, for example.

## Mode Register 1

Mode register 1 (MR1) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR1 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR1 Register Definition table.

**Table 9: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET command.

**Table 10: MR1 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>000 = MR0<br>**001 = MR1**<br>010 = MR2<br>011 = MR3<br>100 = MR4<br>101 = MR5<br>110 = MR6<br>111 = DNU |
| 17 | **N/A on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 12 | **Data output disable (Qoff) – Output buffer disable**<br>0 = Enabled (normal operation)<br>1 = Disabled (both ODI and $R_{TT}$) |
| 11 | **Termination data strobe (TDQS) – Additional termination pins (x8 configuration only)**<br>0 = TDQS disabled<br>1 = TDQS enabled |

**Table 10: MR1 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 10, 9, 8 | **Nominal ODT ($R_{TT(NOM)}$ – Data bus termination setting**<br>000 = $R_{TT(NOM)}$ disabled<br>001 = RZQ/4 (60 ohm)<br>010 = RZQ/2 (120 ohm)<br>011 = RZQ/6 (40 ohm)<br>100 = RZQ/1 (240 ohm)<br>101 = RZQ/5 (48 ohm)<br>110 = RZQ/3 (80 ohm)<br>111 = RZQ/7 (34 ohm) |
| 7 | **Write leveling (WL) – Write leveling mode**<br>0 = Disabled (normal operation)<br>1 = Enabled (enter WL mode) |
| 13, 6, 5 | **Rx CTLE Control**<br>000 = Vendor Default<br>001 = Vendor Defined<br>010 = Vendor Defined<br>011 = Vendor Defined<br>100 = Vendor Defined<br>101 = Vendor Defined<br>110 = Vendor Defined<br>111 = Vendor Defined |
| 4, 3 | **Additive latency (AL) – Command additive latency setting**<br>00 = 0 (AL disabled)<br>01 = CL - 1[1]<br>10 = CL - 2<br>11 = Reserved |
| 2, 1 | **Output driver impedance (ODI) – Output driver impedance setting**<br>00 = RZQ/7 (34 ohm)<br>01 = RZQ/5 (48 ohm)<br>10 = Reserved (Although not JEDEC-defined and not tested, this setting will provide RZQ/6 or 40 ohm)<br>11 = Reserved |
| 0 | **DLL enable – DLL enable feature**<br>0 = DLL disabled<br>1 = DLL enabled (normal operation) |

Note: 1. Not allowed when 1/4 rate gear-down mode is enabled.

## DLL Enable/DLL Disable

The DLL must be enabled for normal operation and is required during power-up initialization and upon returning to normal operation after having the DLL disabled. During normal operation (DLL enabled with MR1[0]) the DLL is automatically disabled when entering the SELF REFRESH operation and is automatically re-enabled upon exit of the SELF REFRESH operation. Any time the DLL is enabled and subsequently reset,

$^{t}$DLLK clock cycles must occur before a READ or SYNCHRONOUS ODT command can be issued to allow time for the internal clock to be synchronized with the external clock. Failing

to wait for synchronization to occur may result in a violation of the $^{t}$DQSCK, $^{t}$AON, or $^{t}$AOF parameters.

During $^{t}$DLLK, CKE must continuously be registered HIGH. The device does not require DLL for any WRITE operation, except when $R_{TT(WR)}$ is enabled and the DLL is required for proper ODT operation.

The direct ODT feature is not supported during DLL off mode. The ODT resistors must be disabled by continuously registering the ODT pin LOW and/or by programming the $R_{TT(NOM)}$ bits MR1[9,6,2] = 000 via an MRS command during DLL off mode.

The dynamic ODT feature is not supported in DLL off mode; to disable dynamic ODT externally, use the MRS command to set $R_{TT(WR)}$, MR2[10:9] = 00.

## Output Driver Impedance Control

The output driver impedance of the device is selected by MR1[2,1], as shown in the MR1 Register Definition table.

## ODT $R_{TT(NOM)}$ Values

The device is capable of providing three different termination values: $R_{TT(Park)}$, $R_{TT(NOM)}$, and $R_{TT(WR)}$. The nominal termination value, $R_{TT(NOM)}$, is programmed in MR1. A separate value, $R_{TT(WR)}$, may be programmed in MR2 to enable a unique $R_{TT}$ value when ODT is enabled during WRITE operations. The $R_{TT(WR)}$ value can be applied during WRITE commands even when $R_{TT(NOM)}$ is disabled. A third $R_{TT}$ value, $R_{TT(Park)}$, is programed in MR5. $R_{TT(Park)}$ provides a termination value when the ODT signal is LOW.

## Additive Latency

The ADDITIVE LATENCY (AL) operation is supported to make command and data buses efficient for sustainable bandwidths in the device. In this operation, the device allows a READ or WRITE command (either with or without auto precharge) to be issued immediately after the ACTIVATE command. The command is held for the time of AL before it is issued inside the device. READ latency (RL) is controlled by the sum of the AL and CAS latency (CL) register settings. WRITE latency (WL) is controlled by the sum of the AL and CAS WRITE latency (CWL) register settings.

**Table 11: Additive Latency (AL) Settings**

| A4 | A3 | AL |
|---|---|---|
| 0 | 0 | 0 (AL disabled) |
| 0 | 1 | CL - 1 |
| 1 | 0 | CL - 2 |
| 1 | 1 | Reserved |

Note: 1. AL has a value of CL - 1 or CL - 2 based on the CL values programmed in the MR0 register

## Rx CTLE Control

The Mode Register for Rx CTLE Control MR1[A13,A6,A5] is vendor specific. Since CTLE circuits can not be typically bypassed a disable option is not provided. Instead, a vendor optimized setting is given. It should be noted that the settings are not specifically linear

in relationship to the vendor optimized setting, so the host may opt to instead walk through all the provided options and use the setting that works best in their environment.

## Write Leveling

For better signal integrity, the device uses fly-by topology for the commands, addresses, control signals, and clocks. Fly-by topology benefits from a reduced number of stubs and their lengths, but it causes flight-time skew between clock and strobe at every DRAM on the DIMM. This makes it difficult for the controller to maintain $^{t}$DQSS, $^{t}$DSS, and $^{t}$DSH specifications. Therefore, the device supports a write leveling feature that allows the controller to compensate for skew.

## Output Disable

The device outputs may be enabled/disabled by MR1[12] as shown in the MR1 Register Definition table. When MR1[12] is enabled (MR1[12] = 1) all output pins (such as DQ and DQS) are disconnected from the device, which removes any loading of the output drivers. For example, this feature may be useful when measuring module power. For normal operation, set MR1[12] to 0.

## Mode Register 2

Mode register 2 (MR2) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR2 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR2 Register Definition table.

**Table 12: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET command.

**Table 13: MR2 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>000 = MR0<br>001 = MR1<br>**010 = MR2**<br>011 = MR3<br>100 = MR4<br>101 = MR5<br>110 = MR6<br>111 = DNU |
| 17 | **N/A on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 13 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 12 | **WRITE data bus CRC**<br>0 = Disabled<br>1 = Enabled |

**Table 13: MR2 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 11:9 | **Dynamic ODT ($R_{TT(WR)}$) – Data bus termination setting during WRITEs**<br>000 = $R_{TT(WR)}$ disabled (WRITE does not affect $R_{TT}$ value)<br>001 = RZQ/2 (120 ohm)<br>010 = RZQ/1 (240 ohm)<br>011 = High-Z<br>100 = RZQ/3 (80 ohm)<br>101 = Reserved<br>110 = Reserved<br>111 = Reserved |
| 7:6 | **Low-power auto self refresh (LPASR) – Mode summary**<br>00 = Manual mode - Normal operating temperature range ($T_C$: -40°C–85°C)<br>01 = Manual mode - Reduced operating temperature range ($T_C$: -40°C–45°C)<br>10 = Manual mode - Extended operating temperature range ($T_C$: -40°C–95°<br>C) 11 = ASR mode - Automatically switching among all modes |
| 5:3 | **CAS WRITE latency (CWL) – Delay in clock cycles from the internal WRITE command to first data-in 1$^t$CK WRITE preamble**<br>000 = 9 (DDR4-1600)[1]<br>001 = 10 (DDR4-1866)<br>010 = 11 (DDR4-2133/1600)[1]<br>011 = 12 (DDR4-2400/1866)<br>100 = 14 (DDR4-2666/2133)<br>101 = 16 (DDR4-2933,3200/2400)<br>110 = 18 (DDR4-2666)<br>111 = 20 (DDR4-2933, 3200) |
| | **CAS WRITE latency (CWL) – Delay in clock cycles from the internal WRITE command to first data-in 2$^t$CK WRITE preamble**<br>000 = N/A<br>001 = N/A<br>010 = N/A<br>011 = N/A<br>100 = 14 (DDR4-2400)<br>101 = 16 (DDR4-2666/2400)<br>110 = 18 (DDR4-2933, 3200/2666)<br>111 = 20 (DDR4-2933, 3200) |
| 8, 2 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 1:0 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |

Note: 1. Not allowed when 1/4 rate gear-down mode is enabled.

## CAS WRITE Latency

CAS WRITE latency (CWL) is defined by MR2[5:3] as shown in the MR2 Register Definition table. CWL is the delay, in clock cycles, between the internal WRITE command and the availability of the first bit of input data. The device does not support any half-clock latencies. The overall WRITE latency (WL) is defined as additive latency (AL) + parity latency (PL) + CAS WRITE latency (CWL): WL = AL +PL + CWL.

## Low-Power Auto Self Refresh

Low-power auto self refresh (LPASR) is supported in the device. Applications requiring SELF REFRESH operation over different temperature ranges can use this feature to opti-mize the $I_{DD6}$ current for a given temperature range as specified in the MR2 Register Definition table.

## Dynamic ODT

In certain applications and to further enhance signal integrity on the data bus, it is desirable to change the termination strength of the device without issuing an MRS command. This may be done by configuring the dynamic ODT ($R_{TT(WR)}$) settings in MR2[11:9]. In write leveling mode, only $R_{TT(NOM)}$ is available.

## Write Cyclic Redundancy Check Data Bus

The write cyclic redundancy check (CRC) data bus feature during writes has been added to the device. When enabled via the mode register, the data transfer size goes from the normal 8-bit (BL8) frame to a larger 10-bit UI frame, and the extra two UIs are used for the CRC information.

## Mode Register 3

Mode register 3 (MR3) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR3 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR3 Register Definition table.

**Table 14: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET command.

**Table 15: MR3 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>000 = MR0<br>001 = MR1<br>010 = MR2<br>**011 = MR3**<br>100 = MR4<br>101 = MR5<br>110 = MR6<br>111 = DNU |
| 17 | **N/A on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 13 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 12:11 | **Multipurpose register (MPR) – Read format**<br>00 = Serial<br>01 = Parallel<br>10 = Staggered<br>11 = Reserved |
| 10:9 | **WRITE CMD latency when CRC/DM enabled**<br>00 = 4CK (DDR4-1600)<br>01 = 5CK (DDR4-1866/2133/2400/2666)<br>10 = 6CK (DDR4-2933/3200)<br>11 = Reserved |

**Table 15: MR3 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 8:6 | **Fine granularity refresh mode**<br>000 = Normal mode (fixed 1x)<br>001 = Fixed 2x<br>010 = Fixed 4x<br>011 = Reserved<br>100 = Reserved<br>101 = On-the-fly 1x/2x<br>110 = On-the-fly 1x/4x<br>111 = Reserved |
| 5 | **Temperature sensor status**<br>0 = Disabled<br>1 = Enabled |
| 4 | **Per-DRAM addressability**<br>0 = Normal operation (disabled)<br>1 = Enable |
| 3 | **Gear-down mode – Ratio of internal clock to external data rate**<br>0 = [1:1]; (1/2 rate data)<br>1 = [2:1]; (1/4 rate data) |
| 2 | **Multipurpose register (MPR) access**<br>0 = Normal operation<br>1 = Data flow from MPR |
| 1:0 | **MPR page select**<br>00 = Page 0<br>01 = Page 1<br>10 = Page 2<br>11 = Page 3 (restricted for DRAM manufacturer use only) |

## Multipurpose Register

The multipurpose register (MPR) is used for several features:

- Readout of the contents of the MR*n* registers
- WRITE and READ system patterns used for data bus calibration
- Readout of the error frame when the command address parity feature is enabled

To enable MPR, issue an MRS command to MR3[2] = 1. MR3[12:11] define the format of read data from the MPR. Prior to issuing the MRS command, all banks must be in the idle state (all banks precharged and $^{t}$RP met). After MPR is enabled, any subsequent RD or RDA commands will be redirected to a specific mode register.

The mode register location is specified with the READ command using address bits. The MR is split into upper and lower halves to align with a burst length limitation of 8. Power-down mode, SELF REFRESH, and any other nonRD/RDA or nonWR/WRA commands are not allowed during MPR mode. The RESET function is supported during MPR mode, which requires device re-initialization.

## WRITE Command Latency When CRC/DM is Enabled

The WRITE command latency (WCL) must be set when both write CRC and DM are enabled for write CRC persistent mode. This provides the extra time required when completing a WRITE burst when write CRC and DM are enabled. This means at data rates less than or equal to 1600 MT/s then 4nCK is used, 5nCK or 6nCK are not allowed; at data rates greater than 1600 MT/s and less than or equal to 2666 MT/s then 5nCK is used, 4nCK or 6nCK are not allowed; and at data rates greater than 2666 MT/s and less than or equal to 3200 MT/s then 6nCK is used; 4nCK or 5nCK are not allowed.

## Fine Granularity Refresh Mode

This mode had been added to DDR4 to help combat the performance penalty due to refresh lockout at high densities. Shortening $^{t}$RFC and decreasing cycle time allows more accesses to the chip and allows for increased scheduling flexibility.

## Temperature Sensor Status

This mode directs the DRAM to update the temperature sensor status at MPR Page 2, MPR0 [4,3]. The temperature sensor setting should be updated within 32ms; when an MPR read of the temperature sensor status bits occurs, the temperature sensor status should be no older than 32ms.

## Per-DRAM Addressability

This mode allows commands to be masked on a per device basis providing any device in a rank (devices sharing the same command and address signals) to be programmed individually. As an example, this feature can be used to program different ODT or $V_{REF}$ values on DRAM devices within a given rank.

## Gear-Down Mode

The device defaults in 1/2 rate (1N) clock mode and uses a low frequency MRS command followed by a sync pulse to align the proper clock edge for operating the control lines CS_n, CKE, and ODT when in 1/4 rate (2N) mode. For operation in 1/2 rate mode, no MRS command or sync pulse is required.

## Mode Register 4

Mode register 4 (MR4) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR4 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR4 Register Definition table.

**Table 16: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET (MRS) command.

**Table 17: MR4 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>000 = MR0<br>001 = MR1<br>010 = MR2<br>011 = MR3<br>**100 = MR4**<br>101 = MR5<br>110 = MR6<br>111 = DNU |
| 17 | **N/A on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 13 | **Hard Post Package Repair (hPPR mode)**<br>0 = Disabled<br>1 = Enabled |
| 12 | **WRITE preamble setting**<br>0 = 1$^{t}$CK toggle[1]<br>1 = 2$^{t}$CK toggle (When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.) |
| 11 | **READ preamble setting**<br>0 = 1$^{t}$CK toggle[1]<br>1 = 2$^{t}$CK toggle |
| 10 | **READ preamble training**<br>0 = Disabled<br>1 = Enabled |

**Table 17: MR4 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 9 | **Self refresh abort mode**<br>0 = Disabled<br>1 = Enabled |
| 8:6 | **CMD (CAL) address latency**<br>000 = 0 clocks (disabled)<br>001 =3 clocks[1]<br>010 = 4 clocks<br>011 = 5 clocks[1]<br>100 = 6 clocks<br>101 = 8 clocks<br>110 = Reserved<br>111 = Reserved |
| 5 | **soft Post Package Repair (sPPR mode)**<br>0 = Disabled<br>1 = Enabled |
| 4 | **Internal $V_{REF}$ monitor**<br>0 = Disabled<br>1 = Enabled |
| 3 | **Temperature controlled refresh mode**<br>0 = Disabled<br>1 = Enabled |
| 2 | **Temperature controlled refresh range**<br>0 = Normal temperature mode<br>1 = Extended temperature mode |
| 1 | **Maximum power savings mode**<br>0 = Normal operation<br>1 = Enabled |
| 0 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |

Note: 1. Not allowed when 1/4 rate gear-down mode is enabled.

## Hard Post Package Repair Mode

The hard post package repair (hPPR) mode feature is JEDEC optional for 4Gb DDR4 memories. Performing an MPR read to page 2 MPR0 [7] indicates whether hPPR mode is available (A7 = 1) or not available (A7 = 0). hPPR mode provides a simple and easy repair method of the device after placed in the system. One row per bank can be repaired. The repair process is irrevocable so great care should be exercised when using.

## Soft Post Package Repair Mode

The soft post package repair (sPPR) mode feature is JEDEC optional for 4Gb and 8Gb DDR4 memories. Performing an MPR read to page 2 MPR0 [6] indicates whether sPPR mode is available (A6 = 1) or not available (A6 = 0). sPPR mode provides a simple and

easy repair method of the device after placed in the system. One row per bank can be repaired. The repair process is revocable by either doing a reset or power-down or by rewriting a new address in the same bank.

## WRITE Preamble

Programmable WRITE preamble, $^{t}$WPRE, can be set to 1$^{t}$CK or 2$^{t}$CK via the MR4 register. The 1$^{t}$CK setting is similar to DDR3. However, when operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.

Some even settings will require addition of 2 clocks. If the alternate longer CWL was used, the additional clocks will not be required.

## READ Preamble

Programmable READ preamble $^{t}$RPRE can be set to 1$^{t}$CK or 2$^{t}$CK via the MR4 register. Both the 1$^{t}$CK and 2$^{t}$CK DDR4 preamble settings are different from that defined for the DDR3 SDRAM. Both DDR4 READ preamble settings may require the memory controller to train (or read level) its data strobe receivers using the READ preamble training.

## READ Preamble Training

Programmable READ preamble training can be set to 1$^{t}$CK or 2$^{t}$CK. This mode can be used by the memory controller to train or READ level its data strobe receivers.

## Temperature-Controlled Refresh

When temperature-controlled refresh mode is enabled, the device may adjust the internal refresh period to be longer than $^{t}$REFI of the normal temperature range by skipping external REFRESH commands with the proper gear ratio. For example, the DRAM temperature sensor detected less than 45°C. Normal temperature mode covers the range of -40°C to 85°C, while the extended temperature range covers -40°C to 95°C.

## Command Address Latency

COMMAND ADDRESS LATENCY (CAL) is a power savings feature and can be enabled or disabled via the MRS setting. CAL is defined as the delay in clock cycles ($^{t}$CAL) between a CS_n registered LOW and its corresponding registered command and address. The value of CAL (in clocks) must be programmed into the mode register according to the $^{t}$CAL(ns)/$^{t}$CK(ns) rounding algorithms found in the Converting Time-Based Specifications to Clock-Based Requirements section.

## Internal $V_{REF}$ Monitor

This mode enables output of internally generated $V_{REFDQ}$ for monitoring on DQ0, DQ1, DQ2. and DQ3. May be used during $V_{REFDQ}$ training and test. While in this mode, $R_{TT}$ should be set to High-Z. $V_{REF,time}$ must be increased by 10ns if DQ load is 0pF, plus an additional 15ns per pF of loading. This measurement is for verification purposes and is NOT an external voltage supply pin.

## Maximum Power Savings Mode

This mode provides the lowest power mode where data retention is not required. When the device is in the maximum power saving mode, it does not need to guarantee data retention or respond to any external command (except the MAXIMUM POWER SAVING MODE EXIT command and during the assertion of RESET_n signal LOW).

## Mode Register 5

Mode register 5 (MR5) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR5 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR5 Register Definition table.

**Table 18: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET command.

**Table 19: MR5 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>000 = MR0<br>001 = MR1<br>010 = MR2<br>011 = MR3<br>100 = MR4<br>**101 = MR5**<br>110 = MR6<br>111 = DNU |
| 17 | **N/A on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 13 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 12 | **Data bus inversion (DBI) – READ DBI enable**<br>0 = Disabled<br>1 = Enabled |
| 11 | **Data bus inversion (DBI) – WRITE DBI enable**<br>0 = Disabled<br>1 = Enabled |
| 10 | **Data mask (DM)**<br>0 = Disabled<br>1 = Enabled |

**Table 19: MR5 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 9 | **CA parity persistent error mode**<br>0 = Disabled<br>1 = Enabled |
| 8:6 | **Parked ODT value ($R_{TT(Park)}$)**<br>000 = $R_{TT(Park)}$ disabled<br>001 = RZQ/4 (60 ohm)<br>010 = RZQ/2 (120 ohm)<br>011 = RZQ/6 (40 ohm)<br>100 = RZQ/1 (240 ohm)<br>101 = RZQ/5 (48 ohm)<br>110 = RZQ/3 (80 ohm)<br>111 = RZQ/7 (34 ohm) |
| 5 | **ODT input buffer for power-down**<br>0 = Buffer enabled<br>1 = Buffer disabled |
| 4 | **CA parity error status**<br>0 = Clear<br>1 = Error |
| 3 | **CRC error status**<br>0 = Clear<br>1 = Error |
| 2:0 | **CA parity latency mode**<br>000 = Disable<br>001 = 4 clocks (DDR4-1600/1866/2133)<br>010 = 5 clocks (DDR4-2400/2666)[1]<br>011 = 6 clocks (DDR4-2933/3200)<br>100 = Reserved<br>101 = Reserved<br>110 = Reserved<br>111 = Reserved |

Note: 1. Not allowed when 1/4 rate gear-down mode is enabled.

## Data Bus Inversion

The DATA BUS INVERSION (DBI) function has been added to the device and is supported only for x16 configurations (x4 is not supported). The DBI function shares a common pin with the DM and TDQS functions. The DBI function applies to both READ and WRITE operations; Write DBI cannot be enabled at the same time the DM function is enabled. Refer to the TDQS Function Matrix table for valid configurations for all three functions (TDQS/DM/DBI). DBI is not allowed during MPR READ operation; during an MPR read, the DRAM ignores the read DBI enable setting in MR5 bit A12.

DBI is not supported for 3DS devices and should be disabled in MR5.

## Data Mask

The DATA MASK (DM) function, also described as a partial write, has been added to the device and is supported only for x8 and x16 configurations (x4 is not supported). The DM function shares a common pin with the DBI and TDQS functions. The DM function applies only to WRITE operations and cannot be enabled at the same time the write DBI function is enabled. Refer to the TDQS Function Matrix table for valid configurations for all three functions (TDQS/DM/DBI).

## CA Parity Persistent Error Mode

Normal CA parity mode (CA parity persistent mode disabled) no longer performs CA parity checking while the parity error status bit remains set at 1. However, with CA parity persistent mode enabled, CA parity checking continues to be performed when the parity error status bit is set to a 1.

## ODT Input Buffer for Power-Down

This feature determines whether the ODT input buffer is on or off during power-down. If the input buffer is configured to be on (enabled during power-down), the ODT input signal must be at a valid logic level. If the input buffer is configured to be off (disabled during power-down), the ODT input signal may be floating and the device does not provide $R_{TT(NOM)}$ termination. However, the device may provide $R_{TT(Park)}$ termination depending on the MR settings. This is primarily for additional power savings.

## CA Parity Error Status

The device will set the error status bit to 1 upon detecting a parity error. The parity error status bit remains set at 1 until the device controller clears it explicitly using an MRS command.

## CRC Error Status

The device will set the error status bit to 1 upon detecting a CRC error. The CRC error status bit remains set at 1 until the device controller clears it explicitly using an MRS command.

## CA Parity Latency Mode

CA parity is enabled when a latency value, dependent on $^{t}$CK, is programmed; this accounts for parity calculation delay internal to the device. The normal state of CA parity is to be disabled. If CA parity is enabled, the device must ensure there are no parity errors before executing the command. CA parity signal (PAR) covers ACT_n, RAS_n/A16 , CAS_n/A15, WE_n/A14, and the address bus including bank address and bank group bits. The control signals CKE, ODT, and CS_n are not included in the parity calculation.

## Mode Register 6

Mode register 6 (MR6) controls various device operating modes as shown in the following register definition table. Not all settings listed may be available on a die; only settings required for speed bin support are available. MR6 is written by issuing the MRS command while controlling the states of the BG*x*, BA*x*, and A*x* address pins. The mapping of address pins during the MRS command is shown in the following MR6 Register Definition table.

**Table 20: Address Pin Mapping**

| Address bus | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n | CAS_n | WE_n | A13 | A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode register | 21 | 20 | 19 | 18 | 17 | – | – | – | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

Note: 1. RAS_n, CAS_n, and WE_n must be LOW during MODE REGISTER SET command.

**Table 21: MR6 Register Definition**

| Mode Register | Description |
|---|---|
| 21 | **RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 20:18 | **MR select**<br>000 = MR0<br>001 = MR1<br>010 = MR2<br>011 = MR3<br>100 = MR4<br>101 = MR5<br>**110 = MR6**<br>111 = DNU |
| 17 | **NA on 4Gb and 8Gb, RFU**<br>0 = Must be programmed to 0<br>1 = Reserved |
| 12:10 | **Data Rate**<br>000 = Data rate≤ 1333 Mb/s (1333 Mb/s)<br>001 = 1333 Mb/s <Data rate ≤1866 Mb/s (1600, 1866 Mb/s)<br>010 = 1866 Mb/s <Data rate ≤2400 Mb/s (2133, 2400 Mb/s)<br>011 = 2400 Mb/s <Data rate ≤2666 Mb/s (2666 Mb/s)<br>100 = 2666 Mb/s <Data rate ≤3200 Mb/s (2933, 3200 Mb/s)<br>101 = Reserved<br>110 = Reserved<br>111 = Reserved |

**Table 21: MR6 Register Definition (Continued)**

| Mode Register | Description |
|---|---|
| 13, 9, 8 | **RFU**<br>Default = 000; Must be programmed to 000<br>001 = Reserved<br>010 = Reserved<br>011 = Reserved<br>100 = Reserved<br>101 = Reserved<br>110 = Reserved<br>111 = Reserved |
| 7 | **$V_{REF}$ Calibration Enable**<br>0 = Disable<br>1 = Enable |
| 6 | **$V_{REF}$ Calibration Range**<br>0 = Range 1<br>1 = Range 2 |
| 5:0 | **$V_{REF}$ Calibration Value**<br>See the $V_{REFDQ}$ Range and Levels table in the $V_{REFDQ}$ Calibration section |

## Data Rate Programming

The device controller must program the correct data rate according to the operating frequency.

## $V_{REFDQ}$ Calibration Enable

$V_{REFDQ}$ calibration is where the device internally generates its own $V_{REFDQ}$ to be used by the DQ input receivers. The $V_{REFDQ}$ value will be output on any DQ of DQ[3:0] for evaluation only. The device controller is responsible for setting and calibrating the internal $V_{REFDQ}$ level using an MRS protocol (adjust up, adjust down, and so on). It is assumed that the controller will use a series of writes and reads in conjunction with $V_{REFDQ}$ adjustments to optimize and verify the data eye. Enabling $V_{REFDQ}$ calibration must be used whenever values are being written to the MR6[6:0] register.

## $V_{REFDQ}$ Calibration Range

The device defines two $V_{REFDQ}$ calibration ranges: Range 1 and Range 2. Range 1 supports $V_{REFDQ}$ between 60% and 92% of $V_{DDQ}$ while Range 2 supports $V_{REFDQ}$ between 45% and 77% of $V_{DDQ}$, as seen in $V_{REFDQ}$ Specification table. Although not a restriction, Range 1 was targeted for module-based designs and Range 2 was added to target point-to-point designs.

## $V_{REFDQ}$ Calibration Value

Fifty settings provide approximately 0.65% of granularity steps sizes for both Range 1 and Range 2 of $V_{REFDQ}$, as seen in $V_{REFDQ}$ Range and Levels table in the $V_{REFDQ}$ Calibration section.

# Truth Tables

## Table 22: Truth Table – Command

Notes 1–5 apply to the entire table; Note 6 applies to all READ/WRITE commands

| Function | | Symbol | Prev. CKE | Pres. CKE | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | BG[1:0] | BA [1:0] | C[2:0] | A12/BC_n | A[13,11] | A10/AP | A[9:0] | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MODE REGISTER SET | | MRS | H | H | L | H | L | L | L | BG | BA | V | OP code | | | | 7 |
| REFRESH | | REF | H | H | L | H | L | L | H | V | V | V | V | V | V | V | |
| Self refresh entry | | SRE | H | L | L | H | L | L | H | V | V | V | V | V | V | V | 8, 9, 10 |
| Self refresh exit | | SRX | L | H | H | X | X | X | X | X | X | X | X | X | X | X | 8, 9, 10, 11 |
| | | | | | L | H | H | H | H | V | V | V | V | V | V | V | |
| Single-bank PRECHARGE | | PRE | H | H | L | H | L | H | L | BG | BA | V | V | V | L | V | |
| PRECHARGE all banks | | PREA | H | H | L | H | L | H | L | V | V | V | V | V | H | V | |
| Reserved for future use | | RFU | H | H | L | H | L | H | H | RFU | | | | | | | |
| Bank ACTIVATE | | ACT | H | H | L | L | Row address (RA) | | | BG | BA | V | Row address (RA) | | | | |
| WRITE | BL8 fixed, BC4 fixed | WR | H | H | L | H | H | L | L | BG | BA | V | V | V | L | CA | |
| | BC4OTF | WRS4 | H | H | L | H | H | L | L | BG | BA | V | L | V | L | CA | |
| | BL8OTF | WRS8 | H | H | L | H | H | L | L | BG | BA | V | H | V | L | CA | |
| WRITE with auto precharge | BL8 fixed, BC4 fixed | WRA | H | H | L | H | H | L | L | BG | BA | V | V | V | H | CA | |
| | BC4OTF | WRAS4 | H | H | L | H | H | L | L | BG | BA | V | L | V | H | CA | |
| | BL8OTF | WRAS8 | H | H | L | H | H | L | L | BG | BA | V | H | V | H | CA | |
| READ | BL8 fixed, BC4 fixed | RD | H | H | L | H | H | L | H | BG | BA | V | V | V | L | CA | |
| | BC4OTF | RDS4 | H | H | L | H | H | L | H | BG | BA | V | L | V | L | CA | |
| | BL8OTF | RDS8 | H | H | L | H | H | L | H | BG | BA | V | H | V | L | CA | |
| READ with auto precharge | BL8 fixed, BC4 fixed | RDA | H | H | L | H | H | L | H | BG | BA | V | V | V | H | CA | |
| | BC4OTF | RDAS4 | H | H | L | H | H | L | H | BG | BA | V | L | V | H | CA | |
| | BL8OTF | RDAS8 | H | H | L | H | H | L | H | BG | BA | V | H | V | H | CA | |
| NO OPERATION | | NOP | H | H | L | H | H | H | H | V | V | V | V | V | V | V | 12 |
| Device DESELECTED | | DES | H | H | H | X | X | X | X | X | X | X | X | X | X | X | 13 |
| Power-down entry | | PDE | H | L | H | X | X | X | X | X | X | X | X | X | X | X | 10, 14 |
| Power-down exit | | PDX | L | H | H | X | X | X | X | X | X | X | X | X | X | X | 10, 14 |
| ZQ CALIBRATION LONG | | ZQCL | H | H | L | H | H | H | L | X | X | X | X | X | H | X | |
| ZQ CALIBRATION SHORT | | ZQCS | H | H | L | H | H | H | L | X | X | X | X | X | L | X | |

Notes: 1. • BG = Bank group address
- BA = Bank address
- RA = Row address
- CA = Column address
- BC_n = Burst chop
- X = "Don't Care"
- V = Valid

2. All DDR4 SDRAM commands are defined by states of CS_n, ACT_n, RAS_n/A16, CAS_n/A15, WE_n/A14, and CKE at the rising edge of the clock. The MSB of BG, BA, RA, and CA are device density and configuration-dependent. When ACT_n = H, pins RAS_n/A16, CAS_n/A15, and WE_n/A14 are used as command pins RAS_n, CAS_n, and WE_n, respectively. When ACT_n = L, pins RAS_n/A16, CAS_n/A15, and WE_n/A14 are used as address pins A16, A15, and A14, respectively.
3. RESET_n is enabled LOW and is used only for asynchronous reset and must be maintained HIGH during any function.
4. Bank group addresses (BG) and bank addresses (BA) determine which bank within a bank group is being operated upon. For MRS commands, the BG and BA selects the specific mode register location.
5. V means HIGH or LOW (but a defined logic level), and X means either defined or undefined (such as floating) logic level.
6. READ or WRITE bursts cannot be terminated or interrupted, and fixed/on-the-fly (OTF) BL will be defined by MRS.
7. During an MRS command, A17 is RFU and is device density and configuration-dependent.
8. The state of ODT does not affect the states described in this table. The ODT function is not available during self refresh.
9. $V_{PP}$ and $V_{REF}$ ($V_{REFCA}$) must be maintained during SELF REFRESH operation.
10. Refer to the Truth Table – CKE table for more details about CKE transition.
11. Controller guarantees self refresh exit to be synchronous. DRAM implementation has the choice of either synchronous or asynchronous.
12. The NO OPERATION (NOP) command may be used only when exiting maximum power saving mode or when entering gear-down mode.
13. The NOP command may not be used in place of the DESELECT command.
14. The power-down mode does not perform any REFRESH operation.

**Table 23: Truth Table – CKE**

Notes 1–7, 9, and 20 apply to the entire table

| Current State | CKE | | Command (n) | Action (n) | Notes |
|---|---|---|---|---|---|
| | Previous Cycle (n - 1) | Present Cycle (n) | | | |
| Power-down | L | L | X | Maintain power-down | 8, 10, 11 |
| | L | H | DES | Power-down exit | 8, 10, 12 |
| Self refresh | L | L | X | Maintain self refresh | 11, 13 |
| | L | H | DES | Self refresh exit | 8, 13, 14, 15 |
| Bank(s) active | H | L | DES | Active power-down entry | 8, 10, 12, 16 |
| Reading | H | L | DES | Power-down entry | 8, 10, 12, 16, 17 |
| Writing | H | L | DES | Power-down entry | 8, 10, 12, 16, 17 |
| Precharging | H | L | DES | Power-down entry | 8, 10, 12, 16, 17 |
| Refreshing | H | L | DES | Precharge power-down entry | 8, 12 |
| All banks idle | H | L | DES | Precharge power-down entry | 8, 10, 12, 16, 18 |
| | H | L | REFRESH | Self refresh | 16, 18, 19 |

Notes:
1. Current state is defined as the state of the DDR4 SDRAM immediately prior to clock edge n.
2. CKE (n) is the logic state of CKE at clock edge n; CKE (n-1) was the state of CKE at the previous clock edge.
3. COMMAND (n) is the command registered at clock edge n, and ACTION (n) is a result of COMMAND (n); ODT is not included here.
4. All states and sequences not shown are illegal or reserved unless explicitly described elsewhere in this document.
5. The state of ODT does not affect the states described in this table. The ODT function is not available during self refresh.
6. During any CKE transition (registration of CKE H->L or CKE H->L), the CKE level must be maintained until 1 nCK prior to $^{t}$CKE (MIN) being satisfied (at which time CKE may transition again).
7. DESELECT and NOP are defined in the Truth Table – Command table.
8. For power-down entry and exit parameters, see the Power-Down Modes section.
9. CKE LOW is allowed only if $^{t}$MRD and $^{t}$MOD are satisfied.
10. The power-down mode does not perform any REFRESH operations.
11. X = "Don't Care" (including floating around $V_{REF}$) in self refresh and power-down. X also applies to address pins.
12. The DESELECT command is the only valid command for power-down entry and exit.
13. $V_{PP}$ and $V_{REFCA}$ must be maintained during SELF REFRESH operation.
14. On self refresh exit, the DESELECT command must be issued on every clock edge occurring during the $^{t}$XS period. READ or ODT commands may be issued only after $^{t}$XSDLL is satisfied.
15. The DESELECT command is the only valid command for self refresh exit.
16. Self refresh cannot be entered during READ or WRITE operations. For a detailed list of restrictions see the SELF REFRESH Operation and Power-Down Modes sections.
17. If all banks are closed at the conclusion of the READ, WRITE, or PRECHARGE command, then precharge power-down is entered; otherwise, active power-down is entered.

18. Idle state is defined as all banks are closed ($^{t}$RP, $^{t}$DAL, and so on, satisfied), no data bursts are in progress, CKE is HIGH, and all timings from previous operations are satisfied ($^{t}$MRD, $^{t}$MOD, $^{t}$RFC, $^{t}$ZQinit, $^{t}$ZQoper, $^{t}$ZQCS, and so on), as well as all self refresh exit and power-down exit parameters are satisfied ($^{t}$XS, $^{t}$XP, $^{t}$XSDLL, and so on).
19. Self refresh mode can be entered only from the all banks idle state.
20. For more details about all signals, see the Truth Table – Command table; must be a legal command as defined in the table.

## NOP Command

The NO OPERATION (NOP) command was originally used to instruct the selected DDR4 SDRAM to perform a NOP (CS_n = LOW and ACT_n, RAS_n/A16, CAS_n/A15, and WE_n/A14 = HIGH). This prevented unwanted commands from being registered during idle or wait states. NOP command general support has been removed and the command should not be used unless specifically allowed, which is when exiting maximum power-saving mode or when entering gear-down mode.

## DESELECT Command

The deselect function (CS_n HIGH) prevents new commands from being executed; therefore, with this command, the device is effectively deselected. Operations already in progress are not affected.

## DLL-Off Mode

DLL-off mode is entered by setting MR1 bit A0 to 0, which will disable the DLL for

subsequent operations until the A0 bit is set back to 1. The MR1 A0 bit for DLL control can be switched either during initialization or during self refresh mode. Refer to the Input Clock Frequency Change section for more details.

The maximum clock frequency for DLL-off mode is specified by the parameter $^{t}$CKDLL_OFF.

Due to latency counter and timing restrictions, only one CL value and CWL value (in MR0 and MR2 respectively) are supported. The DLL-off mode is only required to

support setting both CL = 10 and CWL = 9.

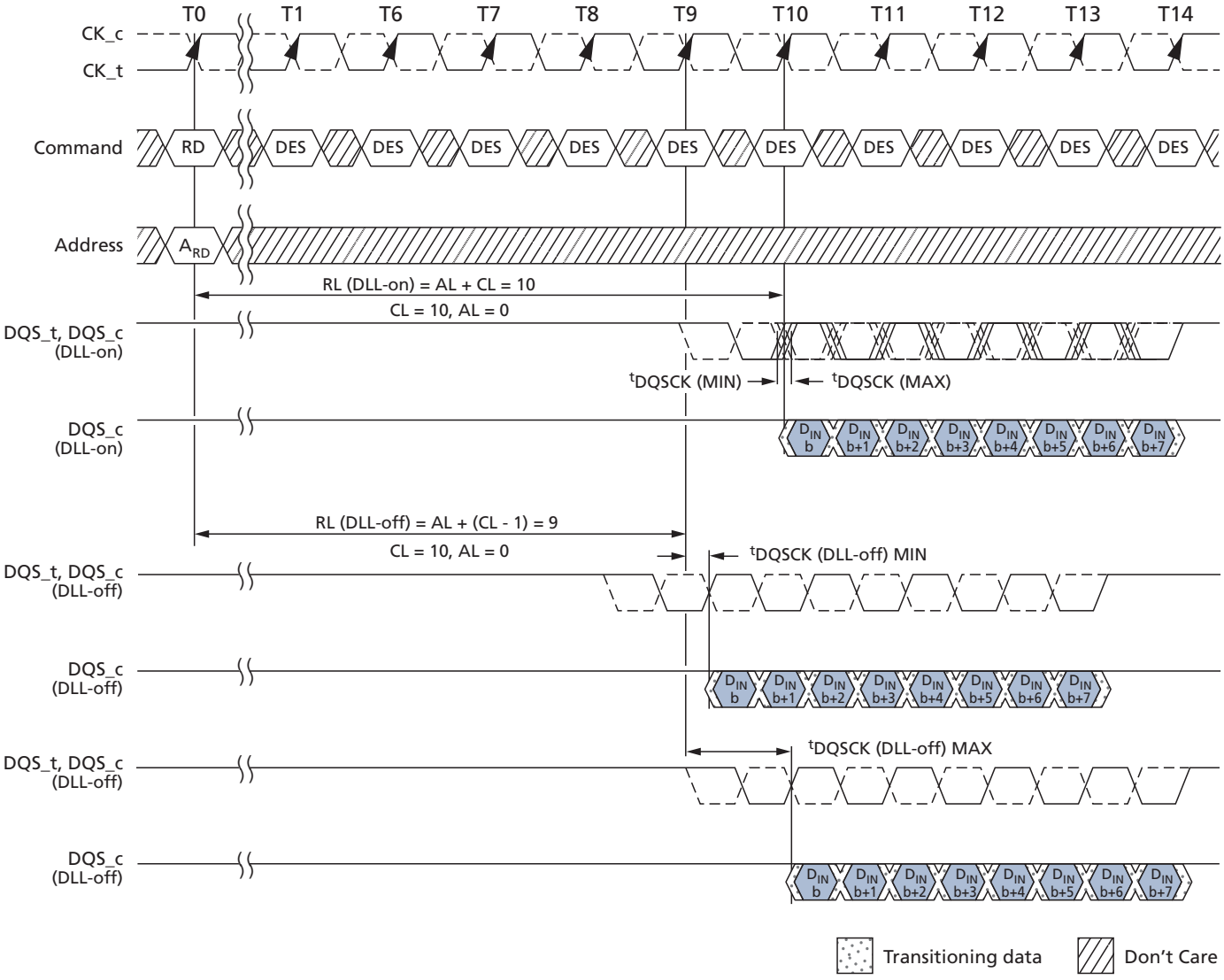
DLL-off mode will affect the read data clock-to-data strobe relationship ($^{t}$DQSCK), but not the data strobe-to-data relationship ($^{t}$DQSQ, $^{t}$QH). Special attention is needed to line up read data to the controller time domain.

Compared with DLL-on mode, where $^{t}$DQSCK starts from the rising clock edge (AL + CL) cycles after the READ command, the DLL-off mode $^{t}$DQSCK starts (AL + CL - 1)

cycles after the READ command. Another difference is that $^{t}$DQSCK may not be small compared to $^{t}$CK (it might even be larger than $^{t}$CK), and the difference between $^{t}$DQSCK (MIN) and $^{t}$DQSCK (MAX) is significantly larger than in DLL-on mode. The $^{t}$DQSCK (DLL-off) values are undefined and the user is responsible for training to the data-eye.

The timing relations on DLL-off mode READ operation are shown in the following diagram, where CL = 10, AL = 0, and BL = 8.

**Figure 9: DLL-Off Mode Read Timing Operation**



## DLL-On/Off Switching Procedures

The DLL-off mode is entered by setting MR1 bit A0 to 0; this will disable the DLL for subsequent operations until the A0 bit is set back to 1.

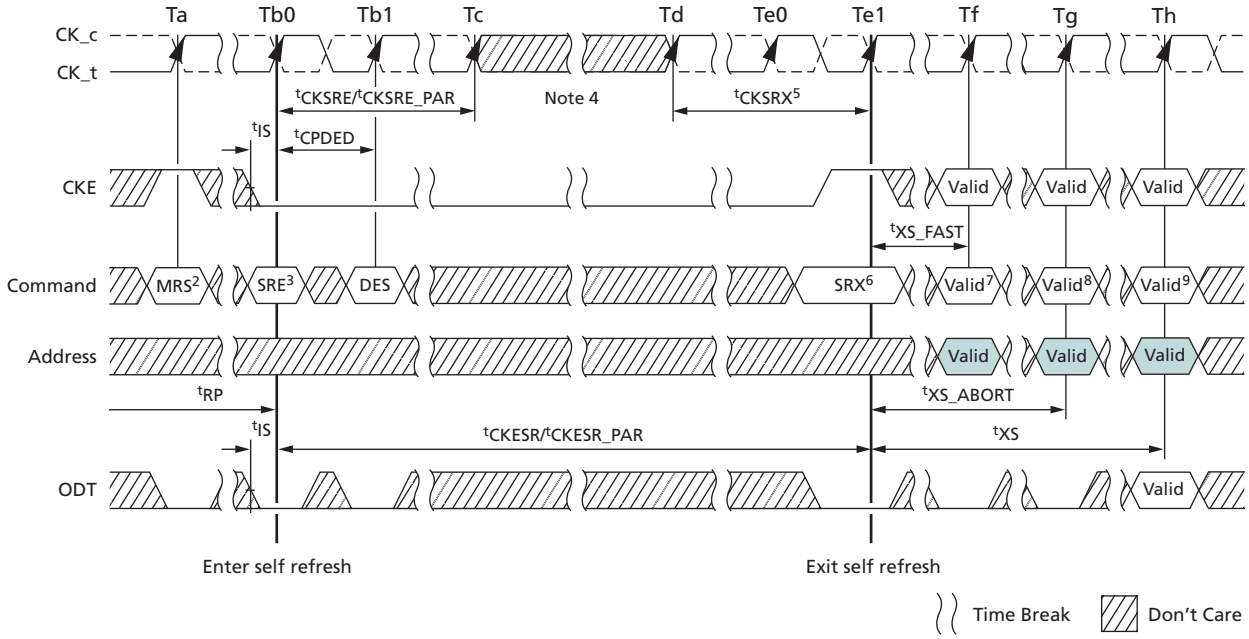
### DLL Switch Sequence from DLL-On to DLL-Off

To switch from DLL-on to DLL-off requires the frequency to be changed during self refresh, as outlined in the following procedure:

1. Starting from the idle state (all banks pre-charged, all timings fulfilled, and, to disable the DLL, the DRAM on-die termination resistors, $R_{TT(NOM)}$, must be in High-Z before MRS to MR1.)
2. Set MR1 bit A0 to 1 to disable the DLL.
3. Wait $^{t}$MOD.
4. Enter self refresh mode; wait until $^{t}$CKSRE/$^{t}$CKSRE_PAR is satisfied.
5. Change frequency, following the guidelines in the Input Clock Frequency Change section.
6. Wait until a stable clock is available for at least $^{t}$CKSRX at device inputs.
7. Starting with the SELF REFRESH EXIT command, CKE must continuously be registered HIGH until all $^{t}$MOD timings from any MRS command are satisfied. In addition, if any ODT features were enabled in the mode registers when self refresh mode was entered, the ODT signal must continuously be registered LOW until all $^{t}$MOD timings from any MRS command are satisfied. If $R_{TT(NOM)}$ was disabled in the mode registers when self refresh mode was entered, the ODT signal is "Don't Care."
8. Wait $^{t}$XS_FAST, $^{t}$XS_ABORT, or $^{t}$XS, and then set mode registers with appropriate values (an update of CL, CWL, and WR may be necessary; a ZQCL command can also be issued after $^{t}$XS_FAST).
   - $^{t}$XS_FAST: ZQCL, ZQCS, and MRS commands. For MRS commands, only CL and WR/RTP registers in MR0, the CWL register in MR2, and gear-down mode in MR3 may be accessed provided the device is not in per-DRAM addressability mode. Access to other device mode registers must satisfy $^{t}$XS timing.
   - $^{t}$XS_ABORT: If MR4 [9] is enabled, then the device aborts any ongoing refresh and does not increment the refresh counter. The controller can issue a valid command after a delay of $^{t}$XS_ABORT. Upon exiting from self refresh, the device requires a minimum of one extra REFRESH command before it is put back into self refresh mode. This requirement remains the same regardless of the MRS bit setting for self refresh abort.
   - $^{t}$XS: ACT, PRE, PREA, REF, SRE, PDE, WR, WRS4, WRS8, WRA, WRAS4, WRAS8, RD, RDS4, RDS8, RDA, RDAS4, and RDAS8.
9. Wait $^{t}$MOD to complete.

The device is ready for the next command.

**Figure 10: DLL Switch Sequence from DLL-On to DLL-Off**




Notes:
1. Starting in the idle state. $R_{TT}$ in stable state.
2. Disable DLL by setting MR1 bit A0 to 0.
3. Enter SR.
4. Change frequency.
5. Clock must be stable $^{t}$CKSRX.
6. Exit SR.
7. Update mode registers allowed with DLL-off settings met.

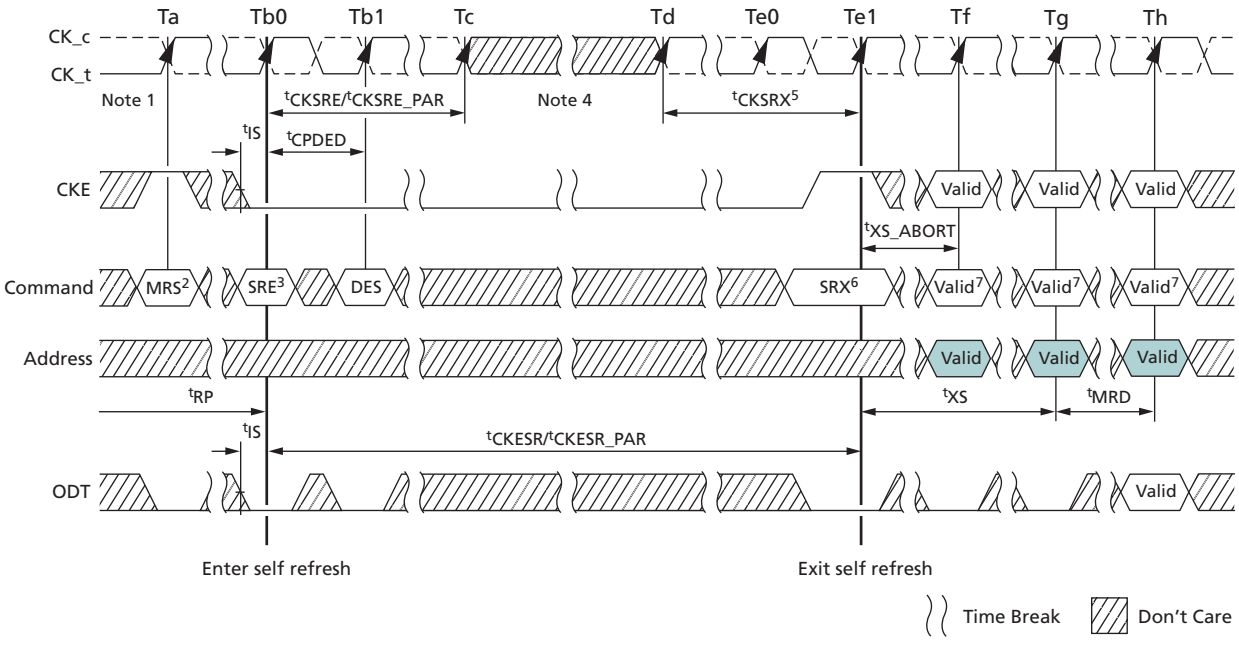
## DLL-Off to DLL-On Procedure

To switch from DLL-off to DLL-on (with required frequency change) during self refresh:

1. Starting from the idle state (all banks pre-charged, all timings fulfilled, and DRAM ODT resistors ($R_{TT(NOM)}$) must be in High-Z before self refresh mode is entered.)
2. Enter self refresh mode; wait until $^{t}$CKSRE/$^{t}$CKSRE_PAR are satisfied.
3. Change frequency (following the guidelines in the Input Clock Frequency Change section).
4. Wait until a stable clock is available for at least $^{t}$CKSRX at device inputs.
5. Starting with the SELF REFRESH EXIT command, CKE must continuously be registered HIGH until $^{t}$DLLK timing from the subsequent DLL RESET command is satisfied. In addition, if any ODT features were enabled in the mode registers when self refresh mode was entered, the ODT signal must continuously be registered LOW or HIGH until $^{t}$DLLK timing from the subsequent DLL RESET command is satisfied. If $R_{TT(NOM)}$ disabled in the mode registers when self refresh mode was entered, the ODT signal is "Don't Care."
6. Wait $^{t}$XS or $^{t}$XS_ABORT, depending on bit 9 in MR4, then set MR1 bit A0 to 0 to enable the DLL.
7. Wait $^{t}$MRD, then set MR0 bit A8 to 1 to start DLL reset.
8. Wait $^{t}$MRD, then set mode registers with appropriate values; an update of CL, CWL, and WR may be necessary. After $^{t}$MOD is satisfied from any proceeding MRS command, a ZQCL command can also be issued during or after $^{t}$DLLK.
9. Wait for $^{t}$MOD to complete. Remember to wait $^{t}$DLLK after DLL RESET before applying any command requiring a locked DLL. In addition, wait for $^{t}$ZQoper in case a ZQCL command was issued.

The device is ready for the next command.

**Figure 11: DLL Switch Sequence from DLL-Off to DLL-On**




Notes: 1. Starting in the idle state.

2. Enter SR.
3. Change frequency.
4. Clock must be stable $^{t}$CKSRX.
5. Exit SR.
6. Set DLL to on by setting MR1 to A0 = 0.
7. Update mode registers.
8. Issue any valid command.

## Input Clock Frequency Change

After the device is initialized, it requires the clock to be stable during almost all states of normal operation. This means that after the clock frequency has been set and is in the stable state, the clock period is not allowed to deviate except for what is allowed by the clock jitter and spread spectrum clocking (SSC) specifications. The input clock frequency can be changed from one stable clock rate to another stable clock rate only when in self refresh mode. Outside of self refresh mode, it is illegal to change the clock frequency.

After the device has been successfully placed in self refresh mode and $^{t}$CKSRE/$^{t}$CKSRE_PAR have been satisfied, the state of the clock becomes a "Don't Care." Following a "Don't Care" changing the clock frequency is permissible, provided the new clock frequency is stable prior to $^{t}$CKSRX. When entering and exiting self refresh mode for the sole purpose of changing the clock frequency, the self refresh entry and exit specifications must still be met as outlined in SELF REFRESH Operation.

For the new clock frequency, additional MRS commands to MR0, MR2, MR3, MR4, MR5, and MR6 may need to be issued to program appropriate CL, CWL, gear-down mode, READ and WRITE preamble, Command Address Latency, and data rate values.

When the clock rate is being increased (faster), the MR settings that require additional clocks should be updated prior to the clock rate being increased. In particular, the PL latency must be disabled when the clock rate changes, ie. while in self refresh mode. For example, if changing the clock rate from DDR4-2133 to DDR4-2933 with CA parity mode enabled, MR5[2:0] must first change from PL = 4 to PL = disable prior to PL = 6. The correct procedure would be to (1) change PL = 4 to disable via MR5 [2:0], (2) enter self refresh mode, (3) change clock rate from DDR4-2133 to DDR4-2933, (4) exit self re-fresh mode, (5) Enable CA parity mode setting PL = 6 vis MR5 [2:0].

If the MR settings that require additional clocks are updated after the clock rate has been increased, for example. after exiting self refresh mode, the required MR settings must be updated prior to removing the DRAM from the IDLE state, unless the DRAM is RESET. If the DRAM leaves the IDLE state to enter self refresh mode or ZQ Calibration, the updating of the required MR settings may be deferred to the next time the DRAM enters the IDLE state.

If MR6 is issued prior to self refresh entry for the new data rate value, DLL will relock automatically at self refresh exit. However, if MR6 is issued after self refresh entry, MR0 must be issued to reset the DLL.

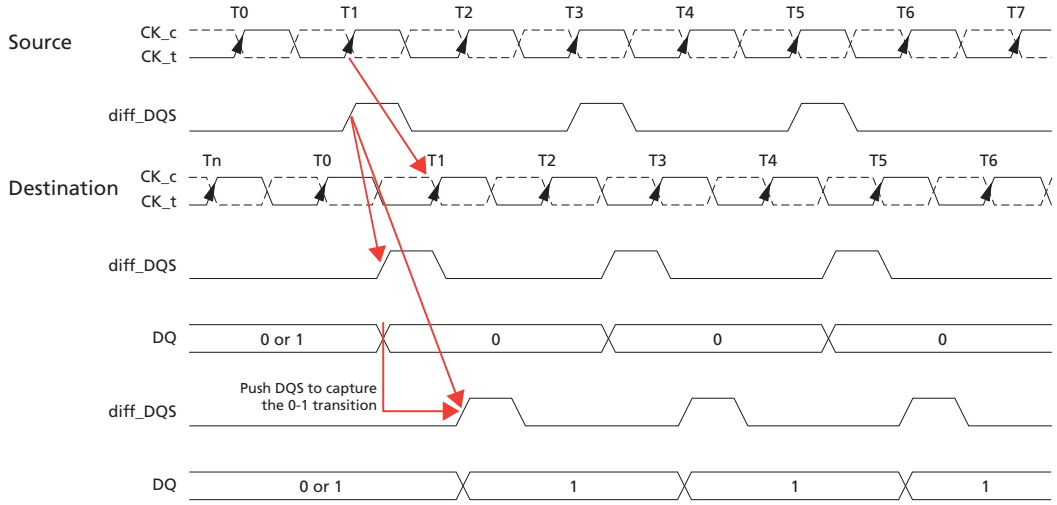
The device input clock frequency can change only within the minimum and maximum operating frequency specified for the particular speed grade. Any frequency change below the minimum operating frequency would require the use of DLL-on mode to DLL-off mode transition sequence (see DLL-On/Off Switching Procedures).

## Write Leveling

For better signal integrity, DDR4 memory modules use fly-by topology for the commands, addresses, control signals, and clocks. Fly-by topology has benefits from the reduced number of stubs and their length, but it also causes flight-time skew between clock and strobe at every DRAM on the DIMM. This makes it difficult for the controller to maintain $^{t}$DQSS, $^{t}$DSS, and $^{t}$DSH specifications. Therefore, the device supports a write leveling feature to allow the controller to compensate for skew. This feature may not be required under some system conditions, provided the host can maintain the $^{t}$DQSS, $^{t}$DSS, and $^{t}$DSH specifications.

The memory controller can use the write leveling feature and feedback from the device to adjust the DQS (DQS_t, DQS_c) to CK (CK_t, CK_c) relationship. The memory controller involved in the leveling must have an adjustable delay setting on DQS to align the rising edge of DQS with that of the clock at the DRAM pin. The DRAM asynchronously feeds back CK, sampled with the rising edge of DQS, through the DQ bus. The controller repeatedly delays DQS until a transition from 0 to 1 is detected. The DQS delay established though this exercise would ensure the $^{t}$DQSS specification. Besides $^{t}$DQSS, $^{t}$DSS and $^{t}$DSH specifications also need to be fulfilled. One way to achieve this is to combine the actual $^{t}$DQSS in the application with an appropriate duty cycle and jitter on the DQS signals. Depending on the actual $^{t}$DQSS in the application, the actual values for $^{t}$DQSL and $^{t}$DQSH may have to be better than the absolute limits provided in the AC Timing Parameters section in order to satisfy $^{t}$DSS and $^{t}$DSH specifications. A conceptual timing of this scheme is shown below.

**Figure 12: Write Leveling Concept, Example 1**

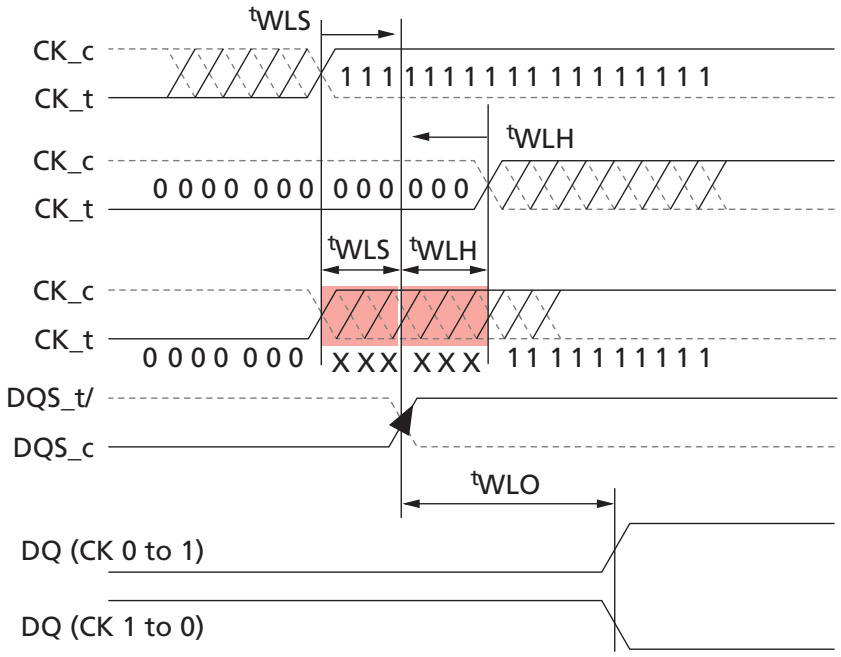



DQS driven by the controller during leveling mode must be terminated by the DRAM based on the ranks populated. Similarly, the DQ bus driven by the DRAM must also be terminated at the controller.

All data bits carry the leveling feedback to the controller across the DRAM configurations: x4, x8, and x16. On a x16 device, both byte lanes should be leveled independently. Therefore, a separate feedback mechanism should be available for each byte lane. The upper data bits should provide the feedback of the upper diff_DQS(diff_UDQS)-to-clock relationship; the lower data bits would indicate the lower diff_DQS(diff_LDQS)-to-clock relationship.

The figure below is another representative way to view the write leveling procedure. Although it shows the clock varying to a static strobe, this is for illustrative purpose only; the clock does not actually change phase, the strobe is what actually varies. By issuing multiple WL bursts, the DQS strobe can be varied to capture with fair accuracy the time at which the clock edge arrives at the DRAM clock input buffer.

**Figure 13: Write Leveling Concept, Example 2**




## DRAM Setting for Write Leveling and DRAM TERMINATION Function in that Mode

The DRAM enters into write leveling mode if A7 in MR1 is HIGH. When leveling is finished, the DRAM exits write leveling mode if A7 in MR1 is LOW (see the MR Leveling Procedures table). Note that in write leveling mode, only DQS terminations are activated and deactivated via the ODT pin, unlike normal operation (see DRAM DRAM TERMINATION Function in Leveling Mode table).

**Table 24: MR Settings for Leveling Procedures**

| Function | MR1 | Enable | Disable |
|---|---|---|---|
| Write leveling enable | A7 | 1 | 0 |
| Output buffer mode (Q off) | A12 | 0 | 1 |

**Table 25: DRAM TERMINATION Function in Leveling Mode**

| ODT Pin at DRAM | DQS_t/DQS_c Termination | DQ Termination |
|---|---|---|
| $R_{TT(NOM)}$ with ODT HIGH | On | Off |

**Table 25: DRAM TERMINATION Function in Leveling Mode (Continued)**

| ODT Pin at DRAM | DQS_t/DQS_c Termination | DQ Termination |
|---|---|---|
| $R_{TT(Park)}$ with ODT LOW | On | Off |

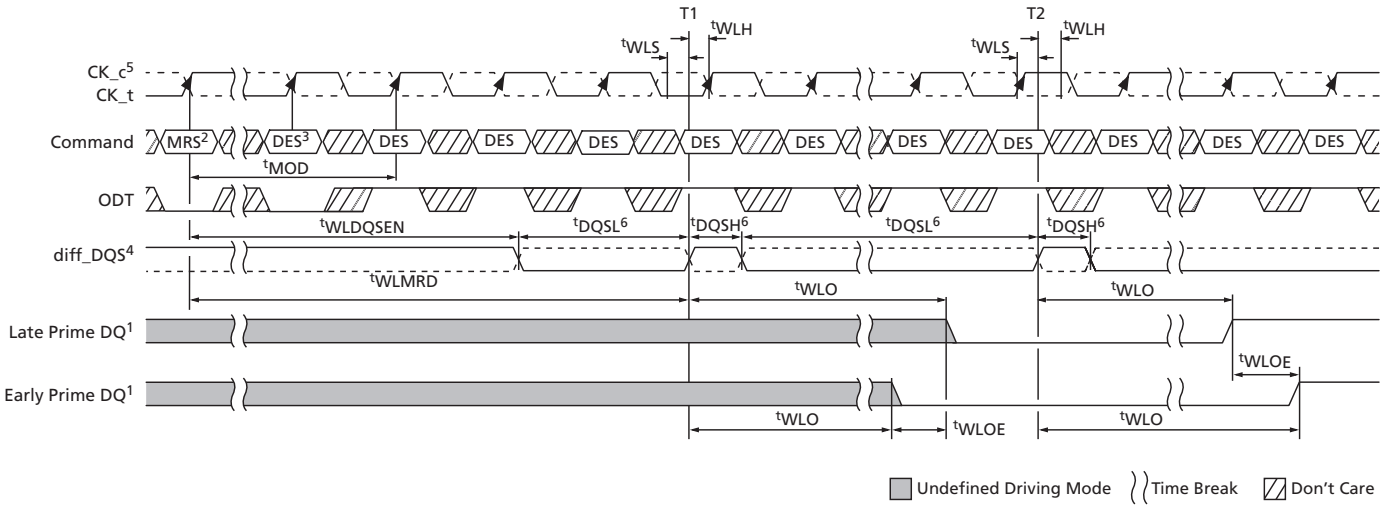
Notes:
1. In write leveling mode, with the mode's output buffer either disabled (MR1[bit7] = 1 and MR1[bit12] = 1) or with its output buffer enabled (MR1[bit7] = 1 and MR1[bit12] = 0), all $R_{TT(NOM)}$ and $R_{TT(Park)}$ settings are supported.
2. $R_{TT(WR)}$ is not allowed in write leveling mode and must be set to disable prior to entering write leveling mode.

## Procedure Description

The memory controller initiates the leveling mode of all DRAM by setting bit 7 of MR1 to 1. When entering write leveling mode, the DQ pins are in undefined driving mode. During write leveling mode, only the DESELECT command is supported, other than MRS commands to change the Qoff bit (MR1[A12]) and to exit write leveling (MR1[A7]). Upon exiting write leveling mode, the MRS command performing the exit (MR1[A7] = 0) may also change the other MR1 bits. Because the controller levels one rank at a time, the output of other ranks must be disabled by setting MR1 bit A12 to 1. The controller may assert ODT after $^{t}$MOD, at which time the DRAM is ready to accept the ODT signal, unless DODTLon or DODTLoff have been altered (the ODT internal pipe delay is increased when increasing WRITE latency [WL] or READ latency [RL] by the previous MR command), then ODT assertion should be delayed by DODTLon after $^{t}$MOD is satisfied, which means the delay is now $^{t}$MOD + DODTLon.
The controller may drive DQS_t LOW and DQS_c HIGH after a delay of $^{t}$WLDQSEN, at which time the DRAM has applied ODT to these signals. After $^{t}$DQSL and $^{t}$WLMRD, the controller provides a single DQS_t, DQS_c edge, which is used by the DRAM to sample CK driven from the controller. $^{t}$WLMRD (MAX) timing is controller dependent.

The DRAM samples CK status with the rising edge of DQS and provides feedback on all the DQ bits asynchronously after $^{t}$WLO timing. There is a DQ output uncertainty of $^{t}$WLOE defined to allow mismatch on DQ bits. The $^{t}$WLOE period is defined from the transition of the earliest DQ bit to the corresponding transition of the latest DQ bit. There are no read strobes (DQS_t, DQS_c) needed for these DQs. The controller samples incoming DQ and either increments or decrements DQS delay setting and launches the next DQS pulse after some time, which is controller dependent. After a 0-to-1 transition is detected, the controller locks the DQS delay setting, and write leveling is achieved for the device. The following figure shows the timing diagram and parameters for the overall write leveling procedure.

**Figure 14: Write Leveling Sequence (DQS Capturing CK LOW at T1 and CK HIGH at T2)**



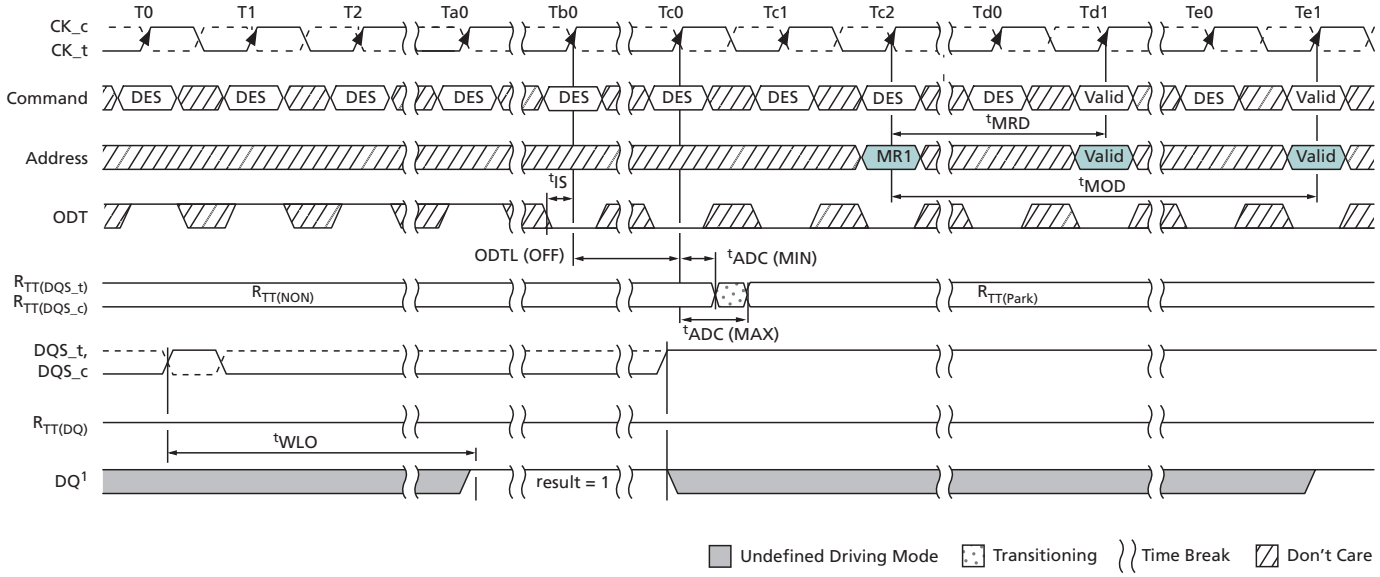

Notes:
1. The device drives leveling feedback on all DQs.
2. MRS: Load MR1 to enter write leveling mode.
3. diff_DQS is the differential data strobe. Timing reference points are the zero crossings. DQS_t is shown with a solid line; DQS_c is shown with a dotted line.
4. CK_t is shown with a solid dark line; CK_c is shown with a dotted line.
5. DQS needs to fulfill minimum pulse width requirements, tDQSH (MIN) and tDQSL (MIN), as defined for regular WRITEs; the maximum pulse width is system dependent.
6. tWLDQSEN must be satisfied following equation when using ODT:
   - DLL = Enable, then tWLDQSEN > tMOD (MIN) + DODTLon + tADC
   - DLL = Disable, then tWLDQSEN > tMOD (MIN) + tAONAS

## Write Leveling Mode Exit

Write leveling mode should be exited as follows:

1. After the last rising strobe edge (see ~T0), stop driving the strobe signals (see ~Tc0). Note that from this point on, DQ pins are in undefined driving mode and will remain undefined, until tMOD after the respective MR command (Te1).
2. Drive ODT pin LOW (tIS must be satisfied) and continue registering LOW (see Tb0).
3. After $R_{TT}$ is switched off, disable write leveling mode via the MRS command (see Tc2).
4. After tMOD is satisfied (Te1), any valid command can be registered. (MR commands can be issued after tMRD [Td1]).

**Figure 15: Write Leveling Exit**

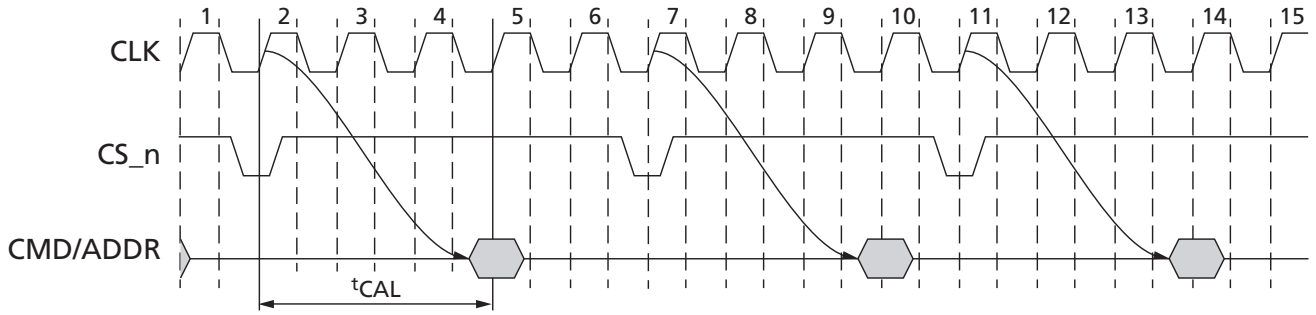



Notes:
1. The DQ result = 1 between Ta0 and Tc0 is a result of the DQS signals capturing CK_t HIGH just after the T0 state.
2. See previous figure for specific $^{t}$WLO timing.

## Command Address Latency

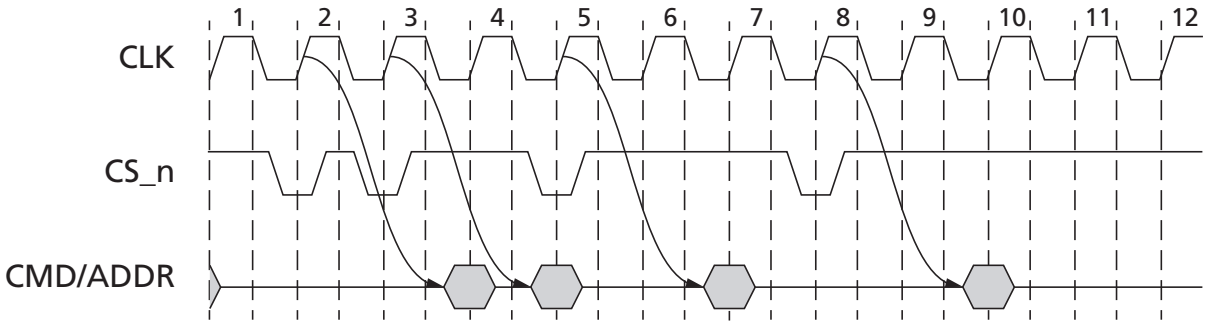
DDR4 supports the command address latency (CAL) function as a power savings feature. This feature can be enabled or disabled via the MRS setting. CAL timing is defined as the delay in clock cycles ($^{t}$CAL) between a CS_n registered LOW and its corresponding registered command and address. The value of CAL in clocks must be programmed into the mode register (see MR1 Register Definition table) and is based on the $^{t}$CAL(ns)/$^{t}$CK(ns) rounding algorithms found in the Converting Time-Based Specifications to Clock-Based Requirements section.

**Figure 16: CAL Timing Definition**



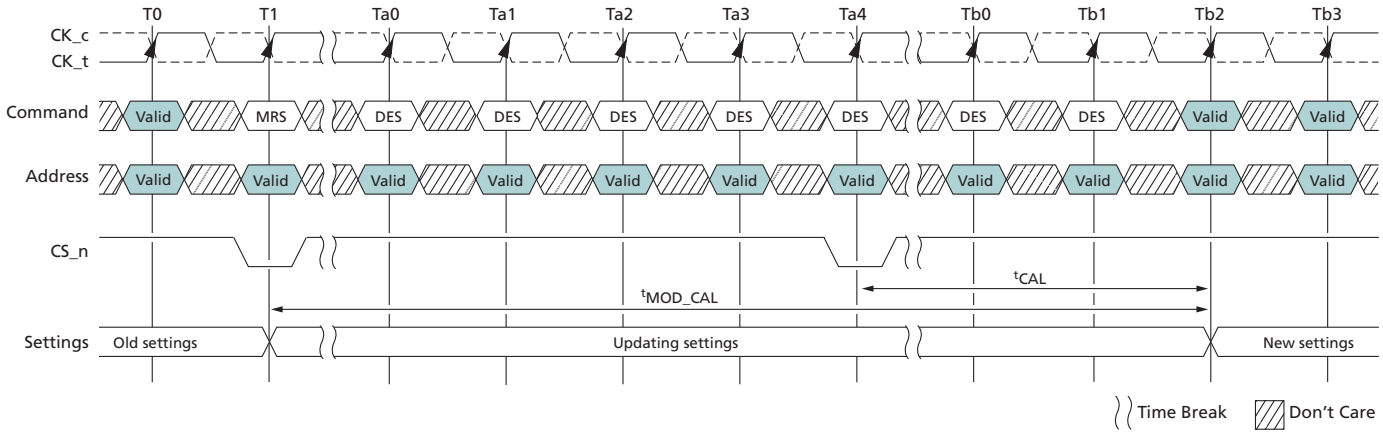

CAL gives the DRAM time to enable the command and address receivers before a command is issued. After the command and the address are latched, the receivers can be disabled if CS_n returns to HIGH. For consecutive commands, the DRAM will keep the command and address input receivers enabled for the duration of the command sequence.

**Figure 17: CAL Timing Example (Consecutive CS_n = LOW)**



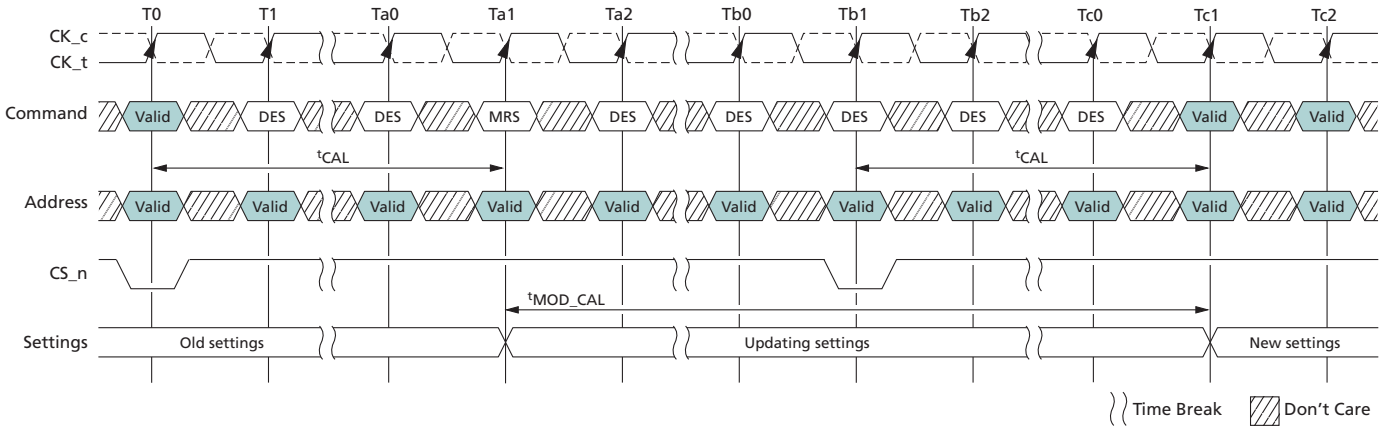
When the CAL mode is enabled, additional time is required for the MRS command to complete. The earliest the next valid command can be issued is $^{t}$MOD_CAL, which should be equal to $^{t}$MOD + $^{t}$CAL. The two following figures are examples.

**Figure 18: CAL Enable Timing – $^{t}$MOD_CAL**




Note: 1. CAL mode is enabled at T1.

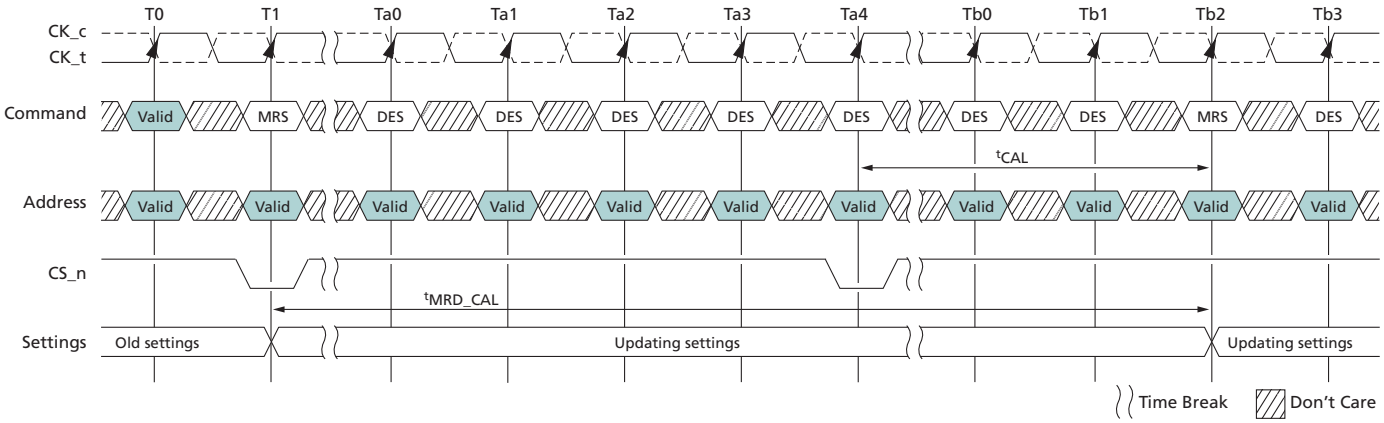
**Figure 19: $^{t}$MOD_CAL, MRS to Valid Command Timing with CAL Enabled**




Note: 1. MRS at Ta1 may or may not modify CAL, $^{t}$MOD_CAL is computed based on new $^{t}$CAL setting if modified.

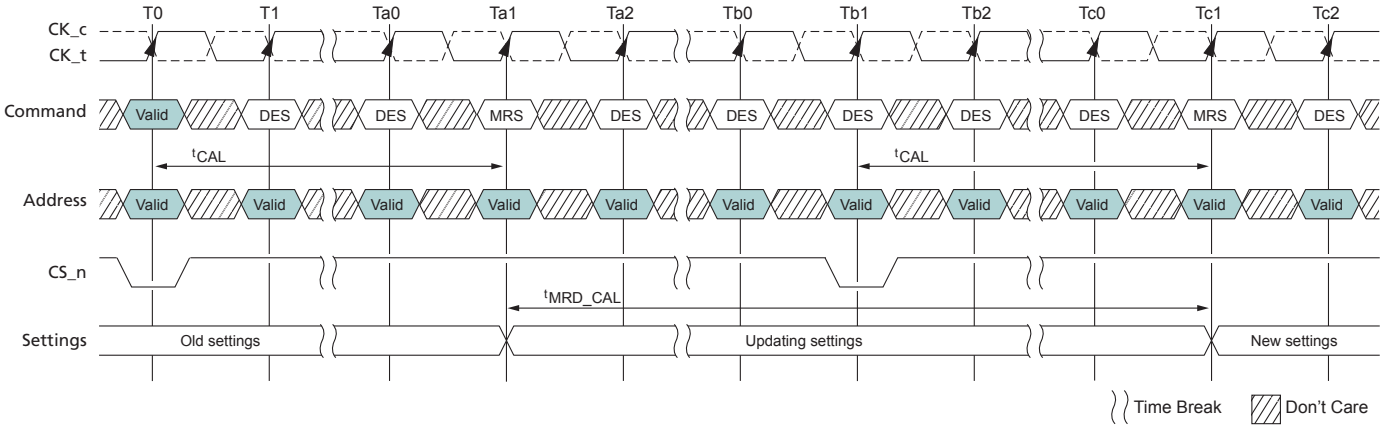
When the CAL mode is enabled or being enabled, the earliest the next MRS command can be issued is $^{t}$MRD_CAL is equal to $^{t}$MOD + $^{t}$CAL. The two following figures are examples.

**Figure 20: CAL Enabling MRS to Next MRS Command, $^{t}$MRD_CAL**




Note: 1. Command address latency mode is enabled at T1.

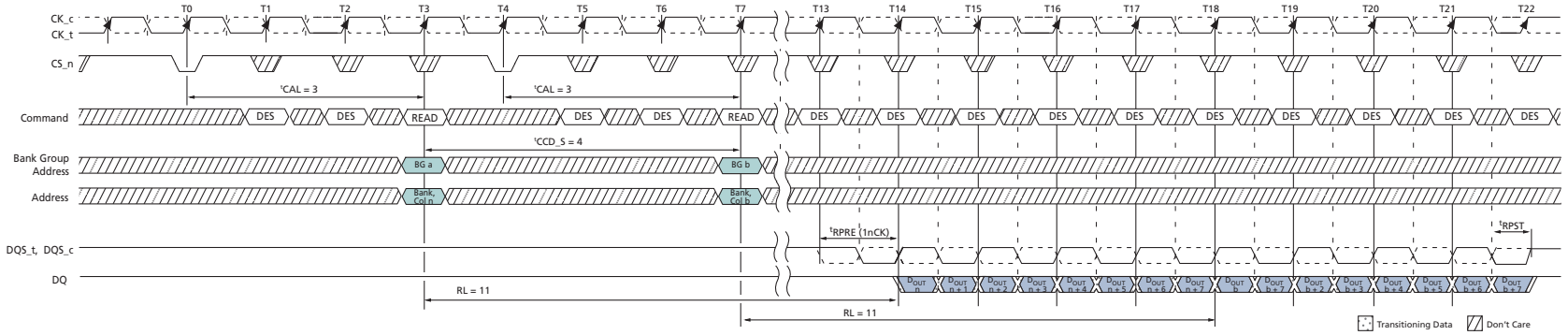
**Figure 21: $^{t}$MRD_CAL, Mode Register Cycle Time With CAL Enabled**




Note: 1. MRS at Ta1 may or may not modify CAL, $^{t}$MRD_CAL is computed based on new $^{t}$CAL setting if modified.

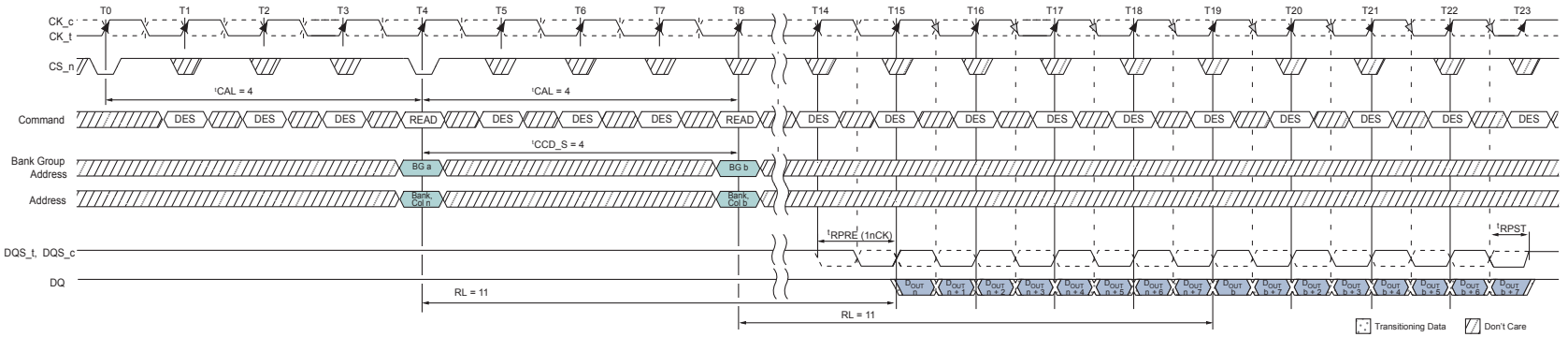
CAL Examples: Consecutive READ BL8 with two different CALs and 1$^{t}$CK preamble in different bank group shown in the following figures.

**Figure 22: Consecutive READ BL8, CAL3, 1tCK Preamble, Different Bank Group**




Notes:
1. BL = 8, AL = 0, CL = 11, CAL = 3, Preamble = 1tCK.
2. $D_{OUT}$ n = data-out from column n; $D_{OUT}$ b = data-out from column b.
3. DES commands are shown for ease of illustration, other commands may be valid at these times.
4. BL8 setting activated by either MR0[A1:0 = 00] or MR0[A1:0 = 01] and A12 = 1 during READ command at T3 and T7.
5. CA parity = Disable, CS to CA latency = Enable, Read DBI = Disable.
6. Enabling CAL mode does not impact ODT control timings. ODT control timings should be maintained with the same timing relationship relative to the command/address bus as when CAL is disabled.

**Figure 23: Consecutive READ BL8, CAL4, 1tCK Preamble, Different Bank Group**




Notes:
1. BL = 8, AL = 0, CL = 11, CAL = 4, Preamble = 1tCK.
2. $D_{OUT}$ n = data-out from column n; $D_{OUT}$ b = data-out from column b.
3. DES commands are shown for ease of illustration, other commands may be valid at these times.
4. BL8 setting activated by either MR0[A1:0 = 00] or MR0[A1:0 = 01] and A12 = 1 during READ command at T4 and T8.

5. CA parity = Disable, CS to CA latency = Enable, Read DBI = Disable.
6. Enabling CAL mode does not impact ODT control timings. ODT control timings should be maintained with the same timing relationship relative to the command/address bus as when CAL is disabled.

## Low-Power Auto Self Refresh Mode

An auto self refresh mode is provided for application ease. Auto self refresh mode is enabled by setting MR2[6] = 1 and MR2[7] = 1. The device will manage self refresh entry over the supported temperature range of the DRAM. In this mode, the device will change its self refresh rate as the DRAM operating temperature changes, going lower at low temperatures and higher at high temperatures.

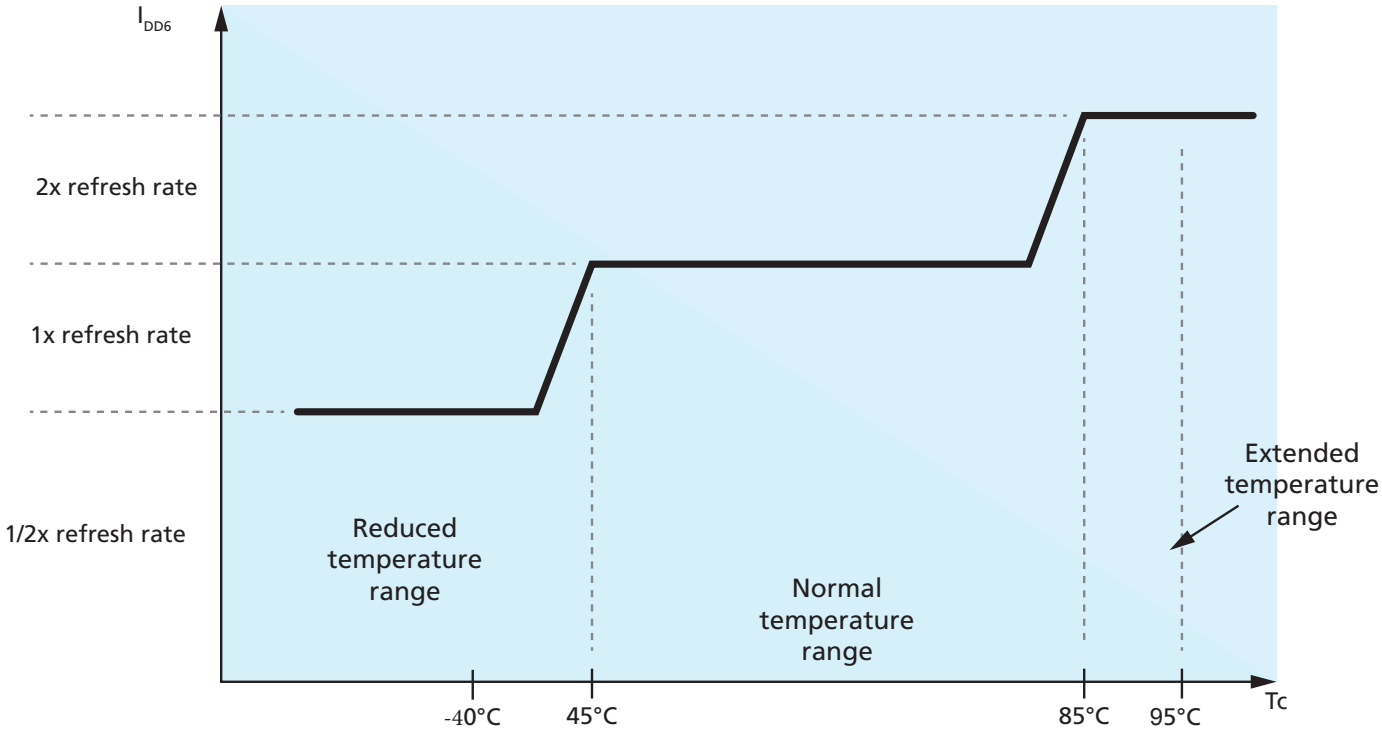
## Manual Self Refresh Mode

If auto self refresh mode is not enabled, the low-power auto self refresh mode register must be manually programmed to one of the three self refresh operating modes. This mode provides the flexibility to select a fixed self refresh operating mode at the entry of the self refresh, according to the system memory temperature conditions. The user is responsible for maintaining the required memory temperature condition for the mode selected during the SELF REFRESH operation. The user may change the selected mode after exiting self refresh and before entering the next self refresh. If the temperature condition is exceeded for the mode selected, there is a risk to data retention resulting in loss of data.

**Table 26: Auto Self Refresh Mode**

| MR2[7] | MR2[6] | Low-Power Auto Self Refresh Mode | SELF REFRESH Operation | Operating Temperature Range for Self Refresh Mode (DRAM $T_{CASE}$) |
|---|---|---|---|---|
| 0 | 0 | Normal | Variable or fixed normal self refresh rate maintains data retention at the normal operating temperature. User is required to ensure that 85°C DRAM $T_{CASE}$ (MAX) is not exceeded to avoid any risk of data loss. | -40°C to 85°C |
| 1 | 0 | Extended temperature | Variable or fixed high self refresh rate optimizes data retention to support the extended temperature range. | -40°C to 95°C |
| 0 | 1 | Reduced temperature | Variable or fixed self refresh rate or any other DRAM power consumption reduction control for the reduced temperature range. User is required to ensure 45°C DRAM $T_{CASE}$ (MAX) is not exceeded to avoid any risk of data loss. | -40°C to 45°C |
| 1 | 1 | Auto self refresh | Auto self refresh mode enabled. Self refresh power consumption and data retention are optimized for any given operating temperature condition. | All of the above |

**Figure 24: Auto Self Refresh Ranges**



## Multipurpose Register

The MULTIPURPOSE REGISTER (MPR) function, MPR access mode, is used to write/read specialized data to/from the DRAM. The MPR consists of four logical pages, MPR Page 0 through MPR Page 3, with each page having four 8-bit registers, MPR0 through MPR3. Page 0 can be read by any of three readout modes (serial, parallel, or staggered) while Pages 1, 2, and 3 can be read by only the serial readout mode. Page 3 is for DRAM vendor use only. MPR mode enable and page selection is done with MRS commands. Data bus inversion (DBI) is not allowed during MPR READ operation.

Once the MPR access mode is enabled (MR3[2] = 1), only the following commands are allowed: MRS, RD, RDA WR, WRA, DES, REF, and RESET; RDA/WRA have the same functionality as RD/WR which means the auto precharge part of RDA/WRA is ignored. Power-down mode and SELF REFRESH command are not allowed during MPR enable mode. No other command can be issued within $^{t}$RFC after a REF command has been issued; 1x refresh (only) is to be used during MPR access mode. While in MPR access mode, MPR read or write sequences must be completed prior to a REFRESH command.

**Figure 25: MPR Block Diagram**

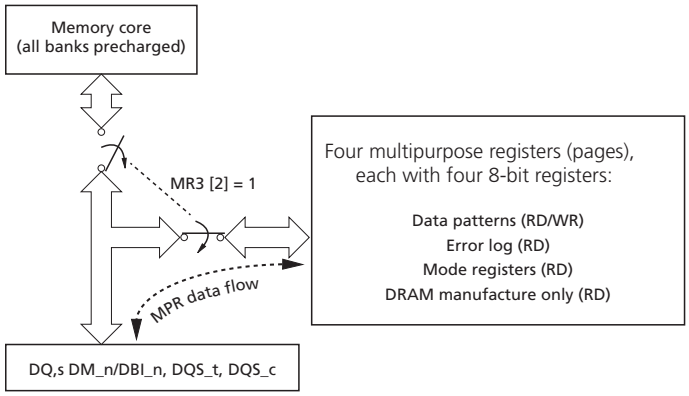



**Table 27: MR3 Setting for the MPR Access Mode**

| Address | Operation Mode | Description |
|---|---|---|
| A[12:11] | MPR data read format | 00 = Serial ..... 01 = Parallel<br>10 = Staggered .... 11 = Reserved |
| A2 | MPR access | 0 = Standard operation (MPR not enabled)<br>1 = MPR data flow enabled |
| A[1:0] | MPR page selection | 00 = Page 0 .... 01 = Page 1<br>10 = Page 2 .... 11 = Page 3 |

**Table 28: DRAM Address to MPR UI Translation**

| MPR Location | [7] | [6] | [5] | [4] | [3] | [2] | [1] | [0] |
|---|---|---|---|---|---|---|---|---|
| DRAM address – A*x* | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
| MPR UI – UI*x* | UI0 | UI1 | UI2 | UI3 | UI4 | UI5 | UI6 | UI7 |

**Table 29: MPR Page and MPR*x* Definitions**

| Address | MPR Location | [7] | [6] | [5] | [4] | [3] | [2] | [1] | [0] | Note |
|---|---|---|---|---|---|---|---|---|---|---|
| **MPR Page 0 – Read or Write (Data Patterns)** | | | | | | | | | | |
| BA[1:0] | 00 = MPR0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | Read/ Write (default value listed) |
| | 01 = MPR1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | |
| | 10 = MPR2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | |
| | 11 = MPR3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **MPR Page 1 – Read-only (Error Log)** | | | | | | | | | | |
| BA[1:0] | 00 = MPR0 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 | Read-only |
| | 01 = MPR1 | CAS_n/A15 | WE_n/A14 | A13 | A12 | A11 | A10 | A9 | A8 | |
| | 10 = MPR2 | PAR | ACT_n | BG1 | BG0 | BA1 | BA0 | A17 | RAS_n/A16 | |
| | 11 = MPR3 | CRC error status | CA parity error status | CA parity latency: [5] = MR5[2], [4] = MR5[1], [3] = MR5[0] | | | C2 | C1 | C0 | |
| **MPR Page 2 – Read-only (MRS Readout)** | | | | | | | | | | |
| BA[1:0] | 00 = MPR0 | hPPR support | sPPR support | $R_{TT(WR)}$ MR2[11] | Temperature sensor status[2] | | CRC write enable MR2[12] | $R_{TT(WR)}$ MR2[10:9] | | Read-only |
| | 01 = MPR1 | $V_{REFDQ}$ training range MR6[6] | $V_{REFDQ}$ training value: [6:1] = MR6[5:0] | | | | | | Gear-down enable MR3[3] | |
| | 10 = MPR2 | CAS latency: [7:3] = MR0[6:4,2,12] | | | | | CAS write latency [2:0] = MR2[5:3] | | | |
| | 11 = MPR3 | $R_{TT(NOM)}$: [7:5] = MR1[10:8] | | | $R_{TT(Park)}$: [4:2] = MR5[8:6] | | | $R_{ON}$: [1:0] = MR2[2:1] | | |
| **MPR Page 3 – Read-only (Restricted, except for MPR3 [3:0])** | | | | | | | | | | |
| BA[1:0] | 00 = MPR0 | DC | DC | DC | DC | DC | DC | DC | DC | Read-only |
| | 01 = MPR1 | DC | DC | DC | DC | DC | DC | DC | DC | |
| | 10 = MPR2 | DC | DC | DC | DC | DC | DC | DC | DC | |
| | 11 = MPR3 | DC | DC | DC | DC | MAC | MAC | MAC | MAC | |

Notes: 1. DC = "Don't Care"
2. MPR[4:3] 00 = Sub 1X refresh; MPR[4:3] 01 = 1X refresh; MPR[4:3] 10 = 2X refresh; MPR[4:3] 11 = Reserved

## MPR Reads

MPR reads are supported using BL8 and BC4 modes. Burst length on-the-fly is not supported for MPR reads. Data bus inversion (DBI) is not allowed during MPR READ operation; the device will ignore the Read DBI enable setting in MR5 [12] when in MPR mode. READ commands for BC4 are supported with a starting column address of A[2:0] = 000

or 100. After power-up, the content of MPR Page 0 has the default values, which are defined in Table 29. MPR page 0 can be rewritten via an MPR WRITE command. The device maintains the default values unless it is rewritten by the DRAM controller. If the DRAM controller does overwrite the default values (Page 0 only), the device will main-tain the new values unless re-initialized or there is power loss.
Timing in MPR mode:

- Reads (back-to-back) from Page 0 may use $^{t}$CCD_S or $^{t}$CCD_L timing between READ commands
- Reads (back-to-back) from Pages 1, 2, or 3 may not use $^{t}$CCD_S timing between READ commands; $^{t}$CCD_L must be used for timing between READ commands

The following steps are required to use the MPR to read out the contents of a mode register (MPR Page *x*, MPR*y*).

1. The DLL must be locked if enabled.
2. Precharge all; wait until $^{t}$RP is satisfied.
3. MRS command to MR3[2] = 1 (Enable MPR data flow), MR3[12:11] = MPR read format, and MR3[1:0] MPR page.
    a. MR3[12:11] MPR read format:
        1. 00 = Serial read format
        2. 01 = Parallel read format
        3. 10 = staggered read format
        4. 11 = RFU
    b. MR3[1:0] MPR page:
        1. 00 = MPR Page 0
        2. 01 = MPR Page 1
        3. 10 = MPR Page 2
        4. 11 = MPR Page 3
4. $^{t}$MRD and $^{t}$MOD must be satisfied.
5. Redirect all subsequent READ commands to specific MPR*x* location.
6. Issue RD or RDA command.
    a. BA1 and BA0 indicate MPR*x* location:
        1. 00 = MPR0
        2. 01 = MPR1
        3. 10 = MPR2
        4. 11 = MPR3
    b. A12/BC = 0 or 1; BL8 or BC4 fixed-only, BC4 OTF not supported.
        1. If BL = 8 and MR0 A[1:0] = 01, A12/BC must be set to 1 during MPR READ commands.
    c. A2 = burst-type dependant:
        1. BL8: A2 = 0 with burst order fixed at 0, 1, 2, 3, 4, 5, 6, 7
        2. BL8: A2 = 1 not allowed
        3. BC4: A2 = 0 with burst order fixed at 0, 1, 2, 3, T, T, T, T
        4. BC4: A2 = 1 with burst order fixed at 4, 5, 6, 7, T, T, T, T
    d. A[1:0] = 00, data burst is fixed nibble start at 00.
    e. Remaining address inputs, including A10, and BG1 and BG0 are "Don't Care."
7. After RL = AL + CL, DRAM bursts data from MPR*x* location; MPR readout format determined by MR3[A12,11,1,0].
8. Steps 5 through 7 may be repeated to read additional MPR*x* locations.
9. After the last MPR*x* READ burst, $^{t}$MPRR must be satisfied prior to exiting.
10. Issue MRS command to exit MPR mode; MR3[2] = 0.

11. After the $^{t}$MOD sequence is completed, the DRAM is ready for normal operation from the core (such as ACT).

## MPR Readout Format

The MPR read data format can be set to three different settings: serial, parallel, and staggered.

## MPR Readout Serial Format

The serial format is required when enabling the MPR function to read out the contents of an MR*x*, temperature sensor status, and the command address parity error frame. However, data bus calibration locations (four 8-bit registers) can be programmed to read out any of the three formats. The DRAM is required to drive associated strobes with the read data similar to normal operation (such as using MRS preamble settings).

Serial format implies that the same pattern is returned on all DQ lanes, as shown the table below, which uses values programmed into the MPR via [7:0] as 0111 1111.

**Table 30: MPR Readout Serial Format**

| Serial | UI0 | UI1 | UI2 | UI3 | UI4 | UI5 | UI6 | UI7 |
|---|---|---|---|---|---|---|---|---|
| **x16 Device** | | | | | | | | |
| DQ0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ3 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ4 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ6 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ7 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ8 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ9 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ10 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ11 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ12 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ13 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ14 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ15 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

## MPR Readout Parallel Format

Parallel format implies that the MPR data is returned in the first data UI and then repeated in the remaining UIs of the burst, as shown in the table below. Data pattern location 0 is the only location used for the parallel format. RD/RDA from data pattern locations 1, 2, and 3 are not allowed with parallel data return mode. In this example, the pattern programmed in the data pattern location 0 is 0111 1111. The x4 configuration only out-puts the first four bits (0111 in this example). For the x16 configuration, the same pattern is repeated on both the upper and lower bytes.

**Table 31: MPR Readout – Parallel Format**

| Parallel | UI0 | UI1 | UI2 | UI3 | UI4 | UI5 | UI6 | UI7 |
|---|---|---|---|---|---|---|---|---|
| **x16 Device** | | | | | | | | |
| DQ0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DQ1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DQ9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ14 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ15 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

## MPR Readout Staggered Format

Staggered format of data return is defined as the staggering of the MPR data across the lanes. In this mode, an RD/RDA command is issued to a specific data pattern location and then the data is returned on the DQ from each of the different data pattern locations. A read example to MPR0 for x16 configurations is shown below.

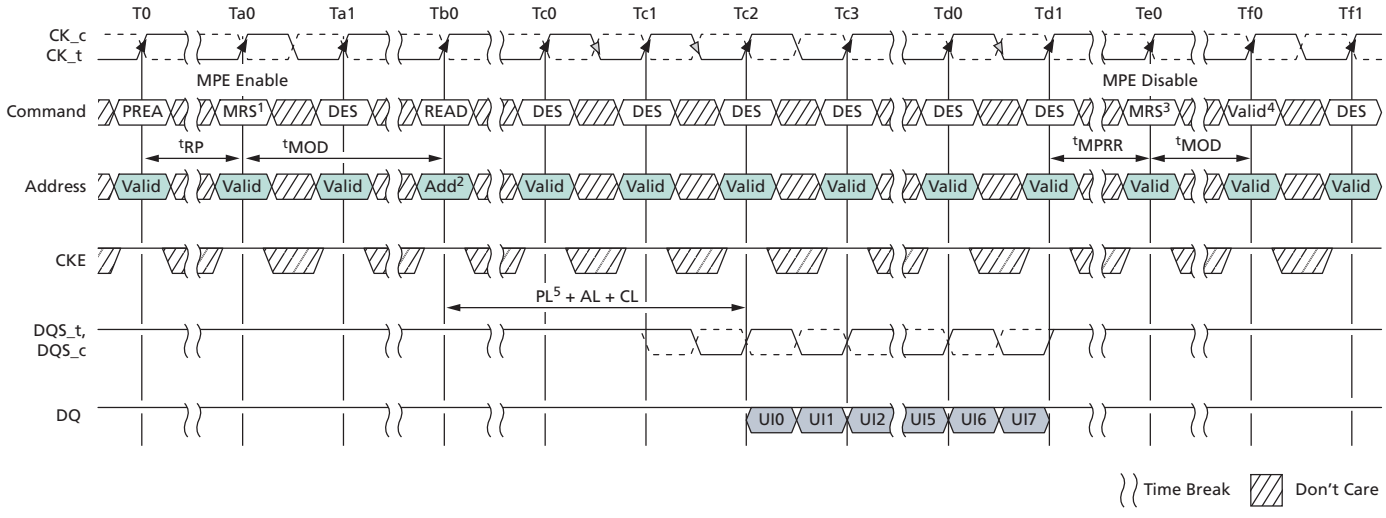
**Table 32: MPR Readout Staggered Format, x16**

| x16 READ MPR0 Command | | x16 READ MPR0 Command | |
|---|---|---|---|
| **Stagger** | **UI[7:0]** | **Stagger** | **UI[7:0]** |
| DQ0 | MPR0 | DQ8 | MPR0 |
| DQ1 | MPR1 | DQ9 | MPR1 |
| DQ2 | MPR2 | DQ10 | MPR2 |
| DQ3 | MPR3 | DQ11 | MPR3 |
| DQ4 | MPR0 | DQ12 | MPR0 |
| DQ5 | MPR1 | DQ13 | MPR1 |
| DQ6 | MPR2 | DQ14 | MPR2 |
| DQ7 | MPR3 | DQ15 | MPR3 |

## MPR READ Waveforms

The following waveforms show MPR read accesses.

**Figure 26: MPR READ Timing**

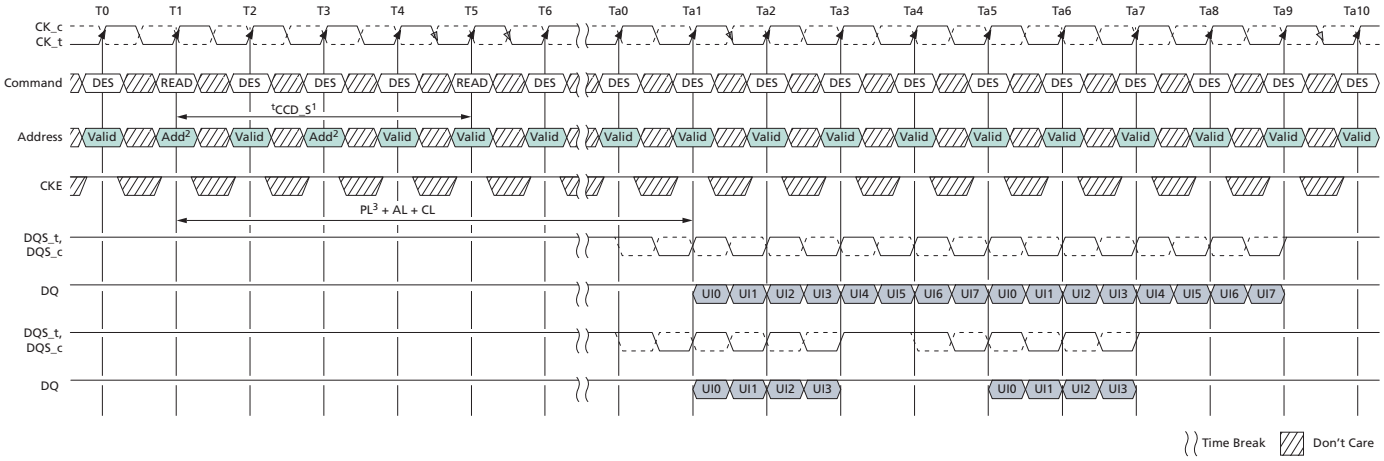



Notes: 1. $^{t}$CCD_S = 4$^{t}$CK, Read Preamble = 1$^{t}$CK.
2. Address setting:
A[1:0] = 00b (data burst order is fixed starting at nibble, always 00b here)

A2 = 0b (for BL = 8, burst order is fixed at 0, 1, 2, 3, 4, 5, 6, 7)
BA1 and BA0 indicate the MPR location
A10 and other address pins are "Don't Care," including BG0. A12 is "Don't Care" when MR0 A[1:0] = 00 or 10 and must be 1b when MR0 A[1:0] = 01

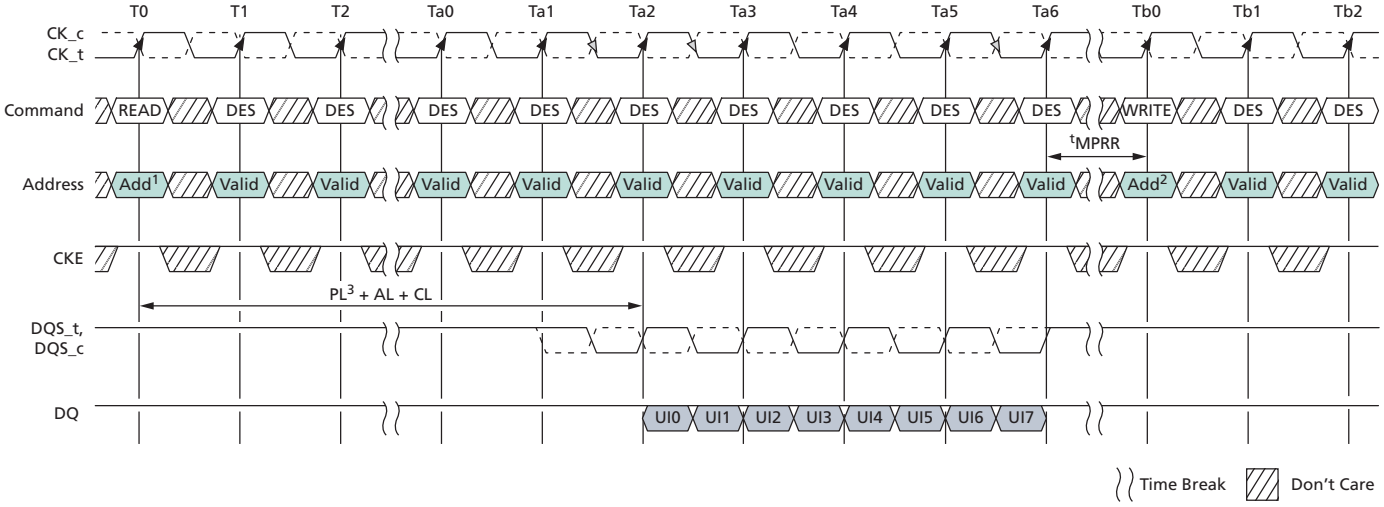
3. Multipurpose registers read/write disable (MR3 A2 = 0).
4. Continue with regular DRAM command.
5. Parity latency (PL) is added to data output delay when CA parity latency mode is enabled.

**Figure 27: MPR Back-to-Back READ Timing**




Notes:
1. $^{t}$CCD_S = 4$^{t}$CK, Read Preamble = 1$^{t}$CK.
2. Address setting:
   A[1:0] = 00b (data burst order is fixed starting at nibble, always 00b here)
   A2 = 0b (for BL = 8, burst order is fixed at 0, 1, 2, 3, 4, 5, 6, 7; for BC = 4, burst order is fixed at 0, 1, 2, 3, T, T, T, T)
   BA1 and BA0 indicate the MPR location
   A10 and other address pins are "Don't Care," including BG0. A12 is "Don't Care" when MR0 A[1:0] = 00 or 10 and must be 1b when MR0 A[1:0] = 01
3. Parity latency (PL) is added to data output delay when CA parity latency mode is enabled.

**Figure 28: MPR READ-to-WRITE Timing**




Notes:
1. Address setting:
   A[1:0] = 00b (data burst order is fixed starting at nibble, always 00b here)
   A2 = 0b (for BL = 8, burst order is fixed at 0, 1, 2, 3, 4, 5, 6, 7)
   BA1 and BA0 indicate the MPR location
   A10 and other address pins are "Don't Care," including BG0. A12 is "Don't Care" when MR0 A[1:0] = 00 and must be 1b when MR0 A[1:0] = 01
2. Address setting:
   BA1 and BA0 indicate the MPR location
   A[7:0] = data for MPR
   BA1 and BA0 indicate the MPR location
   A10 and other address pins are "Don't Care"
3. Parity latency (PL) is added to data output delay when CA parity latency mode is enabled.

## MPR Writes

MPR access mode allows 8-bit writes to the MPR Page 0 using the address bus A[7:0]. Data bus inversion (DBI) is not allowed during MPR WRITE operation. The DRAM will maintain the new written values unless re-initialized or there is power loss.

The following steps are required to use the MPR to write to mode register MPR Page 0.

1. The DLL must be locked if enabled.
2. Precharge all; wait until $^{t}$RP is satisfied.
3. MRS command to MR3[2] = 1 (enable MPR data flow) and MR3[1:0] = 00 (MPR Page 0); writes to 01, 10, and 11 are not allowed.
4. $^{t}$MRD and $^{t}$MOD must be satisfied.
5. Redirect all subsequent WRITE commands to specific MPR*x* location.
6. Issue WR or WRA command:
   a. BA1 and BA0 indicate MPR*x* location
      1. 00 = MPR0
      2. 01 = MPR1
      3. 10 = MPR2
      4. 11 = MPR3
   b. A[7:0] = data for MPR Page 0, mapped A[7:0] to UI[7:0].

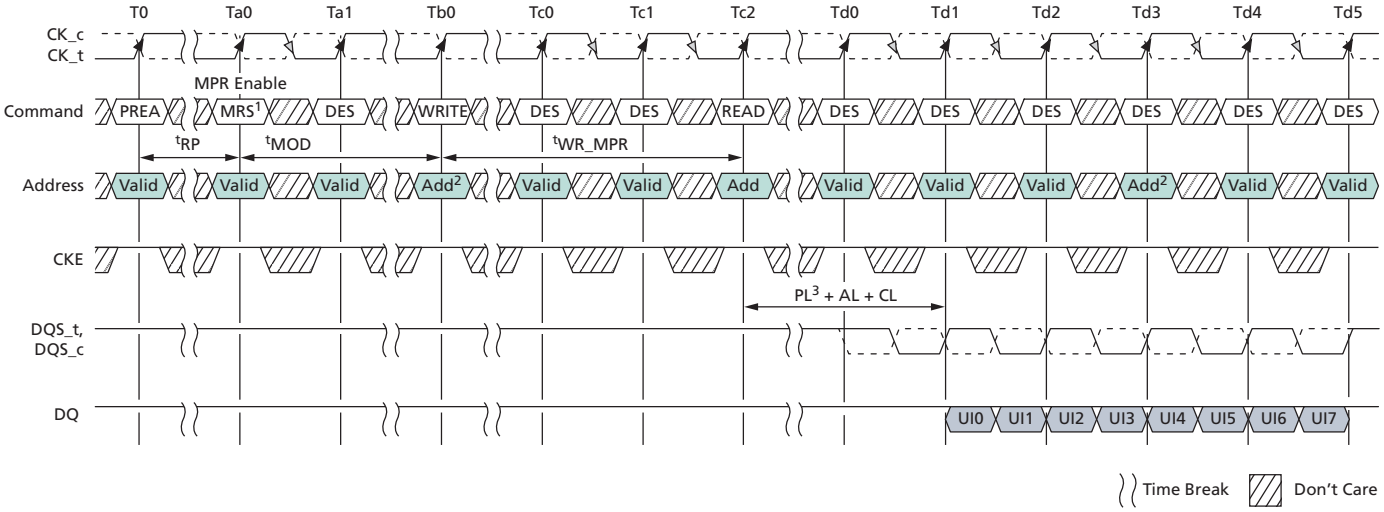
c. Remaining address inputs, including A10, and BG1 and BG0 are "Don't Care."

7. $^{t}$WR_MPR must be satisfied to complete MPR WRITE.
8. Steps 5 through 7 may be repeated to write additional MPR*x* locations.
9. After the last MPR*x* WRITE, $^{t}$MPRR must be satisfied prior to exiting.
10. Issue MRS command to exit MPR mode; MR3[2] = 0.
11. When the $^{t}$MOD sequence is completed, the DRAM is ready for normal operation from the core (such as ACT).

## MPR WRITE Waveforms

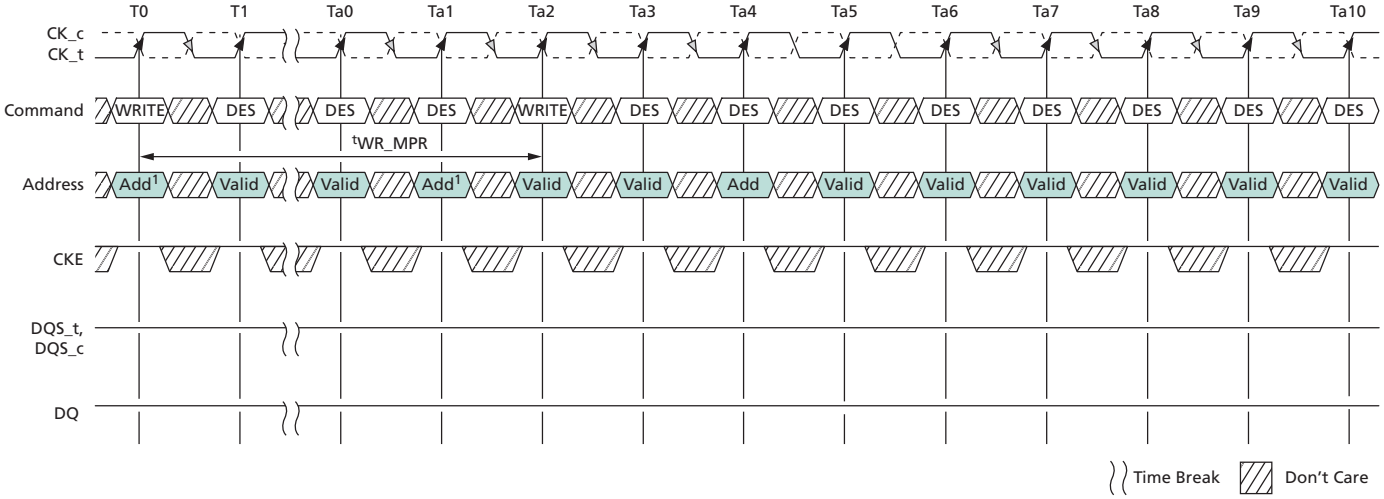
The following waveforms show MPR write accesses.

**Figure 29: MPR WRITE and WRITE-to-READ Timing**




Notes:
1. Multipurpose registers read/write enable (MR3 A2 = 1).
2. Address setting:
   BA1 and BA0 indicate the MPR location
   A10 and other address pins are "Don't Care"
3. Parity latency (PL) is added to data output delay when CA parity latency mode is enabled.

**Figure 30: MPR Back-to-Back WRITE Timing**

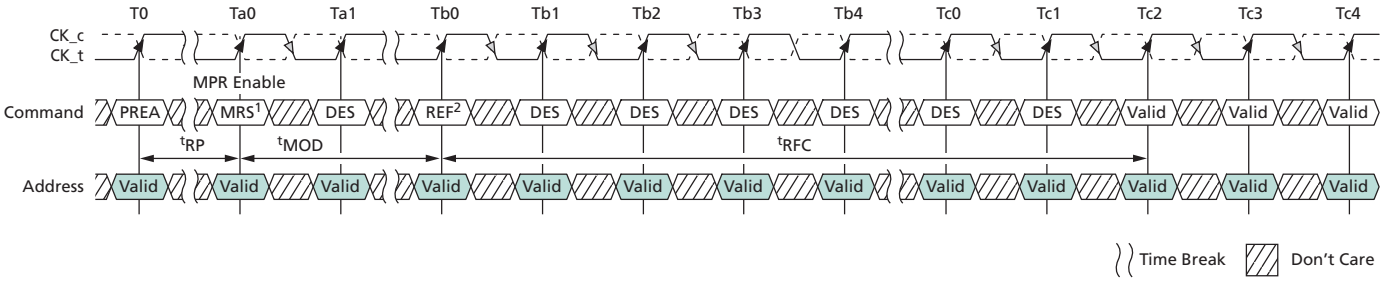



Note: 1. Address setting:
BA1 and BA0 indicate the MPR location
A[7:0] = data for MPR
A10 and other address pins are "Don't Care"

## MPR REFRESH Waveforms

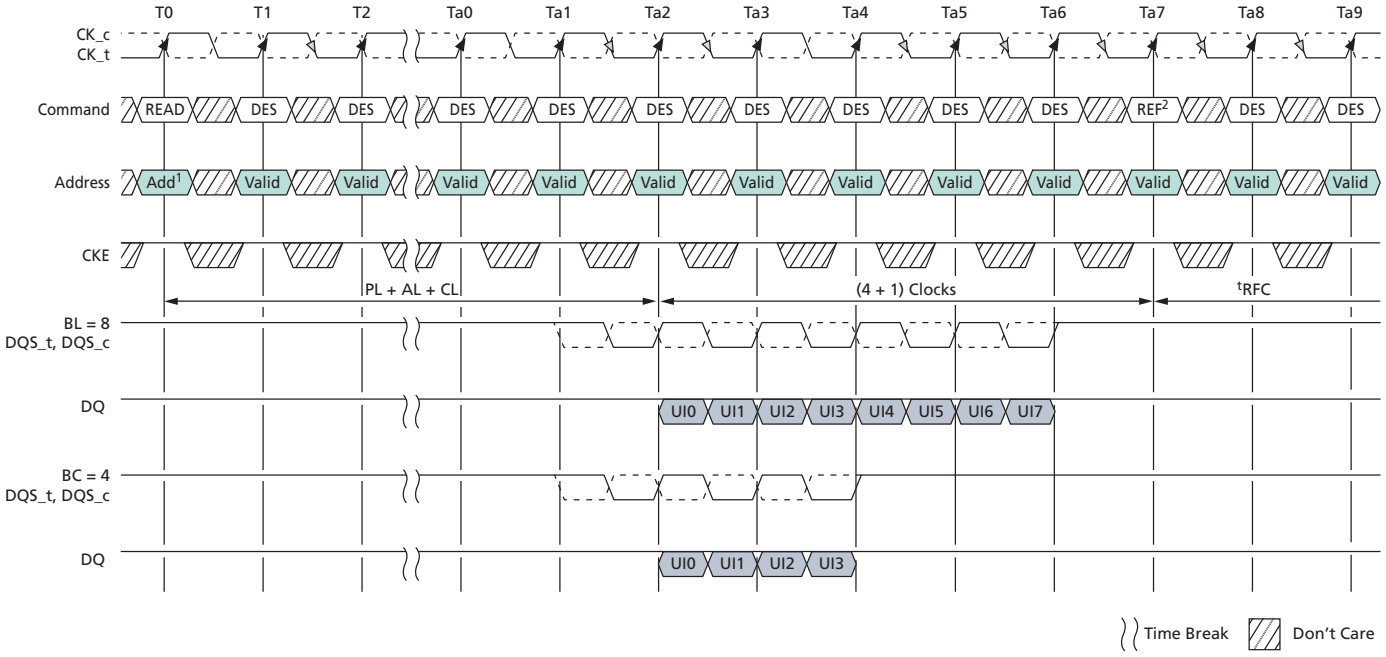
The following waveforms show MPR accesses interaction with refreshes.

**Figure 31: REFRESH Timing**



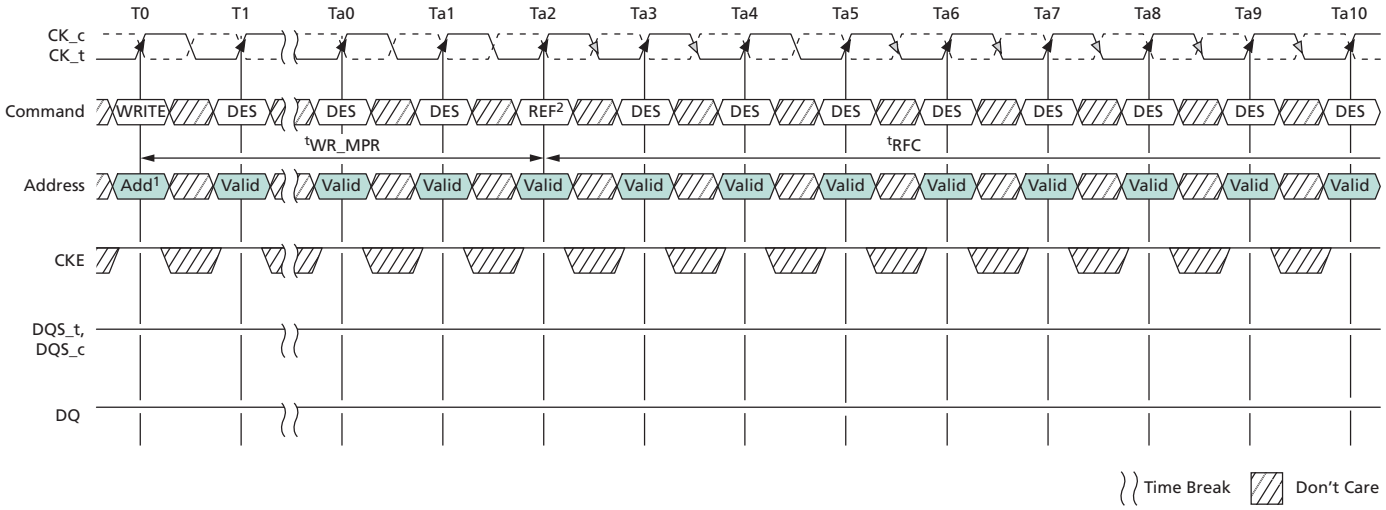

Notes: 1. Multipurpose registers read/write enable (MR3 A2 = 1). Redirect all subsequent read and writes to MPR locations.
2. 1x refresh is only allowed when MPR mode is enabled.

**Figure 32: READ-to-REFRESH Timing**




Notes:
1. Address setting:
   A[1:0] = 00b (data burst order is fixed starting at nibble, always 00b here)
   A2 = 0b (for BL = 8, burst order is fixed at 0, 1, 2, 3, 4, 5, 6, 7)
   BA1 and BA0 indicate the MPR location
   A10 and other address pins are "Don't Care," including BG1 and BG0. A12 is "Don't Care" when MR0 A[1:0] = 00 or 10, and must be 1b when MR0 A[1:0] = 01
2. 1x refresh is only allowed when MPR mode is enabled.

**Figure 33: WRITE-to-REFRESH Timing**




Notes:
1. Address setting:
   BA1 and BA0 indicate the MPR location
   A[7:0] = data for MPR
   A10 and other address pins are "Don't Care"
2. 1x refresh is only allowed when MPR mode is enabled.

## Gear-Down Mode

The DDR4 SDRAM defaults in 1/2 rate (1N) clock mode and uses a low-frequency MRS command (the MRS command has relaxed setup and hold) followed by a sync pulse (first CS pulse after MRS setting) to align the proper clock edge for operating the control lines CS_n, CKE, and ODT when in 1/4 rate (2N) mode. Gear-down mode is only supported at DDR4-2666 and faster. For operation in 1/2 rate mode, neither an MRS command or a sync pulse is required. Gear-down mode may only be entered during initialization or self refresh exit and may only be exited during self refresh exit. CAL mode and CA parity mode must be disabled prior to gear-down mode entry. The two modes may be enabled after $^{t}$SYNC_GEAR and $^{t}$CMD_GEAR periods have been satisfied. The general sequence for operation in 1/4 rate during initialization is as follows:

1. The device defaults to a 1N mode internal clock at power-up/reset.
2. Assertion of reset.
3. Assertion of CKE enables the DRAM.
4. MRS is accessed with a low-frequency N × $^{t}$CK gear-down MRS command. (N$^{t}$CK static MRS command is qualified by 1N CS_n. )
5. The memory controller will send a 1N sync pulse with a low-frequency N × $^{t}$CK NOP command. $^{t}$SYNC_GEAR is an even number of clocks. The sync pulse is on an even edge clock boundary from the MRS command.
6. Initialization sequence, including the expiration of $^{t}$DLLK and $^{t}$ZQinit, starts in 2N mode after $^{t}$CMD_GEAR from 1N sync pulse.

The device resets to 1N gear-down mode after entering self refresh. The general sequence for operation in gear-down after self refresh exit is as follows:

1. MRS is set to 1, via MR3[3], with a low-frequency N × $^{t}$CK gear-down MRS command.
   a. The N$^{t}$CK static MRS command is qualified by 1N CS_n, which meets $^{t}$XS or $^{t}$XS_ABORT.
   b. Only a REFRESH command may be issued to the DRAM before the N$^{t}$CK static MRS command.
2. The DRAM controller sends a 1N sync pulse with a low-frequency N × $^{t}$CK NOP command.
   a. $^{t}$SYNC_GEAR is an even number of clocks.
   b. The sync pulse is on even edge clock boundary from the MRS command.
3. A valid command not requiring locked DLL is available in 2N mode after $^{t}$CMD_GEAR from the 1N sync pulse.
   a. A valid command requiring locked DLL is available in 2N mode after $^{t}$XSDLL or $^{t}$DLLK from the 1N sync pulse.
4. If operation is in 1N mode after self refresh exit, N × $^{t}$CK MRS command or sync pulse is not required during self refresh exit. The minimum exit delay to the first valid command is $^{t}$XS, or $^{t}$XS_ABORT.

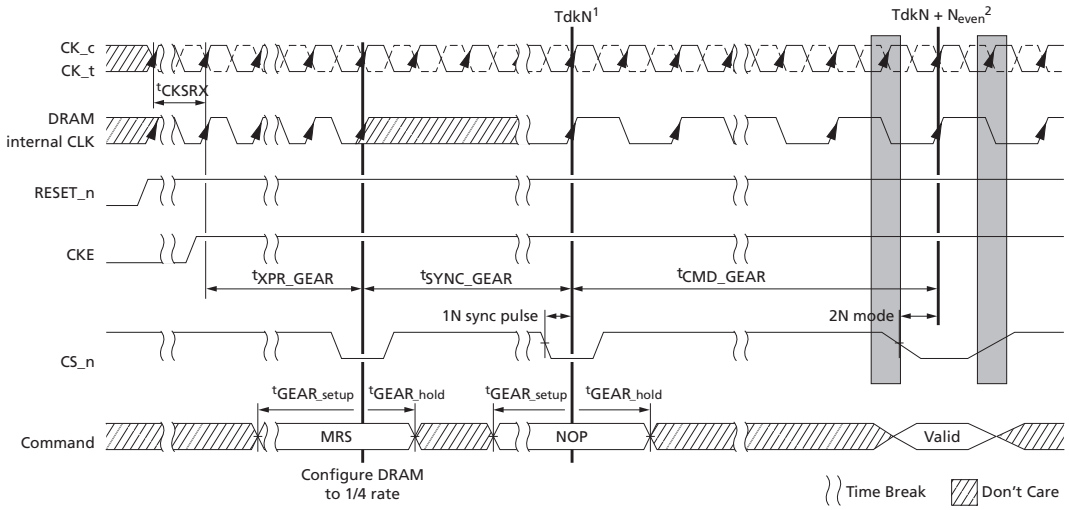
The DRAM may be changed from 2N to 1N by entering self refresh mode, which will re-set to 1N mode. Changing from 2N to by any other means can result in loss of data and make operation of the DRAM uncertain.

When operating in 2N gear-down mode, the following MR settings apply:

- CAS latency (MR0[6:4,2]): Even number of clocks
- Write recovery and read to precharge (MR0[11:9]): Even number of clocks
- Additive latency (MR1[4:3]): CL - 2
- CAS WRITE latency (MR2 A[5:3]): Even number of clocks

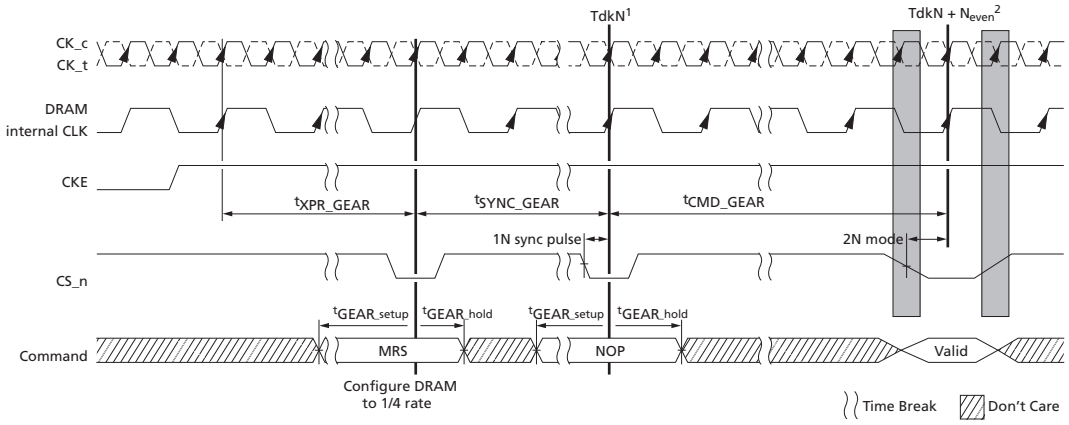
- CS to command/address latency mode (MR4[8:6]): Even number of clocks
- CA parity latency mode (MR5[2:0]): Even number of clocks

**Figure 34: Clock Mode Change from 1/2 Rate to 1/4 Rate (Initialization)**



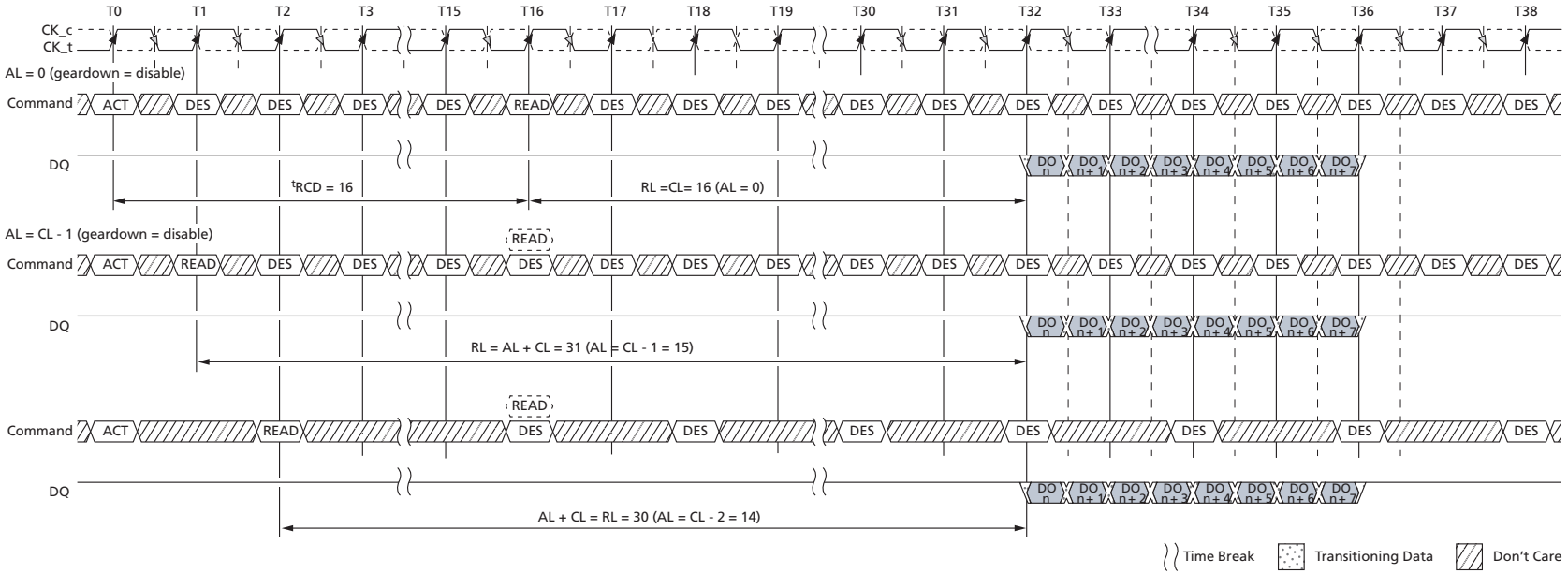

Notes:
1. After tSYNC_GEAR from GEAR-DOWN command, internal clock rate is changed at TdkN.
2. After tSYNC_GEAR + tCMD_GEAR from GEAR-DOWN command, both internal clock rate and command cycle are changed at TdkN + Neven.

**Figure 35: Clock Mode Change After Exiting Self Refresh**




Notes:
1. After tSYNC_GEAR from GEAR-DOWN command, internal clock rate is changed at TdkN.
2. After tSYNC_GEAR + tCMD_GEAR from GEAR-DOWN command, both internal clock rate and command cycle are changed at TdkN + Neven.

**Figure 36: Comparison Between Gear-Down Disable and Gear-Down Enable**



## Maximum Power-Saving Mode

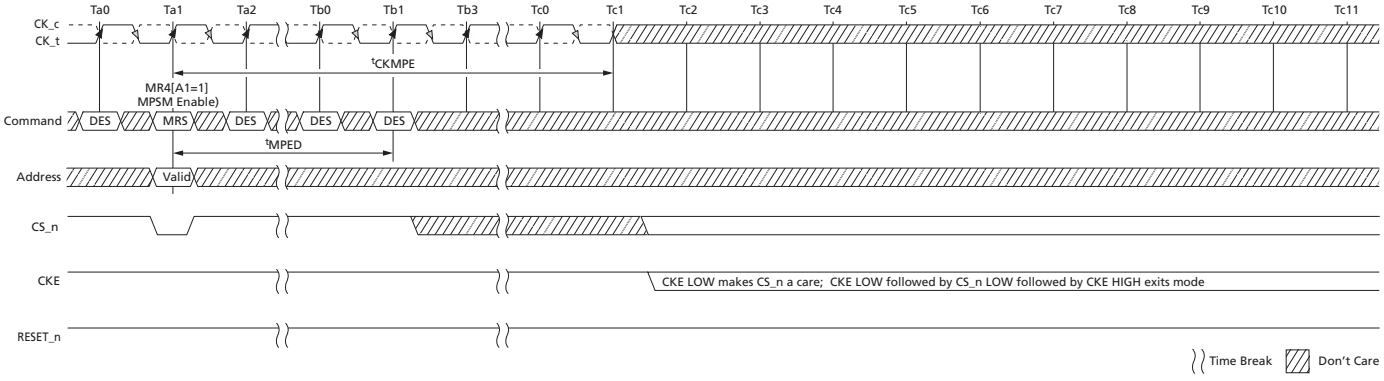
Maximum power-saving mode provides the lowest power mode where data retention is not required. When the device is in the maximum power-saving mode, it does not maintain data retention or respond to any external command, except the MAXIMUM POWER SAVING MODE EXIT command and during the assertion of RESET_n signal LOW. This mode is more like a “hibernate mode” than a typical power-saving mode. The intent is to be able to park the DRAM at a very low-power state; the device can be switched to an active state via the per-DRAM addressability (PDA) mode.

### Maximum Power-Saving Mode Entry

Maximum power-saving mode is entered through an MRS command. For devices with shared control/address signals, a single DRAM device can be entered into the maximum power-saving mode using the per-DRAM addressability MRS command. Large CS_n hold time to CKE upon the mode exit could cause DRAM malfunction; as a result, CA parity, CAL, and gear-down modes must be disabled prior to the maximum power-saving mode entry MRS command.

The MRS command may use both address and DQ information, as defined in the Per-DRAM Addressability section. As illustrated in the figure below, after $^{t}$MPED from the mode entry MRS command, the DRAM is not responsive to any input signals except CKE, CS_n, and RESET_n. All other inputs are disabled (external input signals may be-come High-Z). The system will provide a valid clock until $^{t}$CKMPE expires, at which time clock inputs (CK) should be disabled (external clock signals may become High-Z).

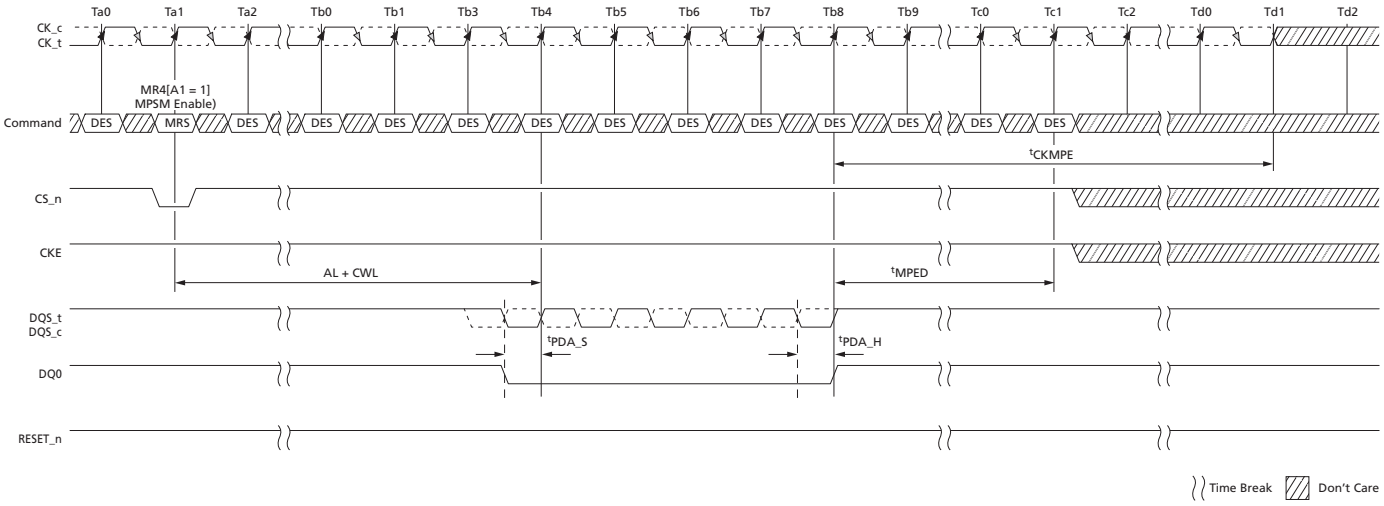
**Figure 37: Maximum Power-Saving Mode Entry**



## Maximum Power-Saving Mode Entry in PDA

The sequence and timing required for the maximum power-saving mode with the per-DRAM addressability enabled is illustrated in the figure below.

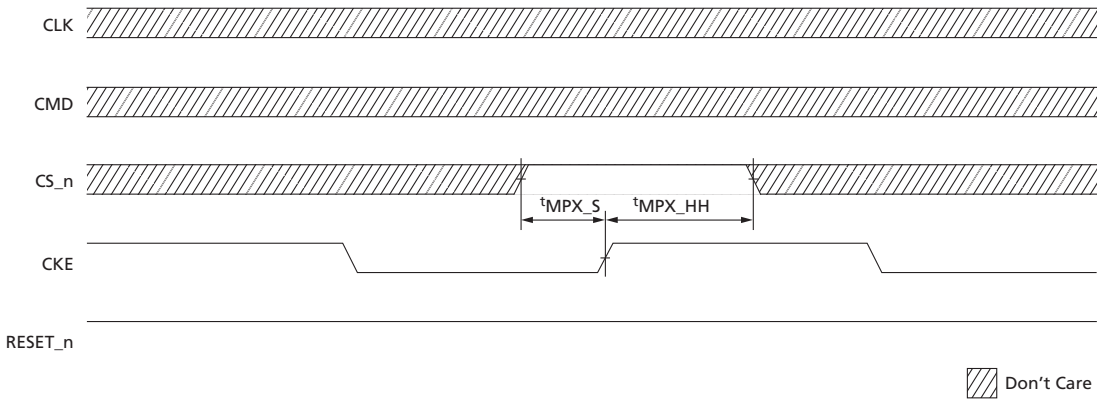
**Figure 38: Maximum Power-Saving Mode Entry with PDA**




## CKE Transition During Maximum Power-Saving Mode

The following figure shows how to maintain maximum power-saving mode even though the CKE input may toggle. To prevent the device from exiting the mode, CS_n should be HIGH at the CKE LOW-to-HIGH edge, with appropriate setup ($^{t}$MPX_S) and hold ($^{t}$MPX_H) timings.

**Figure 39: Maintaining Maximum Power-Saving Mode with CKE Transition**

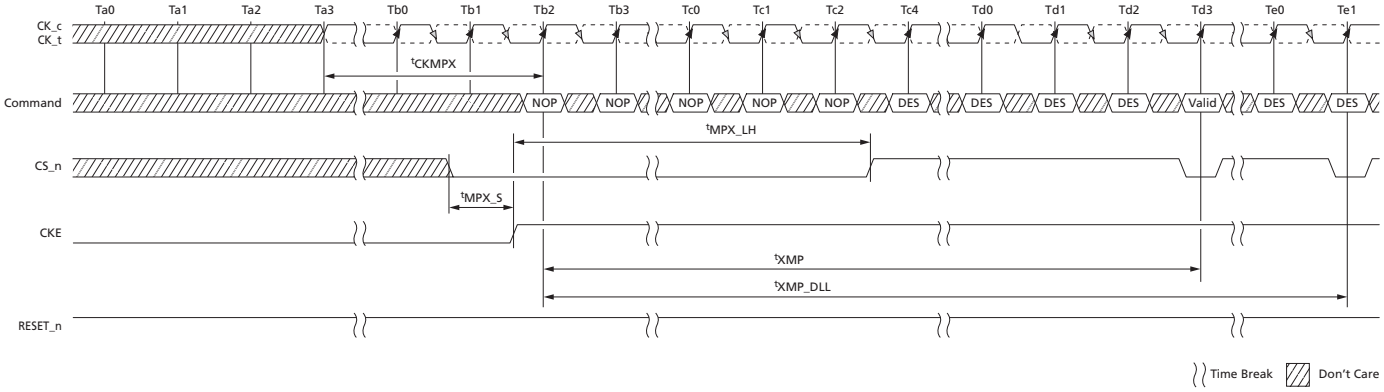



## Maximum Power-Saving Mode Exit

To exit the maximum power-saving mode, CS_n should be LOW at the CKE LOW-to-HIGH transition, with appropriate setup ($^{t}$MPX_S) and hold ($^{t}$MPX_LH) timings, as

shown in the figure below. Because the clock receivers (CK_t, CK_c) are disabled during this mode, CS_n = LOW is captured by the rising edge of the CKE signal. If the CS_n signal level is detected LOW, the DRAM clears the maximum power-saving mode MRS bit and begins the exit procedure from this mode. The external clock must be restarted and be stable by $^{t}$CKMPX before the device can exit the maximum power-saving mode. Dur-ing the exit time ($^{t}$XMP), only NOP and DES commands are allowed: NOP during $^{t}$MPX_LH and DES the remainder of $^{t}$XMP. After $^{t}$XMP expires, valid commands not requiring a locked DLL are allowed; after $^{t}$XMP_DLL expires, valid commands requiring a locked DLL are allowed.

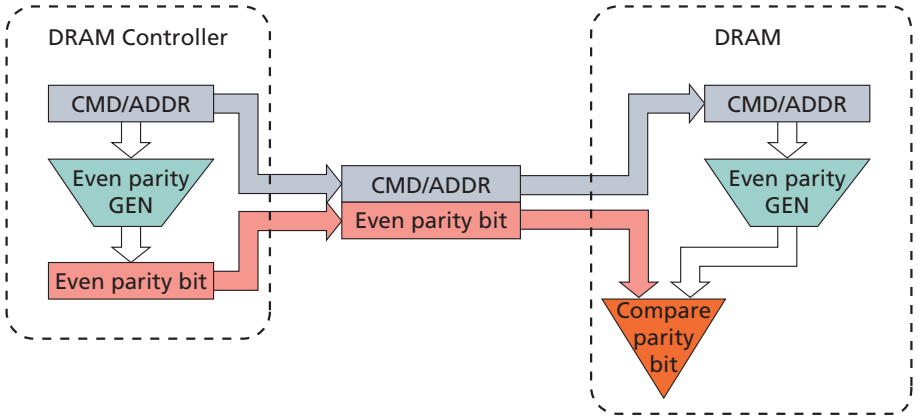
**Figure 40: Maximum Power-Saving Mode Exit**



## Command/Address Parity

Command/address (CA) parity takes the CA parity signal (PAR) input carrying the parity bit for the generated address and commands signals and matches it to the internally generated parity from the captured address and commands signals. CA parity is supported in the DLL enabled state only; if the DLL is disabled, CA parity is not supported.

**Figure 41: Command/Address Parity Operation**




CA parity is disabled or enabled via an MRS command. If CA parity is enabled by programming a non-zero value to CA parity latency in the MR, the DRAM will ensure that there is no parity error before executing commands. There is an additional delay required for executing the commands versus when parity is disabled. The delay is programmed in the MR when CA parity is enabled (parity latency) and applied to all commands which are registered by CS_n (rising edge of CK_t and falling CS_n). The command is held for the time of the parity latency (PL) before it is executed inside the device. The command captured by the input clock has an internal delay before executing and is determined with PL. ALERT_n will go active when the DRAM detects a CA parity error.

CA parity covers ACT_n, RAS_n/A16, CAS_n/A15, WE_n/A14, the address bus including bank address and bank group bits, and C[2:0] on 3DS devices; the control signals CKE, ODT, and CS_n are not covered. For example, for a 4Gb x4 monolithic device, parity is computed across BG0, BA[1:0], A16/ RAS_n, A15/CAS_n, A14/ WE_n, A[13:0], and ACT_n. The DRAM treats any unused address pins internally as zeros; for example, if a common die has stacked pins but the device is used in a monolithic application, then the address pins used for stacking and not connected are treated internally as zeros.

The convention for parity is even parity; for example, valid parity is defined as an even number of ones across the inputs used for parity computation combined with the pari-ty signal. In other words, the parity bit is chosen so that the total number of ones in the transmitted signal, including the parity bit, is even.

If a DRAM device detects a CA parity error in any command qualified by CS_n, it will perform the following steps:

1. Ignore the erroneous command. Commands in the MAX N*n*CK window

   ($^{t}$PAR_UNKNOWN) prior to the erroneous command are not guaranteed to be executed. When a READ command in this N*n*CK window is not executed, the device

does not activate DQS outputs. If WRITE CRC is enabled and a WRITE CRC occurs during the tPAR_UNKNOWN window, the WRITE CRC Error Status Bit located at MR5[3] may or may not get set. When CA Parity and WRITE CRC are both enabled and a CA Parity occurs, the WRITE CRC Error Status Bit should be reset.

2. Log the error by storing the erroneous command and address bits in the MPR error log.
3. Set the parity error status bit in the mode register to 1. The parity error status bit must be set before the ALERT_n signal is released by the DRAM (that is, tPAR_ALERT_ON + tPAR_ALERT_PW (MIN)).
4. Assert the ALERT_n signal to the host (ALERT_n is active LOW) within tPAR_ALERT_ON time.
5. Wait for all in-progress commands to complete. These commands were received tPAR_UNKOWN before the erroneous command.
6. Wait for tRAS (MIN) before closing all the open pages. The DRAM is not executing any commands during the window defined by (tPAR_ALERT_ON + tPAR_ALERT_PW).
7. After tPAR_ALERT_PW (MIN) has been satisfied, the device may de-assert ALERT_n.
    a. When the device is returned to a known precharged state, ALERT_n is allowed to be de-asserted.
8. After (tPAR_ALERT_PW (MAX)) the DRAM is ready to accept commands for normal operation. Parity latency will be in effect; however, parity checking will not resume until the memory controller has cleared the parity error status bit by writing a zero. The DRAM will execute any erroneous commands until the bit is cleared; unless persistent mode is enabled.

- It is possible that the device might have ignored a REFRESH command during tPAR_ALERT_PW or the REFRESH command is the first erroneous frame, so it is recommended that extra REFRESH cycles be issued, as needed.
- The parity error status bit may be read anytime after tPAR_ALERT_ON + tPAR_ALERT_PW to determine which DRAM had the error. The device maintains the error log for the first erroneous command until the parity error status bit is reset to a zero or a second CA parity occurs prior to resetting.

The mode register for the CA parity error is defined as follows: CA parity latency bits are write only, the parity error status bit is read/write, and error logs are read-only bits. The DRAM controller can only program the parity error status bit to zero. If the DRAM controller illegally attempts to write a 1 to the parity error status bit, the DRAM can not be certain that parity will be checked; the DRAM may opt to block the DRAM controller from writing a 1 to the parity error status bit.

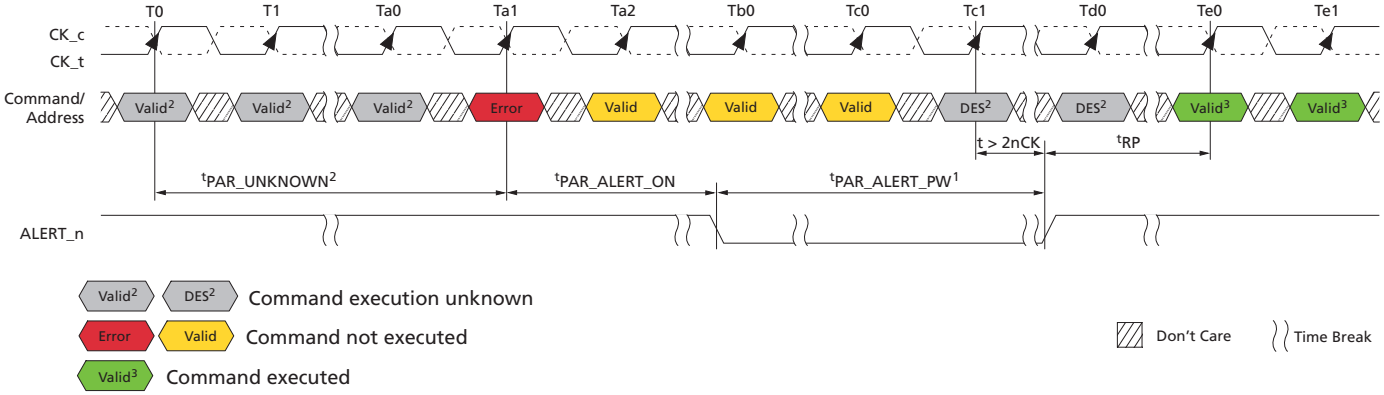
The device supports persistent parity error mode. This mode is enabled by setting MR5[9] = 1; when enabled, CA parity resumes checking after the ALERT_n is de-asserted, even if the parity error status bit remains a 1. If multiple errors occur before the error status bit is cleared the error log in MPR Page 1 should be treated as "Don't Care." In persistent parity error mode the ALERT_n pulse will be asserted and de-asserted by the DRAM as defined with the MIN and MAX value tPAR_ALERT_PW. The DRAM controller must issue DESELECT commands once it detects the ALERT_n signal, this response time is defined as tPAR_ALERT_RSP. The following figures capture the flow of events on the CA bus and the ALERT_n signal.

### Table 33: Mode Register Setting for CA Parity

| CA Parity Latency MR5[2:0][1] | Applicable Speed Bin | Parity Error Status | Parity Persistent Mode | Erroneous CA Frame |
|---|---|---|---|---|
| 000 = Disabled | N/A | MR5 [4] 0 = Clear<br>MR5 [4] 1 = Error | MR5 [9] 0 = DisabledMR5 [9] 1 = Enabled | C[2:0], ACT_n, BG0, BA[1:0], PAR, A16/ RAS_n, A15/CAS_n, A14/WE_n, A[13:0] |
| 001 = 4 clocks | 1600, 1866, 2133 | | | |
| 010 = 5 clocks | 2400, 2666 | | | |
| 011 = 6 clocks | 2933, 3200 | | | |
| 100 = 8 clocks | RFU | | | |
| 101 = Reserved | RFU | | | |
| 110 = Reserved | RFU | | | |
| 111 = Reserved | RFU | | | |

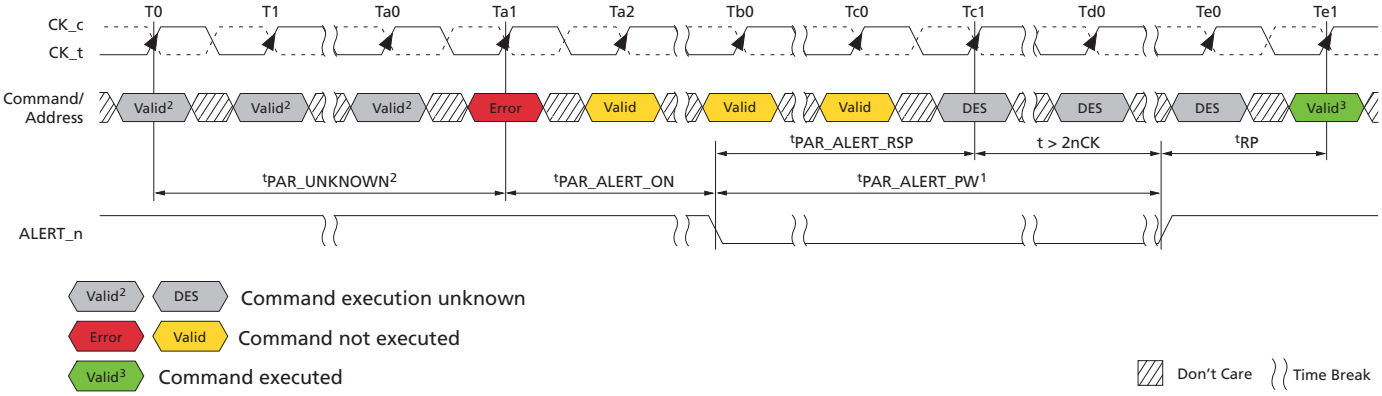
Notes:
1. Parity latency is applied to all commands.
2. Parity latency can be changed only from a CA parity disabled state; for example, a direct change from PL = 3 to PL = 4 is not allowed. The correct sequence is PL = 3 to disabled to PL = 4.
3. Parity latency is applied to WRITE and READ latency. WRITE latency = AL + CWL + PL. READ latency = AL + CL + PL.

### Figure 42: Command/Address Parity During Normal Operation



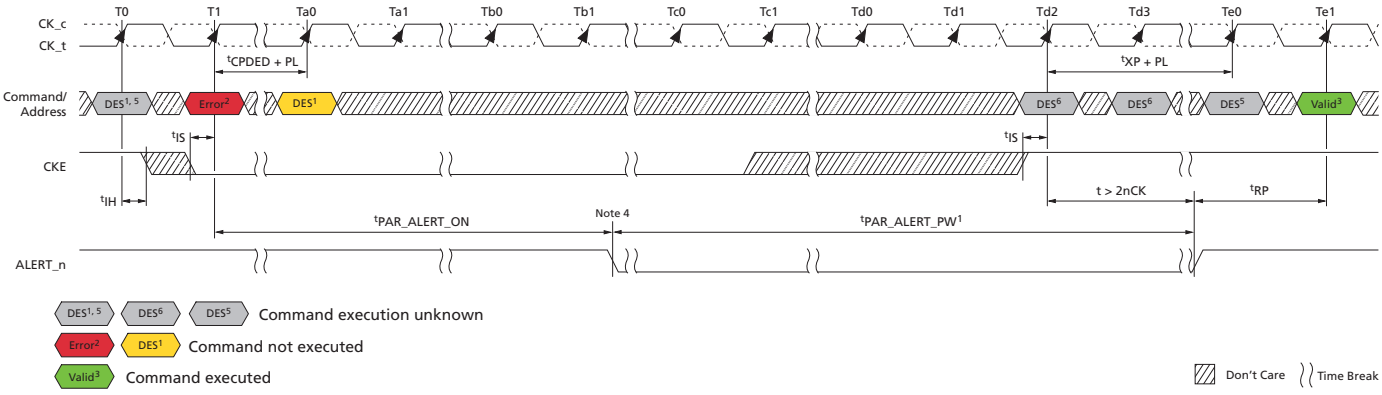

Notes:
1. DRAM is emptying queues. Precharge all and parity checking are off until parity error status bit is cleared.
2. Command execution is unknown; the corresponding DRAM internal state change may or may not occur. The DRAM controller should consider both cases and make sure that the command sequence meets the specifications. If WRITE CRC is enabled and a WRITE CRC occurs during the $^{t}$PAR_UNKNOWN window, the WRITE CRC Error Status Bit located at MR5[3] may or may not get set.
3. Normal operation with parity latency (CA parity persistent error mode disabled). Parity checking is off until parity error status bit is cleared.

## Figure 43: Persistent CA Parity Error Checking Operation



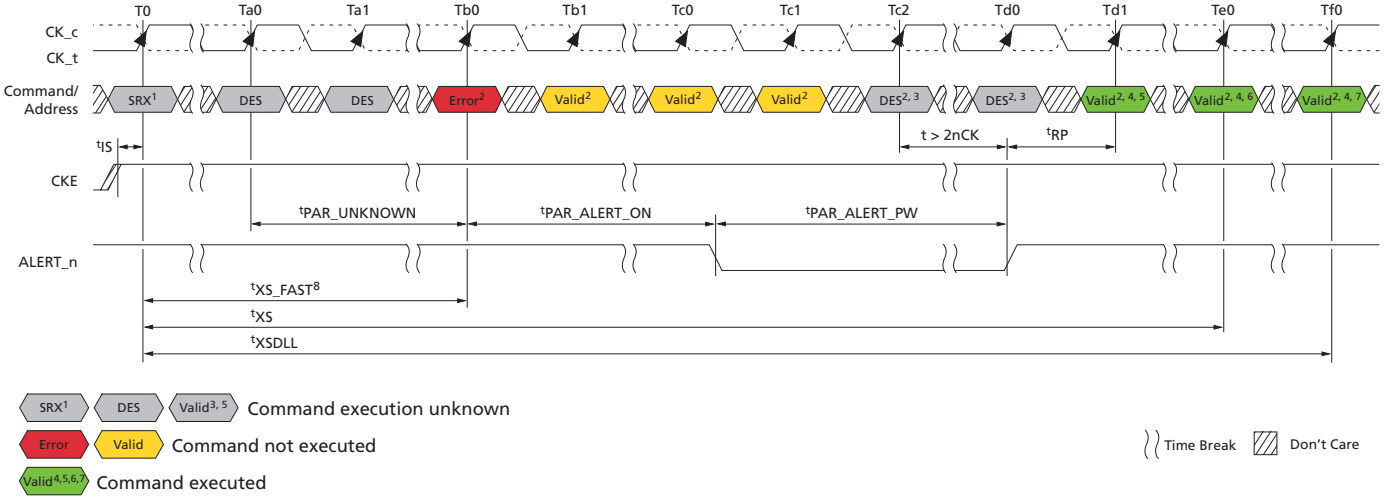

Notes:
1. DRAM is emptying queues. Precharge all and parity check re-enable finished by tPAR_ALERT_PW.
2. Command execution is unknown; the corresponding DRAM internal state change may or may not occur. The DRAM controller should consider both cases and make sure that the command sequence meets the specifications. If WRITE CRC is enabled and a WRITE CRC occurs during the tPAR_UNKNOWN window, the WRITE CRC Error Status Bit located at MR5[3] may or may not get set
3. Normal operation with parity latency and parity checking (CA parity persistent error mode enabled).

## Figure 44: CA Parity Error Checking – SRE Attempt



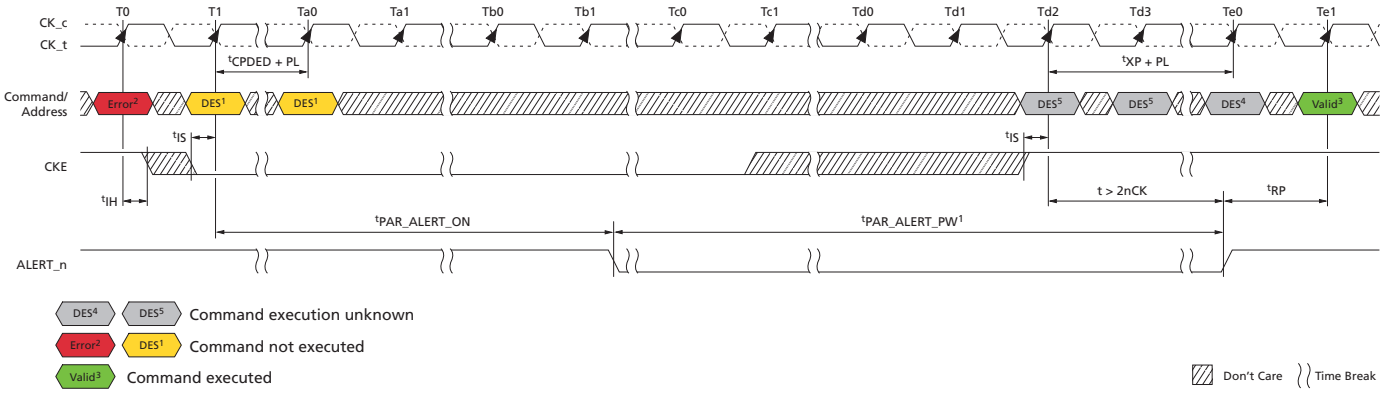

Notes:
1. Only DESELECT command is allowed.
2. SELF REFRESH command error. The DRAM masks the intended SRE command and enters precharge power-down.
3. Normal operation with parity latency (CA parity persistent error mode disabled). Parity checking is off until the parity error status bit cleared.
4. The controller cannot disable the clock until it has been capable of detecting a possible CA parity error.
5. Command execution is unknown; the corresponding DRAM internal state change may or may not occur. The DRAM controller should consider both cases and make sure that the command sequence meets the specifications.
6. Only a DESELECT command is allowed; CKE may go HIGH prior to Tc2 as long as DES commands are issued.

## Figure 45: CA Parity Error Checking – SRX Attempt




Notes:
1. Self refresh abort = disable: MR4 [9] = 0.
2. Input commands are bounded by tXSDLL, tXS, tXS_ABORT, and tXS_FAST timing.
3. Command execution is unknown; the corresponding DRAM internal state change may or may not occur. The DRAM controller should consider both cases and make sure that the command sequence meets the specifications.
4. Normal operation with parity latency (CA parity persistent error mode disabled). Parity checking off until parity error status bit cleared.
5. Only an MRS (limited to those described in the SELF REFRESH Operation section), ZQCS, or ZQCL command is allowed.
6. Valid commands not requiring a locked DLL.
7. Valid commands requiring a locked DLL.
8. This figure shows the case from which the error occurred after tXS_FAST. An error may also occur after tXS_ABORT and tXS.

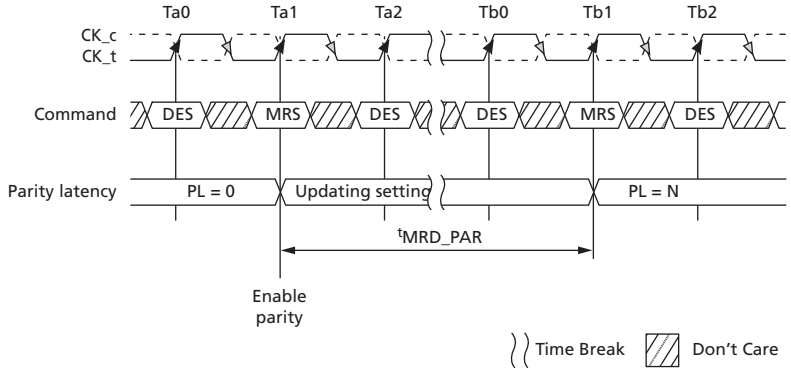
## Figure 46: CA Parity Error Checking – PDE/PDX




Notes:
1. Only DESELECT command is allowed.
2. Error could be precharge or activate.
3. Normal operation with parity latency (CA parity persistent error mode disabled). Parity checking is off until parity error status bit cleared.

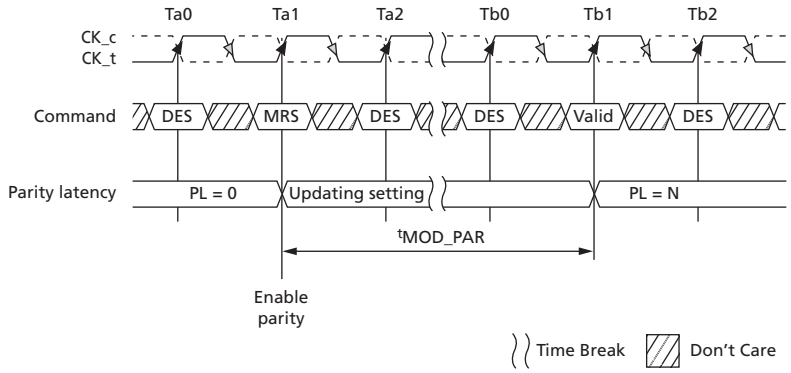
4. Command execution is unknown; the corresponding DRAM internal state change may or may not occur. The DRAM controller should consider both cases and make sure that the command sequence meets the specifications.
5. Only a DESELECT command is allowed; CKE may go HIGH prior to Td2 as long as DES commands are issued.

**Figure 47: Parity Entry Timing Example – $^{t}$MRD_PAR**



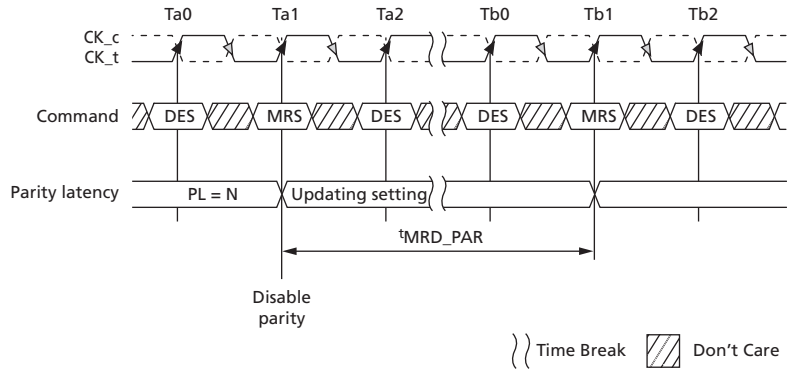

Note: 1. $^{t}$MRD_PAR = $^{t}$MOD + N; where N is the programmed parity latency.

**Figure 48: Parity Entry Timing Example – $^{t}$MOD_PAR**



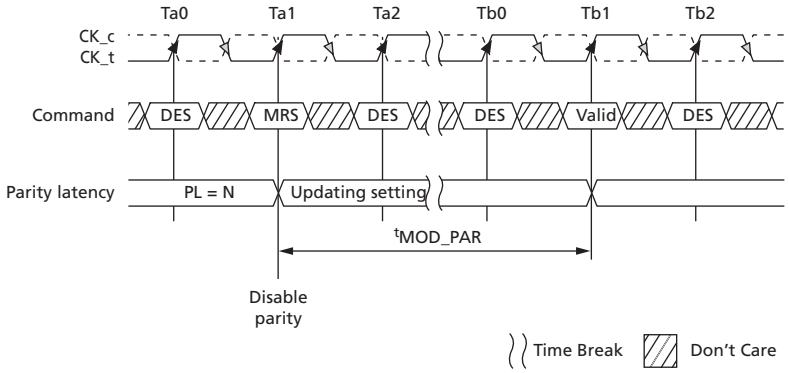

Note: 1. $^{t}$MOD_PAR = $^{t}$MOD + N; where N is the programmed parity latency.

**Figure 49: Parity Exit Timing Example – $^{t}$MRD_PAR**



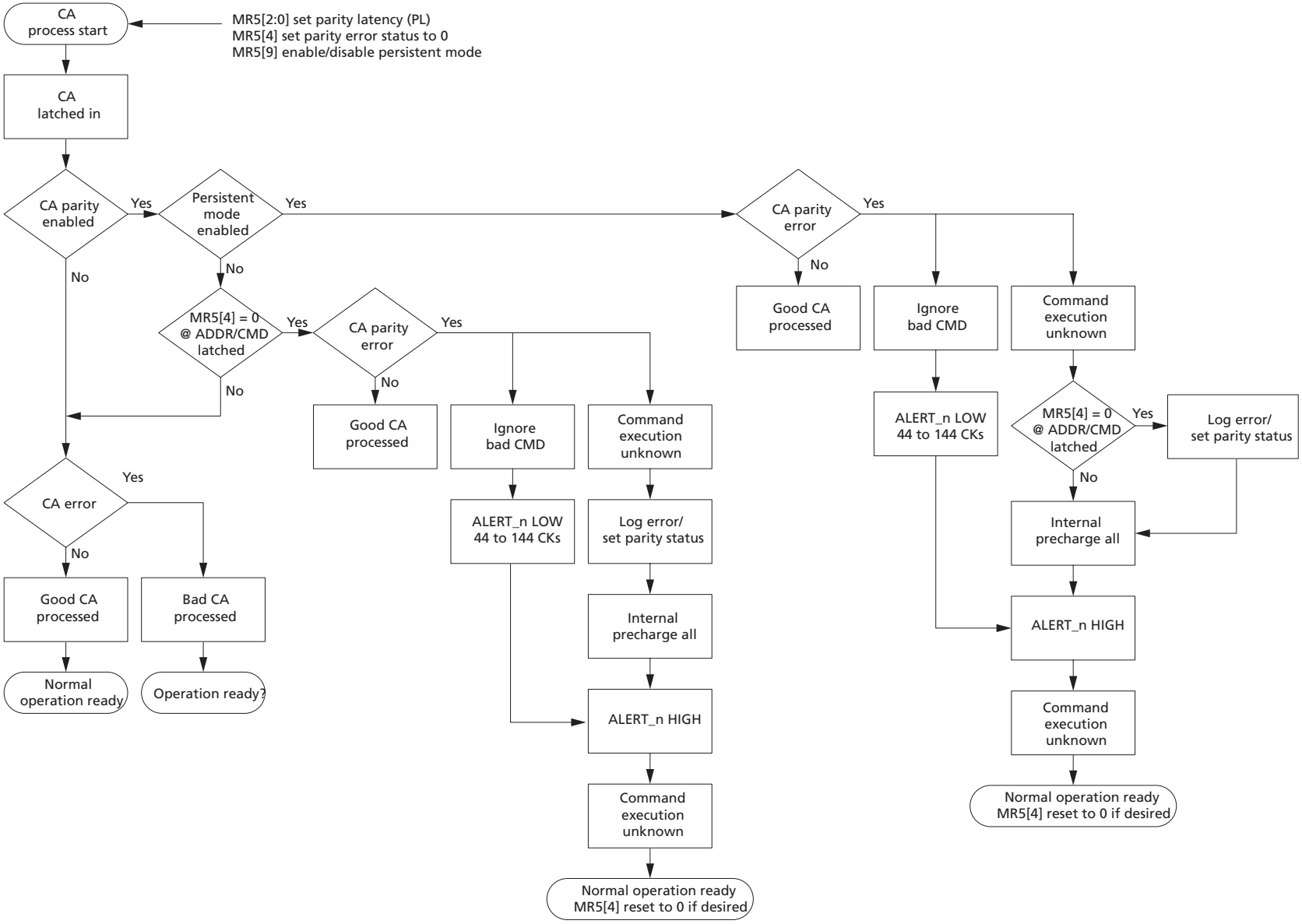

Note: 1. $^{t}$MRD_PAR = $^{t}$MOD + N; where N is the programmed parity latency.

**Figure 50: Parity Exit Timing Example – $^{t}$MOD_PAR**




Note: 1. $^{t}$MOD_PAR = $^{t}$MOD + N; where N is the programmed parity latency.

**Figure 51: CA Parity Flow Diagram**



## Per-DRAM Addressability

DDR4 allows programmability of a single, specific DRAM on a rank. As an example, this feature can be used to program different ODT or $V_{REF}$ values on each DRAM on a given rank. Because per-DRAM addressability (PDA) mode may be used to program optimal $V_{REF}$ for the DRAM, the data set up for first DQ0 transfer or the hold time for the last DQ0 transfer cannot be guaranteed. The DRAM may sample DQ0 on either the first falling or second rising DQS transfer edge. This supports a common implementation be-tween BC4 and BL8 modes on the DRAM. The DRAM controller is required to drive DQ0 to a stable LOW or HIGH state during the length of the data transfer for BC4 and BL8 cases. Note, both fixed and on-the-fly (OTF) modes are supported for BC4 and BL8 dur-ing PDA mode.

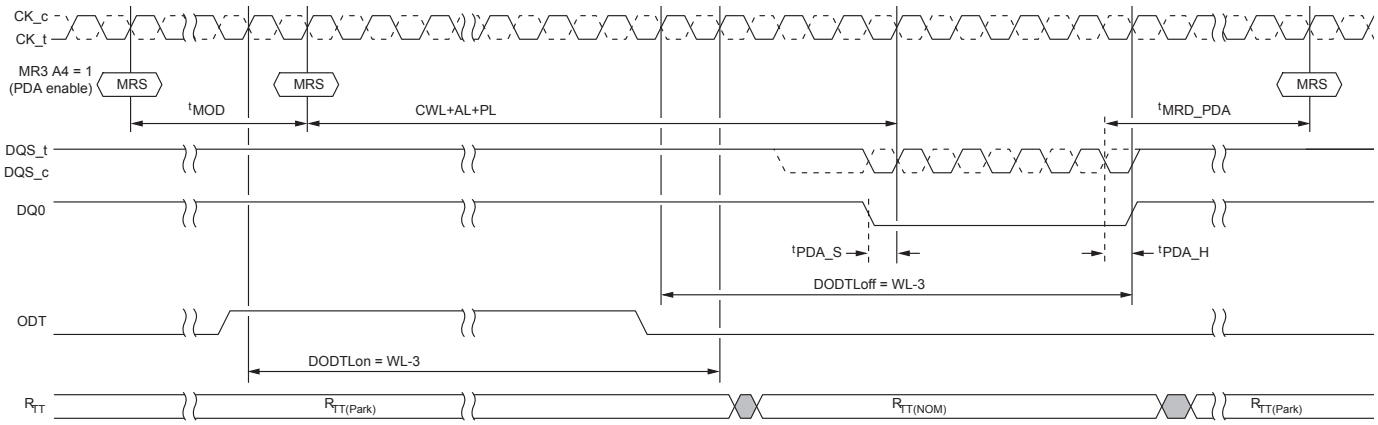
1. Before entering PDA mode, write leveling is required.
   - BL8 or BC4 may be used.
2. Before entering PDA mode, the following MR settings are possible:
   - $R_{TT(Park)}$ MR5 A[8:6] = Enable
   - $R_{TT(NOM)}$ MR1 A[10:8] = Enable
3. Enable PDA mode using MR3 [4] = 1. (The default programed value of MR3[4] = 0.)
4. In PDA mode, all MRS commands are qualified with DQ0. The device captures DQ0 by using DQS signals. If the value on DQ0 is LOW, the DRAM executes the MRS command. If the value on DQ0 is HIGH, the DRAM ignores the MRS command. The controller can choose to drive all the DQ bits.
5. Program the desired DRAM and mode registers using the MRS command and DQ0.
6. In PDA mode, only MRS commands are allowed.
7. The MODE REGISTER SET command cycle time in PDA mode, AL + CWL + BL/2 -0.5$^{t}$CK + $^{t}$MRD_PDA + PL, is required to complete the WRITE operation to the mode register and is the minimum time required between two MRS commands.
8. Remove the device from PDA mode by setting MR3[4] = 0. (This command requires DQ0 = 0.)

**Note:** Removing the device from PDA mode will require programming the entire MR3 when the MRS command is issued. This may impact some PDA values programmed within a rank as the EXIT command is sent to the rank. To avoid such a case, the PDA enable/disable control bit is located in a mode register that does not have any PDA mode controls.

In PDA mode, the device captures DQ0 using DQS signals the same as in a normal WRITE operation; however, dynamic ODT is not supported. Extra care is required for the ODT setting. If $R_{TT(NOM)}$ MR1 [10:8] = enable, device data termination needs to be controlled by the ODT pin, and applies the same timing parameters (defined below).

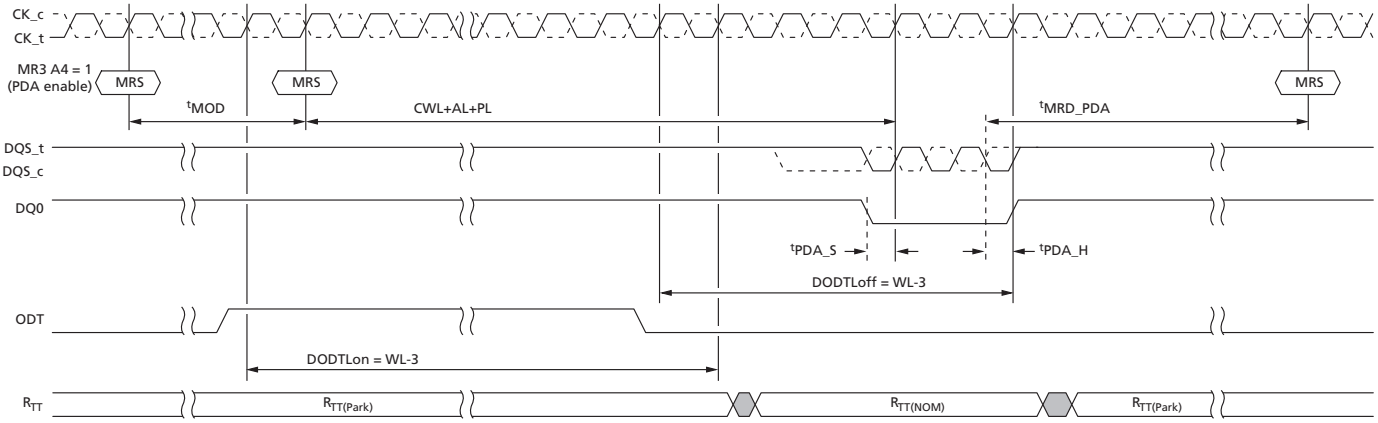
| Symbol | Parameter |
|---|---|
| DODTLon | Direct ODT turnon latency |
| DODTLoff | Direct ODT turn off latency |
| $^{t}$ADC | $R_{TT}$ change timing skew |
| $^{t}$AONAS | Asynchronous $R_{TT(NOM)}$ turn-on delay |
| $^{t}$AOFAS | Asynchronous $R_{TT(NOM)}$ turn-off delay |

**Figure 52: PDA Operation Enabled, BL8**



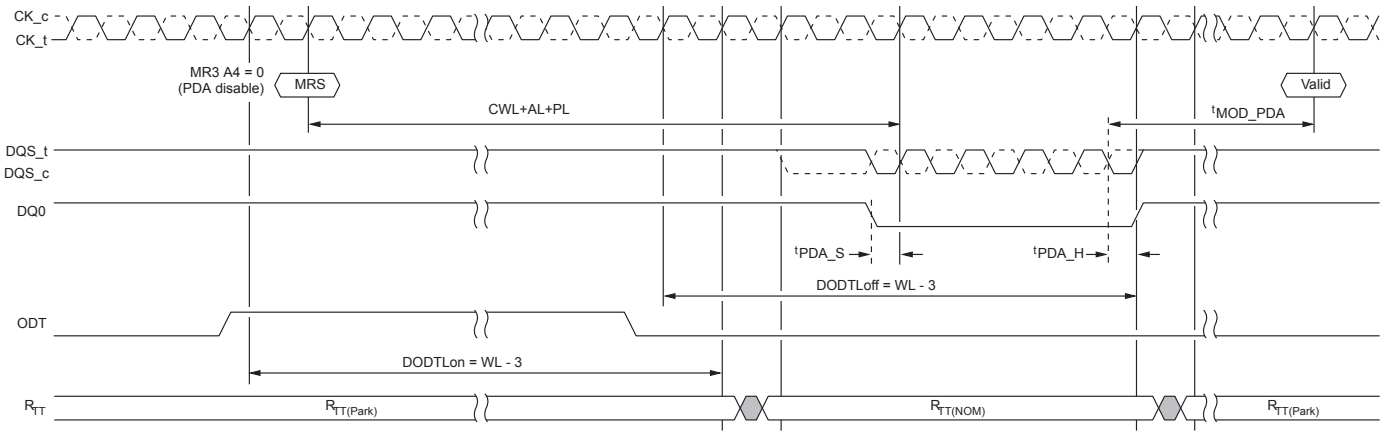

Note: 1. $R_{TT(Park)}$ = Enable; $R_{TT(NOM)}$ = Enable; WRITE preamble set = 2$^t$CK; and DLL = On.

**Figure 53: PDA Operation Enabled, BC4**




Note: 1. $R_{TT(Park)}$ = Enable; $R_{TT(NOM)}$ = Enable; WRITE preamble set = 2$^t$CK; and DLL = On.

**Figure 54: MRS PDA Exit**



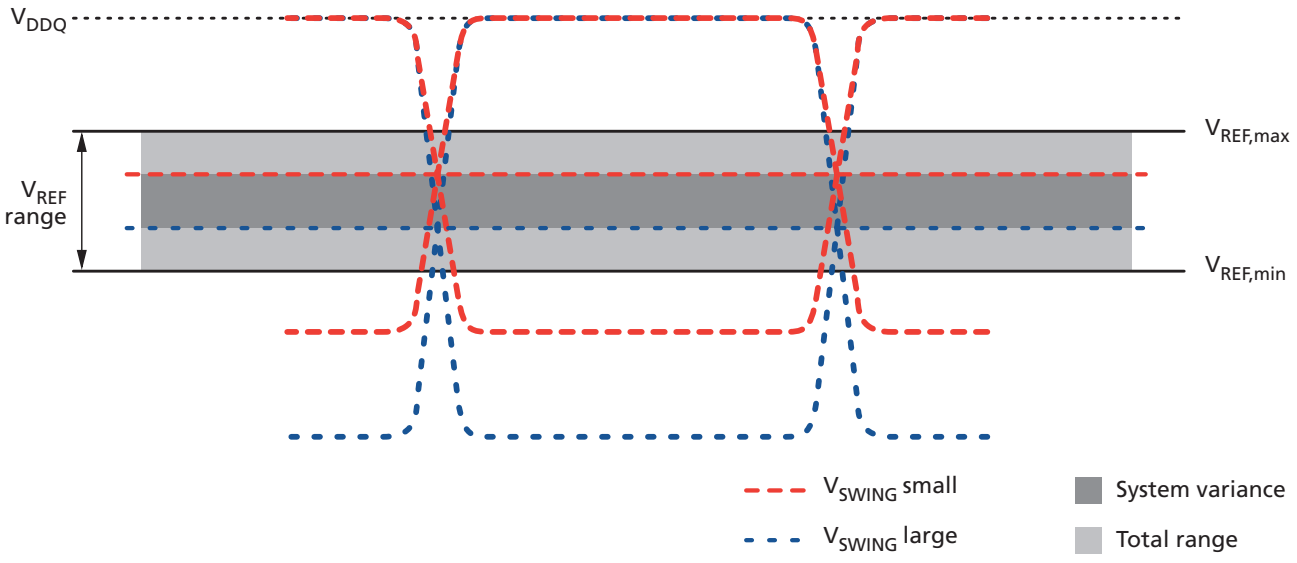

Note: 1. $R_{TT(Park)}$ = Enable; $R_{TT(NOM)}$ = Enable; WRITE preamble set = 2$^{t}$CK; and DLL = On.

## $V_{REFDQ}$ Calibration

The $V_{REFDQ}$ level, which is used by the DRAM DQ input receivers, is internally generated. The DRAM $V_{REFDQ}$ does not have a default value upon power-up and must be set to the desired value, usually via $V_{REFDQ}$ calibration mode. If PDA or PPR modes (hPPR or sPPR) are used prior to $V_{REFDQ}$ calibration, $V_{REFDQ}$ should initially be set at the midpoint between the $V_{DD,max,}$ and the LOW as determined by the driver and ODT termination selected with wide voltage swing on the input levels and setup and hold times of approximately 0.75UI. The memory controller is responsible for $V_{REFDQ}$ calibration to determine the best internal $V_{REFDQ}$ level. The $V_{REFDQ}$ calibration is enabled/disabled via MR6[7], MR6[6] selects Range 1 (60% to 92.5% of $V_{DDQ}$) or Range 2 (45% to 77.5% of $V_{DDQ}$), and an MRS protocol using MR6[5:0] to adjust the $V_{REFDQ}$ level up and down. MR6[6:0] bits can be altered using the MRS command if MR6[7] is enabled. The DRAM controller will likely use a series of writes and reads in conjunction with $V_{REFDQ}$ adjust-ments to obtain the best $V_{REFDQ}$, which in turn optimizes the data eye.

The internal $V_{REFDQ}$ specification parameters are voltage range, step size, $V_{REF}$ step time, $V_{REF}$ full step time, and $V_{REF}$ valid level. The voltage operating range specifies the minimum required $V_{REF}$ setting range for DDR4 SDRAM devices. The minimum range is defined by $V_{REFDQ,min}$ and $V_{REFDQ,max}$. As noted, a calibration sequence, determined by the DRAM controller, should be performed to adjust $V_{REFDQ}$ and optimize the timing and voltage margin of the DRAM data input receivers. The internal $V_{REFDQ}$ voltage value may not be exactly within the voltage range setting coupled with the $V_{REF}$ set tolerance; the device must be calibrated to the correct internal $V_{REFDQ}$ voltage.

**Figure 55: $V_{REFDQ}$ Voltage Range**



## $V_{REFDQ}$ Range and Levels

**Table 34: $V_{REFDQ}$ Range and Levels**

| MR6[5:0] | Range 1 MR6[6] 0 | Range 2 MR6[6] 1 | MR6[5:0] | Range 1 MR6[6] 0 | Range 2 MR6[6] 1 |
|---|---|---|---|---|---|
| 00 0000 | 60.00% | 45.00% | 01 1010 | 76.90% | 61.90% |
| 00 0001 | 60.65% | 45.65% | 01 1011 | 77.55% | 62.55% |
| 00 0010 | 61.30% | 46.30% | 01 1100 | 78.20% | 63.20% |
| 00 0011 | 61.95% | 46.95% | 01 1101 | 78.85% | 63.85% |
| 00 0100 | 62.60% | 47.60% | 01 1110 | 79.50% | 64.50% |
| 00 0101 | 63.25% | 48.25% | 01 1111 | 80.15% | 65.15% |
| 00 0110 | 63.90% | 48.90% | 10 0000 | 80.80% | 65.80% |
| 00 0111 | 64.55% | 49.55% | 10 0001 | 81.45% | 66.45% |
| 00 1000 | 65.20% | 50.20% | 10 0010 | 82.10% | 67.10% |
| 00 1001 | 65.85% | 50.85% | 10 0011 | 82.75% | 67.75% |
| 00 1010 | 66.50% | 51.50% | 10 0100 | 83.40% | 68.40% |
| 00 1011 | 67.15% | 52.15% | 10 0101 | 84.05% | 69.05% |
| 00 1100 | 67.80% | 52.80% | 10 0110 | 84.70% | 69.70% |
| 00 1101 | 68.45% | 53.45% | 10 0111 | 85.35% | 70.35% |
| 00 1110 | 69.10% | 54.10% | 10 1000 | 86.00% | 71.00% |
| 00 1111 | 69.75% | 54.75% | 10 1001 | 86.65% | 71.65% |
| 01 0000 | 70.40% | 55.40% | 10 1010 | 87.30% | 72.30% |
| 01 0001 | 71.05% | 56.05% | 10 1011 | 87.95% | 72.95% |
| 01 0010 | 71.70% | 56.70% | 10 1100 | 88.60% | 73.60% |
| 01 0011 | 72.35% | 57.35% | 10 1101 | 89.25% | 74.25% |
| 01 0100 | 73.00% | 58.00% | 10 1110 | 89.90% | 74.90% |
| 01 0101 | 73.65% | 58.65% | 10 1111 | 90.55% | 75.55% |
| 01 0110 | 74.30% | 59.30% | 11 0000 | 91.20% | 76.20% |
| 01 0111 | 74.95% | 59.95% | 11 0001 | 91.85% | 76.85% |
| 01 1000 | 75.60% | 60.60% | 11 0010 | 92.50% | 77.50% |
| 01 1001 | 76.25% | 61.25% | 11 0011 to 11 1111 = Reserved | | |

## $V_{REFDQ}$ Step Size

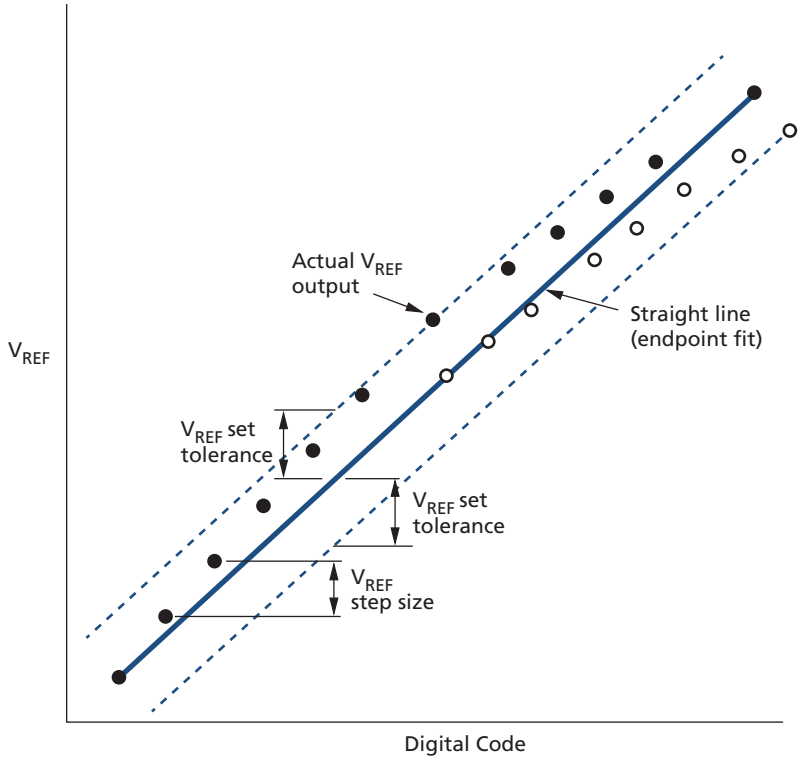
The $V_{REF}$ step size is defined as the step size between adjacent steps. $V_{REF}$ step size ranges from 0.5% $V_{DDQ}$ to 0.8% $V_{DDQ}$. However, for a given design, the device has one value for $V_{REF}$ step size that falls within the range.

The $V_{REF}$ set tolerance is the variation in the $V_{REF}$ voltage from the ideal setting. This accounts for accumulated error over multiple steps. There are two ranges for $V_{REF}$ set tolerance uncertainty. The range of $V_{REF}$ set tolerance uncertainty is a function of number of steps *n*.

The $V_{REF}$ set tolerance is measured with respect to the ideal line, which is based on the MIN and MAX $V_{REF}$ value endpoints for a specified range. The internal $V_{REFDQ}$ voltage

value may not be exactly within the voltage range setting coupled with the $V_{REF}$ set tolerance; the device must be calibrated to the correct internal $V_{REFDQ}$ voltage.

**Figure 56: Example of $V_{REF}$ Set Tolerance and Step Size**

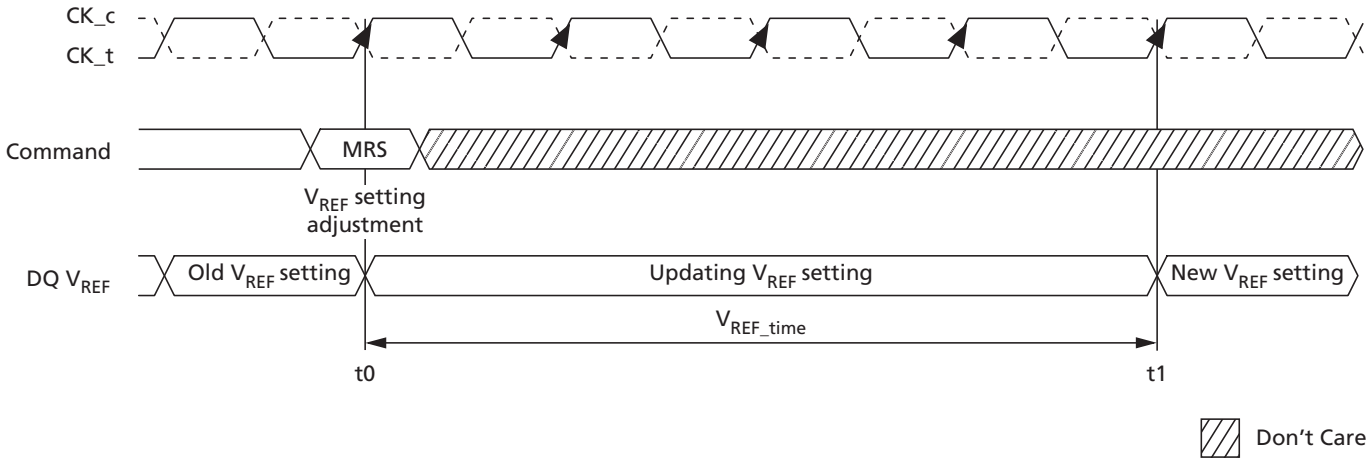



Note: 1. Maximum case shown.

## $V_{REFDQ}$ Increment and Decrement Timing

The $V_{REF}$ increment/decrement step times are defined by $V_{REF,time}$. $V_{REF,time}$ is defined from t0 to t1, where t1 is referenced to the $V_{REF}$ voltage at the final DC level within the $V_{REF}$ valid tolerance ($V_{REF,val\_tol}$). The $V_{REF}$ valid level is defined by $V_{REF,val}$ tolerance to qualify the step time t1. This parameter is used to insure an adequate RC time constant behavior of the voltage level change after any $V_{REF}$ increment/decrement adjustment.

**Figure 57: $V_{REFDQ}$ Timing Diagram for $V_{REF,time}$ Parameter**




Note: 1. t0 is referenced to the MRS command clock
t1 is referenced to $V_{REF,tol}$

$V_{REFDQ}$ calibration mode is entered via an MRS command, setting MR6[7] to 1 (0 disables $V_{REFDQ}$ calibration mode) and setting MR6[6] to either 0 or 1 to select the desired range (MR6[5:0] are "Don't Care"). After $V_{REFDQ}$ calibration mode has been entered, $V_{REFDQ}$ calibration mode legal commands may be issued once $^{t}$VREFDQE has been satisfied. Legal commands for $V_{REFDQ}$ calibration mode are ACT, WR, WRA, RD, RDA, PRE, DES, and MRS to set $V_{REFDQ}$ values, and MRS to exit $V_{REFDQ}$ calibration mode. Also, after $V_{REFDQ}$ calibration mode has been entered, “dummy” WRITE commands are allowed prior to adjusting the $V_{REFDQ}$ value the first time $V_{REFDQ}$ calibration is performed after initialization.

Setting $V_{REFDQ}$ values requires MR6[7] be set to 1 and MR6[6] be unchanged from the initial range selection; MR6[5:0] may be set to the desired $V_{REFDQ}$ values. If MR6[7] is set to 0, MR6[6:0] are not written. $V_{REF,time-short}$ or $V_{REF,time-long}$ must be satisfied after each MR6 command to set $V_{REFDQ}$ value before the internal $V_{REFDQ}$ value is valid.

If PDA mode is used in conjunction with $V_{REFDQ}$ calibration, the PDA mode requirement that only MRS commands are allowed while PDA mode is enabled is not waived. That is, the only $V_{REFDQ}$ calibration mode legal commands noted above that may be used are the MRS commands: MRS to set $V_{REFDQ}$ values and MRS to exit $V_{REFDQ}$ calibration mode.
The last MR6[6:0] setting written to MR6 prior to exiting $V_{REFDQ}$ calibration mode is the range and value used for the internal $V_{REFDQ}$ setting. $V_{REFDQ}$ calibration mode may be exited when the DRAM is in idle state. After the MRS command to exit $V_{REFDQ}$ calibration mode has been issued, DES must be issued until $^{t}$VREFDQX has been satisfied where any legal command may then be issued. $V_{REFDQ}$ setting should be updated if the die temperature changes too much from the calibration temperature.
The following are typical script when applying the above rules for $V_{REFDQ}$ calibration routine when performing $V_{REFDQ}$ calibration in Range 1:

- MR6[7:6]10 [5:0]XXXXXXX.

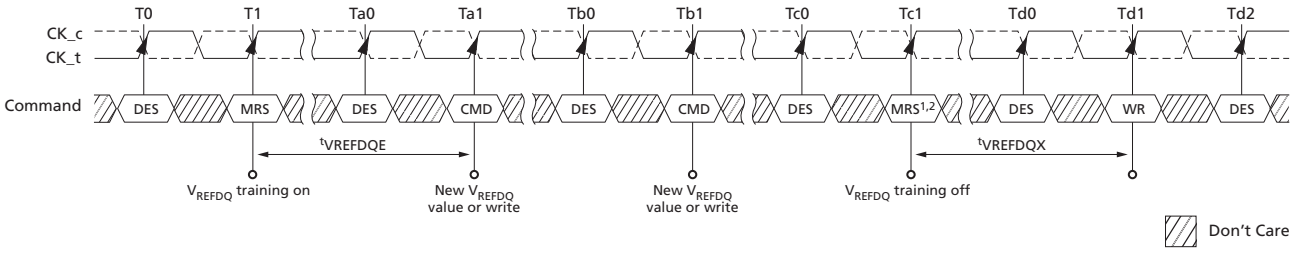
  - Subsequent legal commands while in $V_{REFDQ}$ calibration mode: ACT, WR, WRA, RD, RDA, PRE, DES, and MRS (to set $V_{REFDQ}$ values and exit $V_{REFDQ}$ calibration mode).
- All subsequent $V_{REFDQ}$ calibration MR setting commands are MR6[7:6]10 [5:0]VVVVVV.
  - "VVVVVV" are desired settings for $V_{REFDQ}$.
- Issue ACT/WR/RD looking for pass/fail to determine $V_{CENT}$ (midpoint) as needed.
- To exit $V_{REFDQ}$ calibration, the last two $V_{REFDQ}$ calibration MR commands are:
  - MR6[7:6]10 [5:0]VVVVVV* where VVVVVV* = desired value for $V_{REFDQ}$.
  - MR6[7]0 [6:0]XXXXXXX to exit $V_{REFDQ}$ calibration mode.

The following are typical script when applying the above rules for $V_{REFDQ}$ calibration routine when performing $V_{REFDQ}$ calibration in Range 2:

- MR6[7:6]11 [5:0]XXXXXXX.
  - Subsequent legal commands while in $V_{REFDQ}$ calibration mode: ACT, WR, WRA, RD, RDA, PRE, DES, and MRS (to set $V_{REFDQ}$ values and exit $V_{REFDQ}$ calibration mode).
- All subsequent $V_{REFDQ}$ calibration MR setting commands are MR6[7:6]11 [5:0]VVVVVV.
  - "VVVVVV" are desired settings for $V_{REFDQ}$.
- Issue ACT/WR/RD looking for pass/fail to determine $V_{CENT}$ (midpoint) as needed.
- To exit $V_{REFDQ}$ calibration, the last two $V_{REFDQ}$ calibration MR commands are:
  - MR6[7:6]11 [5:0]VVVVVV* where VVVVVV* = desired value for $V_{REFDQ}$.
  - MR6[7]0 [6:0]XXXXXXX to exit $V_{REFDQ}$ calibration mode.

**Note:** Range may only be set or changed when entering $V_{REFDQ}$ calibration mode; changing range while in or exiting $V_{REFDQ}$ calibration mode is illegal.

**Figure 58: $V_{REFDQ}$ Training Mode Entry and Exit Timing Diagram**




Notes:
1. New $V_{REFDQ}$ values are not allowed with an MRS command during calibration mode entry.
2. Depending on the step size of the latest programmed $V_{REF}$ value, $V_{REF}$ must be satisfied before disabling $V_{REFDQ}$ training mode.

**Figure 59: $V_{REF}$ Step: Single Step Size Increment Case**

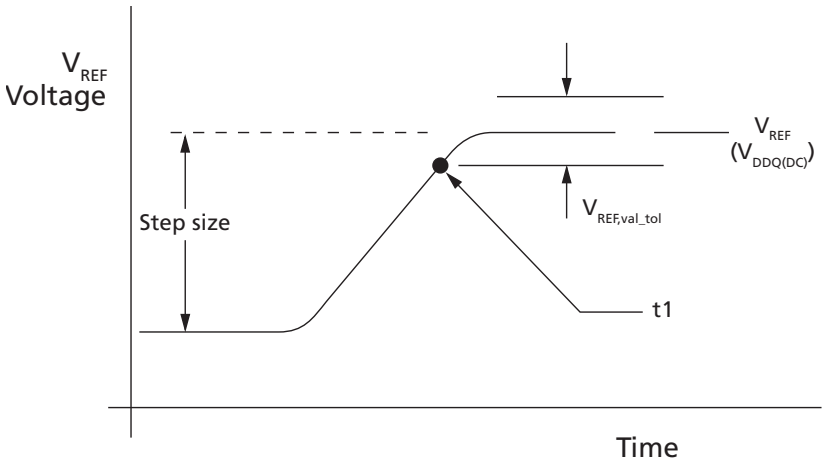



**Figure 60: $V_{REF}$ Step: Single Step Size Decrement Case**

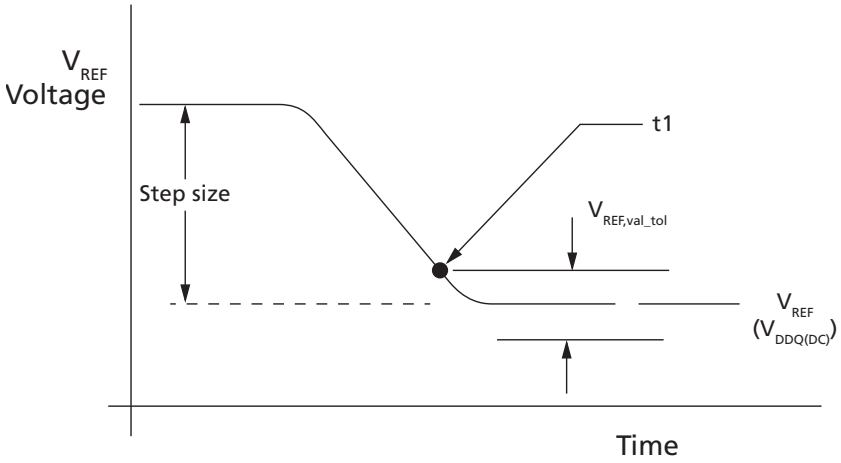


**Figure 61: $V_{REF}$ Full Step: From $V_{REF,min}$ to $V_{REF,max}$Case**

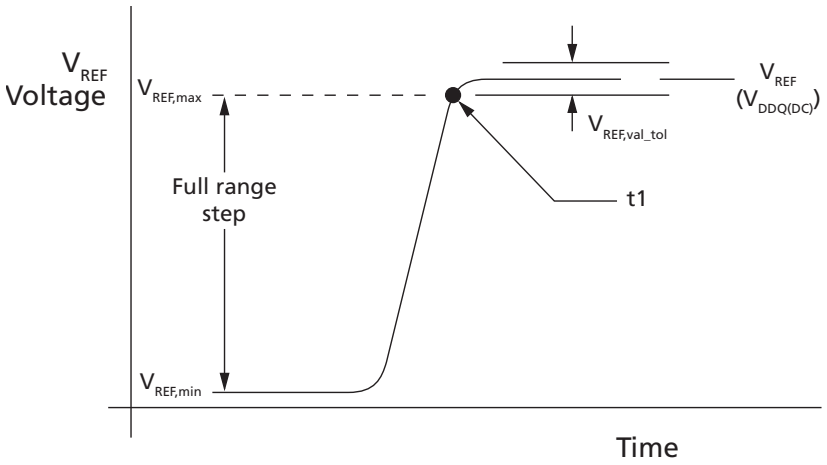
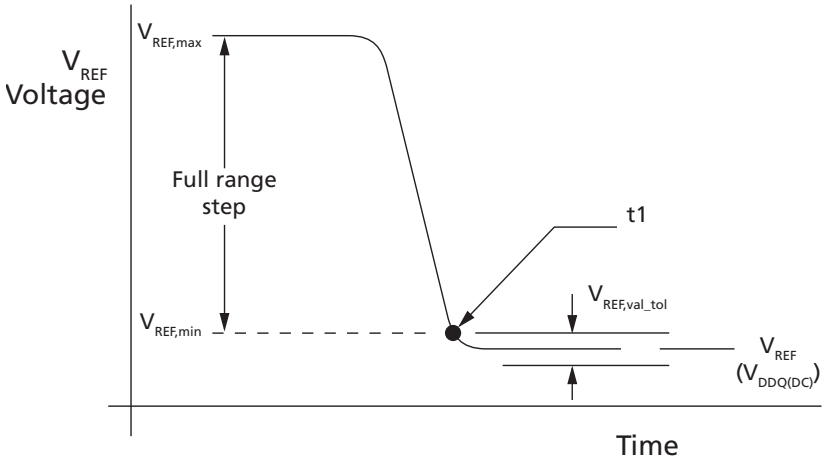



**Figure 62: $V_{REF}$ Full Step: From $V_{REF,max}$ to $V_{REF,min}$Case**



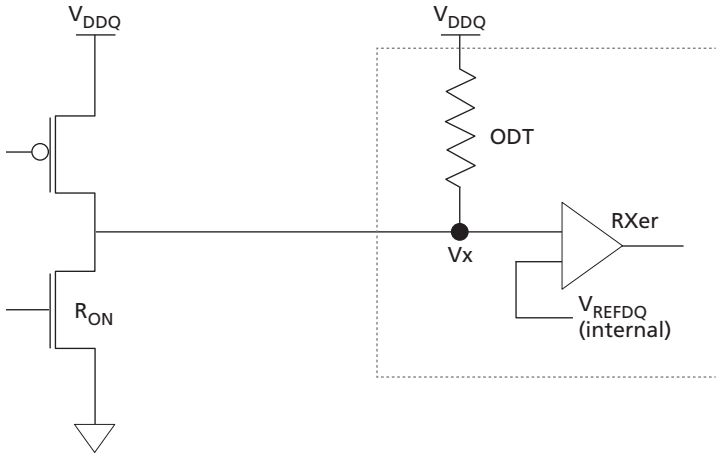

## $V_{REFDQ}$ Target Settings

The $V_{REFDQ}$ initial settings are largely dependant on the ODT termination settings. The table below shows all of the possible initial settings available for $V_{REFDQ}$ training; it is unlikely the lower ODT settings would be used in most cases.

**Table 35: $V_{REFDQ}$ Settings ($V_{DDQ}$ = 1.2V)**

| $R_{ON}$ | ODT | Vx – $V_{IN}$ LOW (mV) | $V_{REFDQ}$ (mv) | $V_{REFDQ}$ (%$V_{DDQ}$) |
|---|---|---|---|---|
| 34 ohm | 34 ohm | 600 | 900 | 75% |
| | 40 ohm | 550 | 875 | 73% |
| | 48 ohm | 500 | 850 | 71% |
| | 60 ohm | 435 | 815 | 68% |
| | 80 ohm | 360 | 780 | 65% |
| | 120 ohm | 265 | 732 | 61% |
| | 240 ohm | 150 | 675 | 56% |
| 48 ohm | 34 ohm | 700 | 950 | 79% |
| | 40 ohm | 655 | 925 | 77% |
| | 48 ohm | 600 | 900 | 75% |
| | 60 ohm | 535 | 865 | 72% |
| | 80 ohm | 450 | 825 | 69% |
| | 120 ohm | 345 | 770 | 64% |
| | 240 ohm | 200 | 700 | 58% |

**Figure 63: $V_{REFDQ}$ Equivalent Circuit**



## Connectivity Test Mode

Connectivity test (CT) mode is similar to boundary scan testing but is designed to significantly speed up the testing of electrical continuity of pin interconnections between the device and the memory controller on the PC boards. Designed to work seamlessly with any boundary scan device, CT mode is supported in ×16 non-3DS devices . 3DS devices do not support CT mode and the TEN pin should be considered RFU maintained LOW at all times.

Contrary to other conventional shift-register-based test modes, where test patterns are shifted in and out of the memory devices serially during each clock, the CT mode allows test patterns to be entered on the test input pins in parallel and the test results to be extracted from the test output pins of the device in parallel. These two functions are also performed at the same time, significantly increasing the speed of the connectivity check. When placed in CT mode, the device appears as an asynchronous device to the external controlling agent. After the input test pattern is applied, the connectivity test results are available for extraction in parallel at the test output pins after a fixed propagation delay time.

**Note:** A reset of the device is required after exiting CT mode (see RESET and Initialization Procedure).

### Pin Mapping

Only digital pins can be tested using the CT mode. For the purposes of a connectivity check, all the pins used for digital logic in the device are classified as one of the following types:

- **Test enable (TEN):** When asserted HIGH, this pin causes the device to enter CT mode. In CT mode, the normal memory function inside the device is bypassed and the I/O pins appear as a set of test input and output pins to the external controlling agent. Additionally, the device will set the internal $V_{REFDQ}$ to $V_{DDQ} \times 0.5$ during CT mode (this is the only time the DRAM takes direct control over setting the internal $V_{REFDQ}$). The TEN pin is dedicated to the connectivity check function and will not be used during normal device operation.
- **Chip select (CS_n):** When asserted LOW, this pin enables the test output pins in the device. When de-asserted, these output pins will be High-Z. The CS_n pin in the device serves as the CS_n pin in CT mode.
- **Test input:** A group of pins used during normal device operation designated as test input pins. These pins are used to enter the test pattern in CT mode.
- **Test output:** A group of pins used during normal device operation designated as test output pins. These pins are used for extraction of the connectivity test results in CT mode.
- **RESET_n:** This pin must be fixed high level during CT mode, as in normal function.

**Table 36: Connectivity Mode Pin Description and Switching Levels**

| CT Mode Pins | | Pin Name During Normal Memory Operation | Switching Level | Notes |
|---|---|---|---|---|
| Test enable | | TEN | CMOS (20%/80% $V_{DD}$) | 1, 2 |
| Chip select | | CS_n | $V_{REFCA}$ ±200mV | 3 |
| Test input | A | BA[1:0], BG0, A[9:0], A10/AP, A11, A12/BC_n, A13, WE_n/A14, CAS_n/A15, RAS_n/A16, CKE, ACT_n, ODT, CLK_t, CLK_c, PAR | $V_{REFCA}$ ±200mV | 3 |
| | B | LDM_n/LDBI_n, UDM_n/UDBI_n; DM_n/DBI_n | $V_{REFDQ}$ ±200mV | 4 |
| | C | ALERT_n | CMOS (20%/80% $V_{DD}$) | 2, 5 |
| | D | RESET_n | CMOS (20%/80% $V_{DD}$) | 2 |
| Test output | | DQ[15:0], UDQS_t, UDQS_c, LDQS_t, LDQS_c; DQS_t, DQS_c | $V_{TT}$ ±100mV | 6 |

Notes:
1. TEN: Connectivity test mode is active when TEN is HIGH and inactive when TEN is LOW. TEN must be LOW during normal operation.
2. CMOS is a rail-to-rail signal with DC HIGH at 80% and DC LOW at 20% of $V_{DD}$ (960mV for DC HIGH and 240mV for DC LOW.)
3. $V_{REFCA}$ should be $V_{DD}/2$.
4. $V_{REFDQ}$ should be $V_{DDQ}/2$.
5. ALERT_n switching level is not a final setting.
6. $V_{TT}$ should be set to $V_{DD}/2$.

## Minimum Terms Definition for Logic Equations

The test input and output pins are related by the following equations, where INV denotes a logical inversion operation and XOR a logical exclusive OR operation:

MT0 = XOR (A1, A6, PAR)
MT1 = XOR (A8, ALERT_n, A9)
MT2 = XOR (A2, A5, A13)
MT3 = XOR (A0, A7, A11)
MT4 = XOR (CK_c, ODT, CAS_n/A15)
MT5 = XOR (CKE, RAS_n/A16, A10/AP)
MT6 = XOR (ACT_n, A4, BA1)
MT7 = ×16: XOR (DMU_n/DBIU_n , DML_n/DBIL_n, CK_t)
MT8 = XOR (WE_n/A14, A12 / BC, BA0)
MT9 = XOR (BG0, A3, RESET_n and TEN)

## Logic Equations for a x16 Device

| | |
|---|---|
| DQ0 = MT0 | DQ10 = INV DQ2 |
| DQ1 = MT1 | DQ11 = INV DQ3 |
| DQ2 = MT2 | DQ12 = INV DQ4 |
| DQ3 = MT3 | DQ13 = INV DQ5 |
| DQ4 = MT4 | DQ14 = INV DQ6 |
| DQ5 = MT5 | DQ15 = INV DQ7 |
| DQ6 = MT6 | LDQS_t = MT8 |
| DQ7 = MT7 | LDQS_c = MT9 |
| DQ8 = INV DQ0 | UDQS_t = INV LDQS_t |
| DQ9 = INV DQ1 | UDQS_c = INV LDQS_c |

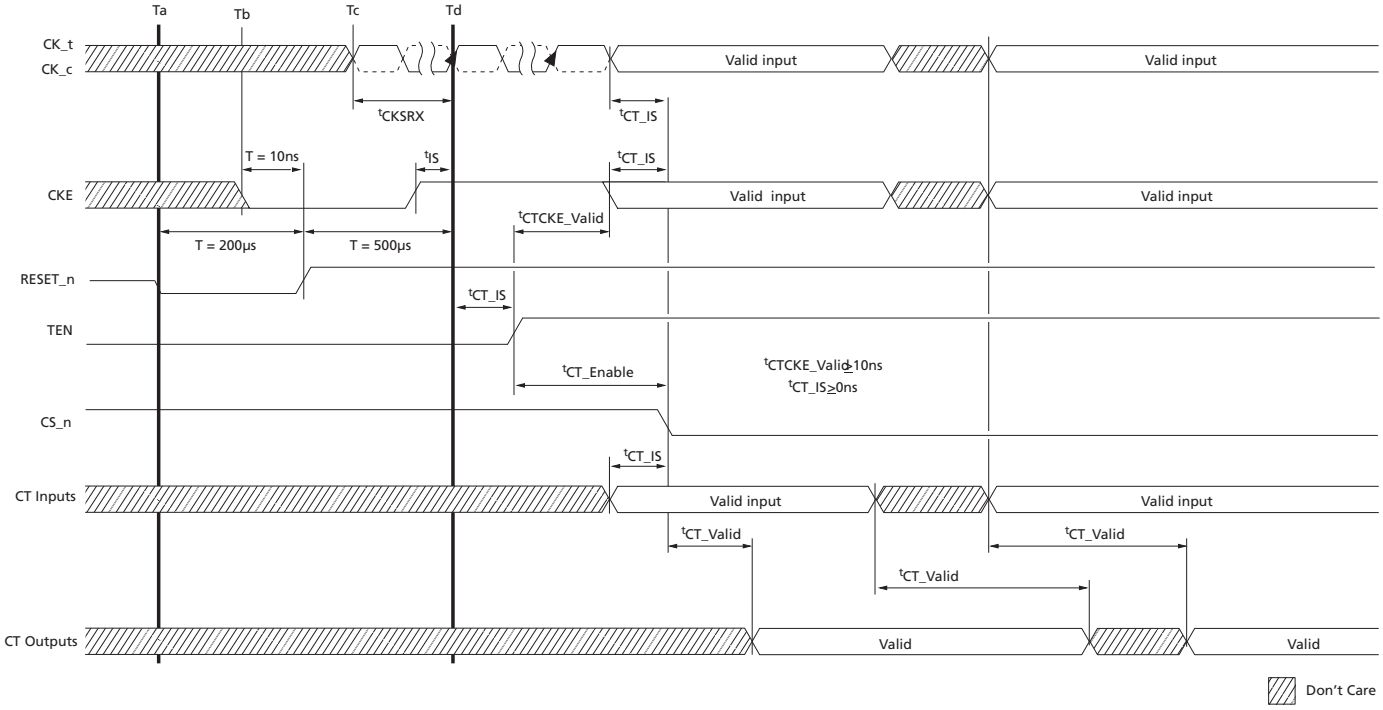
## CT Input Timing Requirements

Prior to the assertion of the TEN pin, all voltage supplies, including $V_{REFCA}$, must be valid and stable and RESET_n registered high prior to entering CT mode. Upon the assertion of the TEN pin HIGH with RESET_n, CKE, and CS_n held HIGH; CLK_t, CLK_c, and CKE signals become test inputs within $^{t}$CTECT_Valid. The remaining CT inputs become valid $^{t}$CT_Enable after TEN goes HIGH when CS_n allows input to begin sampling, provided inputs were valid for at least $^{t}$CT_Valid. While in CT mode, refresh activities in the memory arrays are not allowed; they are initiated either externally (auto refresh) or internally (self refresh).

The TEN pin may be asserted after the DRAM has completed power-on. After the DRAM is initialized and $V_{REFDQ}$ is calibrated, CT mode may no longer be used. The TEN pin may be de-asserted at any time in CT mode. Upon exiting CT mode, the states and the integrity of the original content of the memory array are unknown. A full reset of the memory device is required.

After CT mode has been entered, the output signals will be stable within $^{t}$CT_Valid after the test inputs have been applied as long as TEN is maintained HIGH and CS_n is maintained LOW.

**Figure 64: Connectivity Test Mode Entry**



## Excessive Row Activation

Rows can be accessed a limited number of times within a certain time period before adjacent rows require refresh. The maximum activate count (MAC) is the maximum number of activates that a single row can sustain within a time interval of equal to or less than the maximum activate window ($^{t}$MAW) before the adjacent rows need to be refreshed, regardless of how the activates are distributed over $^{t}$MAW.

Alliance's DDR4 devices automatically perform a type of TRR mode in the background and provide an MPR Page 3 MPR3[3:0] of 1000, indicating there is no restriction to the number of ACTIVATE commands to a given row in a refresh period provided DRAM tim-ing specifications are not violated. However, specific attempts to by-pass TRR may re-sult in data disturb.

**Table 37: MAC Encoding of MPR Page 3 MPR3**

| [7] | [6] | [5] | [4] | [3] | [2] | [1] | [0] | MAC | Comments |
|---|---|---|---|---|---|---|---|---|---|
| x | x | x | x | 0 | 0 | 0 | 0 | Untested | The device has not been tested for MAC. |
| x | x | x | x | 0 | 0 | 0 | 1 | $^{t}$MAC = 700K | |
| x | x | x | x | 0 | 0 | 1 | 0 | $^{t}$MAC = 600K | |
| x | x | x | x | 0 | 0 | 1 | 1 | $^{t}$MAC = 500K | |
| x | x | x | x | 0 | 1 | 0 | 0 | $^{t}$MAC = 400K | |
| x | x | x | x | 0 | 1 | 0 | 1 | $^{t}$MAC = 300K | |
| x | x | x | x | 0 | 1 | 1 | 0 | Reserved | |
| x | x | x | x | 0 | 1 | 1 | 1 | $^{t}$MAC = 200K | |
| x | x | x | x | 1 | 0 | 0 | 0 | Unlimited | There is no restriction to the number of ACTIVATE commands to a given row in a re-fresh period provided DRAM timing specifi-cations are not violated. |
| x | x | x | x | 1 | 0 | 0 | 1 | Reserved | |
| x | x | x | x | : | : | : | : | Reserved | |
| x | x | x | x | 1 | 1 | 1 | 1 | Reserved | |

Note: 1. MAC encoding in MPR Page 3 MPR3.

# Post Package Repair

## Post Package Repair

JEDEC defines two modes of Post Package Repair (PPR): soft Post Package Repair (sPPR) and hard Post Package Repair (hPPR). sPPR is non-persistent so the repair row maybe altered; that is, sPPR is NOT a permanent repair and even though it will repair a row, the repair can be reversed, reassigned via another sPPR, or made permanent via hPPR. Hard Post Package Repair is persistent so once the repair row is assigned for a hPPR address, further PPR commands to a previous hPPR section should not be performed, that is, hPPR is a permanent repair; once repaired, it cannot be reversed. The controller provides the failing row address in the hPPR/sPPR sequence to the device to perform the row repair. hPPR Mode and sPPR Mode may not be enabled at the same time.

JEDEC states hPPR is optional for 4Gb and sPPR is optional for 4Gb and 8Gb parts however Alliance 4Gb and 8Gb DDR4 DRAMs should have both sPPR and hPPR support. The hPPR support is identified via an MPR read from MPR Page 2, MPR0[7] and sPPR

support is identified via an MPR read from MPR Page 2, MPR0[6].

The JEDEC minimum support requirement for DDR4 PPR (hPPR or sPPR) is to provide one row of repair per bank group (BG), x16 has 2 BG; this is a total of 2 repair rows available on x16. Alliance PPR support exceeds the JEDEC minimum requirements; Alliance DDR4 DRAMs have at least one row of repair for each bank which is essentially 4 row repairs per BG for a total of 8 repair rows for x16; a 4x increase in repair rows.

JEDEC requires the user to have all sPPR row repair addresses reset and cleared prior to enabling hPPR Mode. Alliance DDR4 PPR does not have this restriction, the existing sPPR row repair addresses are not required to be cleared prior to entering hPPR mode. Each bank in a BG is PPR independent: sPPR or hPPR issued to a bank will not alter a sPPR row repair existing in a different bank.

**sPPR followed by sPPR to same bank**

When PPR is issued to a bank for the first time and is a sPPR command, the repair row will be a sPPR. When a subsequent sPPR is issued to the same bank, the previous sPPR repair row will be cleared and used for the subsequent sPPR address as the sPPR operation is non-persistent.

**sPPR followed by hPPR to same bank**

When a PPR is issued to a bank for the first time and is a sPPR command, the repair row will be a sPPR. When a subsequent hPPR is issued to the same bank, the initial sPPR repair row will be cleared and used for the hPPR address. If a further subsequent PPR (hPPR or sPPR) is issued to the same bank, the further subsequent PPR ( hPPR or sPPR) repair row will not clear or overwrite the previous hPPR address as the hPPR operation is persistent.

**hPPR followed by hPPR or sPPR to same bank**

When a PPR is issued to a bank for the first time and is a hPPR command, the repair row will be a hPPR. When a subsequent PPR (hPPR or sPPR) is issued to the same bank, the subsequent PPR ( hPPR or sPPR) repair row will not clear or overwrite the initial hPPR address as the initial hPPR is persistent.

## Hard Post Package Repair

All banks must be precharged and idle. DBI and CRC modes must be disabled. Both sPPR and hPPR must be disabled. sPPR is disabled with MR4[5] = 0. hPPR is disabled with MR4[13] = 0, which is the normal state, and hPPR is enabled with MR4 [13]= 1, which is the hPPR enabled state. There are two forms of hPPR mode. Both forms of hPPR have the same entry requirement as defined in the sections below. The first command sequence uses a WRA command and supports data retention with a REFRESH operation except for the bank containing the row that is being repaired; JEDEC has relaxed this requirement and allows BA[0] to be a don't care regarding the banks which are not required to maintain data a REFRESH operation during hPPR. The second command sequence uses a WR command (a REFRESH operation can't be performed in this command sequence). The second command sequence doesn't support data retention for the target DRAM.

### hPPR Row Repair - Entry

As stated above, all banks must be precharged and idle. DBI and CRC modes must be disabled, and all timings must be followed as shown in the timing diagram that follows.

All other commands except those listed in the following sequences are illegal.

1. Issue MR4[13] 1 to enter hPPR mode enable.
   a. All DQ are driven HIGH.
2. Issue four consecutive guard key commands (shown in the table below) to MR0 with each command separated by $^{t}$MOD. The PPR guard key settings are the same whether performing sPPR or hPPR mode.
   a. Any interruption of the key sequence by other commands, such as ACT, WR, RD, PRE, REF, ZQ, and NOP, are not allowed.
   b. If the guard key bits are not entered in the required order or interrupted with other MR commands, hPPR will not be enabled, and the programming cycle will result in a NOP.
   c. When the hPPR entry sequence is interrupted and followed by ACT and WR commands, these commands will be conducted as normal DRAM commands.
   d. JEDEC allows A6:0 to be "Don't Care" on 4Gb and 8Gb devices from a suppli-er perspective and the user should rely on vendor datasheet.

**Table 38: PPR MR0 Guard Key Settings**

| MR0 | BG0 | BA1:0 | A17:12 | A11 | A10 | A9 | A8 | A7 | A6:0 |
|---|---|---|---|---|---|---|---|---|---|
| First guard key | 0 | 0 | xxxxxx | 1 | 1 | 0 | 0 | 1 | 1111111 |
| Second guard key | 0 | 0 | xxxxxx | 0 | 1 | 1 | 1 | 1 | 1111111 |
| Third Guard key | 0 | 0 | xxxxxx | 1 | 0 | 1 | 1 | 1 | 1111111 |
| Fourth guard key | 0 | 0 | xxxxxx | 0 | 0 | 1 | 1 | 1 | 1111111 |

### hPPR Row Repair – WRA Initiated (REF Commands Allowed)

1. Issue an ACT command with failing BG and BA with the row address to be repaired.
2. Issue a WRA command with BG and BA of failing row address.
   a. The address must be at valid levels, but the address is "Don't Care."

3. All DQ of the target DRAM should be driven LOW for 4*n*CK (bit 0 through bit 7) after WL (WL = CWL + AL + PL) in order for hPPR to initiate repair.
    a. Repair **will be** initiated to the target DRAM only if all DQ during bit 0 through bit 7 are LOW. The bank under repair does not get the REFRESH command applied to it.
    b. Repair **will not be** initiated to the target DRAM if any DQ during bit 0 through bit 7 is HIGH.
        1. JEDEC states: All DQs of target DRAM should be LOW for 4$^{t}$CK. If HIGH is driven to all DQs of a DRAM consecutively for equal to or longer than 2$^{t}$CK, then DRAM does not conduct hPPR and retains data if REF command is properly issued; if all DQs are neither LOW for 4$^{t}$CK nor HIGH for equal to or longer than 2$^{t}$CK, then hPPR mode execution is un-known.
    c. DQS should function normally.
4. REF command may be issued anytime after the WRA command followed by WL + 4*n*CK + $^{t}$WR + $^{t}$RP.
    a. Multiple REF commands are issued at a rate of $^{t}$REFI or $^{t}$REFI/2, however back-to-back REF commands must be separated by at least $^{t}$REFI/4 when the DRAM is in hPPR mode.
    b. All banks except the bank under repair will perform refresh.
5. Issue PRE after $^{t}$PGM time so that the device can repair the target row during $^{t}$PGM time.
    a. Wait $^{t}$PGM_Exit after PRE to allow the device to recognize the repaired target row address.
6. Issue MR4[13] 0 command to hPPR mode disable.
    a. Wait $^{t}$PGMPST for hPPR mode exit to complete.
    b. After $^{t}$PGMPST has expired, any valid command may be issued.

The entire sequence from hPPR mode enable through hPPR mode disable may be repeated if more than one repair is to be done.

After completing hPPR mode, MR0 must be re-programmed to a prehPPR mode state if the device is to be accessed.

After hPPR mode has been exited, the DRAM controller can confirm if the target row was repaired correctly by writing data into the target row and reading it back.

**Figure 65: hPPR WRA – Entry**

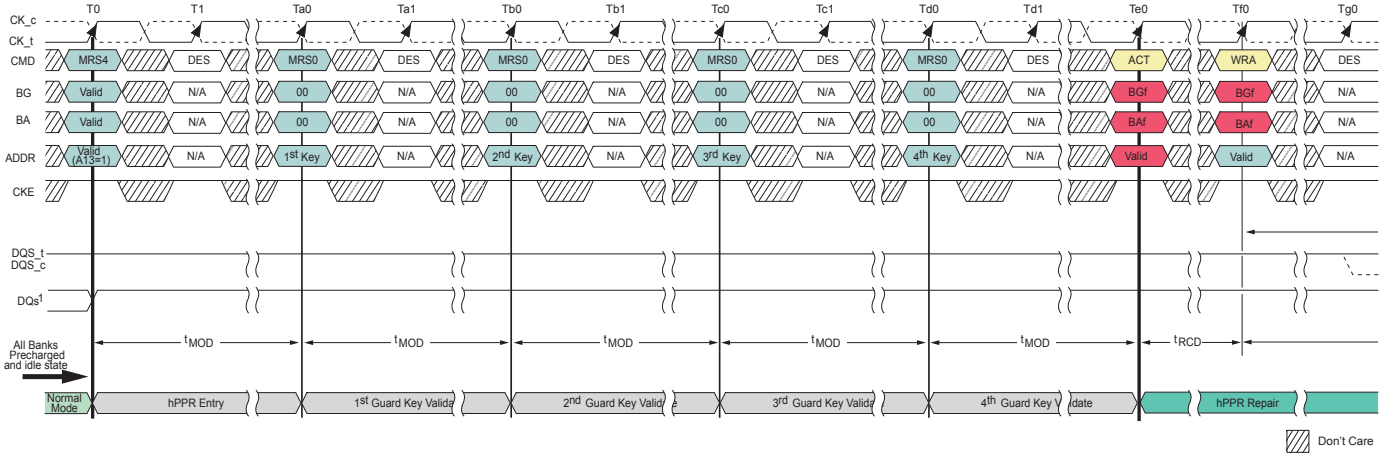
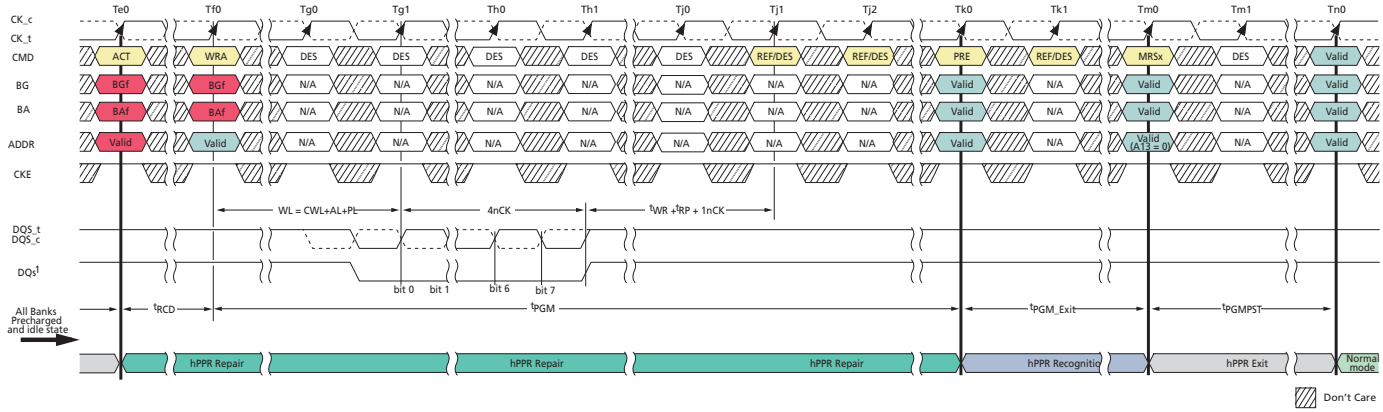



**Figure 66: hPPR WRA – Repair and Exit**




## hPPR Row Repair – WR Initiated (REF Commands NOT Allowed)

1. Issue an ACT command with failing BG and BA with the row address to be repaired.
2. Issue a WR command with BG and BA of failing row address.
   a. The address must be at valid levels, but the address is "Don't Care."
3. All DQ of the target DRAM should be driven LOW for 4*n*CK (bit 0 through bit 7) after WL (WL = CWL + AL + PL) in order for hPPR to initiate repair.
   a. Repair **will be** initiated to the target DRAM only if all DQ during bit 0 through bit 7 are LOW.
   b. Repair **will not be** initiated to the target DRAM if any DQ during bit 0 through bit 7 is HIGH.
      1. JEDEC states: All DQs of target DRAM should be LOW for 4$^{t}$CK. If HIGH is driven to all DQs of a DRAM consecutively for equal to or longer than 2$^{t}$CK, then DRAM does not conduct hPPR and retains data if REF com-mand is properly issued; if all DQs are neither LOW for 4$^{t}$CK nor HIGH for equal to or longer than 2$^{t}$CK, then hPPR mode execution is un-known.

c. DQS should function normally.

4. REF commands may NOT be issued at anytime while in PPT mode.
5. Issue PRE after $^{t}$PGM time so that the device can repair the target row during $^{t}$PGM time.
   a. Wait $^{t}$PGM_Exit after PRE to allow the device to recognize the repaired target row address.
6. Issue MR4[13] 0 command to hPPR mode disable.
   a. Wait $^{t}$PGMPST for hPPR mode exit to complete.
   b. After $^{t}$PGMPST has expired, any valid command may be issued.

The entire sequence from hPPR mode enable through hPPR mode disable may be repeated if more than one repair is to be done.

After completing hPPR mode, MR0 must be re-programmed to a prehPPR mode state if the device is to be accessed.

After hPPR mode has been exited, the DRAM controller can confirm if the target row was repaired correctly by writing data into the target row and reading it back.

**Figure 67: hPPR WR – Entry**

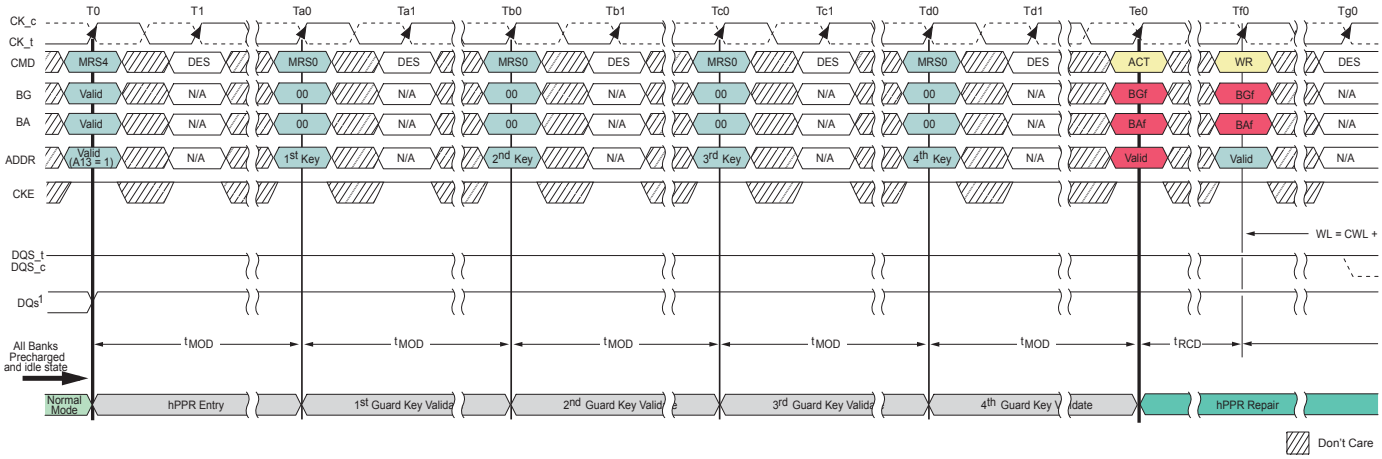



**Figure 68: hPPR WR – Repair and Exit**

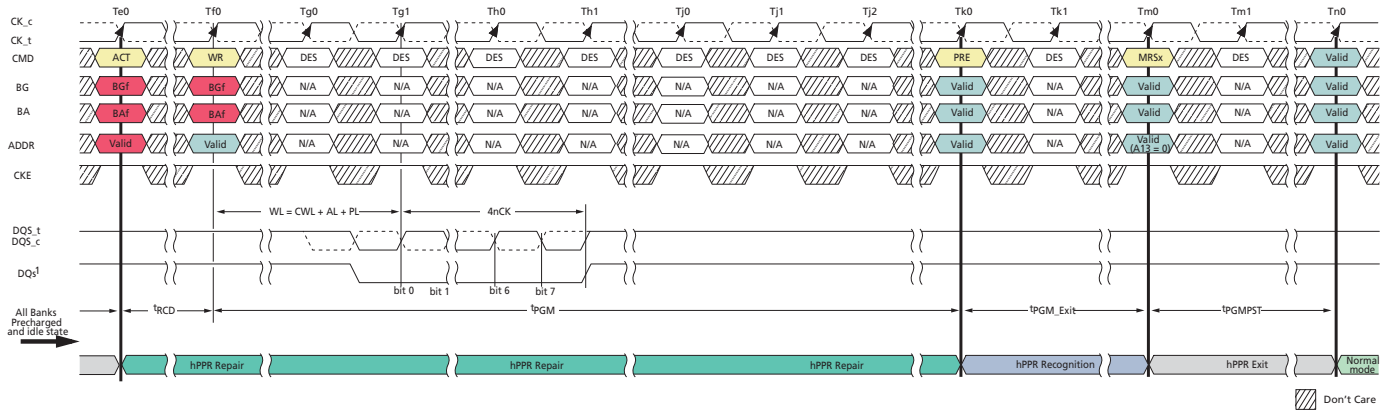


**Table 39: DDR4 hPPR Timing Parameters DDR4-1600 through DDR4-3200**

| Parameter | Symbol | | Min | Max | Unit |
|---|---|---|---|---|---|
| hPPR programming time | $^{t}$PGM | ×16 | 2000 | – | ms |
| hPPR precharge exit time | $^{t}$PGM_Exit | | 15 | – | ns |
| hPPR exit time | $^{t}$PGMPST | | 50 | – | µs |

## sPPR Row Repair

Soft post package repair (sPPR) is a way to quickly, but temporarily, repair a row element in a bank on a DRAM device, where hPPR takes longer but permanently repairs a row element. sPPR mode is entered in a similar fashion as hPPR, sPPR uses MR4[5] while hPPR uses MR4[13]. sPPR is disabled with MR4[5] = 0, which is the normal state, and sPPR is enabled with MR4[5] = 1, which is the sPPR enabled state.

sPPR requires the same guard key sequence as hPPR to qualify the MR4 PPR entry. After sPPR entry, an ACT command will capture the target bank and target row, herein seed row, where the row repair will be made. After $^{t}$RCD time, a WR command is used to select the individual DRAM, through the DQ bits, to transfer the repair address into an internal register in the DRAM. After a write recovery time and PRE command, the sPPR mode can be exited and normal operation can resume.

The DRAM will retain the soft repair information as long as $V_{DD}$ remains within the operating region unless rewritten by a subsequent sPPR entry to the same bank. If DRAM power is removed or the DRAM is reset, the soft repair will revert to the unrepaired state. hPPR and sPPR should not be enabled at the same time; Alliance sPPR does not have to be disabled and cleared prior to entering hPPR mode.
With sPPR, Alliance DDR4 can repair one row per bank. When a subsequent sPPR request is made to the same bank, the subsequently issued sPPR address will replace the previous sPPR address. When the hPPR resource for a bank is used up, the bank should be assumed to not have available resources for sPPR. If a repair sequence is issued to a bank with no repair resource available, the DRAM will ignore the programming sequence.

The bank receiving sPPR change is expected to retain memory array data in all rows except for the seed row and its associated row addresses. If the data in the memory array in the bank under sPPR repair is not required to be retained, then the handling of the seed row's associated row addresses is not of interest and can be ignored. If the data in the memory array is required to be retained in the bank under sPPR mode, then prior to executing the sPPR mode, the seed row and its associated row addresses should be backed up and subsequently restored after sPPR has been completed. sPPR associated seed row addresses are specified in the Table below; BA0 is not required by Alliance DRAMs however it is JEDEC reserved.

**Table 40: sPPR Associated Rows**

| sPPR Associated Row Address | | | | | | | |
|---|---|---|---|---|---|---|---|
| BA0* | A17 | A16 | A15 | A14 | A13 | A1 | A0 |

All banks must be precharged and idle. DBI and CRC modes must be disabled, and all sPPR timings must be followed as shown in the timing diagram that follows.

All other commands except those listed in the following sequences are illegal.

1. Issue MR4[5] 1 to enter sPPR mode enable.
   a. All DQ are driven HIGH.
2. Issue four consecutive guard key commands (shown in the table below) to MR0 with each command separated by $^{t}$MOD. Please note that JEDEC recently added the four guard key entry used for hPPR to sPPR entry; early DRAMs may not require four guard key entry code. A prudent controller design should accommodate either option in case an earlier DRAM is used.
   a. Any interruption of the key sequence by other commands, such as ACT, WR, RD, PRE, REF, ZQ, and NOP, are not allowed.
   b. If the guard key bits are not entered in the required order or interrupted with other MR commands, sPPR will not be enabled, and the programming cycle will result in a NOP.
   c. When the sPPR entry sequence is interrupted and followed by ACT and WR commands, these commands will be conducted as normal DRAM commands.
   d. JEDEC allows A6:0 to be "Don't Care" on 4Gb and 8Gb devices from a supplier perspective and the user should rely on vendor datasheet.

**Table 41: PPR MR0 Guard Key Settings**

| MR0 | BG1:0 | BA1:0 | A17:12 | A11 | A10 | A9 | A8 | A7 | A6:0 |
|---|---|---|---|---|---|---|---|---|---|
| First guard key | 0 | 0 | xxxxxx | 1 | 1 | 0 | 0 | 1 | 1111111 |
| Second guard key | 0 | 0 | xxxxxx | 0 | 1 | 1 | 1 | 1 | 1111111 |
| Third guard key | 0 | 0 | xxxxxx | 1 | 0 | 1 | 1 | 1 | 1111111 |
| Fourth guard key | 0 | 0 | xxxxxx | 0 | 0 | 1 | 1 | 1 | 1111111 |

3. After $^{t}$MOD, issue an ACT command with failing BG and BA with the row address to be repaired.
4. After $^{t}$RCD, issue a WR command with BG and BA of failing row address.
   a. The address must be at valid levels, but the address is a "Don't Care."
5. All DQ of the target DRAM should be driven LOW for 4*n*CK (bit 0 through bit 7) after WL (WL = CWL + AL + PL) in order for sPPR to initiate repair.
   a. Repair **will be** initiated to the target DRAM only if all DQ during bit 0 through bit 7 are LOW.
   b. Repair **will not be** initiated to the target DRAM if any DQ during bit 0 through bit 7 is HIGH.
      1. JEDEC states: All DQs of target DRAM should be LOW for 4$^{t}$CK. If HIGH is driven to all DQs of a DRAM consecutively for equal to or longer than the first 2$^{t}$CK, then DRAM does not conduct hPPR and retains data if REF command is properly issued; if all DQs are neither LOW for 4$^{t}$CK nor HIGH for equal to or longer than the first 2$^{t}$CK, then hPPR mode execution is unknown.
   c. DQS should function normally.
6. REF command may NOT be issued at anytime while in sPPR mode.
7. Issue PRE after $^{t}$WR time so that the device can repair the target row during $^{t}$WR time.
   a. Wait $^{t}$PGM_Exit_s after PRE to allow the device to recognize the repaired target row address.

8. Issue MR4[5] 0 command to sPPR mode disable.
   a. Wait $^{t}$PGMPST_s for sPPR mode exit to complete.
   b. After $^{t}$PGMPST_s has expired, any valid command may be issued.

The entire sequence from sPPR mode enable through sPPR mode disable may be repeated if more than one repair is to be done.

After sPPR mode has been exited, the DRAM controller can confirm if the target row was repaired correctly by writing data into the target row and reading it back.

**Figure 69: sPPR – Entry**

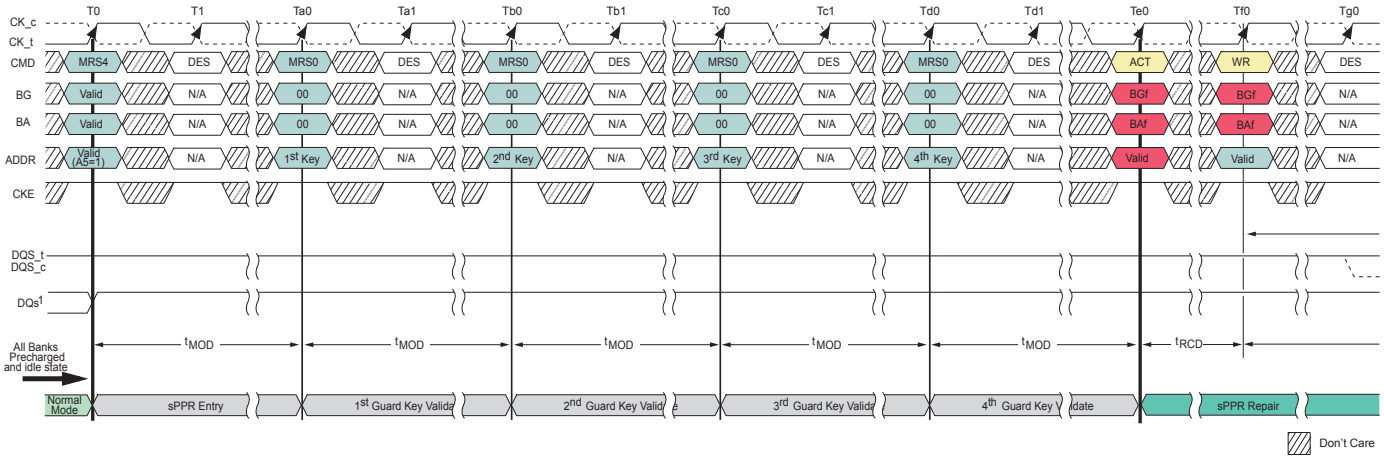



**Figure 70: sPPR – Repair, and Exit**

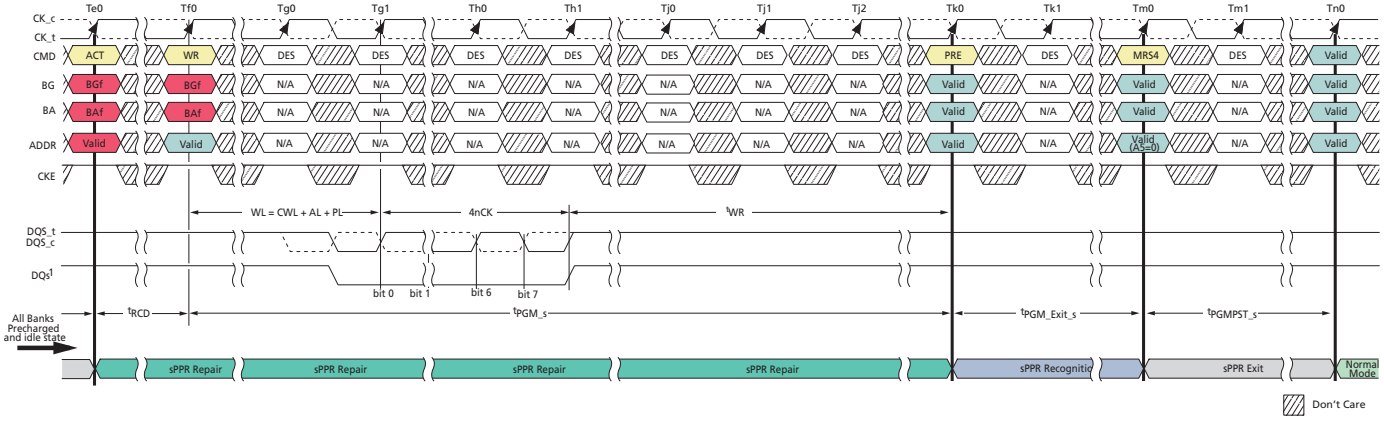



**Table 42: DDR4 sPPR Timing Parameters DDR4-1600 through DDR4-3200**

| Parameter | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| sPPR programming time | $^{t}$PGM_s | $^{t}$ RCD(MIN)+ WL + 4nCK + $^{t}$WR(MIN) | – | ns |
| sPPR precharge exit time | $^{t}$PGM_Exit_s | 20 | – | ns |
| sPPR exit time | $^{t}$PGMPST_s | $^{t}$MOD | – | ns |

## hPPR/sPPR Support Identifier

**Table 43: DDR4 Repair Mode Support Identifier**

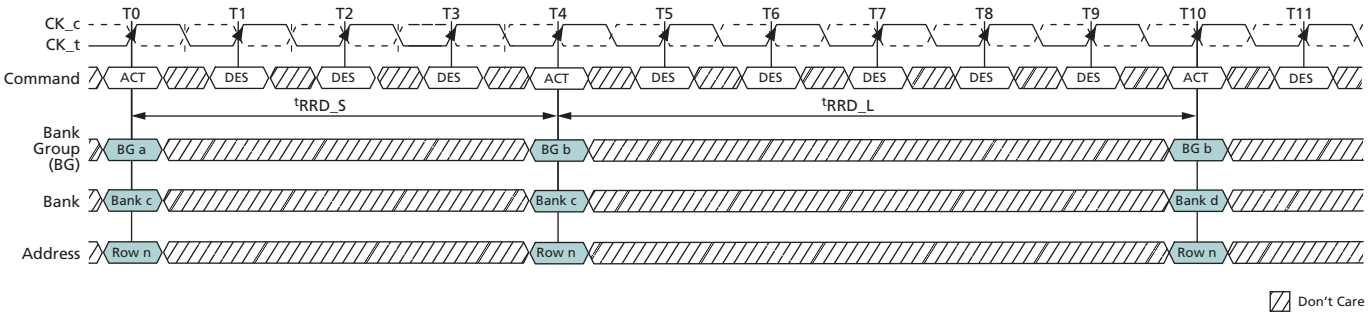
| MPR Page 2 | A7 | A6 | A5 | A4 | A3 | A2 | A1 | A0 |
|---|---|---|---|---|---|---|---|---|
| | UI0 | UI1 | UI2 | UI3 | UI4 | UI5 | UI6 | UI7 |
| MPR0 | hPPR[1] | sPPR[2] | $R_{TT\_WR}$ | Temp sensor | | CRC | $R_{TT\_WR}$ | |

Notes:
1. 0 = hPPR mode is not available, 1 = hPPR mode is available.
2. 0 = sPPR mode is not available, 1 = sPPR mode is available.
3. Gray shaded areas are for reference only.

## ACTIVATE Command

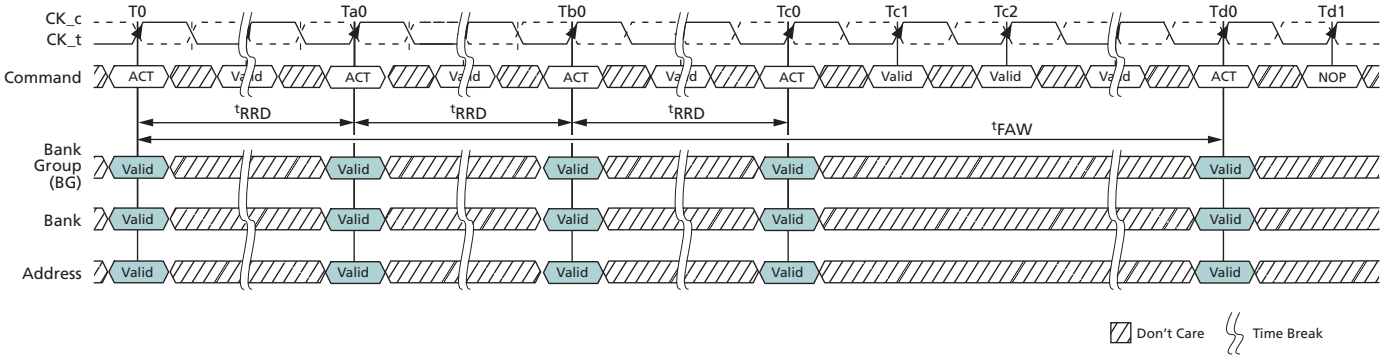
The ACTIVATE command is used to open (activate) a row in a particular bank for subsequent access. The values on the BG0 inputs select the bank group, the BA[1:0] inputs select the bank within the bank group, and the address provided on inputs A[17:0] selects the row within the bank. This row remains active (open) for accesses until a PRE-CHARGE command is issued to that bank. A PRECHARGE command must be issued before opening a different row in the same bank. Bank-to-bank command timing for ACTIVATE commands uses two different timing parameters, depending on whether the banks are in the same or different bank group. $^{t}$RRD_S (short) is used for timing between banks located in different bank groups. $^{t}$RRD_L (long) is used for timing between banks located in the same bank group. Another timing restriction for consecutive ACTIVATE commands [issued at $^{t}$RRD (MIN)] is $^{t}$FAW (four activate window). Because there is a maximum of four banks in a bank group, the $^{t}$FAW parameter applies across different bank groups (five ACTIVATE commands issued at $^{t}$RRD_L (MIN) to the same bank group would be limited by $^{t}$RC).

**Figure 71: $^{t}$RRD Timing**




Notes:
1. $^{t}$RRD_S; ACTIVATE-to-ACTIVATE command period (short); applies to consecutive ACTIVATE commands to different bank groups (that is, T0 and T4).
2. $^{t}$RRD_L; ACTIVATE-to-ACTIVATE command period (long); applies to consecutive ACTIVATE commands to the different banks in the same bank group (that is, T4 and T10).

**Figure 72: $^{t}$FAW Timing**




Note: 1. $^{t}$FAW; four activate windows.

## PRECHARGE Command

The PRECHARGE command is used to deactivate the open row in a particular bank or the open row in all banks. The bank(s) will be available for a subsequent row activation for a specified time ($^{t}$RP) after the PRECHARGE command is issued. An exception to this is the case of concurrent auto precharge, where a READ or WRITE command to a different bank is allowed as long as it does not interrupt the data transfer in the current bank and does not violate any other timing parameters.

After a bank is precharged, it is in the idle state and must be activated prior to any READ or WRITE commands being issued to that bank. A PRECHARGE command is allowed if there is no open row in that bank (idle state) or if the previously open row is already in the process of precharging. However, the precharge period will be determined by the last PRECHARGE command issued to the bank.

The auto precharge feature is engaged when a READ or WRITE command is issued with A10 HIGH. The auto precharge feature uses the RAS lockout circuit to internally delay the PRECHARGE operation until the ARRAY RESTORE operation has completed. The RAS lockout circuit feature allows the PRECHARGE operation to be partially or completely hidden during burst READ cycles when the auto precharge feature is engaged. The PRECHARGE operation will not begin until after the last data of the burst write se-quence is properly stored in the memory array.

## REFRESH Command

The REFRESH command (REF) is used during normal operation of the device. This command is non-persistent, so it must be issued each time a refresh is required. The device requires REFRESH cycles at an average periodic interval of $^{t}$REFI. When CS_n, RAS_n/A16, and CAS_n/A15 are held LOW and WE_n/A14 HIGH at the rising edge of the clock, the device enters a REFRESH cycle. All banks of the SDRAM must be pre-charged and idle for a minimum of the pre-charge time, $^{t}$RP (MIN), before the REFRESH command can be applied. The refresh addressing is generated by the internal DRAM refresh controller. This makes the address bits “Don’t Care” during a REFRESH command. An internal address counter supplies the addresses during the REFRESH cycle. No control of the external address bus is required once this cycle has started. When the REFRESH cycle has completed, all banks of the SDRAM will be in the pre-charged (idle)

state. A delay between the REFRESH command and the next valid command, except DES, must be greater than or equal to the minimum REFRESH cycle time $^{t}$RFC (MIN), as shown in Figure 73 (page 134).

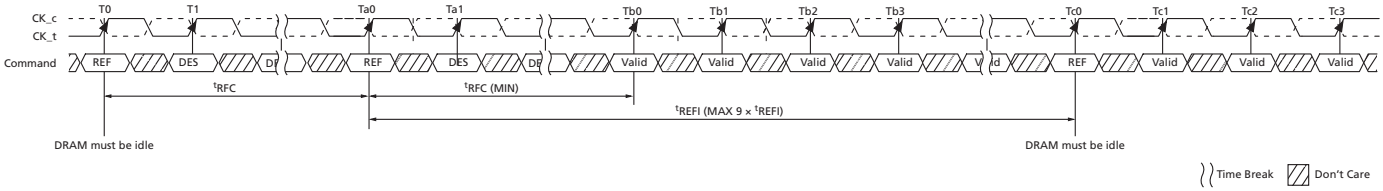
**Note:** The $^{t}$RFC timing parameter depends on memory density.

In general, a REFRESH command needs to be issued to the device regularly every $^{t}$REFI interval. To allow for improved efficiency in scheduling and switching between tasks, some flexibility in the absolute refresh interval is provided for postponing and pulling-in the REFRESH command. A limited number REFRESH commands can be postponed depending on refresh mode: a maximum of 8 REFRESH commands can be postponed when the device is in 1X refresh mode; a maximum of 16 REFRESH commands can be postponed when the device is in 2X refresh mode; and a maximum of 32 REFRESH commands can be postponed when the device is in 4X refresh mode.

When 8 consecutive REFRESH commands are postponed, the resulting maximum interval between the surrounding REFRESH commands is limited to 9 × $^{t}$REFI (see Figure 74 (page 138)). For both the 2X and 4X refresh modes, the maximum interval between sur-rounding REFRESH commands allowed is limited to 17 × $^{t}$REFI2 and 33 × $^{t}$REFI4, re-spectively.

A limited number REFRESH commands can be pulled-in as well. A maximum of 8 additional REFRESH commands can be issued in advance or “pulled-in” in 1X refresh mode, a maximum of 16 additional REFRESH commands can be issued when in advance in 2X refresh mode, and a maximum of 32 additional REFRESH commands can be issued in advance when in 4X refresh mode. Each of these REFRESH commands reduces the number of regular REFRESH commands required later by one. The resulting maximum interval between two surrounding REFRESH commands is limited to 9 × $^{t}$REFI (Figure 79 (page 135)), 17 × $^{t}$RFEI2, or 33 × $^{t}$REFI4. At any given time, a maximum of 16 REF commands can be issued within 2 × $^{t}$REFI, 32 REF2 commands can be issued within 4 × $^{t}$REFI2, and 64 REF4 commands can be issued within 8 × $^{t}$REFI4 (larger densities are limited by tRFC1, tRFC2, and tRFC4, respectively, which must still be met).

**Figure 73: REFRESH Command Timing**




Notes:
1. Only DES commands are allowed after a REFRESH command is registered until $^{t}$RFC (MIN) expires.
2. Time interval between two REFRESH commands may be extended to a maximum of 9 × $^{t}$REFI.

**Figure 74: Postponing REFRESH Commands (Example)**

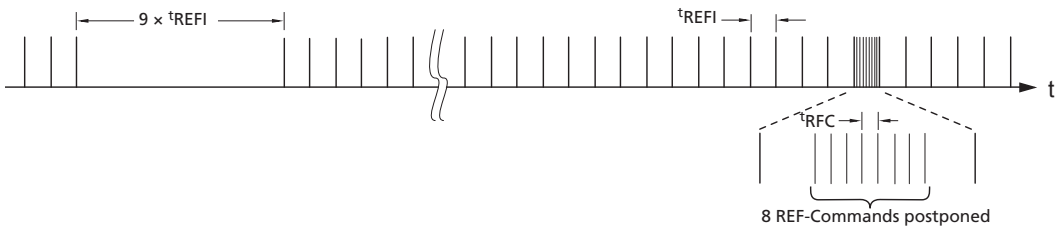
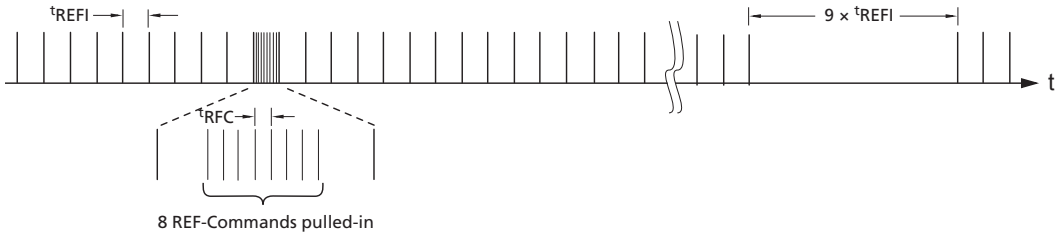



**Figure 75: Pulling In REFRESH Commands (Example)**



## Temperature-Controlled Refresh Mode

During normal operation, temperature-controlled refresh (TCR) mode disabled, the device must have a REFRESH command issued once every $^{t}$REFI, except for what is allowed by posting (see REFRESH Command section). This means a REFRESH command must be issued once every 1.95µs if $T_C$ is greater than 95°C, once every 3.9µs if $T_C$ is greater than 85°C, and once every 7.8µs if $T_C$ is less than or equal to 85°C. TCR mode is disabled by setting MR4[3] = 0 while TCR mode is enabled by setting MR4[3] = 1. When TCR mode is enabled (MR4[3] = 1), the Temperature Mode must be selected where MR4[2] = 0 enables the Normal Temperature Mode while MR4[2] = 1 enables the Extended Temperature Mode. When TCR mode is disabled (MR4[3] = 0), Normal Temperature Mode (MR4[2] = 0) must be selected.

When TCR mode is enabled, the device will register the externally supplied REFRESH command and adjust the internal refresh period to be longer than $^{t}$REFI of the normal temperature range, when allowed, by skipping REFRESH commands with the proper gear ratio. TCR mode has two Temperature Modes to select between the normal temperature range and the extended temperature range; the correct Temperature Mode must be selected so the internal control operates correctly. The DRAM must have the correct refresh rate applied externally; the internal refresh rate is determined by the DRAM based upon the temperature.

### Normal Temperature Mode

REFRESH commands should be issued to the device with the refresh period equal to $^{t}$REFI of normal temperature range (-40°C to 85°C). The system must guarantee that the $T_C$ does not exceed 85°C. The device may adjust the internal refresh period to be longer than $^{t}$REFI of the normal temperature range by skipping external REFRESH commands with the proper gear ratio when $T_C$ is below 85°C. The internal refresh period is auto-matically adjusted inside the DRAM, and the DRAM controller does not need to provide any additional control.

### Extended Temperature Mode

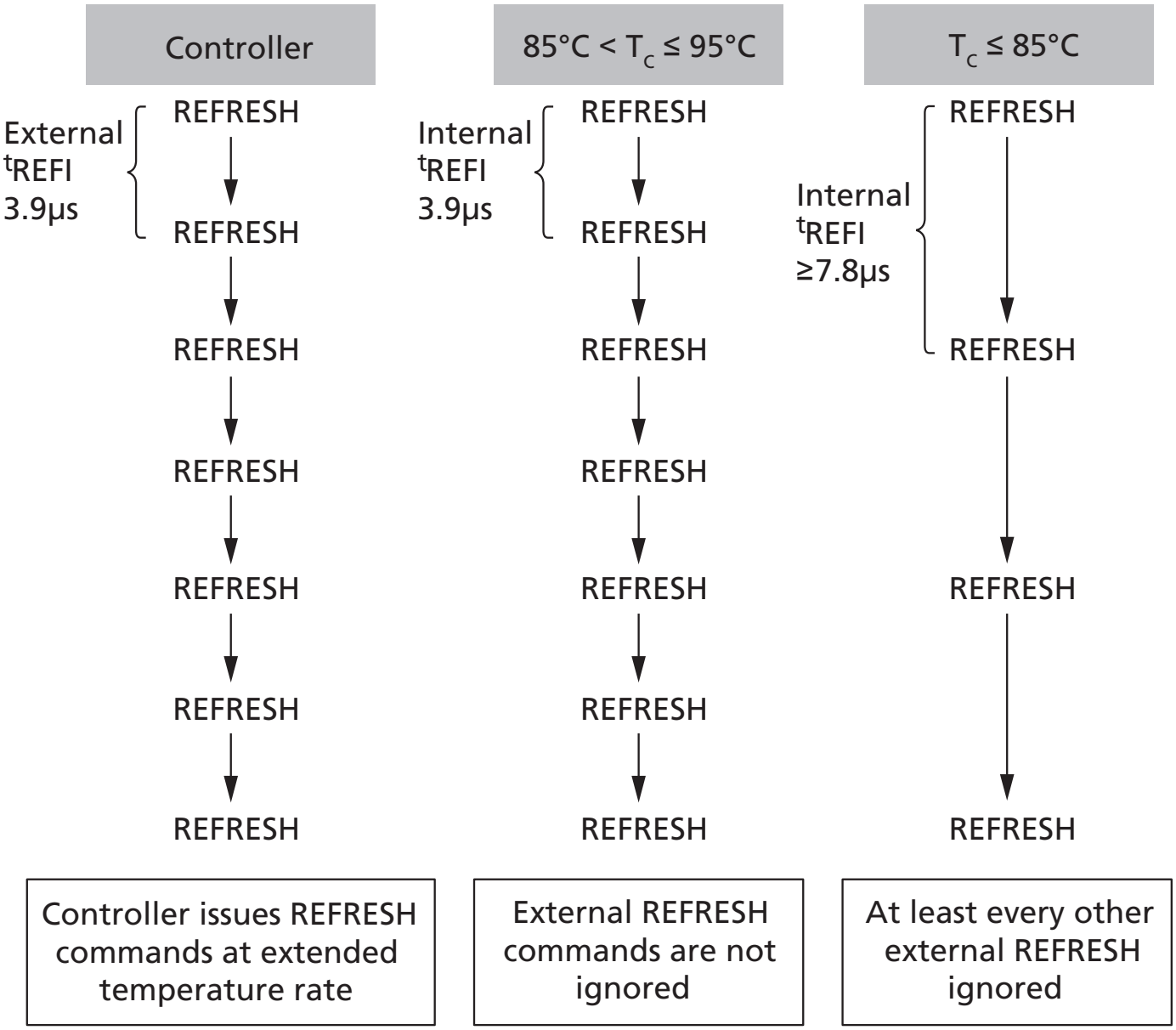
REFRESH commands should be issued to the device with the refresh period equal to $^{t}$REFI of extended temperature range (85°C to 95°C). The system must guarantee that the $T_C$ does not exceed 125°C. Even though the external refresh supports the extended temperature range, the device may adjust its internal refresh period to be equal to or longer than $^{t}$REFI of the normal temperature range (-40°C to 85°C) by skipping external REFRESH commands with the proper gear ratio when $T_C$ is equal to or below 85°C. The internal refresh period is automatically adjusted inside the DRAM, and the DRAM controller does not need to provide any additional control.

**Table 44: Normal $^{t}$REFI Refresh (TCR Enabled)**

| | Normal Temperature Mode | | Extended Temperature Mode | |
|---|---|---|---|---|
| Temperature | External Refresh Period | Internal Refresh Period | External Refresh Period | Internal Refresh Period |
| $T_C \le 85°C$ | 7.8µs | ≥7.8µs | 3.9µs[1] | ≥7.8µs |
| $85°C < T_C \le 95°C$ | N/A | | | 3.9µs |

Note: 1. If the external refresh period is slower than 3.9µs, the device will refresh internally at too slow of a refresh rate and will violate refresh specifications.

**Figure 76: TCR Mode Example[1]**




Note: 1. TCR enabled with Extended Temperature Mode selected.

# Fine Granularity Refresh Mode

## Mode Register and Command Truth Table

The REFRESH cycle time ($^{t}$RFC) and the average refresh interval ($^{t}$REFI) can be programmed by the MRS command. The appropriate setting in the mode register will set a single set of REFRESH cycle times and average refresh interval for the device (fixed mode), or allow the dynamic selection of one of two sets of REFRESH cycle times and average refresh interval for the device (on-the-fly mode [OTF]). OTF mode must be enabled by MRS before any OTF REFRESH command can be issued.

**Table 45: MRS Definition**

| MR3[8] | MR3[7] | MR3[6] | Refresh Rate Mode |
|---|---|---|---|
| 0 | 0 | 0 | Normal mode (fixed 1x) |
| 0 | 0 | 1 | Fixed 2x |
| 0 | 1 | 0 | Fixed 4x |
| 0 | 1 | 1 | Reserved |
| 1 | 0 | 0 | Reserved |
| 1 | 0 | 1 | On-the-fly 1x/2x |
| 1 | 1 | 0 | On-the-fly 1x/4x |
| 1 | 1 | 1 | Reserved |

There are two types of OTF modes (1x/2x and 1x/4x modes) that are selectable by programming the appropriate values into the mode register MR3[8:6]. When either of the two OTF modes is selected, the device evaluates the BG0 bit when a REFRESH command is issued, and depending on the status of BG0, it dynamically switches its internal refresh configuration between 1x and 2x (or 1x and 4x) modes, and then executes the corresponding REFRESH operation.

**Table 46: REFRESH Command Truth Table**

| Refresh | CS_n | ACT_n | RAS_n/A15 | CAS_n/A14 | WE_n/A13 | BG0 | A10/AP | A[9:0], A[12:11], A[20:16] | MR3[8:6] |
|---|---|---|---|---|---|---|---|---|---|
| Fixed rate | L | H | L | L | H | V | V | V | 0vv |
| OTF: 1x | L | H | L | L | H | L | V | V | 1vv |
| OTF: 2x | L | H | L | L | H | H | V | V | 101 |
| OTF: 4x | L | H | L | L | H | H | V | V | 110 |

## $^{t}$REFI and $^{t}$RFC Parameters

The default refresh rate mode is fixed 1x mode where REFRESH commands should be issued with the normal rate; that is, $^{t}$REFI1 = $^{t}$REFI(base) (for $T_C$ ≤85°C), and the duration of each REFRESH command is the normal REFRESH cycle time ($^{t}$RFC1). In 2x mode (either fixed 2x or OTF 2x mode), REFRESH commands should be issued to the device at the double frequency ($^{t}$REFI2 = $^{t}$REFI(base)/2) of the normal refresh rate. In 4x mode, the REFRESH command rate should be quadrupled ($^{t}$REFI4 = $^{t}$REFI(base)/4). Per

each mode and command type, the $^{t}$RFC parameter has different values as defined in the following table.

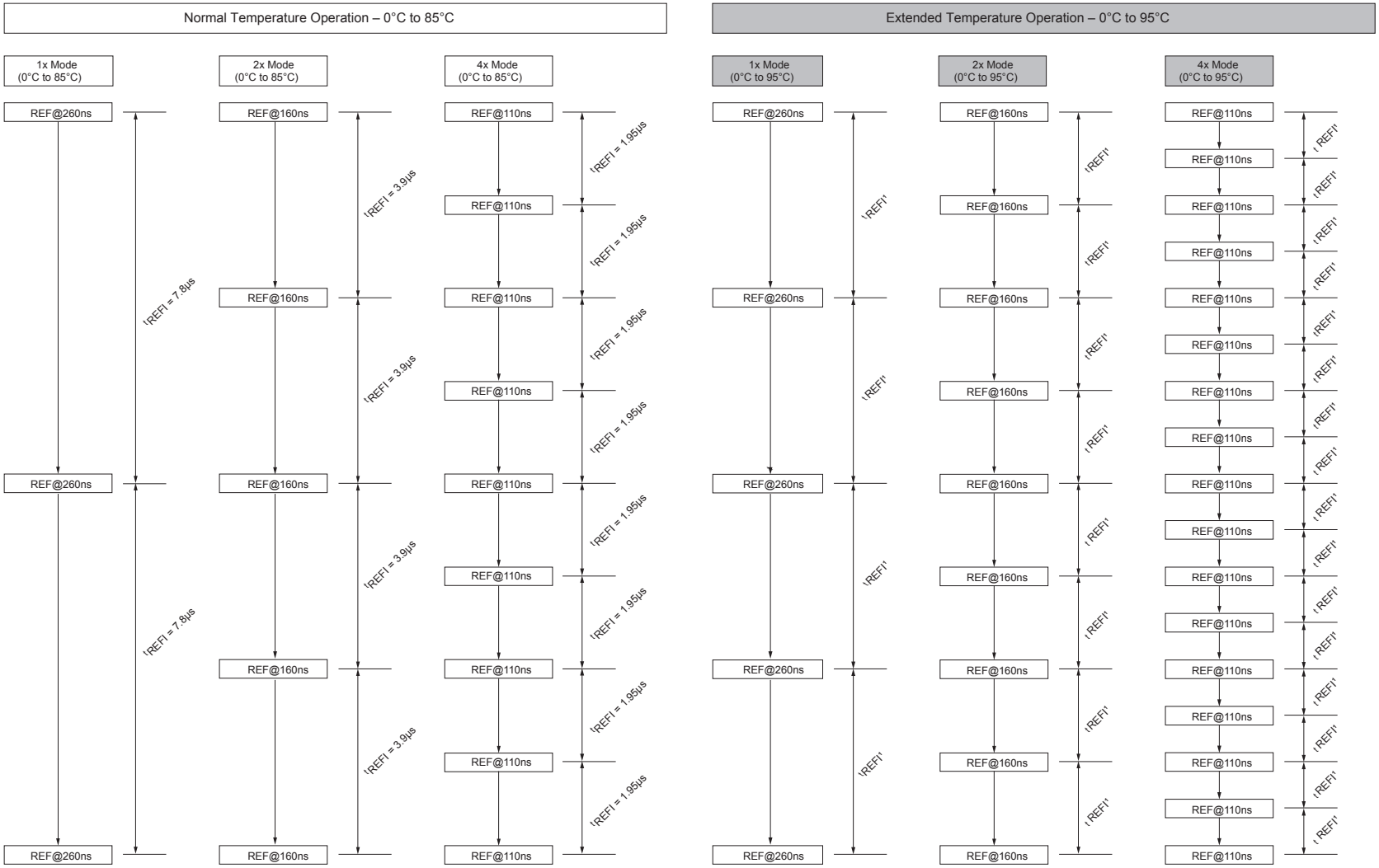
For discussion purposes, the REFRESH command that should be issued at the normal refresh rate and has the normal REFRESH cycle duration may be referred to as an REF1x command. The REFRESH command that should be issued at the double frequency ($^{t}$REFI2 = $^{t}$REFI(base)/2) may be referred to as a REF2x command. Finally, the REFRESH command that should be issued at the quadruple rate ($^{t}$REFI4 = $^{t}$REFI(base)/4) may be referred to as a REF4x command.

In the fixed 1x refresh rate mode, only REF1x commands are permitted. In the fixed 2x refresh rate mode, only REF2x commands are permitted. In the fixed 4x refresh rate mode, only REF4x commands are permitted. When the on-the-fly 1x/2x refresh rate mode is enabled, both REF1x and REF2x commands are permitted. When the OTF 1x/4x refresh rate mode is enabled, both REF1x and REF4x commands are permitted.

**Table 47: $^{t}$REFI and $^{t}$RFC Parameters**

| Refresh Mode | Parameter | | 2Gb | 4Gb | 8Gb | 16Gb | Units |
|---|---|---|---|---|---|---|---|
| | $^{t}$REFI(base) | | 7.8 | 7.8 | 7.8 | 7.8 | µs |
| 1x mode | $^{t}$REFI1 | -40°C ≤ $T_C$ ≤ 85°C | $^{t}$REFI(base) | $^{t}$REFI(base) | $^{t}$REFI(base) | $^{t}$REFI(base) | µs |
| | | 85°C ≤ $T_C$ ≤ 95°C | $^{t}$REFI(base)/2 | $^{t}$REFI(base)/2 | $^{t}$REFI(base)/2 | $^{t}$REFI(base)/2 | µs |
| | $^{t}$RFC1 | | 160 | 260 | 350 | 350 | ns |
| | | | | | | | |
| | | | | | | | |
| 2x mode | $^{t}$REFI2 | -40°C ≤ $T_C$ ≤ 85°C | $^{t}$REFI(base)/2 | $^{t}$REFI(base)/2 | $^{t}$REFI(base)/2 | $^{t}$REFI(base)/2 | µs |
| | | 85°C ≤ $T_C$ ≤ 95°C | $^{t}$REFI(base)/4 | $^{t}$REFI(base)/4 | $^{t}$REFI(base)/4 | $^{t}$REFI(base)/4 | µs |
| | $^{t}$RFC2 | | 110 | 160 | 260 | 260 | ns |
| | | | | | | | |
| | | | | | | | |
| 4x mode | $^{t}$REFI4 | -40°C ≤ $T_C$ ≤ 85°C | $^{t}$REFI(base)/4 | $^{t}$REFI(base)/4 | $^{t}$REFI(base)/4 | $^{t}$REFI(base)/4 | µs |
| | | 85°C ≤ $T_C$ ≤ 95°C | $^{t}$REFI(base)/8 | $^{t}$REFI(base)/8 | $^{t}$REFI(base)/8 | $^{t}$REFI(base)/8 | µs |
| | $^{t}$RFC4 | | 90 | 110 | 160 | 160 | ns |

**Figure 77: 4Gb With Fine Granularity Refresh Mode Example**

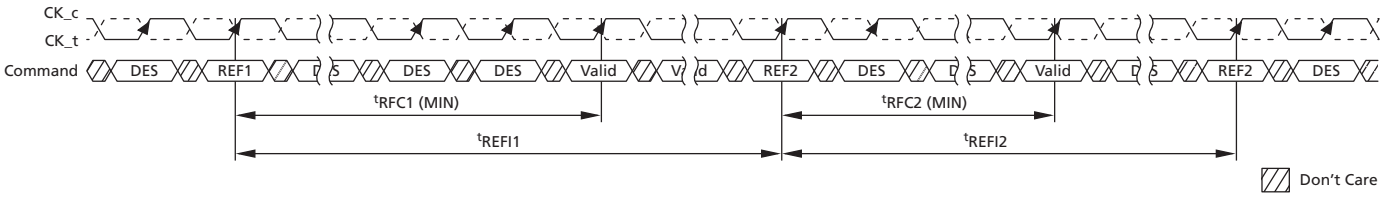


Note: 1. tREFI value is dependent on operating temperature range. See ***Table.144*** .

## Changing Refresh Rate

If the refresh rate is changed by either MRS or OTF. New tREFI and tRFC parameters will be applied from the moment of the rate change. When the REF1x command is issued to the DRAM, tREF1 and tRFC1 are applied from the time that the command was issued; when the REF2x command is issued, tREF2 and tRFC2 should be satisfied.

**Figure 78: OTF REFRESH Command Timing**




The following conditions must be satisfied before the refresh rate can be changed. Otherwise, data retention cannot be guaranteed.

- In the fixed 2x refresh rate mode or the OTF 1x/2x refresh mode, an even number of REF2x commands must be issued because the last change of the refresh rate mode with an MRS command before the refresh rate can be changed by another MRS command.
- In the OTF1x/2x refresh rate mode, an even number of REF2x commands must be issued between any two REF1x commands.
- In the fixed 4x refresh rate mode or the OTF 1x/4x refresh mode, a multiple-of-four number of REF4x commands must be issued because the last change of the refresh rate with an MRS command before the refresh rate can be changed by another MRS command.
- In the OTF1x/4x refresh rate mode, a multiple-of-four number of REF4x commands must be issued between any two REF1x commands.

There are no special restrictions for the fixed 1x refresh rate mode. Switching between fixed and OTF modes keeping the same rate is not regarded as a refresh rate change.

## Usage with TCR Mode

If the temperature controlled refresh mode is enabled, only the normal mode (fixed 1x mode, MR3[8:6] = 000) is allowed. If any other refresh mode than the normal mode is selected, the temperature controlled refresh mode must be disabled.

## Self Refresh Entry and Exit

The device can enter self refresh mode anytime in 1x, 2x, and 4x mode without any restriction on the number of REFRESH commands that have been issued during the mode before the self refresh entry. However, upon self refresh exit, extra REFRESH command(s) may be required, depending on the condition of the self refresh entry.

The conditions and requirements for the extra REFRESH command(s) are defined as follows:

- In the fixed 2x refresh rate mode or the enable-OTF 1x/2x refresh rate mode, it is recommended there be an even number of REF2x commands before entry into self refresh after the last self refresh exit, REF1x command, or MRS command that set the refresh mode. If this condition is met, no additional REFRESH commands are required upon self refresh exit. In the case that this condition is not met, either one ex-tra REF1x command or two extra REF2x commands must be issued upon self refresh exit. These extra REFRESH commands are not counted toward the computation of the average refresh interval ($^{t}$REFI).
- In the fixed 4x refresh rate mode or the enable-OTF 1x/4x refresh rate mode, it is recommended there be a multiple-of-four number of REF4x commands before entry into self refresh after the last self refresh exit, REF1x command, or MRS command that set the refresh mode. If this condition is met, no additional refresh commands are required upon self refresh exit. When this condition is not met, either one extra REF1x command or four extra REF4x commands must be issued upon self refresh exit. These extra REFRESH commands are not counted toward the computation of the average refresh interval ($^{t}$REFI).

There are no special restrictions on the fixed 1x refresh rate mode.

This section does not change the requirement regarding postponed REFRESH commands. The requirement for the additional REFRESH command(s) described above is independent of the requirement for the postponed REFRESH commands.

## SELF REFRESH Operation

The SELF REFRESH command can be used to retain data in the device, even if the rest of the system is powered down. When in self refresh mode, the device retains data with-out external clocking. The device has a built-in timer to accommodate SELF REFRESH operation. The SELF REFRESH command is defined by having CS_n, RAS_n, CAS_n, and CKE held LOW with WE_n and ACT_n HIGH at the rising edge of the clock.

Before issuing the SELF REFRESH ENTRY command, the device must be idle with all banks in the precharge state and $^{t}$RP satisfied. Idle state is defined as: All banks are closed ($^{t}$RP, $^{t}$DAL, and so on, satisfied), no data bursts are in progress, CKE is HIGH, and all timings from previous operations are satisfied ($^{t}$MRD, $^{t}$MOD, $^{t}$RFC, $^{t}$ZQinit, $^{t}$ZQoper, $^{t}$ZQCS, and so on). After the SELF REFRESH ENTRY command is registered, CKE must be held LOW to keep the device in self refresh mode. The DRAM automatically disables ODT termination, regardless of the ODT pin, when it enters self refresh mode and auto-matically enables ODT upon exiting self refresh. During normal operation (DLL_on), the DLL is automatically disabled upon entering self refresh and is automatically ena-bled (including a DLL reset) upon exiting self refresh.

When the device has entered self refresh mode, all of the external control signals, except CKE and RESET_n, are "Don't Care." For proper SELF REFRESH operation, all power supply and reference pins ($V_{DD}$, $V_{DDQ}$, $V_{SS}$, $V_{SSQ}$, $V_{PP}$, and $V_{REFCA}$) must be at valid levels. The DRAM internal $V_{REFDQ}$ generator circuitry may remain on or be turned off depend-ing on the MR6 bit 7 setting. If the internal $V_{REFDQ}$ circuit is on in self refresh, the first WRITE operation or first write-leveling activity may occur after $^{t}$XS time after self refresh exit. If the DRAM internal $V_{REFDQ}$ circuitry is turned off in self refresh, it ensures that the $V_{REFDQ}$ generator circuitry is powered up and stable within the $^{t}$XSDLL period when the DRAM exits the self refresh state. The first WRITE operation or first write-leveling activity may not occur earlier than $^{t}$XSDLL after exiting self refresh. The device initiates a minimum of one REFRESH command internally within the $^{t}$CKE period once it enters self refresh mode. The clock is internally disabled during a SELF REFRESH operation to save power. The minimum time that the device must remain in self refresh mode is $^{t}$CKESR/

$^{t}$CKESR_PAR. The user may change the external clock frequency or halt the external clock $^{t}$CKSRE/ $^{t}$CKSRE_PAR after self refresh entry is registered; however, the clock must be restarted and $^{t}$CKSRX must be stable before the device can exit SELF REFRESH operation.

The procedure for exiting self refresh requires a sequence of events. First, the clock must be stable prior to CKE going back HIGH. Once a SELF REFRESH EXIT command (SRX, combination of CKE going HIGH and DESELECT on the command bus) is registered, the following timing delay must be satisfied:

Commands that do not require locked DLL:

- $^{t}$XS = ACT, PRE, PREA, REF, SRE, and PDE.
- $^{t}$XS_FAST = ZQCL, ZQCS, and MRS commands. For an MRS command, only DRAM CL, WR/RTP register, and DLL reset in MR0; $R_{TT(NOM)}$ register in MR1; the CWL and $R_{TT(WR)}$ registers in MR2; and gear-down mode register in MR3; WRITE and READ pre-amble registers in MR4; $R_{TT(PARK)}$ register in MR5; Data rate and $V_{REFDQ}$ calibration value registers in MR6 may be accessed provided the DRAM is not in per-DRAM mode. Access to other DRAM mode registers must satisfy $^{t}$XS timing. WRITE com-mands (WR, WRS4, WRS8, WRA, WRAS4, and WRAS8) that require synchronous ODT and dynamic ODT controlled by the WRITE command require a locked DLL.

Commands that require locked DLL in the normal operating range:

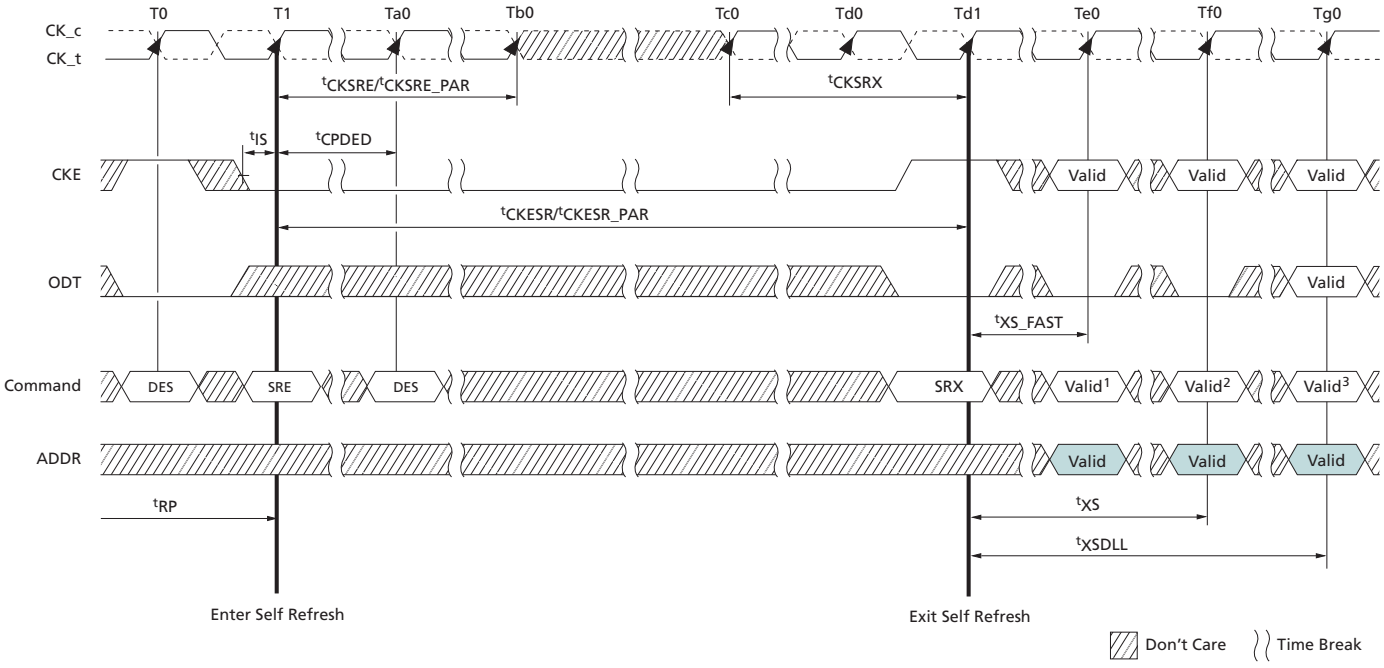
- $^{t}$XSDLL – RD, RDS4, RDS8, RDA, RDAS4, and RDAS8 (unlike DDR3, WR, WRS4, WRS8, WRA, WRAS4, and WRAS8 because synchronous ODT is required).

Depending on the system environment and the amount of time spent in self refresh, ZQ CALIBRATION commands may be required to compensate for the voltage and temperature drift described in the ZQ CALIBRATION Commands section. To issue ZQ CALIBRATION commands, applicable timing requirements must be satisfied (see the ZQ Calibration Timing figure).

CKE must remain HIGH for the entire self refresh exit period $^{t}$XSDLL for proper operation except for self refresh re-entry. Upon exit from self refresh, the device can be put back into self refresh mode or power-down mode after waiting at least $^{t}$XS period and issuing one REFRESH command (refresh period of $^{t}$RFC). The DESELECT command must be registered on each positive clock edge during the self refresh exit interval $^{t}$XS. ODT must be turned off during $^{t}$XSDLL.

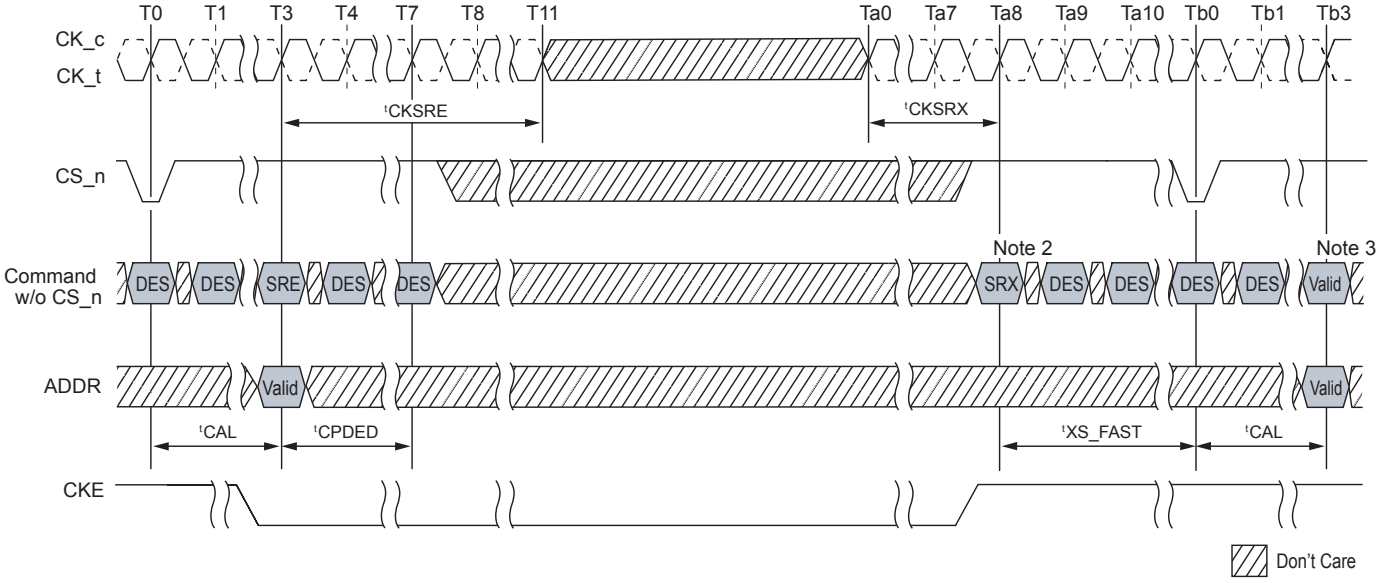
The use of self refresh mode introduces the possibility that an internally timed refresh event can be missed when CKE is raised for exit from self refresh mode. Upon exit from self refresh, the device requires a minimum of one extra REFRESH command before it is put back into self refresh mode.

**Figure 79: Self Refresh Entry/Exit Timing**




Notes:
1. Only MRS (limited to those described in the SELF REFRESH Operation section), ZQCS, or ZQCL commands are allowed.
2. Valid commands not requiring a locked DLL.
3. Valid commands requiring a locked DLL.

**Figure 80: Self Refresh Entry/Exit Timing with CAL Mode**

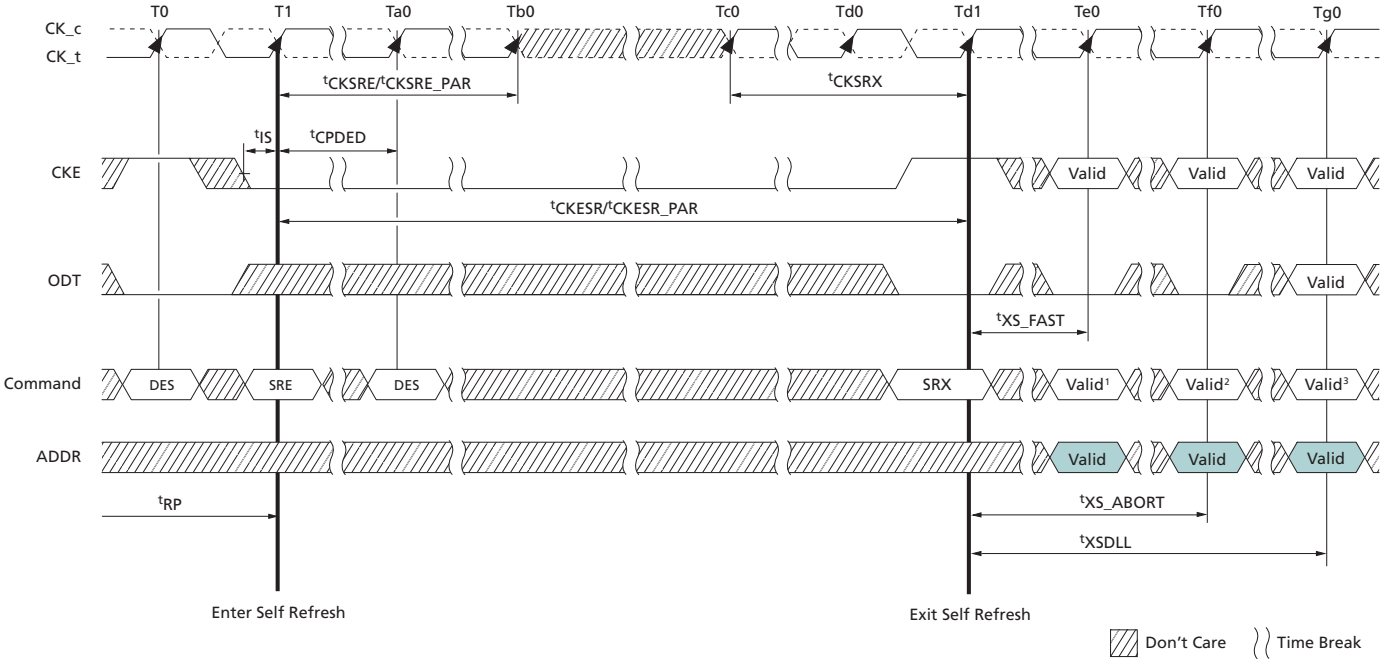



Notes:
1. $^{t}$CAL = 3*n*CK, $^{t}$CPDED = 4*n*CK, $^{t}$CKSRE/$^{t}$CKSRE_PAR = 8*n*CK, $^{t}$CKSRX = 8*n*CK, $^{t}$XS_FAST = $^{t}$REFC4 (MIN) + 10ns.
2. CS_n = HIGH, ACT_n = "Don't Care," RAS_n/A16 = "Don't Care," CAS_n/A15 = "Don't Care," WE_n/A14 = "Don't Care."
3. Only MRS (limited to those described in the SELF REFRESH Operations section), ZQCS, or ZQCL commands are allowed.
4. The figure only displays $^{t}$XS_FAST timing, but $^{t}$CAL must also be added to any $^{t}$XS and $^{t}$XSDLL associated commands during CAL mode.

## Self Refresh Abort

The exit timing from self refresh exit to the first valid command not requiring a locked DLL is $^{t}$XS. The value of $^{t}$XS is ($^{t}$RFC1 + 10ns). This delay allows any refreshes started by the device time to complete. $^{t}$RFC continues to grow with higher density devices, so $^{t}$XS will grow as well. An MRS bit enables the self refresh abort mode. If the bit is disabled, the controller uses $^{t}$XS timings (location MR4, bit 9). If the bit is enabled, the device aborts any ongoing refresh and does not increment the refresh counter. The controller can issue a valid command not requiring a locked DLL after a delay of $^{t}$XS_ABORT. Upon exit from self refresh, the device requires a minimum of one extra REFRESH command before it is put back into self refresh mode. This requirement remains the same irrespective of the setting of the MRS bit for self refresh abort.

**Figure 81: Self Refresh Abort**




Notes:
1. Only MRS (limited to those described in the SELF REFRESH Operation section), ZQCS, or ZQCL commands are allowed.
2. Valid commands not requiring a locked DLL with self refresh abort mode enabled in the mode register.
3. Valid commands requiring a locked DLL.

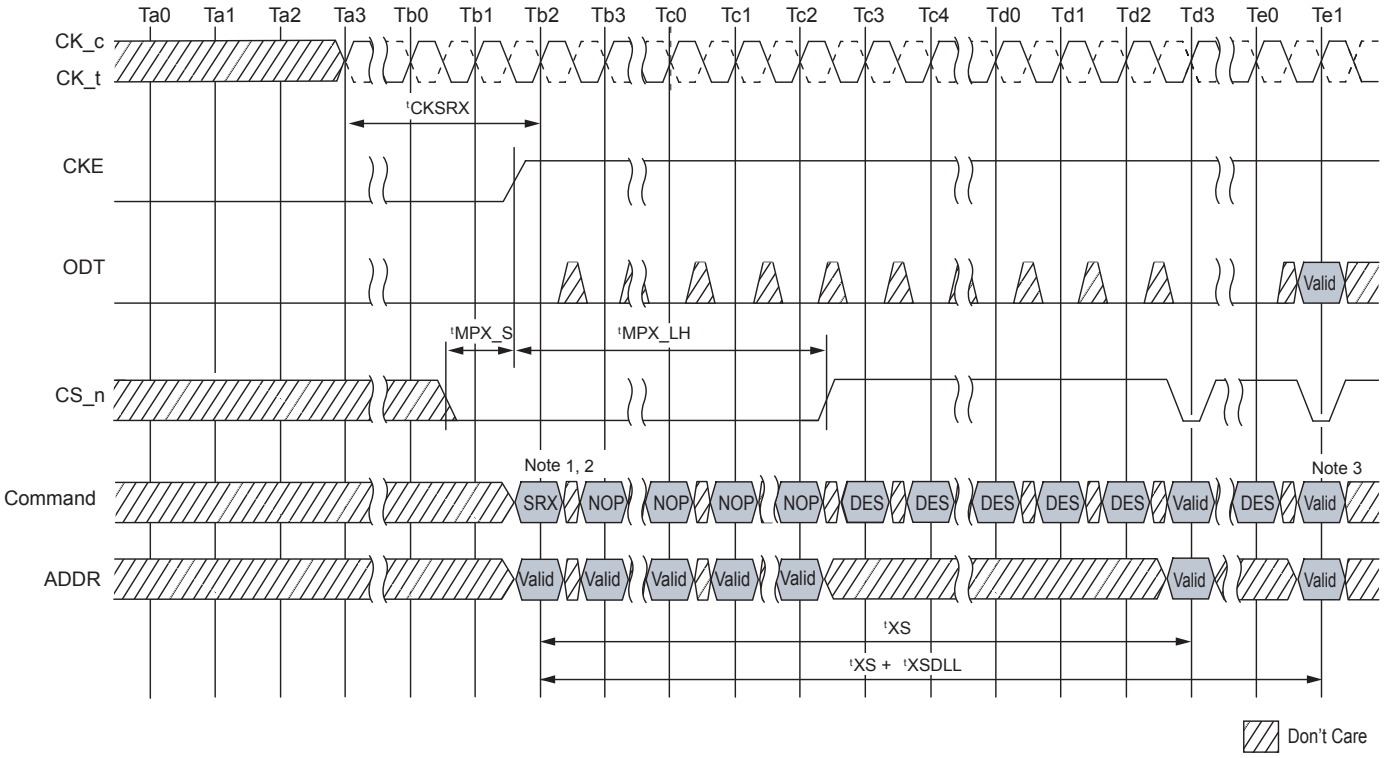
## Self Refresh Exit with NOP Command

Exiting self refresh mode using the NO OPERATION command (NOP) is allowed under a specific system application. This special use of NOP allows for a common command/address bus between active DRAM devices and DRAM(s) in maximum power saving mode. Self refresh mode may exit with NOP commands provided:

- The device entered self refresh mode with CA parity, CAL, and gear-down disabled.
- $^{t}$MPX_S and $^{t}$MPX_LH are satisfied.
- NOP commands are only issued during $^{t}$MPX_LH window.

No other command is allowed during the $^{t}$MPX_LH window after an SELF REFRESH EXIT (SRX) command is issued.

**Figure 82: Self Refresh Exit with NOP Command**



## Power-Down Mode

Power-down is synchronously entered when CKE is registered LOW (along with a DESELECT command). CKE is not allowed to go LOW when the following operations are in progress: MRS command, MPR operations, ZQCAL operations, DLL locking, or READ/WRITE operations. CKE is allowed to go LOW while any other operations, such as ROW ACTIVATION, PRECHARGE or auto pre-charge, or REFRESH, are in progress, but the power-down $I_{DD}$ specification will not be applied until those operations are complete. The timing diagrams that follow illustrate power-down entry and exit.
For the fastest power-down exit timing, the DLL should be in a locked state when power-down is entered. If the DLL is not locked during power-down entry, the DLL must be reset after exiting power-down mode for proper READ operation and synchronous ODT operation. DRAM design provides all AC and DC timing and voltage specification as well as proper DLL operation with any CKE intensive operations as long as the controller complies with DRAM specifications.

During power-down, if all banks are closed after any in-progress commands are completed, the device will be in pre-charge power-down mode; if any bank is open after in-progress commands are completed, the device will be in active power-down mode.

Entering power-down deactivates the input and output buffers, excluding CK, CKE, and RESET_n. In power-down mode, DRAM ODT input buffer deactivation is based on Mode Register 5, bit 5 (MR5[5]). If it is configured to 0b, the ODT input buffer remains on and the ODT input signal must be at valid logic level. If it is configured to 1b, the ODT input buffer is deactivated and the DRAM ODT input signal may be floating and the device does not provide $R_{TT(NOM)}$ termination. Note that the device continues to provide $R_{TT(Park)}$ termination if it is enabled in MR5[8:6]. To protect internal delay on the CKE line to block the input signals, multiple DES commands are needed during the CKE switch off and on cycle(s); this timing period is defined as $^{t}$CPDED. CKE LOW will result in deactivation of command and address receivers after $^{t}$CPDED has expired.

**Table 48: Power-Down Entry Definitions**

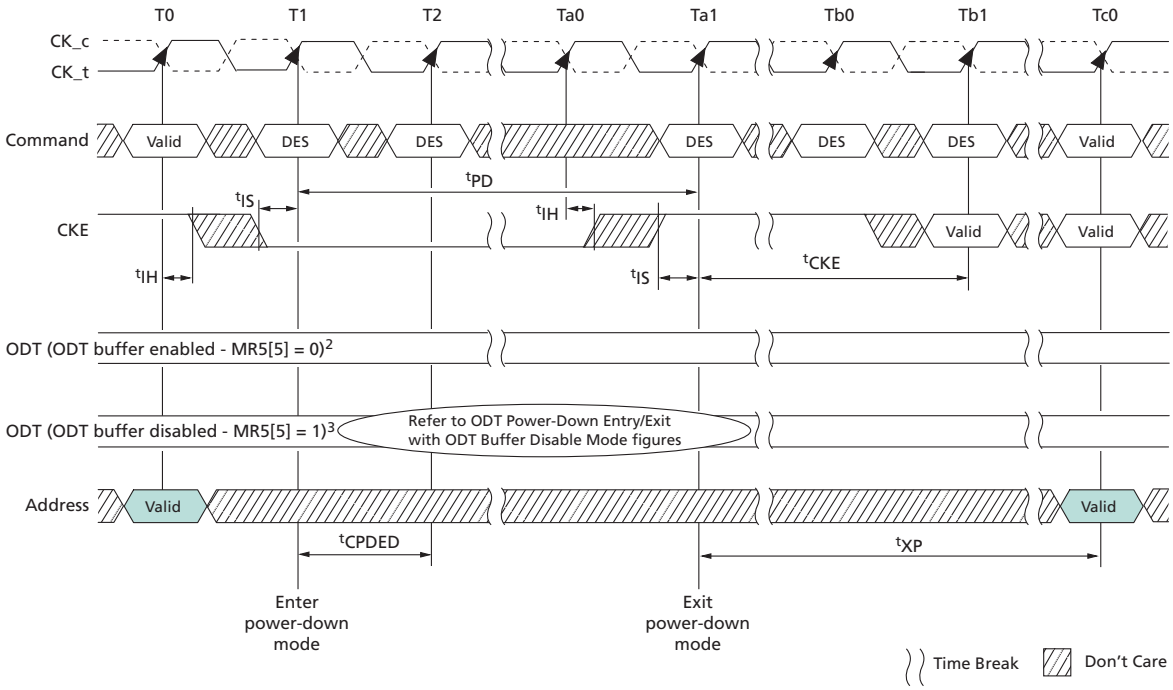
| DRAM Status | DLL | Power-Down Exit | Relevant Parameters |
|---|---|---|---|
| Active (a bank or more open) | On | Fast | $^{t}$XP to any valid command. |
| Precharged (all banks precharged) | On | Fast | $^{t}$XP to any valid command. |

The DLL is kept enabled during precharge power-down or active power-down. In power-down mode, CKE is LOW, RESET_n is HIGH, and a stable clock signal must be maintained at the inputs of the device. ODT should be in a valid state, but all other input signals are "Don't Care." (If RESET_n goes LOW during power-down, the device will be out of power-down mode and in the reset state.) CKE LOW must be maintained until $^{t}$CKE has been satisfied. Power-down duration is limited by 9 × $^{t}$REFI.

The power-down state is synchronously exited when CKE is registered HIGH (along with DES command). CKE HIGH must be maintained until $^{t}$CKE has been satisfied. The ODT input signal must be at a valid level when the device exits from power-down mode,
independent of MR1 bit [10:8] if $R_{TT(NOM)}$ is enabled in the mode register. If $R_{TT(NOM)}$ is disabled, the ODT input signal may remain floating. A valid, executable command can

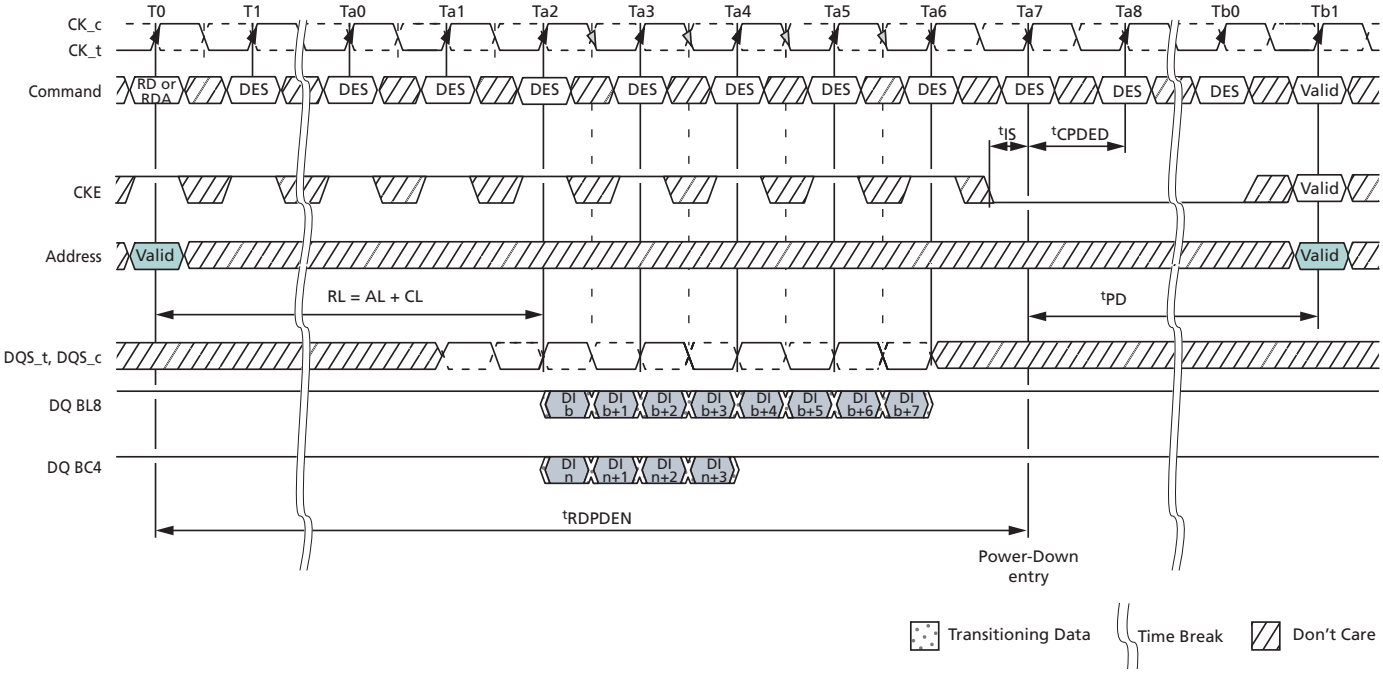
be applied with power-down exit latency, $^{t}$XP, after CKE goes HIGH. Power-down exit latency is defined in the AC Specifications table.

**Figure 83: Active Power-Down Entry and Exit**



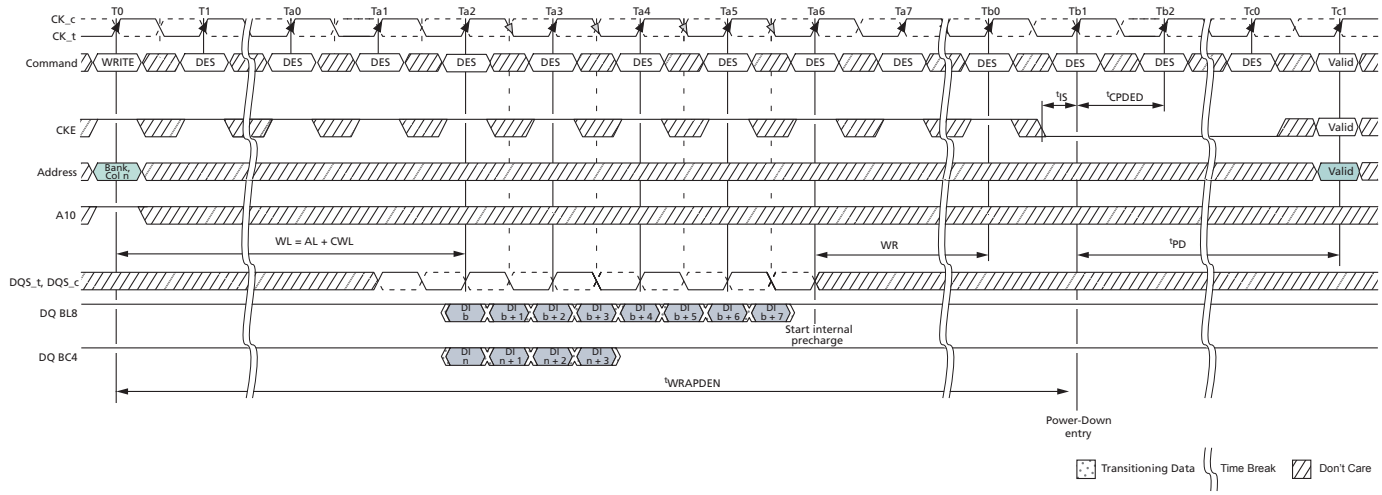

Notes:
1. Valid commands at T0 are ACT, DES, or PRE with one bank remaining open after completion of the PRECHARGE command.
2. ODT pin driven to a valid state; MR5[5] = 0 (normal setting).
3. ODT pin drive/float timing requirements for the ODT input buffer disable option (for additional power savings during active power-down) is described in the section for ODT Input Buffer Disable Mode for Power-Down (page 160); MR5[5] = 1.

**Figure 84: Power-Down Entry After Read and Read with Auto Precharge**



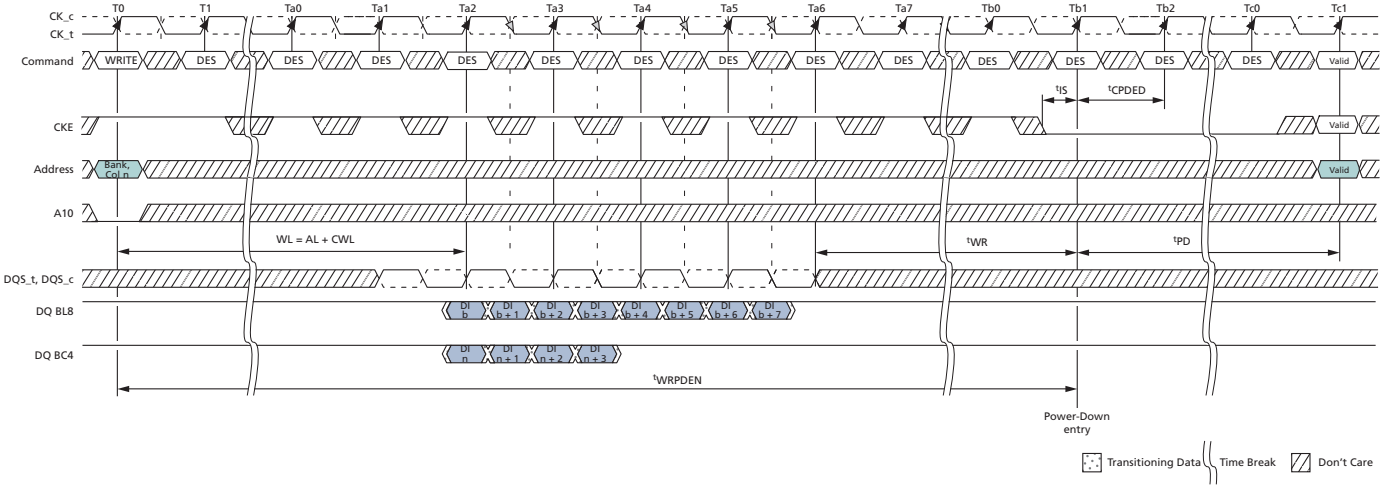

Note: 1. DI n (or b) = data-in from column n (or b).

**Figure 85: Power-Down Entry After Write and Write with Auto Precharge**




Notes: 1. DI n (or b) = data-in from column n (or b).
2. Valid commands at T0 are ACT, DES, or PRE with one bank remaining open after completion of the PRECHARGE command.

**Figure 86: Power-Down Entry After Write**




Note: 1. DI n (or b) = data-in from column n (or b).

**Figure 87: Precharge Power-Down Entry and Exit**

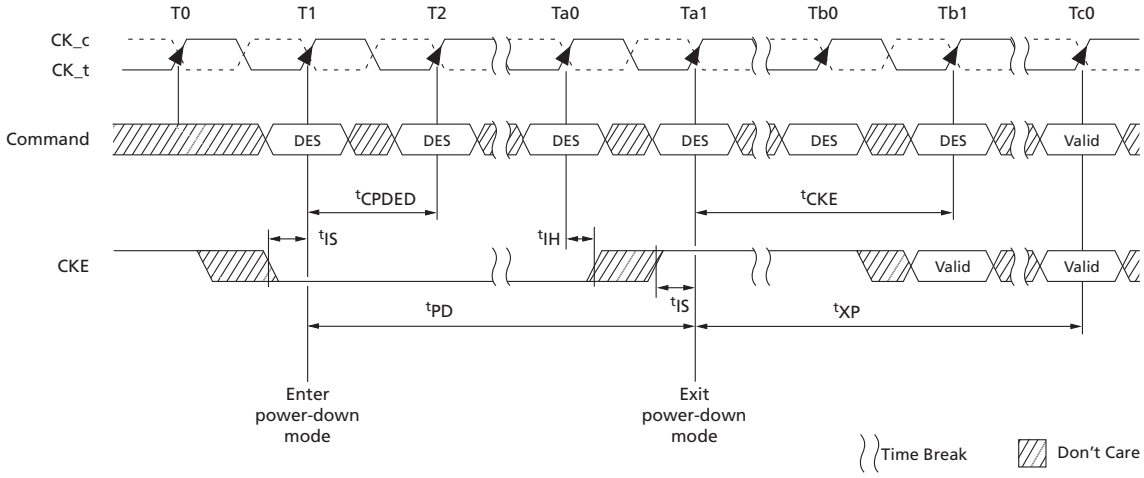


**Figure 88: REFRESH Command to Power-Down Entry**

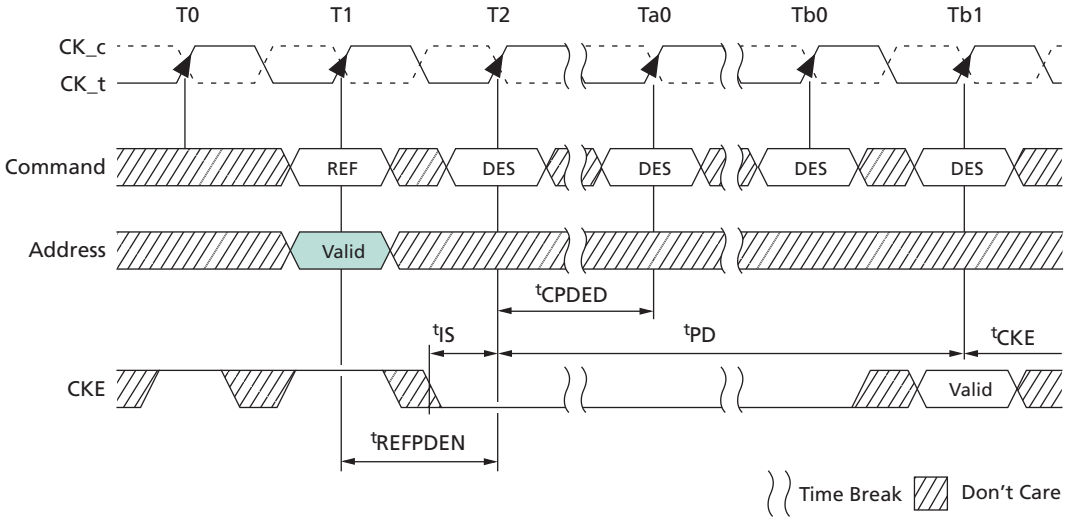



**Figure 89: Active Command to Power-Down Entry**

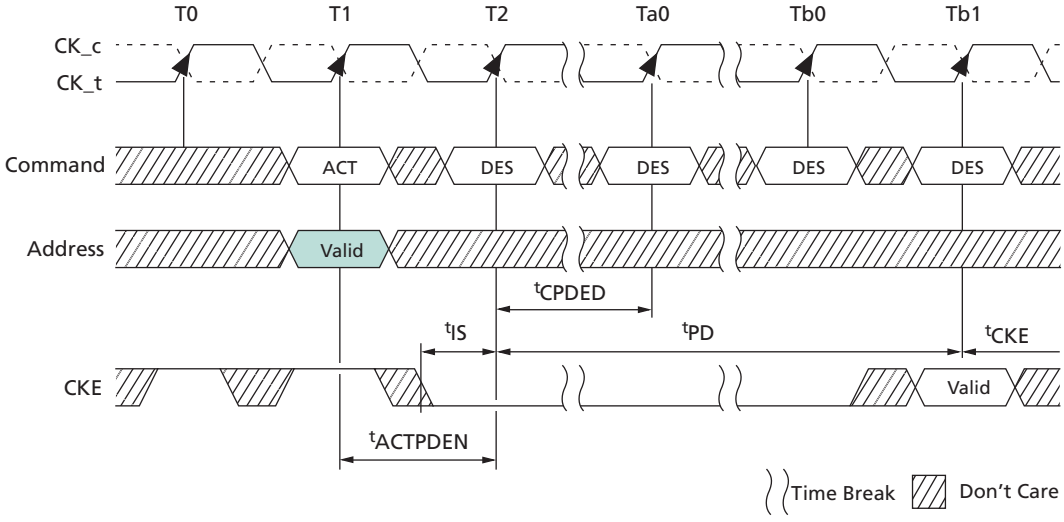


**Figure 90: PRECHARGE/PRECHARGE ALL Command to Power-Down Entry**

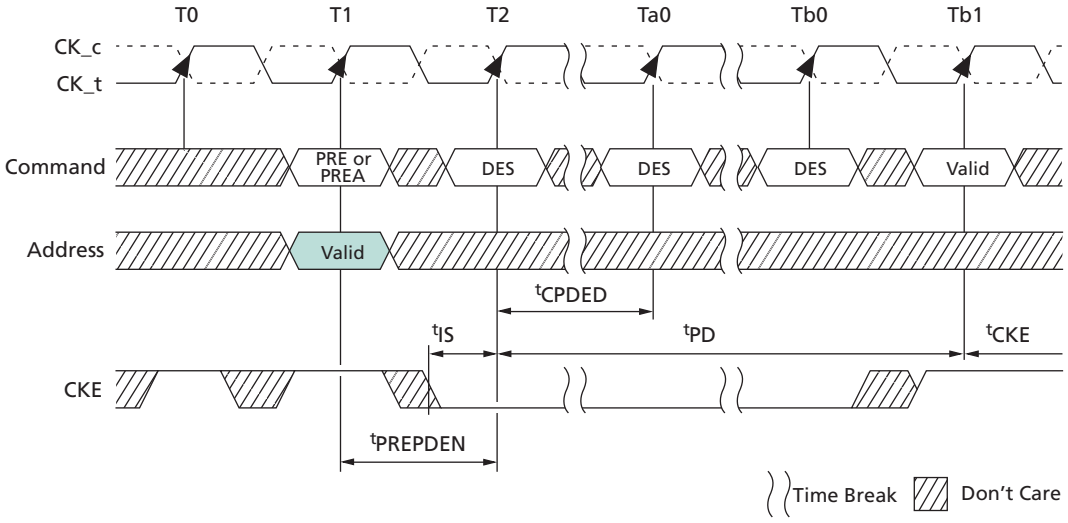
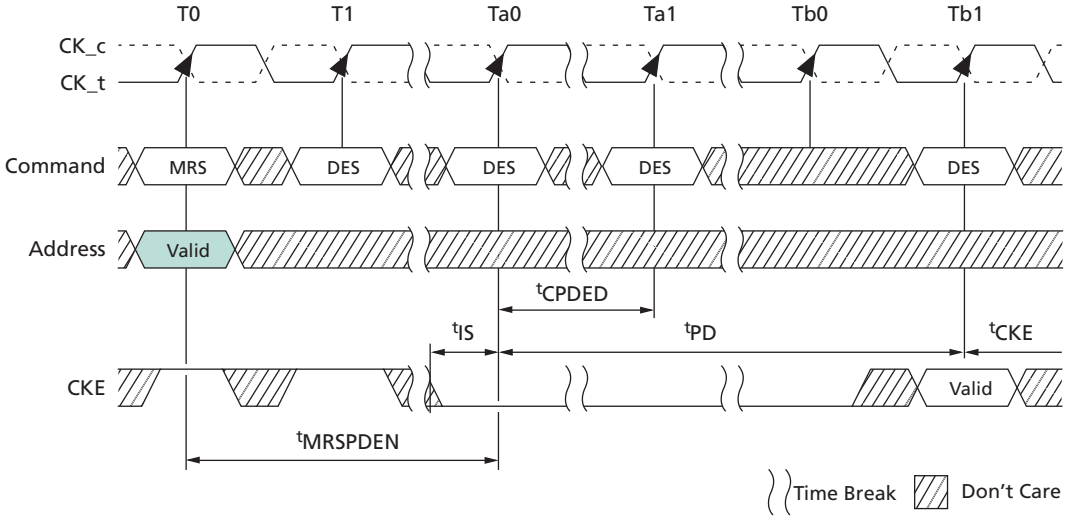


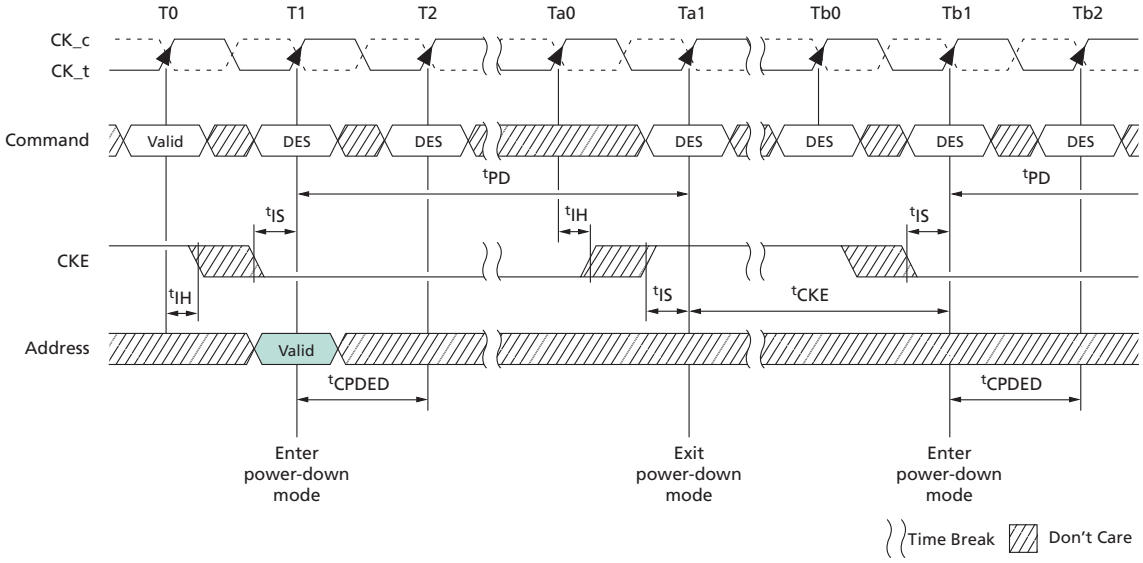

**Figure 91: MRS Command to Power-Down Entry**




## Power-Down Clarifications – Case 1

When CKE is registered LOW for power-down entry, $^{t}$PD (MIN) must be satisfied before CKE can be registered HIGH for power-down exit. The minimum value of parameter $^{t}$PD (MIN) is equal to the minimum value of parameter $^{t}$CKE (MIN) as shown in the Timing Parameters by Speed Bin table. A detailed example of Case 1 follows.

**Figure 92: Power-Down Entry/Exit Clarifications – Case 1**




## Power-Down Entry, Exit Timing with CAL

Command/Address latency is used and additional timing restrictions are required when entering power-down, as noted in the following figures.

**Figure 93: Active Power-Down Entry and Exit Timing with CAL**

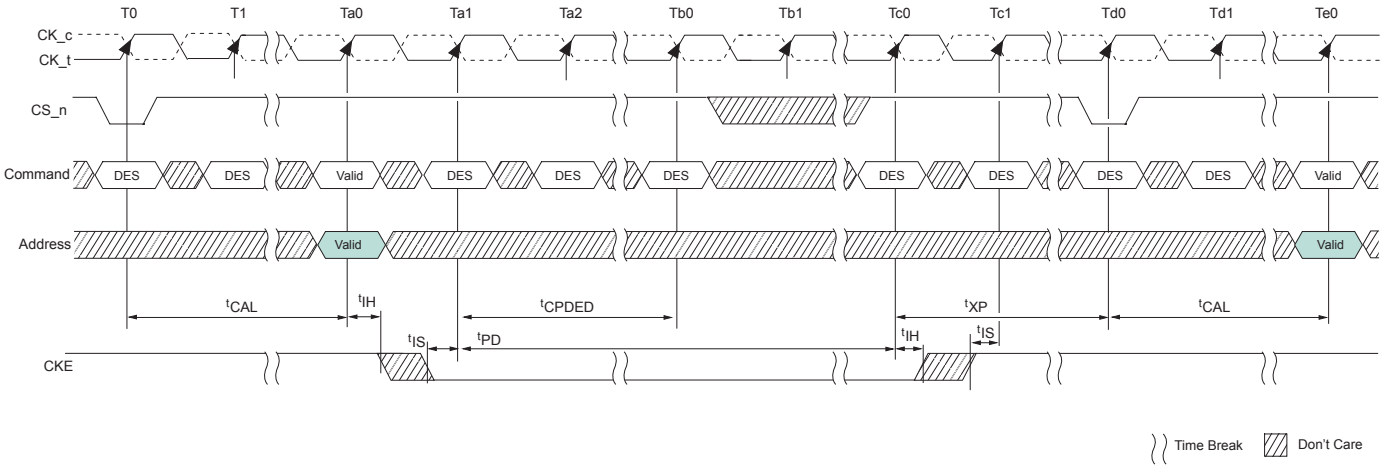
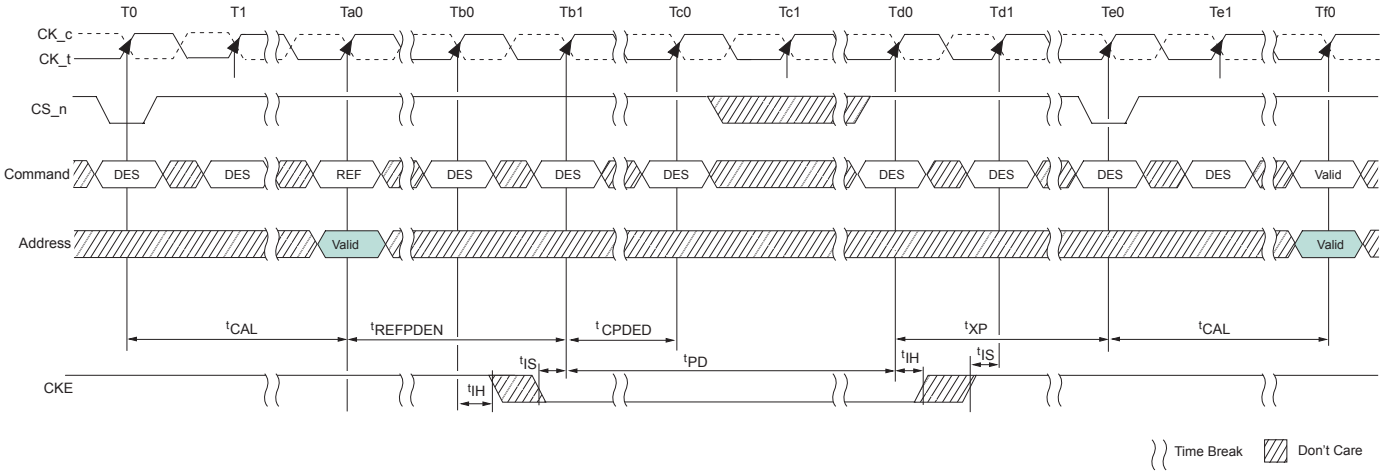


**Figure 94: REFRESH Command to Power-Down Entry with CAL**



## ODT Input Buffer Disable Mode for Power-Down

DRAM does not provide $R_{TT\_NOM}$ termination during power-down when ODT input buffer deactivation mode is enabled in MR5 bit A5.

To account for DRAM internal delay on CKE line to disable the ODT buffer and block the sampled output, the host controller must continuously drive ODT to either low or high when entering power down (from $^{t}$DODTLoff+1 prior to CKE low till $^{t}$CPDED after CKE low).

The ODT signal is allowed to float after $^{t}$CPDEDmin has expired. In this mode, $R_{TT\_NOM}$ termination corresponding to sampled ODT at the input when CKE is registered low (and $^{t}$ANPD before that) may be either $R_{TT\_NOM}$ or $R_{TT\_PARK}$. $^{t}$ANPD is equal to (WL-1) and is counted backwards from PDE.

**Figure 95: ODT Power-Down Entry with ODT Buffer Disable Mode**

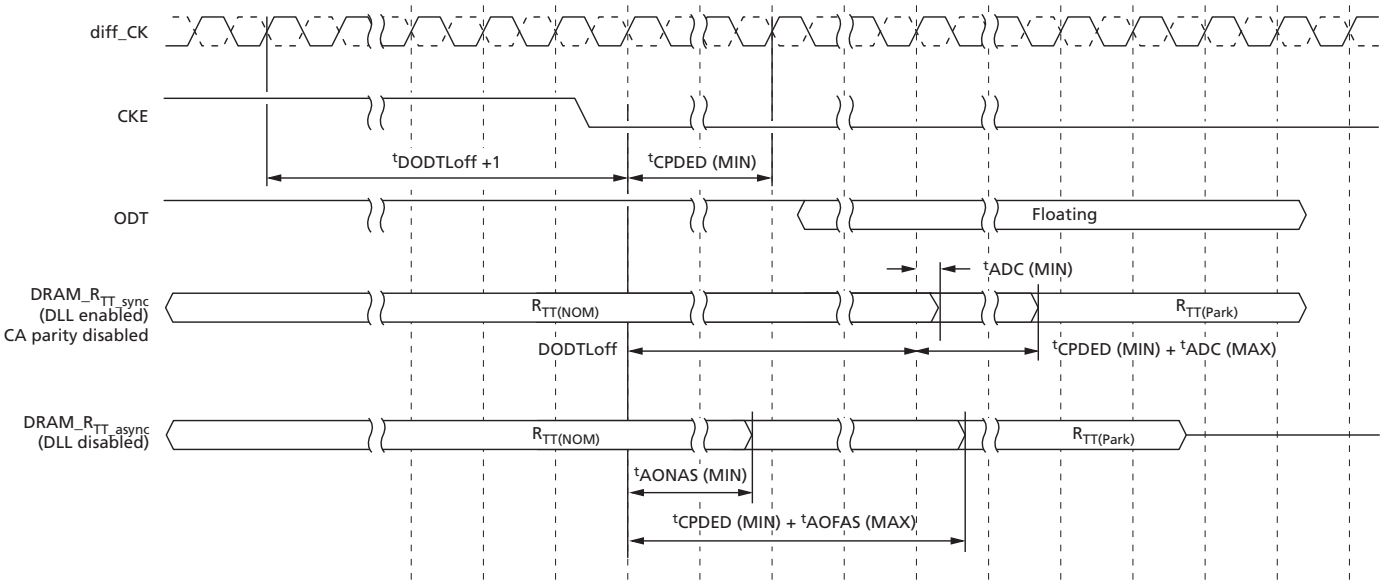
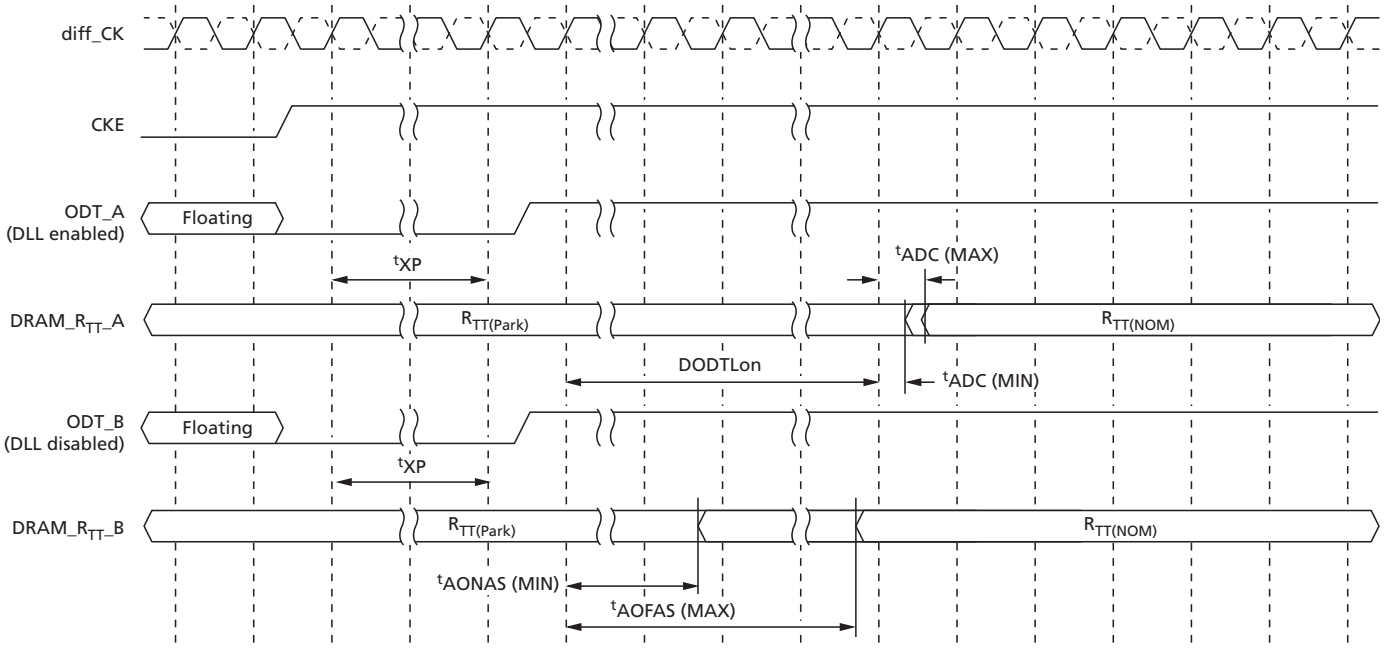


**Figure 96: ODT Power-Down Exit with ODT Buffer Disable Mode**

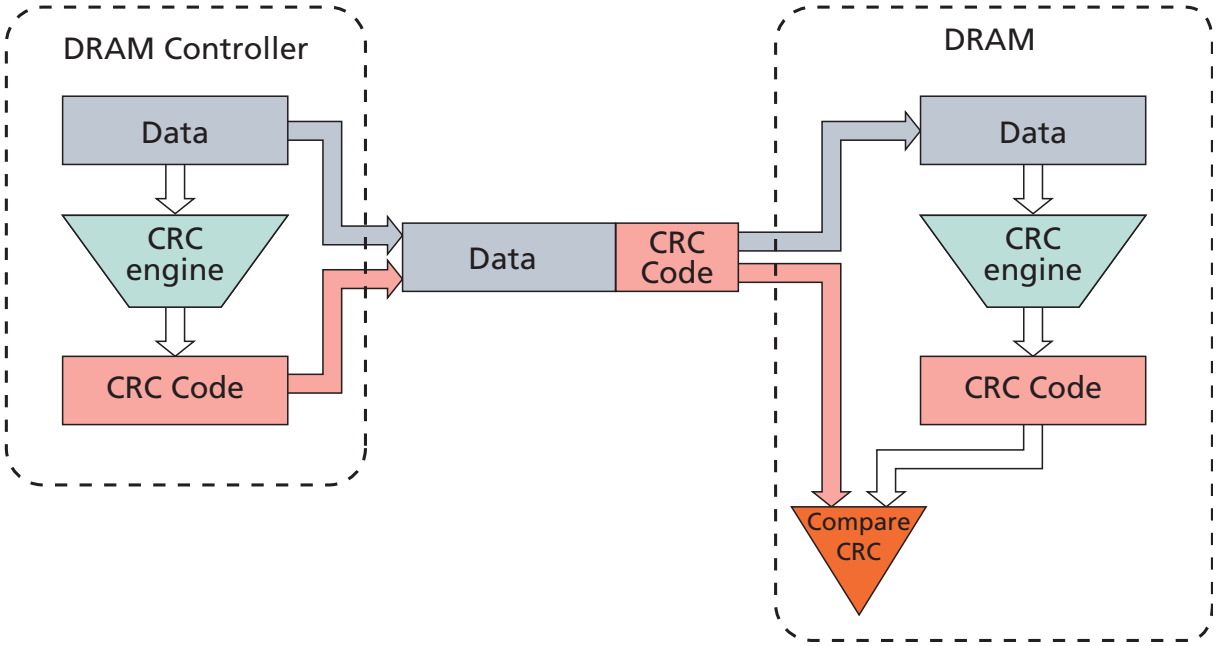


# CRC Write Data Feature

## CRC Write Data

The CRC write data feature takes the CRC generated data from the DRAM controller and compares it to the internally CRC generated data and determines whether the two match (no CRC error) or do not match (CRC error).

**Figure 197: CRC Write Data Operation**




## WRITE CRC DATA Operation

A DRAM controller generates a CRC checksum using a 72-bit CRC tree and forms the write data frames, as shown in the following CRC data mapping tables for the x16 configurations. A x16 device has two identical CRC trees each, one for the lower byte and one for the upper byte, with 64 input data bits used by each, and the remaining upper 8 bits on each byte dependant upon whether DM_n/DBI_n is used (1s are sent when not used). For a x16 DRAMs, the DRAM memory controller must send 1s in transfer 9 location whether or not DM_n/DBI_n is used.

The DRAM checks for an error in a received code word D[71:0] by comparing the received checksum against the computed checksum and reports errors using the ALERT_n signal if there is a mismatch. The DRAM can write data to the DRAM core without waiting for the CRC check for full writes when DM is disabled. If bad data is written to the DRAM core, the DRAM memory controller will try to overwrite the bad data with good data; this means the DRAM controller is responsible for data coherency when DM is disabled. However, in the case where both CRC and DM are enabled via

MRS (that is, persistent mode), the DRAM will not write bad data to the core when a CRC error is detected.

## DBI_n and CRC Both Enabled

The DRAM computes the CRC for received written data D[71:0]. Data is not inverted back based on DBI before it is used for computing CRC. The data is inverted back based on DBI before it is written to the DRAM core.

## DM_n and CRC Both Enabled

When both DM and write CRC are enabled in the DRAM mode register, the DRAM calculates CRC before sending the write data into the array. If there is a CRC error, the DRAM blocks the WRITE operation and discards the data. If a CRC error is encountered from a WRITE with auto precharge (WRA), the DRAM will not block the precharge. The *Nonconsecutive WRITE (BL8/BC4-OTF) with 2tCK Preamble and Write CRC in Same or Different Bank Group* and the *WRITE (BL8/BC4-OTF/Fixed) with 1tCK Preamble and Write CRC in Same or Different BankGroup* figures in the WRITE Operation section show timing differences when DM is enabled.

## DM_n and DBI_n Conflict During Writes with CRC Enabled

Both write DBI_n and DM_n can not be enabled at the same time; read DBI_n and DM_n can be enabled at the same time.

## CRC and Write Preamble Restrictions

When write CRC is enabled:

- And 1tCK WRITE preamble mode is enabled, a tCCD_S or tCCD_L of 4 clocks is not allowed.
- And 2tCK WRITE preamble mode is enabled, a tCCD_S or tCCD_L of 6 clocks is not allowed.

## CRC Simultaneous Operation Restrictions

When write CRC is enabled, neither MPR writes nor per-DRAM mode is allowed.

## CRC Polynomial

The CRC polynomial used by DDR4 is the ATM-8 HEC, $X^8 + X^2 + X^1 + 1$.

A combinatorial logic block implementation of this 8-bit CRC for 72 bits of data includes 272 two-input XOR gates contained in eight 6-XOR-gate-deep trees.

The CRC polynomial and combinatorial logic used by DDR4 is the same as used on GDDR5.

The error coverage from the DDR4 polynomial used is shown in the following table.

**Table 49: CRC Error Detection Coverage**

| Error Type | Detection Capability |
|---|---|
| Random single-bit errors | 100% |
| Random double-bit errors | 100% |

**Table 49: CRC Error Detection Coverage (Continued)**

| Error Type | Detection Capability |
|---|---|
| Random odd count errors | 100% |
| Random multibit UI vertical column error detection excluding DBI bits | 100% |

## CRC Combinatorial Logic Equations

```
module CRC8_D72;
// polynomial: (0 1 2 8)
// data width: 72
// convention: the first serial data bit is D[71]
//initial condition all 0 implied
// "^" = XOR
function [7:0]
nextCRC8_D72;
input [71:0] Data;
input [71:0] D;
reg [7:0] CRC;
begin
D = Data;
```

**CRC[0]** =
D[69]^D[68]^D[67]^D[66]^D[64]^D[63]^D[60]^D[56]^D[54]^D[53]^D[52]^D[50]^D[49]^D[48]^D[45]^D[43]^D[40]^D[39]^D[35]^D[34]^D[31]^D[30]^D[28]^D[23]^D[21]^D[19]^D[18]^D[16]^D[14]^D[12]^D[8]^D[7]^D[6]^D[0];

**CRC[1]** =
D[70]^D[66]^D[65]^D[63]^D[61]^D[60]^D[57]^D[56]^D[55]^D[52]^D[51]^D[48]^D[46]^D[45]^D[44]^D[43]^D[41]^D[39]^D[36]^D[34]^D[32]^D[30]^D[29]^D[28]^D[24]^D[23]^D[22]^D[21]^D[20]^D[18]^D[17]^D[16]^D[15]^D[14]^D[13]^D[12]^D[9]^D[6]^D[1]^D[0];

**CRC[2]** =
D[71]^D[69]^D[68]^D[63]^D[62]^D[61]^D[60]^D[58]^D[57]^D[54]^D[50]^D[48]^D[47]^D[46]^D[44]^D[43]^D[42]^D[39]^D[37]^D[34]^D[33]^D[29]^D[28]^D[25]^D[24]^D[22]^D[17]^D[15]^D[13]^D[12]^D[10]^D[8]^D[6]^D[2]^D[1]^D[0];

**CRC[3]** =
D[70]^D[69]^D[64]^D[63]^D[62]^D[61]^D[59]^D[58]^D[55]^D[51]^D[49]^D[48]^D[47]^D[45]^D[44]^D[43]^D[40]^D[38]^D[35]^D[34]^D[30]^D[29]^D[26]^D[25]^D[23]^D[18]^D[16]^D[14]^D[13]^D[11]^D[9]^D[7]^D[3]^D[2]^D[1];

**CRC[4]** =
D[71]^D[70]^D[65]^D[64]^D[63]^D[62]^D[60]^D[59]^D[56]^D[52]^D[50]^D[49]^D[48]^D[46]^D[45]^D[44]^D[41]^D[39]^D[36]^D[35]^D[31]^D[30]^D[27]^D[26]^D[24]^D[19]^D[17]^D[15]^D[14]^D[12]^D[10]^D[8]^D[4]^D[3]^D[2];

**CRC[5]** =
D[71]^D[66]^D[65]^D[64]^D[63]^D[61]^D[60]^D[57]^D[53]^D[51]^D[50]^D[49]^D[47]^D[46]^D[45]^D[42]^D[40]^D[37]^D[36]^D[32]^D[31]^D[28]^D[27]^D[25]^D[20]^D[18]^D[16]^D[15]^D[13]^D[11]^D[9]^D[5]^D[4]^D[3];

CRC[6] =
D[67]^D[66]^D[65]^D[64]^D[62]^D[61]^D[58]^D[54]^D[52]^D[51]^D[50]^D[48]^D[47]^D[46]^D[43]^D[41]^D[38]^D[37]^D[33]^D[32]^D[29]^D[28]^D[26]^D[21]^D[19]^D[17]^D[16]^D[14]^D[12]^D[10]^D[6]^D[5]^D[4];

CRC[7] =
D[68]^D[67]^D[66]^D[65]^D[63]^D[62]^D[59]^D[55]^D[53]^D[52]^D[51]^D[49]^D[48]^D[47]^D[44]^D[42]^D[39]^D[38]^D[34]^D[33]^D[30]^D[29]^D[27]^D[22]^D[20]^D[18]^D[17]^D[15]^D[13]^D[11]^D[7]^D[6]^D[5];

nextCRC8_D72 = CRC;

## Burst Ordering for BL8

DDR4 supports fixed WRITE burst ordering [A2:A1:A0 = 0:0:0] when write CRC is enabled in BL8 (fixed).

## CRC Data Bit Mapping

**Table 50: CRC Data Mapping for x16 Devices, BL8**

| Function | Transfer | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| DQ0 | D0 | D1 | D2 | D3 | D4 | D5 | D6 | D7 | CRC0 | 1 |
| DQ1 | D8 | D9 | D10 | D11 | D12 | D13 | D14 | D15 | CRC1 | 1 |
| DQ2 | D16 | D17 | D18 | D19 | D20 | D21 | D22 | D23 | CRC2 | 1 |
| DQ3 | D24 | D25 | D26 | D27 | D28 | D29 | D30 | D31 | CRC3 | 1 |
| DQ4 | D32 | D33 | D34 | D35 | D36 | D37 | D38 | D39 | CRC4 | 1 |
| DQ5 | D40 | D41 | D42 | D43 | D44 | D45 | D46 | D47 | CRC5 | 1 |
| DQ6 | D48 | D49 | D50 | D51 | D52 | D53 | D54 | D55 | CRC6 | 1 |
| DQ7 | D56 | D57 | D58 | D59 | D60 | D61 | D62 | D63 | CRC7 | 1 |
| LDM_n/ LDBI_n | D64 | D65 | D66 | D67 | D68 | D69 | D70 | D71 | 1 | 1 |
| DQ8 | D72 | D73 | D74 | D75 | D76 | D77 | D78 | D79 | CRC8 | 1 |
| DQ9 | D80 | D81 | D82 | D83 | D84 | D85 | D86 | D87 | CRC9 | 1 |
| DQ10 | D88 | D89 | D90 | D91 | D92 | D93 | D94 | D95 | CRC10 | 1 |
| DQ11 | D96 | D97 | D98 | D99 | D100 | D101 | D102 | D103 | CRC11 | 1 |
| DQ12 | D104 | D105 | D106 | D107 | D108 | D109 | D110 | D111 | CRC12 | 1 |
| DQ13 | D112 | D113 | D114 | D115 | D116 | D117 | D118 | D119 | CRC13 | 1 |
| DQ14 | D120 | D121 | D122 | D123 | D124 | D125 | D126 | D127 | CRC14 | 1 |
| DQ15 | D128 | D129 | D130 | D131 | D132 | D133 | D134 | D135 | CRC15 | 1 |
| UDM_n/ UDBI_n | D136 | D137 | D138 | D139 | D140 | D141 | D142 | D143 | 1 | 1 |

A x16 device is treated as two x8 devices; a x16 device will have two identical CRC trees implemented. CRC[7:0] covers data bits D[71:0], and CRC[15:8] covers data bits D[143:72].

## CRC Enabled With BC4

If CRC and BC4 are both enabled, then address bit A2 is used to transfer critical data first for BC4 writes.

## CRC with BC4 Data Bit Mapping

There are two identical CRC trees for x16 devices, each have CRC tree inputs of 36 bits.

When A2 = 0, input bits D[67:64] are used if DBI_n or DM_n functions are enabled; if DBI_n and DM_n are disabled, then D[67:64] are 1s. The input bits D[139:136] are used if DBI_n or DM_n functions are enabled; if DBI_n and DM_n are disabled, then D[139:136] are 1s.

When A2 = 1, data bits D[7:4] are used as inputs for D[3:0], D[15:12] are used as inputs for D[11:8], and so forth, for the CRC tree. Input bits D[71:68] are used if DBI_n or DM_n functions are enabled; if DBI_n and DM_n are disabled, then D[71:68] are 1s. The input bits D[143:140] are used if DBI_n or DM_n functions are enabled; if DBI_n and DM_n are disabled, then D[143:140] are 1s.

**Table 51: CRC Data Mapping for x16 Devices, BC4**

| Function | Transfer | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| **A2 = 0** | | | | | | | | | | |
| DQ0 | D0 | D1 | D2 | D3 | 1 | 1 | 1 | 1 | CRC0 | 1 |
| DQ1 | D8 | D9 | D10 | D11 | 1 | 1 | 1 | 1 | CRC1 | 1 |
| DQ2 | D16 | D17 | D18 | D19 | 1 | 1 | 1 | 1 | CRC2 | 1 |
| DQ3 | D24 | D25 | D26 | D27 | 1 | 1 | 1 | 1 | CRC3 | 1 |
| DQ4 | D32 | D33 | D34 | D35 | 1 | 1 | 1 | 1 | CRC4 | 1 |
| DQ5 | D40 | D41 | D42 | D43 | 1 | 1 | 1 | 1 | CRC5 | 1 |
| DQ6 | D48 | D49 | D50 | D51 | 1 | 1 | 1 | 1 | CRC6 | 1 |
| DQ7 | D56 | D57 | D58 | D59 | 1 | 1 | 1 | 1 | CRC7 | 1 |
| LDM_n/LDBI_n | D64 | D65 | D66 | D67 | 1 | 1 | 1 | 1 | 1 | 1 |
| DQ8 | D72 | D73 | D74 | D75 | 1 | 1 | 1 | 1 | CRC8 | 1 |
| DQ9 | D80 | D81 | D82 | D83 | 1 | 1 | 1 | 1 | CRC9 | 1 |
| DQ10 | D88 | D89 | D90 | D91 | 1 | 1 | 1 | 1 | CRC10 | 1 |
| DQ11 | D96 | D97 | D98 | D99 | 1 | 1 | 1 | 1 | CRC11 | 1 |
| DQ12 | D104 | D105 | D106 | D107 | 1 | 1 | 1 | 1 | CRC12 | 1 |
| DQ13 | D112 | D113 | D114 | D115 | 1 | 1 | 1 | 1 | CRC13 | 1 |
| DQ14 | D120 | D121 | D122 | D123 | 1 | 1 | 1 | 1 | CRC14 | 1 |
| DQ15 | D128 | D129 | D130 | D131 | 1 | 1 | 1 | 1 | CRC15 | 1 |
| UDM_n/UDBI_n | D136 | D137 | D138 | D139 | 1 | 1 | 1 | 1 | 1 | 1 |
| **A2 = 1** | | | | | | | | | | |
| DQ0 | D4 | D5 | D6 | D7 | 1 | 1 | 1 | 1 | CRC0 | 1 |
| DQ1 | D12 | D13 | D14 | D15 | 1 | 1 | 1 | 1 | CRC1 | 1 |
| DQ2 | D20 | D21 | D22 | D23 | 1 | 1 | 1 | 1 | CRC2 | 1 |
| DQ3 | D28 | D29 | D30 | D31 | 1 | 1 | 1 | 1 | CRC3 | 1 |
| DQ4 | D36 | D37 | D38 | D39 | 1 | 1 | 1 | 1 | CRC4 | 1 |
| DQ5 | D44 | D45 | D46 | D47 | 1 | 1 | 1 | 1 | CRC5 | 1 |
| DQ6 | D52 | D53 | D54 | D55 | 1 | 1 | 1 | 1 | CRC6 | 1 |
| DQ7 | D60 | D61 | D62 | D63 | 1 | 1 | 1 | 1 | CRC7 | 1 |
| LDM_n/LDBI_n | D68 | D69 | D70 | D71 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 51: CRC Data Mapping for x16 Devices, BC4 (Continued)**

| Function | Transfer | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| DQ8 | D76 | D77 | D78 | D79 | 1 | 1 | 1 | 1 | CRC8 | 1 |
| DQ9 | D84 | D85 | D86 | D87 | 1 | 1 | 1 | 1 | CRC9 | 1 |
| DQ10 | D92 | D93 | D94 | D95 | 1 | 1 | 1 | 1 | CRC10 | 1 |
| DQ11 | D100 | D101 | D102 | D103 | 1 | 1 | 1 | 1 | CRC11 | 1 |
| DQ12 | D108 | D109 | D110 | D111 | 1 | 1 | 1 | 1 | CRC12 | 1 |
| DQ13 | D116 | D117 | D118 | D119 | 1 | 1 | 1 | 1 | CRC13 | 1 |
| DQ14 | D124 | D125 | D126 | D127 | 1 | 1 | 1 | 1 | CRC14 | 1 |
| DQ15 | D132 | D133 | D134 | D135 | 1 | 1 | 1 | 1 | CRC15 | 1 |
| UDM_n/UDBI_n | D140 | D141 | D142 | D143 | 1 | 1 | 1 | 1 | 1 | 1 |

## CRC Equations for x16 Device in BC4 Mode with A2 = 0 and A2 = 1

The following example is of a CRC tree when x8 is used in BC4 mode (x4 and x16 CRC trees have similar differences).

**CRC[0], A2=0** =
1^1^D[67]^D[66]^D[64]^1^1^D[56]^1^1^1^D[50]^D[49]^D[48]^1^D[43]^D[40]^1^D[35]^D[34]^1^1^1^1^1^D[19]^D[18]^D[16]^1^1^D[8] ^1^1^ D[0] ;
**CRC[0], A2=1** =
1^1^D[71]^D[70]^D[68]^1^1^D[60]^1^1^1^D[54]^D[53]^D[52]^1^D[47]^D[44]^1^D[39]^D[38]^1^1^1^1^1^D[23]^D[22]^D[20]^1^1^D[12]^1^1^D[4] ;

**CRC[1], A2=0** =
1^D[66]^D[65]^1^1^1^D[57]^D[56]^1^1^D[51]^D[48]^1^1^1^D[43]^D[41]^1^1^D[34]^D[32]^1^1^1^D[24]^1^1^1^1^D[18]^D[17]^D[16]^1^1^1^1^D[9] ^1^ D[1]^D[0];
**CRC[1], A2=1** =
1^D[70]^D[69]^1^1^1^D[61]^D[60]^1^1^D[55]^D[52]^1^1^1^D[47]^D[45]^1^1^D[38]^D[36]^1^1^1^D[28]^1^1^1^1^D[22]^D[21]^D[20]^1^1^1^1^D[13]^1^D[5]^D[4];

**CRC[2], A2=0** =
1^1^1^1^1^1^1^D[58]^D[57]^1^D[50]^D[48]^1^1^1^D[43]^D[42]^1^1^D[34]^D[33]^1^1^D[25]^D[24]^1^D[17]^1^1^1^D[10]^D[8] ^1^D[2]^D[1]^D[0];
**CRC[2], A2=1** =
1^1^1^1^1^1^1^D[62]^D[61]^1^D[54]^D[52]^1^1^1^D[47]^D[46]^1^1^D[38]^D[37]^1^1^D[29]^D[28]^1^D[21]^1^1^1^D[14]^D12]^1^D[6]^D[5]^D[4];

**CRC[3], A2=0** =
1^1^D[64]^1^1^1^D[59]^D[58]^1^D[51]^D[49]^D[48]^1^1^1^D[43]^D[40]^1^D[35]^D[34]^1^1^D[26]^D[25]^1^D[18]^D[16]^1^1^D[11]^D[9] ^1^D[3]^D[2]^D[1];
**CRC[3], A2=1** =
1^1^D[68]^1^1^1^D[63]^D[62]^1^D[55]^D[53]^D[52]^1^1^1^D[47]^D[44]^1^D[39]^D[38]^1^1^D[30]^D[29]^1^D[22]^D[20]^1^1^D[15]^D[13]^1^D[7]^D[6]^D[5];

**CRC[4], A2=0** =
1^1^D[65]^D[64]^1^1^1^D[59]^D[56]^1^D[50]^D[49]^D[48]^1^1^1^D[41]^1^1^D[35]^1^1^D[27]^D[26]^D[24]^D[19]^D[17]^1^1^1^D[10]^D[8] ^1^D[3]^D[2];
**CRC[4], A2=1** =
1^1^D[69]^D[68]^1^1^1^D[63]^D[60]^1^D[54]^D[53]^D[52]^1^1^1^D[45]^1^1^D[39]^1^1^D[31]^D[30]^D[28]^D[23]^D[21]^1^1^1^D[14]^D[12]^1^D[7]^D[6];

**CRC[5], A2=0** =
1^D[66]^D[65]^D[64]^1^1^1^D[57]^1^D[51]^D[50]^D[49]^1^1^1^D[42]^D[40]^1^1^D[32]^1^1^D[27]^D[25]^1^D[18]^D[16]^1^1^D[11]^D[9] ^1^1^D[3];
**CRC[5], A2=1** =
1^D[70]^D[69]^D[68]^1^1^1^D[61]^1^D[55]^D[54]^D[53]^1^1^1^D[46]^D[44]^1^1^D[36]^1^1^D[31]^D[29]^1^D[22]^D[20]^1^1^D[15]^D[13]^1^1^D[7];

**CRC[6], A2=0** =
D[67]^D[66]^D[65]^D[64]^1^1^D[58]^1^1^D[51]^D[50]^D[48]^1^1^D[43]^D[41]^1^1^D[33]^D[32]^1^1^D[26]^1^D[19]^D[17]^D[16]^1^1^D[10]^1^1^1;
**CRC[6], A2=1** =
D[71]^D[70]^D[69]^D[68]^1^1^D[62]^1^1^D[55]^D[54]^D[52]^1^1^D[47]^D[45]^1^1^D[37]^D[36]^1^1^D[30]^1^D[23]^D[21]^D[20]^1^1^D[14]^1^1^1;

**CRC[7], A2=0** =
1^D[67]^D[66]^D[65]^1^1^D[59]^1^1^1^D[51]^D[49]^D[48]^1^1^D[42]^1^1^D[34]^D[33]^1^1^D[27]^1^1^D[18]^D[17]^1^1^D[11]^1^1^1;
**CRC[7], A2=1** =
1^D[71]^D[70]^D[69]^1^1^D[63]^1^1^1^D[55]^D[53]^D[52]^1^1^D[46]^1^1^D[38]^D[37]^1^1^D[31]^1^1^D[22]^D[21]^1^1^D[15]^1^1^1;

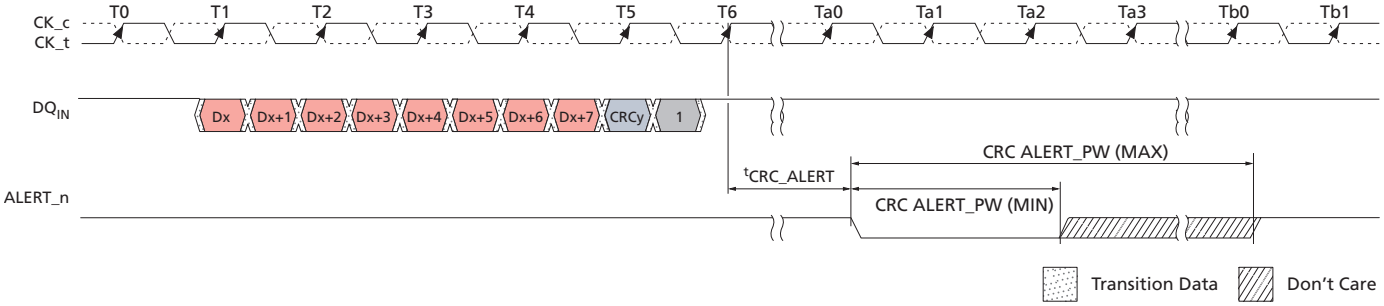
## CRC Error Handling

The CRC error mechanism shares the same ALERT_n signal as CA parity for reporting write errors to the DRAM. The controller has two ways to distinguish between CRC

errors and CA parity errors: 1) Read DRAM mode/MPR registers, and 2) Measure time ALERT_n is LOW. To speed up recovery for CRC errors, CRC errors are only sent back as a "short" pulse; the maximum pulse width is roughly ten clocks (unlike CA parity where ALERT_n is LOW longer than 45 clocks). The ALERT_n LOW could be longer than the maximum limit at the controller if there are multiple CRC errors as the ALERT_n signals are connected by a daisy chain bus. The latency to ALERT_n signal is defined as $^{t}$CRC_ALERT in the following figure.

The DRAM will set the error status bit located at MR5[3] to a 1 upon detecting a CRC error, which will subsequently set the CRC error status flag in the MPR error log HIGH (MPR Page1, MPR3[7]). The CRC error status bit (and CRC error status flag) remains set at 1 until the DRAM controller clears the CRC error status bit using an MRS command to set MR5[3] to a 0. The DRAM controller, upon seeing an error as a pulse width, will retry the write transactions. The controller should consider the worst-case delay for ALERT_n (during initialization) and backup the transactions accordingly. The DRAM controller may also be made more intelligent and correlate the write CRC error to a specific rank or a transaction.

**Figure 98: CRC Error Reporting**

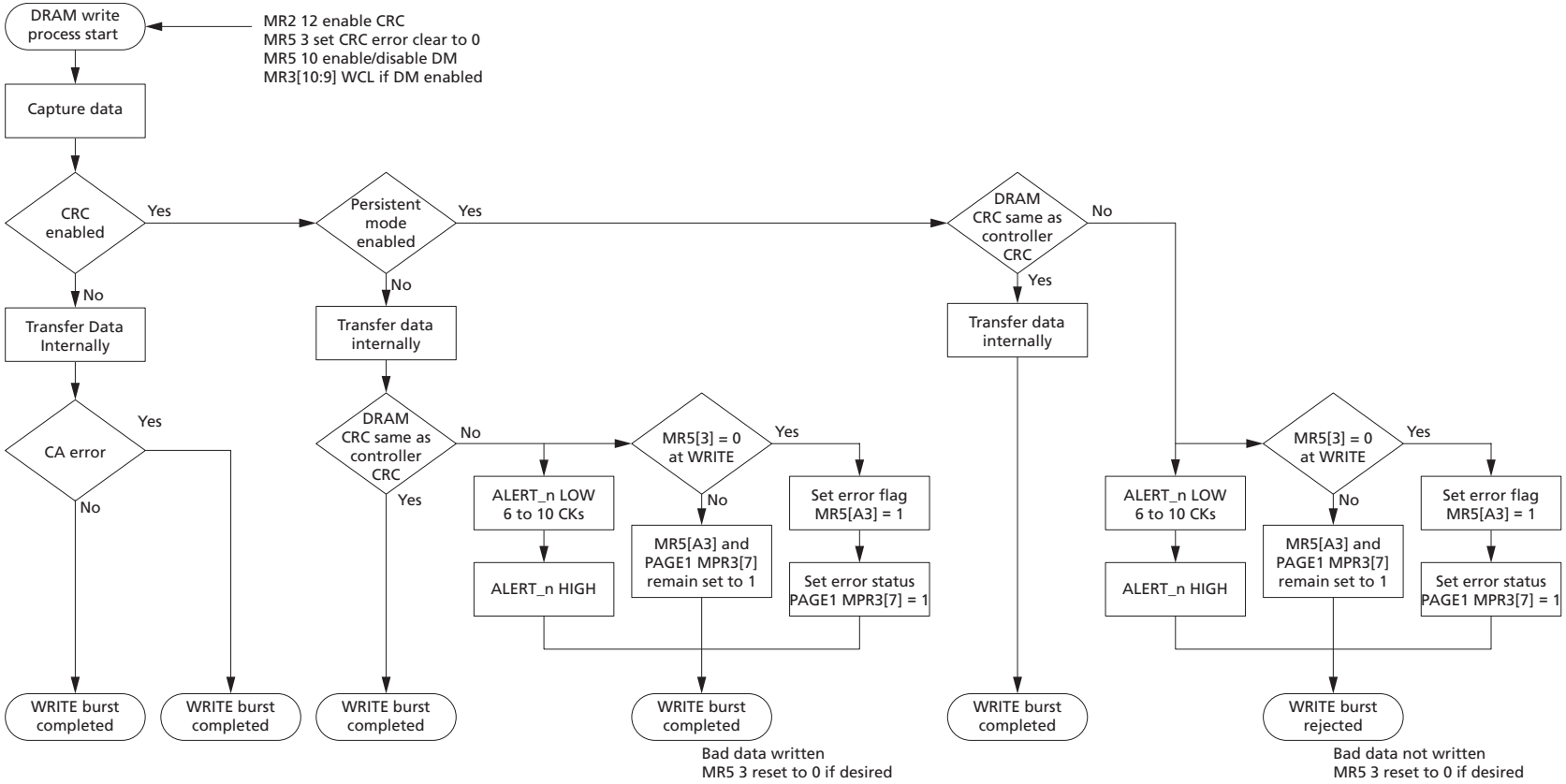



Notes: 1. D[71:1] CRC computed by DRAM did not match CRC[7:0] at T5 and started error generating process at T6.

2. CRC ALERT_PW is specified from the point where the DRAM starts to drive the signal LOW to the point where the DRAM driver releases and the controller starts to pull the signal up.
3. Timing diagram applies to x4, x8, and x16 devices.

## CRC Write Data Flow Diagram

### Figure 99: CA Parity Flow Diagram



## Data Bus Inversion

The DATA BUS INVERSION (DBI) function is supported only for x16 configurations . DBI opportunistically inverts data bits, and in conjunction with the DBI_n I/O, less than half of the DQs will switch LOW for a given DQS strobe edge. The DBI function shares a common pin with the DATA MASK (DM) and TDQS functions. The DBI function applies to either or both READ and WRITE operations: Write DBI cannot be enabled at the same time the DM function is enabled, and DBI is not allowed during MPR READ operation. Valid configurations for DM, and DBI functions are shown below.

**Table 52: DBI vs. DM Function Matrix**

| Read DBI | Write DBI | Data Mask (DM) |
|---|---|---|
| **Enabled** (or Disabled) **MR5[12]=1** (or MR5[12] = 0) | Disabled MR5[11] = 0 | Disabled MR5[10] = 0 |
| | **Enabled** MR5[11] = 1 | Disabled MR5[10] = 0 |
| | Disabled MR5[11] = 0 | **Enabled** MR5[10] = 1 |
| Disabled MR5[12] = 0 | Disabled MR5[11] = 0 | Disabled MR5[10] = 0 |

## DBI During a WRITE Operation

If DBI_n is sampled LOW on a given byte lane during a WRITE operation, the DRAM inverts write data received on the DQ inputs prior to writing the internal memory array. If DBI_n is sampled HIGH on a given byte lane, the DRAM leaves the data received on the DQ inputs non-inverted. The write DQ frame format is shown below for x8 and x16 con-figurations (the x4 configuration does not support the DBI function).

**Table 53: DBI Write, DQ Frame Format (x16)**

| Function | Transfer, Lower (L) and Upper(U) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| DQ[7:0] | LByte 0 | LByte 1 | LByte 2 | LByte 3 | LByte 4 | LByte 5 | LByte 6 | LByte 7 |
| LDM_n or LDBI_n | LDM0 or LDBI0 | LDM1 or LDBI1 | LDM2 or LDBI2 | LDM3 or LDBI3 | LDM4 or LDBI4 | LDM5 or LDBI5 | LDM6 or LDBI6 | LDM7 or LDBI7 |
| DQ[15:8] | UByte 0 | UByte 1 | UByte 2 | UByte 3 | UByte 4 | UByte 5 | UByte 6 | UByte 7 |
| UDM_n or UDBI_n | UDM0 or UDBI0 | UDM1 or UDBI1 | UDM2 or UDBI2 | UDM3 or UDBI3 | UDM4 or UDBI4 | UDM5 or UDBI5 | UDM6 or UDBI6 | UDM7 or UDBI7 |

## DBI During a READ Operation

If the number of 0 data bits within a given byte lane is greater than four during a READ operation, the DRAM inverts read data on its DQ outputs and drives the DBI_n pin LOW; otherwise, the DRAM does not invert the read data and drives the DBI_n pin HIGH. The read DQ frame format is shown below for x16 configurations .

**Table 54: DBI Read, DQ Frame Format (x16)**

| Function | Transfer Byte, Lower (L) and Upper(U) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| DQ[7:0] | LByte 0 | LByte 1 | LByte 2 | LByte 3 | LByte 4 | LByte 5 | LByte 6 | LByte 7 |
| LDBI_n | LDBI0 | LDBI1 | LDBI2 | LDBI3 | LDBI4 | LDBI5 | LDBI6 | LDBI7 |
| DQ[15:8] | UByte 0 | UByte 1 | UByte 2 | UByte 3 | UByte 4 | UByte 5 | UByte 6 | UByte 7 |
| UDBI_n | UDBI0 | UDBI1 | UDBI2 | UDBI3 | UDBI4 | UDBI5 | UDBI6 | UDBI7 |

## Data Mask

The DATA MASK (DM) function, also described as PARTIAL WRITE, is supported only for x16 configurations . The DM function shares a common pin with the DBI_n . The DM function applies only to WRITE operations and cannot be enabled at the same time the WRITE DBI function is enabled. The valid configurations for the DM, and DBI functions are shown here.

**Table 55: DM vs. DBI Function Matrix**

| Data Mask (DM) | Write DBI | Read DBI |
|---|---|---|
| **Enabled** MR5[10] = 1 | Disabled MR5[11] = 0 | **Enabled** or Disabled MR5[12] = 1 or MR5[12] = 0 |
| Disabled MR5[10] = 0 | Disabled MR5[11] = 0 | Disabled MR5[12] = 0 |
| | **Enabled** MR5[11] = 1 | **Enabled** or Disabled MR5[12] = 1 or MR5[12] = 0 |
| | Disabled MR5[11] = 0 | **Enabled** (or Disabled) MR5[12] = 1 (or MR5[12] = 0) |

When enabled, the DM function applies during a WRITE operation. If DM_n is sampled LOW on a given byte lane, the DRAM masks the write data received on the DQ inputs. If DM_n is sampled HIGH on a given byte lane, the DRAM does not mask the data and writes this data into the DRAM core. The DQ frame format for x8 and x16 configurations is shown below. If both CRC write and DM are enabled (via MRS), the CRC will be checked and valid prior to the DRAM writing data into the DRAM core. If a CRC error occurs while the DM feature is enabled, CRC write persistent mode will be enabled and data will not be written into the DRAM core. In the case of CRC write enabled and DM disabled (via MRS), that is, CRC write nonpersistent mode, data is written to the DRAM core even if a CRC error occurs.

**Table 56: Data Mask, DQ Frame Format (x16)**

| | Transfer, Lower (L) and Upper | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Function** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| DQ[7:0] | LByte 0 | LByte 1 | LByte 2 | LByte 3 | LByte 4 | LByte 5 | LByte 6 | LByte 7 |
| LDM_n or LDBI_n | LDM0 or LDBI0 | LDM1 or LDBI1 | LDM2 or LDBI2 | LDM3 or LDBI3 | LDM4 or LDBI4 | LDM5 or LDBI5 | LDM6 or LDBI6 | LDM7 or LDBI7 |
| DQ[15:8] | UByte 0 | UByte 1 | UByte 2 | UByte 3 | UByte 4 | UByte 5 | UByte 6 | UByte 7 |
| UDM_n or UDBI_n | UDM0 or UDBI0 | UDM1 or UDBI1 | UDM2 or UDBI2 | UDM3 or UDBI3 | UDM4 or UDBI4 | UDM5 or UDBI5 | UDM6 or UDBI6 | UDM7 or UDBI7 |

## Programmable Preamble Modes and DQS Postambles

The device supports programmable WRITE and READ preamble modes, either the normal 1$^{t}$CK preamble mode or special 2$^{t}$CK preamble mode. The 2$^{t}$CK preamble mode places special timing constraints on many operational features as well as being supported for data rates of DDR4-2400 and faster. The WRITE preamble 1 $^{t}$CK or 2$^{t}$CK mode can be selected independently from READ preamble 1$^{t}$CK or 2$^{t}$CK mode.

READ preamble training is also supported; this mode can be used by the DRAM controller to train or "read level" the DQS receivers.

There are $^{t}$CCD restrictions under some circumstances:

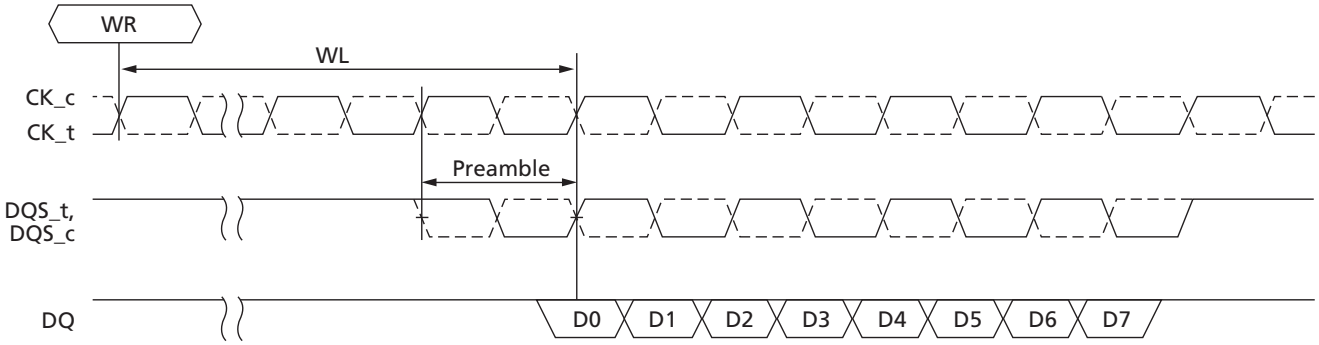
- When 2$^{t}$CK READ preamble mode is enabled, a $^{t}$CCD_S or $^{t}$CCD_L of 5 clocks is not allowed.
- When 2$^{t}$CK WRITE preamble mode is enabled and write CRC is *not* enabled, a $^{t}$CCD_S or $^{t}$CCD_L of 5 clocks is not allowed.
- When 2$^{t}$CK WRITE preamble mode is enabled and write CRC is enabled, a $^{t}$CCD_S or $^{t}$CCD_L of 6 clocks is not allowed.

### WRITE Preamble Mode

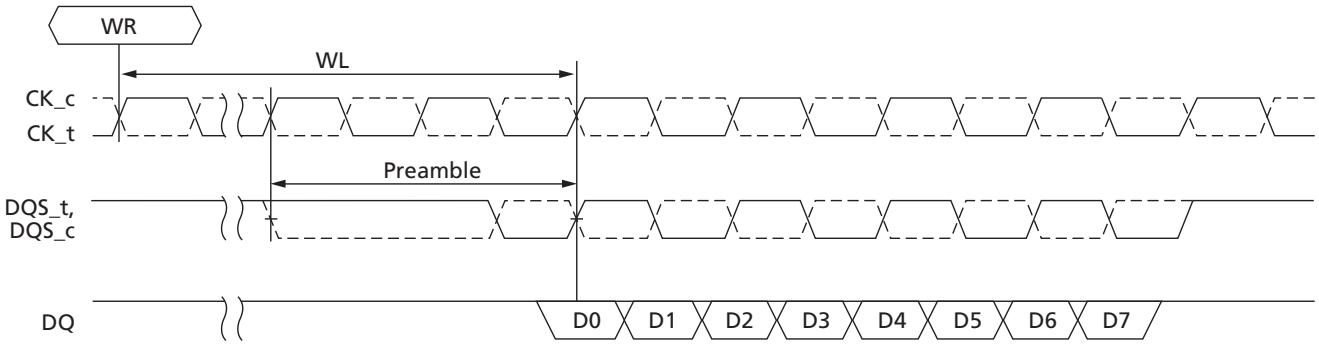
MR4[12] = 0 selects 1$^{t}$CK WRITE preamble mode while MR4[12] = 1 selects 2$^{t}$CK WRITE preamble mode. Examples are shown in the figures below.

**Figure 100: 1$^{t}$CK vs. 2$^{t}$CK WRITE Preamble Mode**

1$^{t}$CK Mode




2$^{t}$CK Mode



CWL has special considerations when in the 2tCK WRITE preamble mode. The CWL value selected in MR2[5:3], as seen in table below, requires at least one additional clock when the primary CWL value and 2tCK WRITE preamble mode are used; no additional clocks are required when the alternate CWL value and 2tCK WRITE preamble mode are used.

**Table 57: CWL Selection**

| | CWL - Primary Choice | | CWL - Alternate Choice | |
|---|---|---|---|---|
| **Speed Bin** | **1tCK Preamble** | **2tCK Preamble** | **1tCK Preamble** | **2tCK Preamble** |
| DDR4-1600 | 9 | N/A | 11 | N/A |
| DDR4-1866 | 10 | N/A | 12 | N/A |
| DDR4-2133 | 11 | N/A | 14 | N/A |
| DDR4-2400 | 12 | 14 | 16 | 16 |
| DDR4-2666 | 14 | 16 | 18 | 18 |
| DDR4-2933 | 16 | 18 | 20 | 20 |
| DDR4-3200 | 16 | 18 | 20 | 20 |

Note: 1. CWL programmable requirement for MR2[5:3].

When operating in 2tCK WRITE preamble mode, tWTR (command based) and tWR (MR0[11:9]) must be programmed to a value 1 clock greater than the tWTR and tWR setting normally required for the applicable speed bin to be JEDEC compliant; however,

Alliance's DDR4 DRAMs do not require these additional tWTR and tWR clocks. The CAS_n-to-CAS_n command delay to either a different bank group (tCCD_S) or the same bank group (tCCD_L) have minimum timing requirements that must be satisfied be-tween WRITE commands and are stated in the Timing Parameters by Speed Bin tables.

**Figure 101: 1tCK vs. 2tCK WRITE Preamble Mode, tCCD = 4**

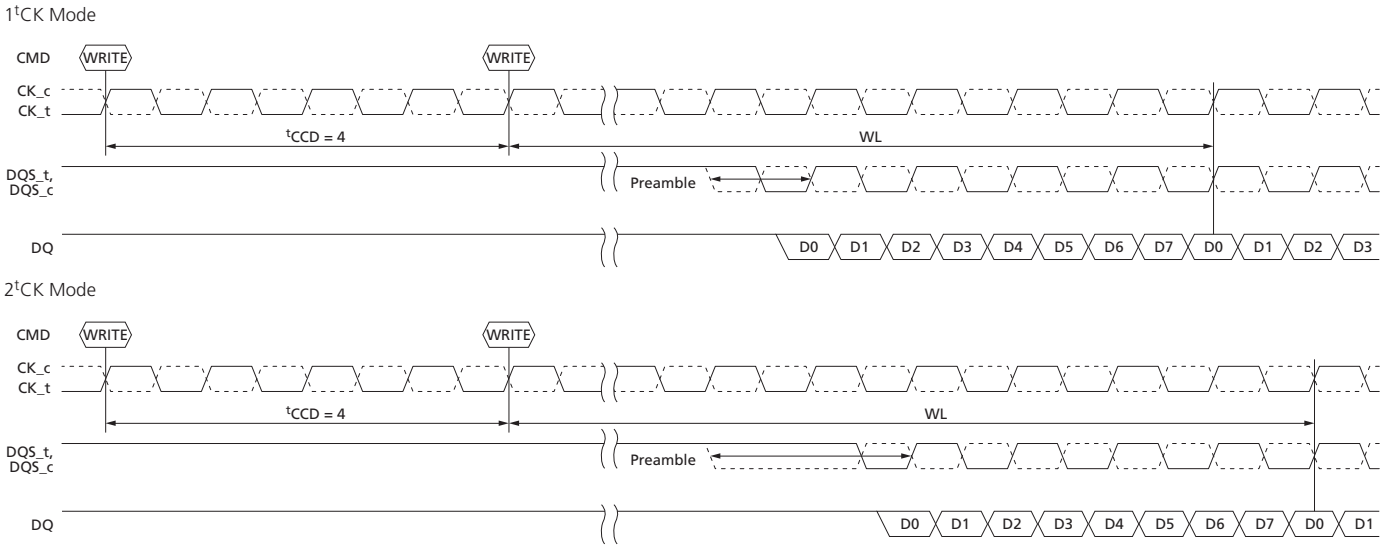
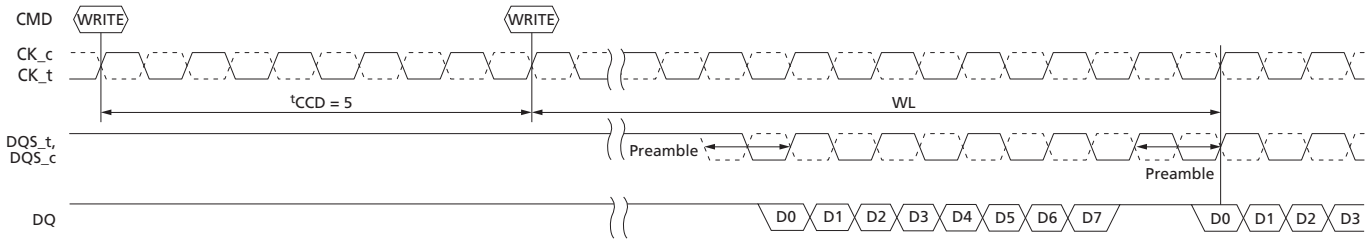


**Figure 102: 1tCK vs. 2tCK WRITE Preamble Mode, tCCD = 5**

1tCK Mode

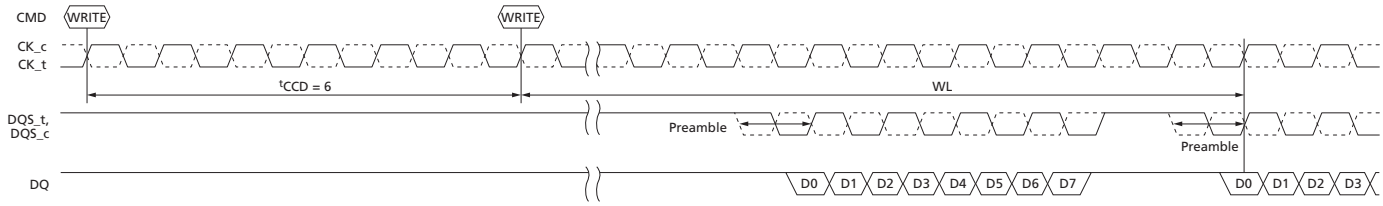



2tCK Mode: tCCD = 5 is not allowed in 2tCK mode.

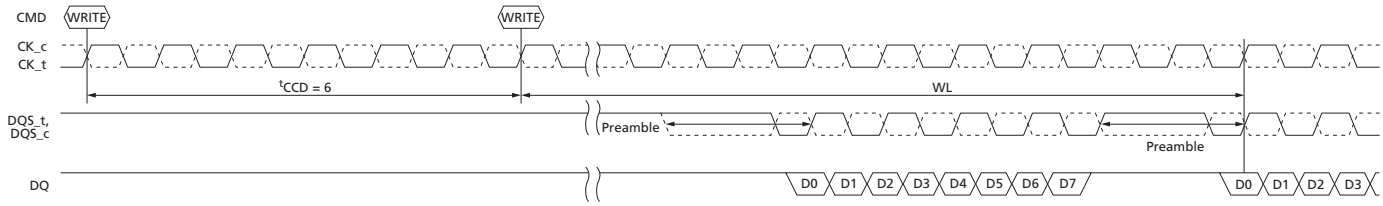
Note: 1. tCCD_S and tCCD_L = 5 tCKs is not allowed when in 2tCK WRITE preamble mode.

**Figure 103: 1tCK vs. 2 tCK WRITE Preamble Mode, tCCD = 6**

1tCK Mode




2tCK Mode

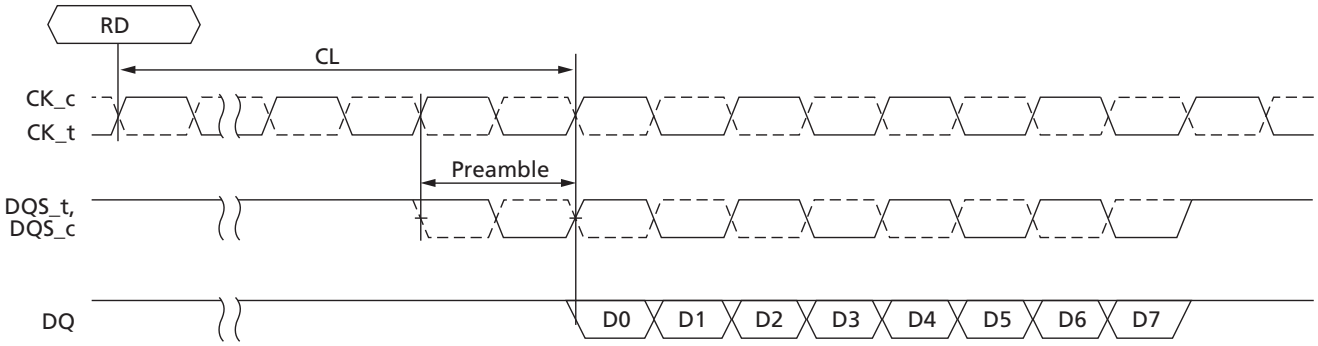


## READ Preamble Mode

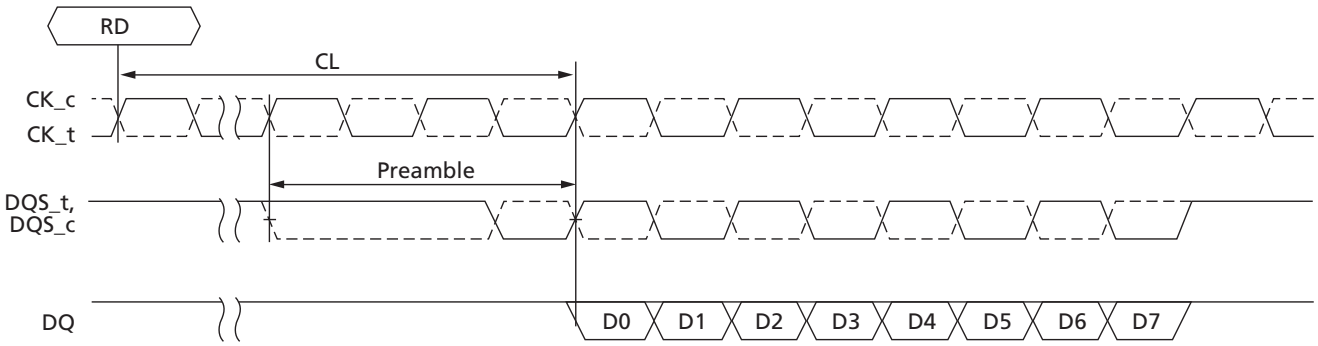
MR4[11] = 0 selects 1tCK READ preamble mode and MR4[11] = 1 selects 2tCK READ preamble mode. Examples are shown in the following figure.

**Figure 104: 1tCK vs. 2tCK READ Preamble Mode**

1tCK Mode



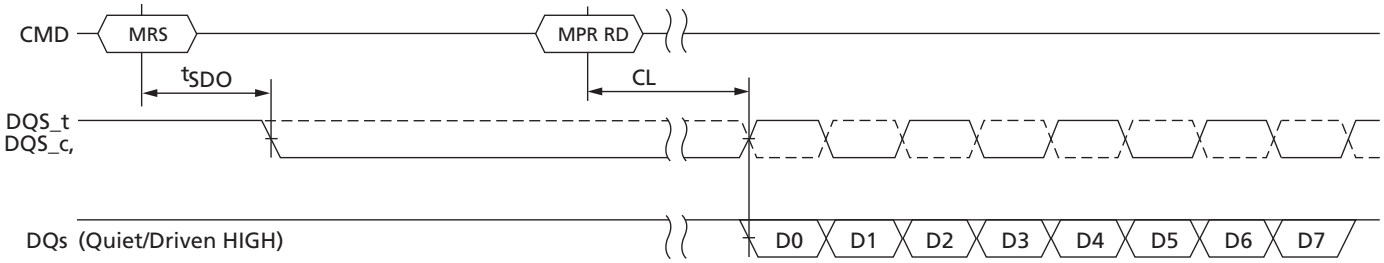

2tCK Mode




## READ Preamble Training

DDR4 supports READ preamble training via MPR reads; that is, READ preamble training is allowed only when the DRAM is in the MPR access mode. The READ preamble training mode can be used by the DRAM controller to train or "read level" its DQS re-ceivers. READ preamble training is entered via an MRS command (MR4[10] = 1 is enabled and MR4[10] = 0 is disabled). After the MRS command is issued to enable READ preamble training, the DRAM DQS signals are driven to a valid level by the time tSDO is satisfied. During this time, the data bus DQ signals are held quiet, that is, driven HIGH. The DQS_t signal remains driven LOW and the DQS_c signal remains driven HIGH until an MPR Page0 READ command is issued (MPR0 through MPR3 determine which pattern is used), and when CAS latency (CL) has expired, the DQS signals will toggle normally depending on the burst length setting. To exit READ preamble training mode, an MRS command must be issued, MR4[10] = 0.

**Figure 105: READ Preamble Training**

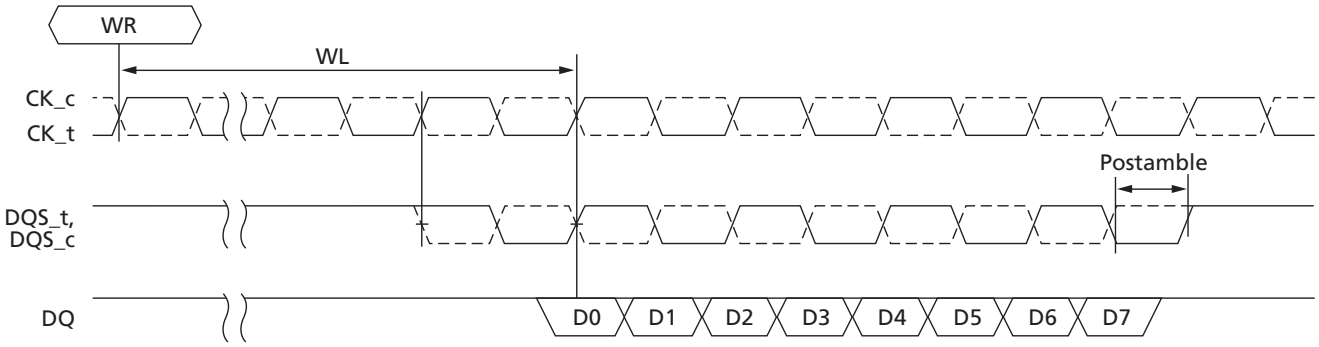



## WRITE Postamble

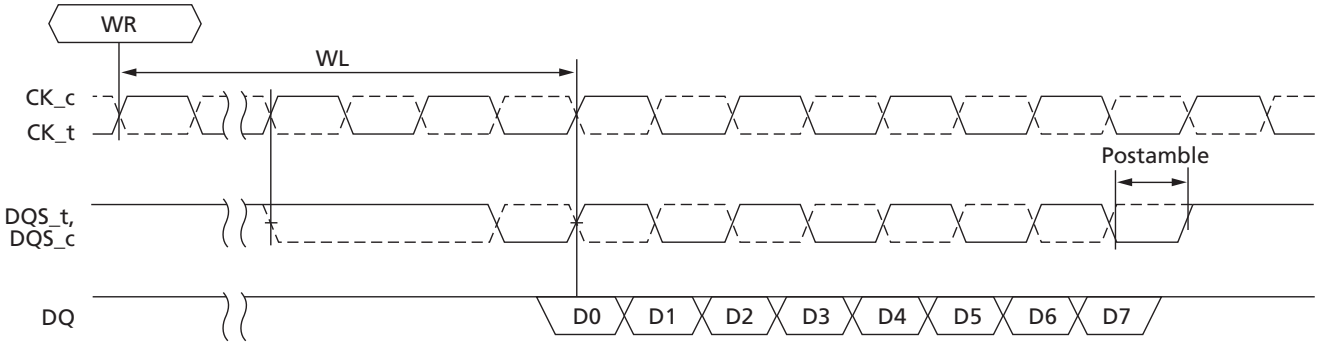
Whether the 1tCK or 2tCK WRITE preamble mode is selected, the WRITE postamble remains the same at ½tCK.

**Figure 106: WRITE Postamble**

1tCK Mode




2tCK Mode

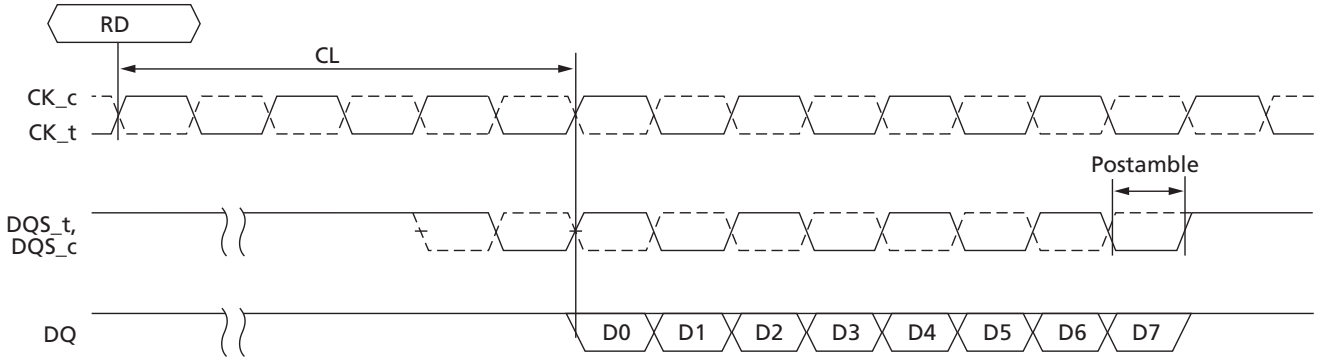



## READ Postamble

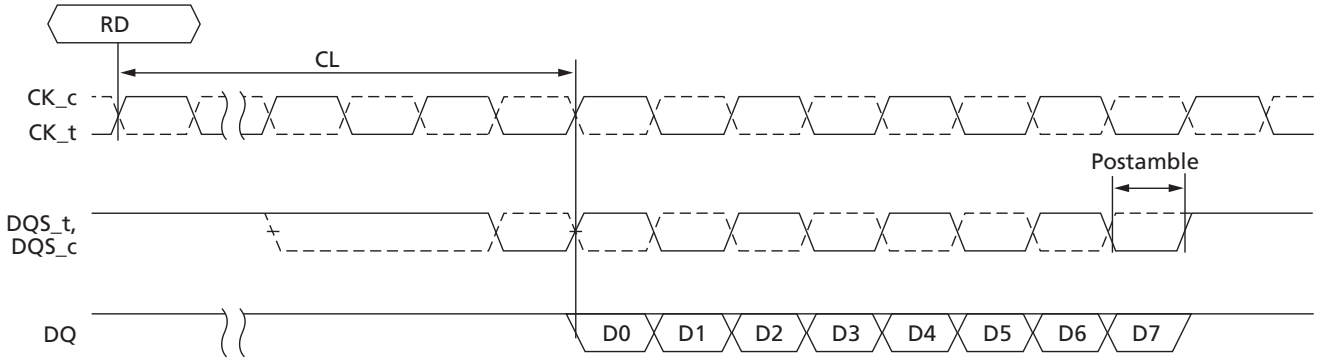
Whether the 1tCK or 2tCK READ preamble mode is selected, the READ postamble remains the same at ½tCK.

**Figure 107: READ Postamble**

1tCK Mode



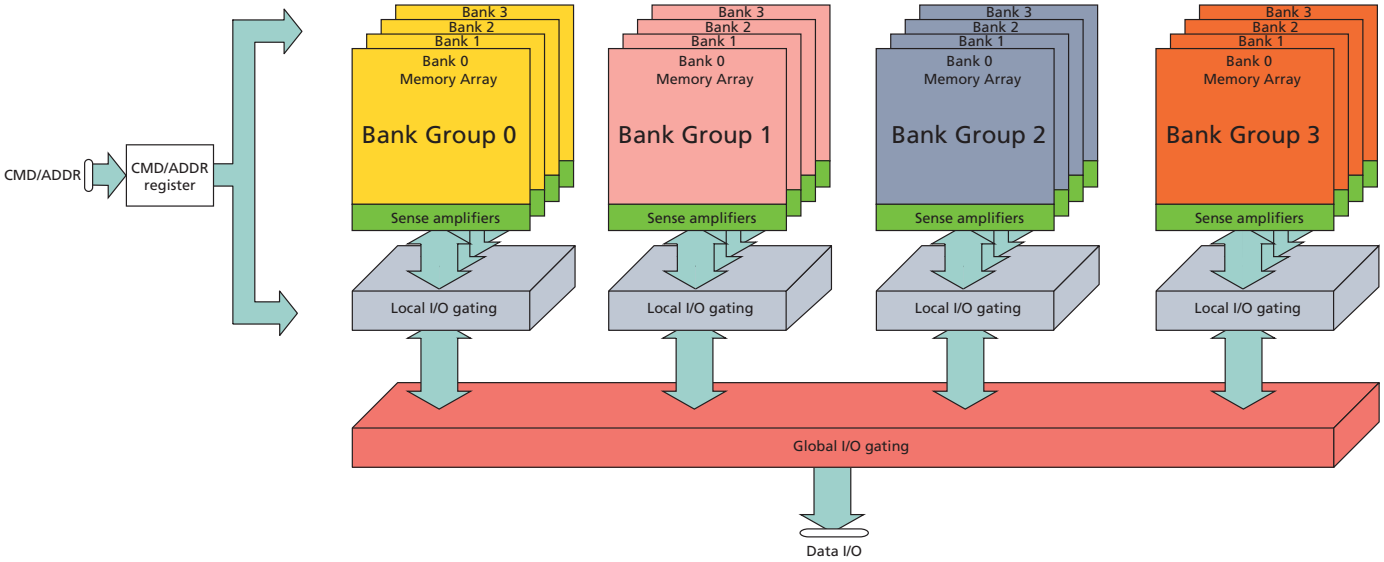

2tCK Mode



## Bank Access Operation

DDR4 supports bank grouping: x16 DRAMs have two bank groups (BG[0]), and each bank group is comprised of four subbanks. Bank accesses to different banks' groups require less time delay between accesses than bank accesses to within the same bank's group. Bank accesses to different bank groups require $^{t}$CCD_S (or short) delay between commands while bank accesses within the same bank group require $^{t}$CCD_L (or long) delay between commands.

**Figure 108: Bank Group x4/x8 Block Diagram**




Notes: 1. Bank accesses to different bank groups require $^{t}$CCD_S.
2. Bank accesses within the same bank group require $^{t}$CCD_L.

**Table 58: DDR4 Bank Group Timing Examples**

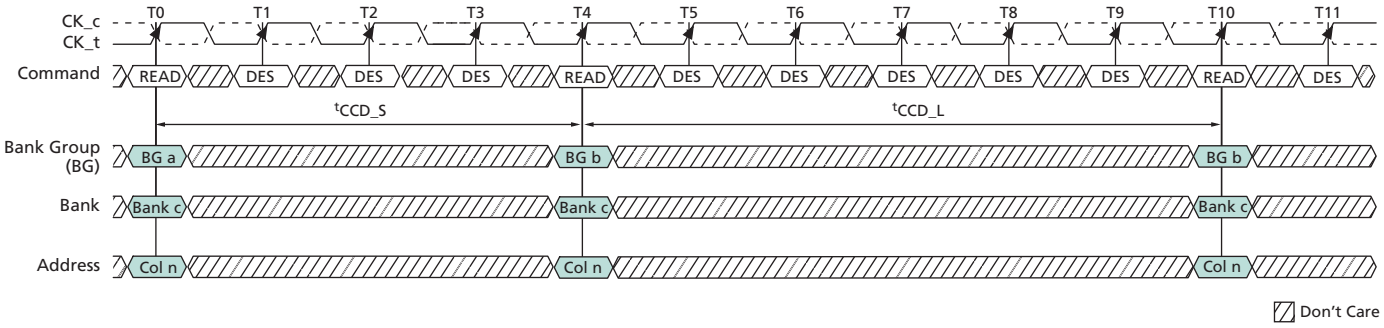
| Parameter | DDR4-1600 | DDR4-2133 | DDR4-2400 |
|---|---|---|---|
| $^{t}$CCD_S | 4*n*CK | 4*n*CK | 4*n*CK |
| $^{t}$CCD_L | 4*n*CK or 6.25ns | 4*n*CK or 5.355ns | 4*n*CK or 5ns |
| | | | |
| $^{t}$RRD_S (½K) | 4*n*CK or 5ns | 4*n*CK or 3.7ns | 4*n*CK or 3.3ns |
| $^{t}$RRD_L (½K) | 4*n*CK or 6ns | 4*n*CK or 5.3ns | 4*n*CK or 4.9ns |
| | | | |
| $^{t}$RRD_S (1K) | 4*n*CK or 5ns | 4*n*CK or 3.7ns | 4*n*CK or 3.3ns |
| $^{t}$RRD_L (1K) | 4*n*CK or 6ns | 4*n*CK or 5.3ns | 4*n*CK or 4.9ns |
| | | | |
| $^{t}$RRD_S (2K) | 4*n*CK or 6ns | 4*n*CK or 5.3ns | 4*n*CK or 5.3ns |
| $^{t}$RRD_L (2K) | 4*n*CK or 7.5ns | 4*n*CK or 6.4ns | 4*n*CK or 6.4ns |
| | | | |

**Table 58: DDR4 Bank Group Timing Examples (Continued)**

| Parameter | DDR4-1600 | DDR4-2133 | DDR4-2400 |
|---|---|---|---|
| $^{t}$WTR_S | 2*n*CK or 2.5ns | 2*n*CK or 2.5ns | 2*n*CK or 2.5ns |
| $^{t}$WTR_L | 4*n*CK or 7.5ns | 4*n*CK or 7.5ns | 4*n*CK or 7.5ns |

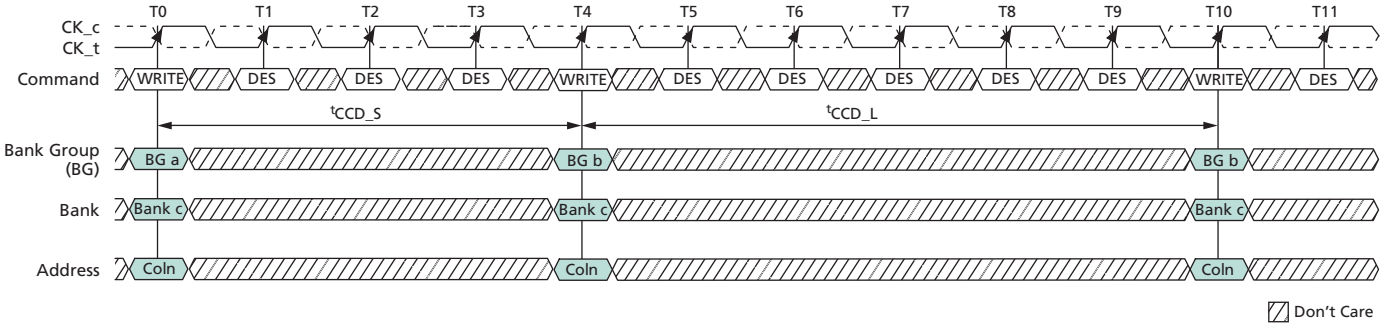
Notes:
1. Refer to Timing Tables for actual specification values, these values are shown for reference only and are not verified for accuracy.
2. Timings with both *n*CK and ns require both to be satisfied; that is, the larger time of the two cases must be satisfied.

**Figure 109: READ Burst $^{t}$CCD_S and $^{t}$CCD_L Examples**



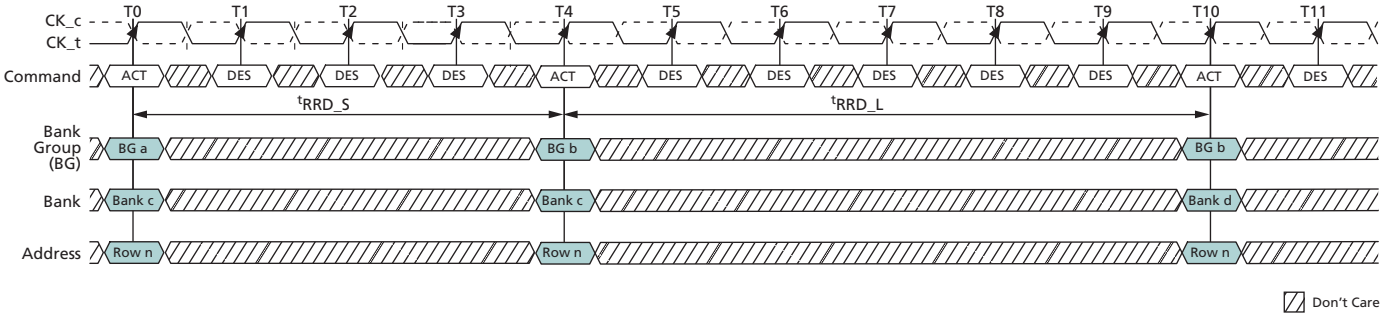

Notes:
1. $^{t}$CCD_S; CAS_n-to-CAS_n delay (short). Applies to consecutive CAS_n to different bank groups (T0 to T4).
2. $^{t}$CCD_L; CAS_n-to-CAS_n delay (long). Applies to consecutive CAS_n to the same bank group (T4 to T10).

**Figure 110: Write Burst $^{t}$CCD_S and $^{t}$CCD_L Examples**



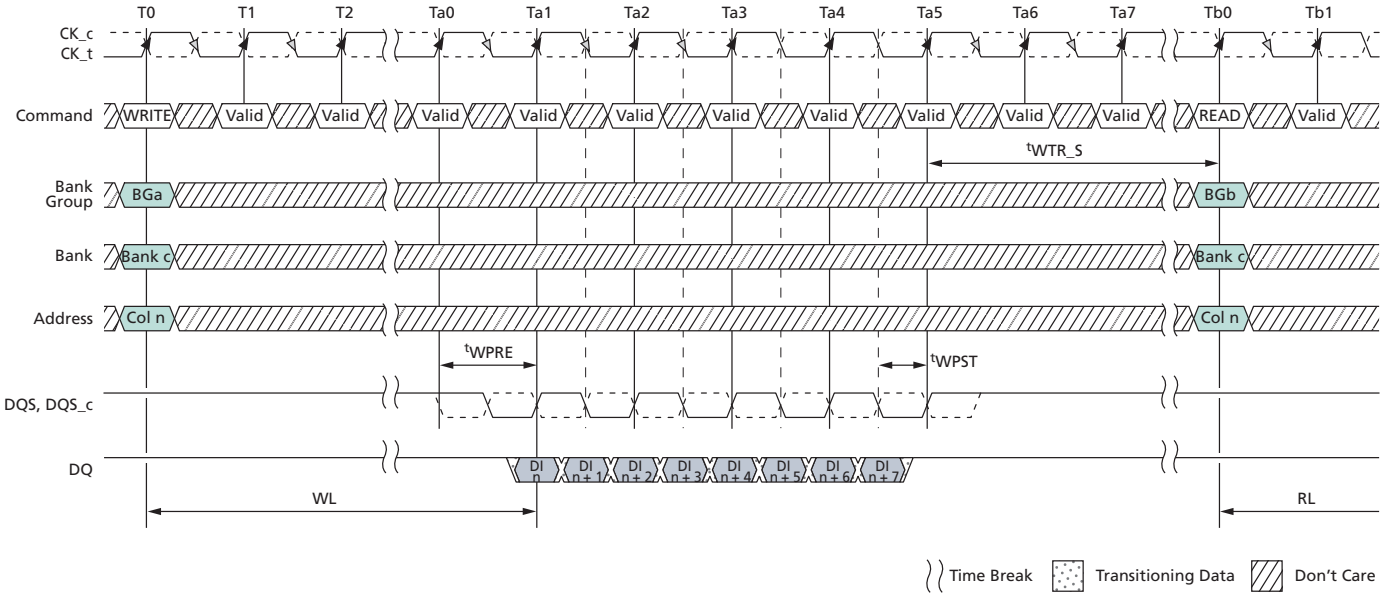

Notes:
1. $^{t}$CCD_S; CAS_n-to-CAS_n delay (short). Applies to consecutive CAS_n to different bank groups (T0 to T4).
2. $^{t}$CCD_L; CAS_n-to-CAS_n delay (long). Applies to consecutive CAS_n to the same bank group (T4 to T10).

**Figure 111: $^{t}$RRD Timing**



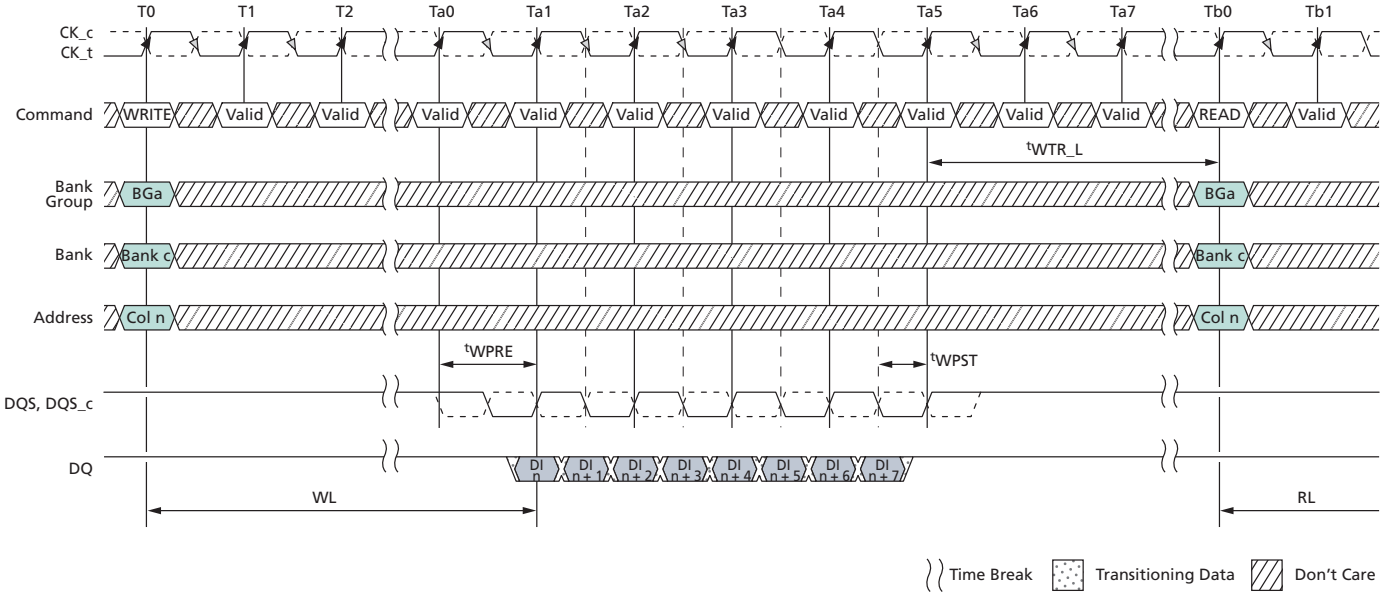

Notes: 1. $^{t}$RRD_S; ACTIVATE-to-ACTIVATE command period (short); applies to consecutive ACTIVATE commands to different bank groups (T0 and T4).
2. $^{t}$RRD_L; ACTIVATE-to-ACTIVATE command period (long); applies to consecutive ACTIVATE commands to the different banks in the same bank group (T4 and T10).

**Figure 112: $^{t}$WTR_S Timing (WRITE-to-READ, Different Bank Group, CRC and DM Disabled)**




Note: 1. $^{t}$WTR_S: delay from start of internal write transaction to internal READ command to a different bank group.

**Figure 113: $^{t}$WTR_L Timing (WRITE-to-READ, Same Bank Group, CRC and DM Disabled)**




Note: 1. $^{t}$WTR_L: delay from start of internal write transaction to internal READ command to the same bank group.

# READ Operation

## Read Timing Definitions

The read timings shown below are applicable in normal operation mode, that is, when the DLL is enabled and locked.

**Note:** $^{t}$DQSQ = both rising/falling edges of DQS; no $^{t}$AC defined.

Rising data strobe edge parameters:

- $^{t}$DQSCK (MIN)/(MAX) describes the allowed range for a rising data strobe edge relative to CK.
- $^{t}$DQSCK is the actual position of a rising strobe edge relative to CK.
- $^{t}$QSH describes the DQS differential output HIGH time.
- $^{t}$DQSQ describes the latest valid transition of the associated DQ pins.
- $^{t}$QH describes the earliest invalid transition of the associated DQ pins.

Falling data strobe edge parameters:

- $^{t}$QSL describes the DQS differential output LOW time.
- $^{t}$DQSQ describes the latest valid transition of the associated DQ pins.
- $^{t}$QH describes the earliest invalid transition of the associated DQ pins.

**Figure 114: Read Timing Definition**

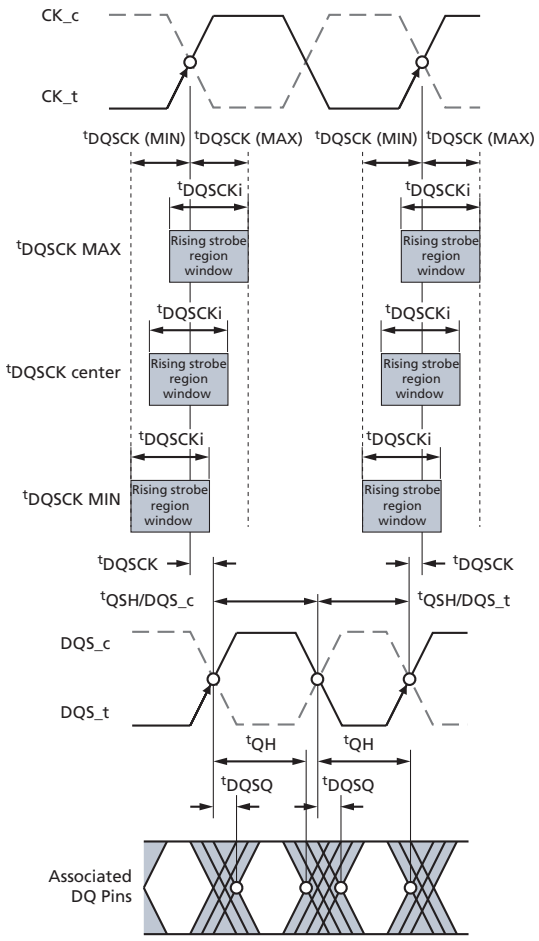



**Table 59: Read-to-Write and Write-to-Read Command Intervals**

| Access Type | Bank Group | Timing Parameters | Note |
|---|---|---|---|
| Read-to-Write, minimum | Same | CL - CWL + RBL/2 + 1$^{t}$CK + $^{t}$WPRE | 1, 2 |
| | Different | CL - CWL + RBL/2 + 1$^{t}$CK + $^{t}$WPRE | 1, 2 |
| Write-to-Read, minimum | Same | CWL + WBL/2 + $^{t}$WTR_L | 1, 3 |
| | Different | CWL + WBL/2 + $^{t}$WTR_S | 1, 3 |

Notes:
1. These timings require extended calibrations times $^{t}$ZQinit and $^{t}$ZQCS.
2. RBL: READ burst length associated with READ command, RBL = 8 for fixed 8 and on-the-fly mode 8 and RBL = 4 for fixed BC4 and on-the-fly mode BC4.
3. WBL: WRITE burst length associated with WRITE command, WBL = 8 for fixed 8 and on-the-fly mode 8 or BC4 and WBL = 4 for fixed BC4 only.

## Read Timing – Clock-to-Data Strobe Relationship

The clock-to-data strobe relationship shown below is applicable in normal operation mode, that is, when the DLL is enabled and locked.

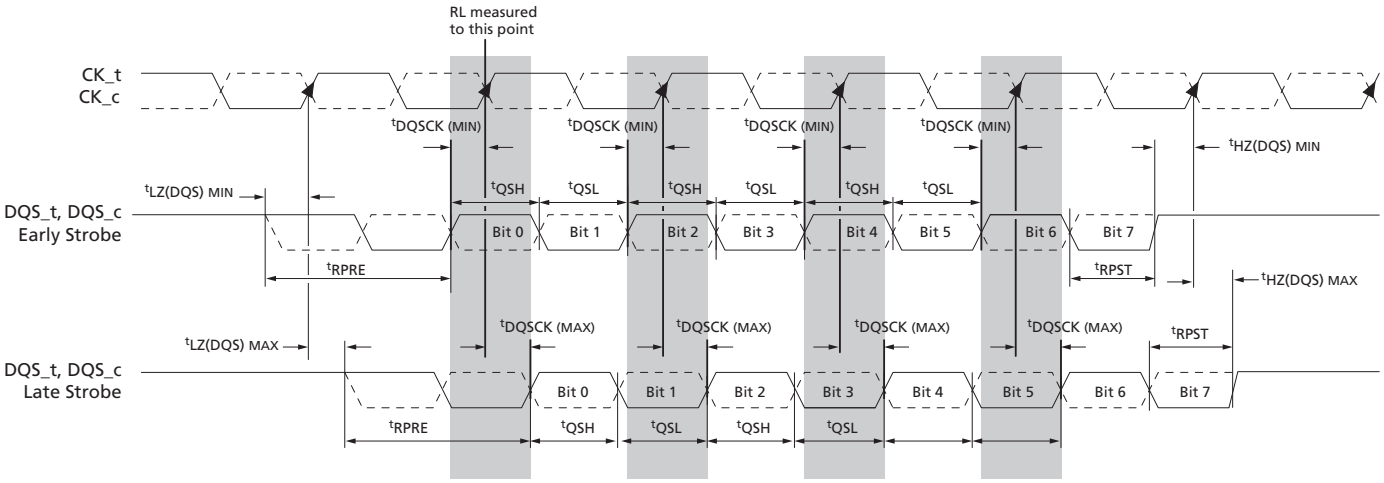
Rising data strobe edge parameters:

- $^{t}$DQSCK (MIN) / (MAX) describes the allowed range for a rising data strobe edge relative to CK.
- $^{t}$DQSCK is the actual position of a rising strobe edge relative to CK.
- $^{t}$QSH describes the data strobe high pulse width.
- $^{t}$HZ(DQS) DQS strobe going to high, nondrive level (shown in the postamble section of the figure below).

Falling data strobe edge parameters:

- $^{t}$QSL describes the data strobe low pulse width.
- $^{t}$LZ(DQS) DQS strobe going to low, initial drive level (shown in the preamble section of the figure below).

**Figure 115: Clock-to-Data Strobe Relationship**




Notes:

1. Within a burst, the rising strobe edge will vary within $^{t}$DQSCKi while at the same **voltage** and temperature. However, when the device, voltage, and temperature variations are incorporated, the rising strobe edge variance window can shift between $^{t}$DQSCK (MIN) and $^{t}$DQSCK (MAX).

   A timing of this window's right edge (latest) from rising CK_t, CK_c is limited by a device's actual $^{t}$DQSCK (MAX). A timing of this window's left inside edge (earliest) from rising CK_t, CK_c is limited by $^{t}$DQSCK (MIN).
2. Notwithstanding Note 1, a rising strobe edge with $^{t}$DQSCK (MAX) at T(n) can not be immediately followed by a rising strobe edge with $^{t}$DQSCK (MIN) at T(n + 1) because other timing relationships ($^{t}$QSH, $^{t}$QSL) exist: if $^{t}$DQSCK(n + 1) < 0: $^{t}$DQSCK(n) < 1.0 $^{t}$CK - ($^{t}$QSH (MIN) + $^{t}$QSL (MIN)) - | $^{t}$DQSCK(n + 1) |.
3. The DQS_t, DQS_c differential output HIGH time is defined by $^{t}$QSH, and the DQS_t, DQS_c differential output LOW time is defined by $^{t}$QSL.
4. $^{t}$LZ(DQS) MIN and $^{t}$HZ(DQS) MIN are not tied to $^{t}$DQSCK (MIN) (early strobe case), and $^{t}$LZ(DQS) MAX and $^{t}$HZ(DQS) MAX are not tied to $^{t}$DQSCK (MAX) (late strobe case).
5. The minimum pulse width of READ preamble is defined by $^{t}$RPRE (MIN).
6. The maximum READ postamble is bound by $^{t}$DQSCK (MIN) plus $^{t}$QSH (MIN) on the left side and $^{t}$HZDSQ (MAX) on the right side.
7. The minimum pulse width of READ postamble is defined by $^{t}$RPST (MIN).

8. The maximum READ preamble is bound by $^{t}$LZDQS (MIN) on the left side and $^{t}$DQSCK (MAX) on the right side.

## Read Timing – Data Strobe-to-Data Relationship

The data strobe-to-data relationship is shown below and is applied when the DLL is enabled and locked.

**Note:** $^{t}$DQSQ: both rising/falling edges of DQS; no $^{t}$AC defined.

Rising data strobe edge parameters:

- $^{t}$DQSQ describes the latest valid transition of the associated DQ pins.
- $^{t}$QH describes the earliest invalid transition of the associated DQ pins.

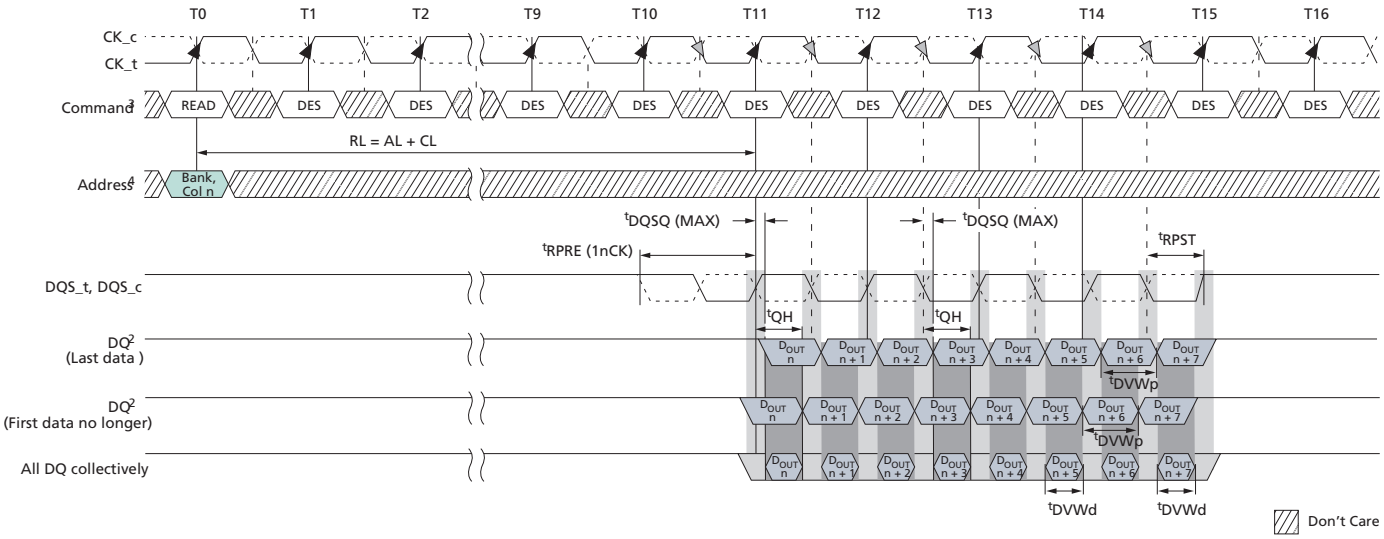
Falling data strobe edge parameters:

- $^{t}$DQSQ describes the latest valid transition of the associated DQ pins.
- $^{t}$QH describes the earliest invalid transition of the associated DQ pins.

Data valid window parameters:

- $^{t}$DVWd is the Data Valid Window per device per UI and is derived from [$^{t}$QH - $^{t}$DQSQ] of each UI on a given DRAM
- $^{t}$DVWp is the Data Valid Window per pin per UI and is derived [$^{t}$QH - $^{t}$DQSQ] of each UI on a pin of a given DRAM

**Figure 116: Data Strobe-to-Data Relationship**



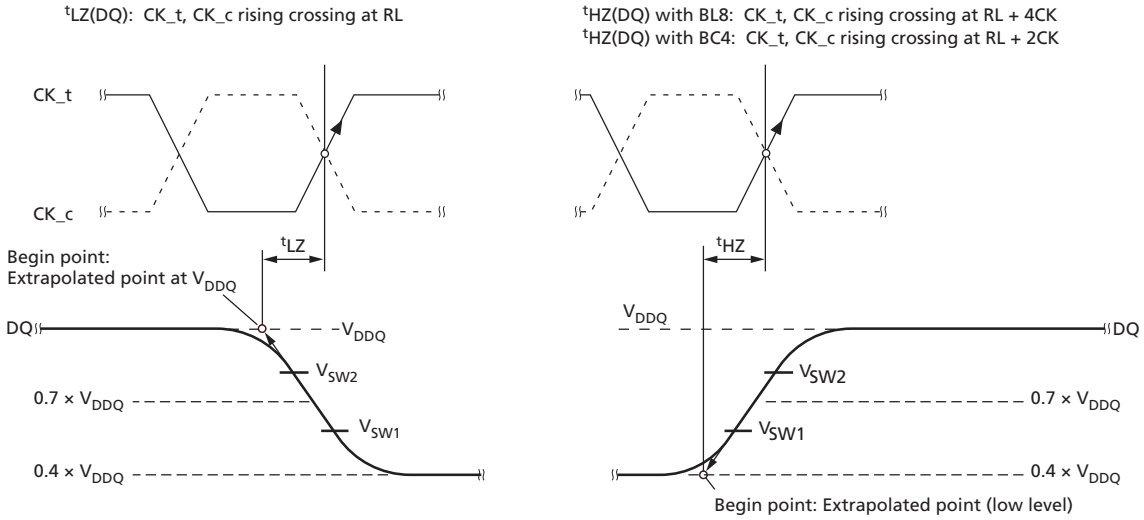

Notes:
1. BL = 8, RL = 11 (AL = 0, CL = 1) , Premable = 1$^{t}$CK.
2. $D_{OUT}n$ = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[A1:0 = 00] or MR0[A1:0 = 01] and A12 = 1 during READ commands at T0.
5. Output timings are referenced to $V_{DDQ}$, and DLL on for locking.
6. $^{t}$DQSQ defines the skew between DQS to data and does not define DQS to clock.

7. Early data transitions may not always happen at the same DQ. Data transitions of a DQ can vary (either early or late) within a burst.

## $^{t}$LZ(DQS), $^{t}$LZ(DQ), $^{t}$HZ(DQS), and $^{t}$HZ(DQ) Calculations

$^{t}$HZ and $^{t}$LZ transitions occur in the same time window as valid data transitions. These parameters are referenced to a specific voltage level that specifies when the device output is no longer driving $^{t}$HZ(DQS) and $^{t}$HZ(DQ), or begins driving $^{t}$LZ(DQS) and $^{t}$LZ(DQ). The figure below shows a method to calculate the point when the device is no longer driving $^{t}$HZ(DQS) and $^{t}$HZ(DQ), or begins driving $^{t}$LZ(DQS) and $^{t}$LZ(DQ), by measuring the signal at two different voltages. The actual voltage measurement points are not critical as long as the calculation is consistent. $^{t}$LZ(DQS), $^{t}$LZ(DQ), $^{t}$HZ(DQS), and $^{t}$HZ(DQ) are defined as singled-ended parameters.

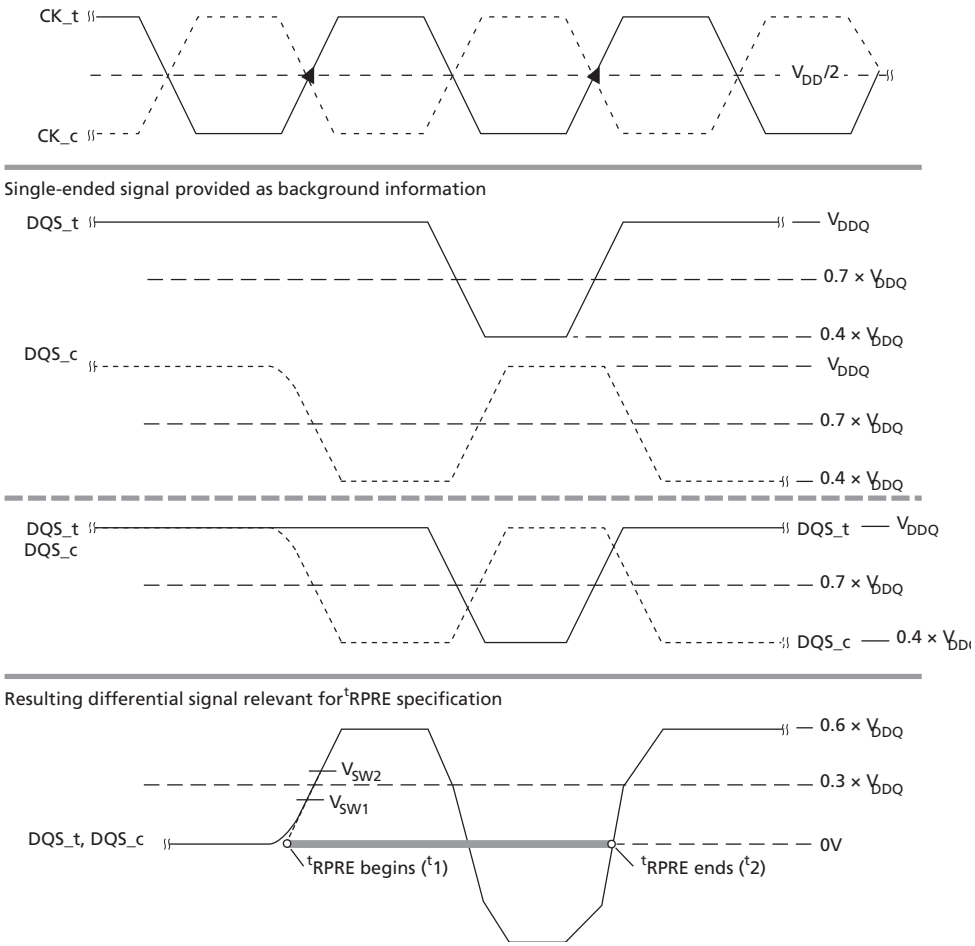
**Figure 117: $^{t}$LZ and $^{t}$HZ Method for Calculating Transitions and Endpoints**




Notes:
1. $V_{sw1}$ = (0.70 - 0.04) × $V_{DDQ}$ for both $^{t}$LZ and $^{t}$HZ.
2. $V_{sw2}$ = (0.70 + 0.04) × $V_{DDQ}$ for both $^{t}$LZ and $^{t}$HZ.
3. Extrapolated point (low level) = $V_{DDQ}$/(50 + 34) × 34 = 0.4 × $V_{DDQ}$
   Driver impedance = RZQ/7 = 34Ω
   $V_{TT}$ test load = 50Ω to $V_{DDQ}$.

## tRPRE Calculation

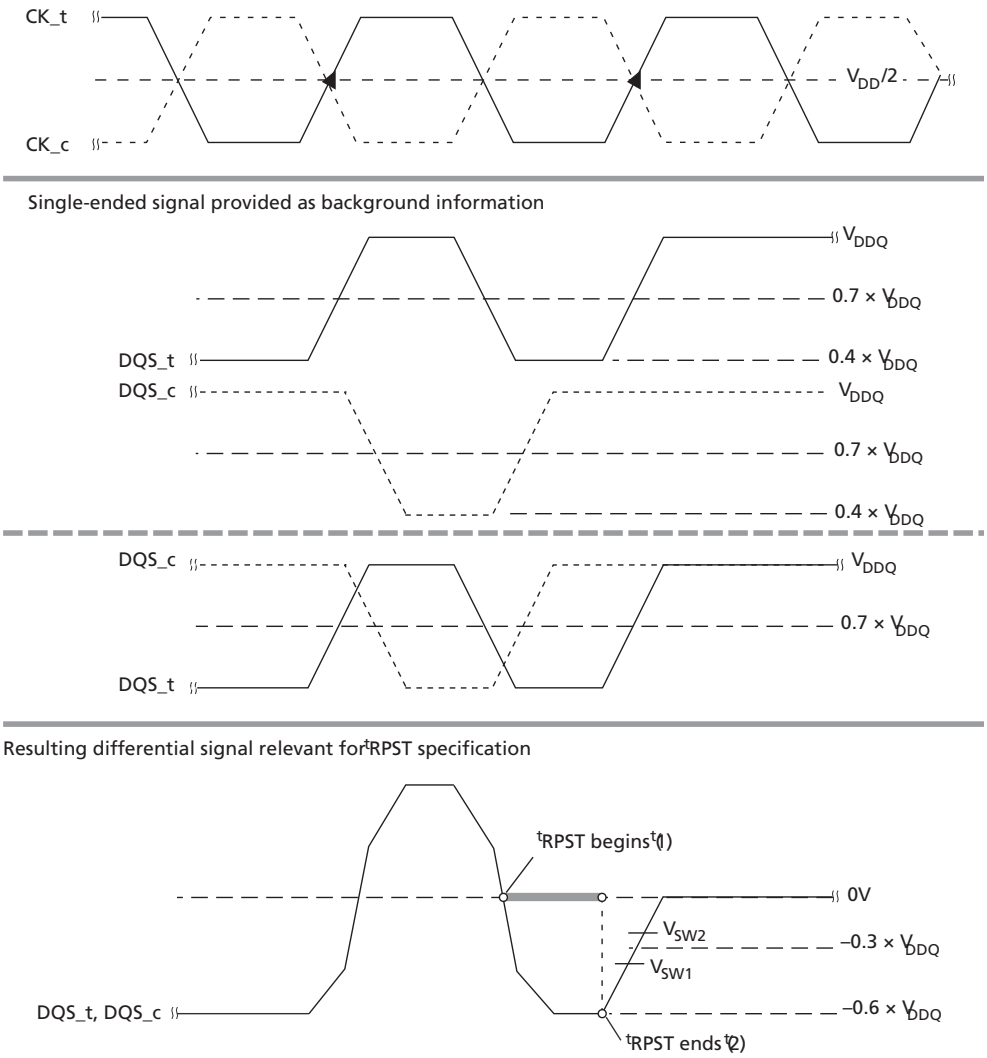
**Figure 118: tRPRE Method for Calculating Transitions and Endpoints**




Notes:
1. $V_{sw1} = (0.3 - 0.04) \times V_{DDQ}$.
2. $V_{sw2} = (0.30 + 0.04) \times V_{DDQ}$.
3. DQS_t and DQS_c low level = $V_{DDQ}/(50 + 34) \times 34 = 0.4 \times V_{DDQ}$
   Driver impedance = RZQ/7 = 34Ω
   $V_{TT}$ test load = 50Ω to $V_{DDQ}$.

## tRPST Calculation

**Figure 119: tRPST Method for Calculating Transitions and Endpoints**




Notes:
1. $V_{sw1}$ = (–0.3 - 0.04) × $V_{DDQ}$.
2. $V_{sw2}$ = (–0.30 + 0.04) × $V_{DDQ}$.
3. DQS_t and DQS_c low level = $V_{DDQ}$/(50 + 34) × 34 = 0.4 × $V_{DDQ}$
   Driver impedance = RZQ/7 = 34Ω
   $V_{TT}$ test load = 50Ω to $V_{DDQ}$.

## READ Burst Operation

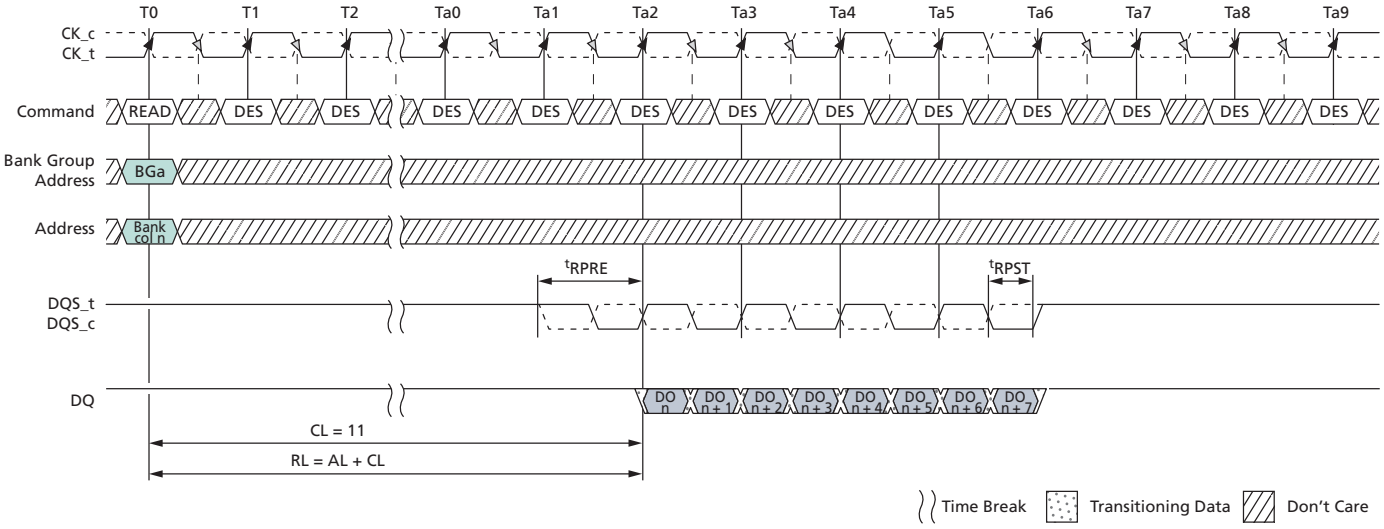
DDR4 READ commands support bursts of BL8 (fixed), BC4 (fixed), and BL8/BC4 on-the-fly (OTF); OTF uses address A12 to control OTF when OTF is enabled:

- A12 = 0, BC4 (BC4 = burst chop)
- A12 = 1, BL8

READ commands can issue precharge automatically with a READ with auto precharge command (RDA), and is enabled by A10 HIGH:

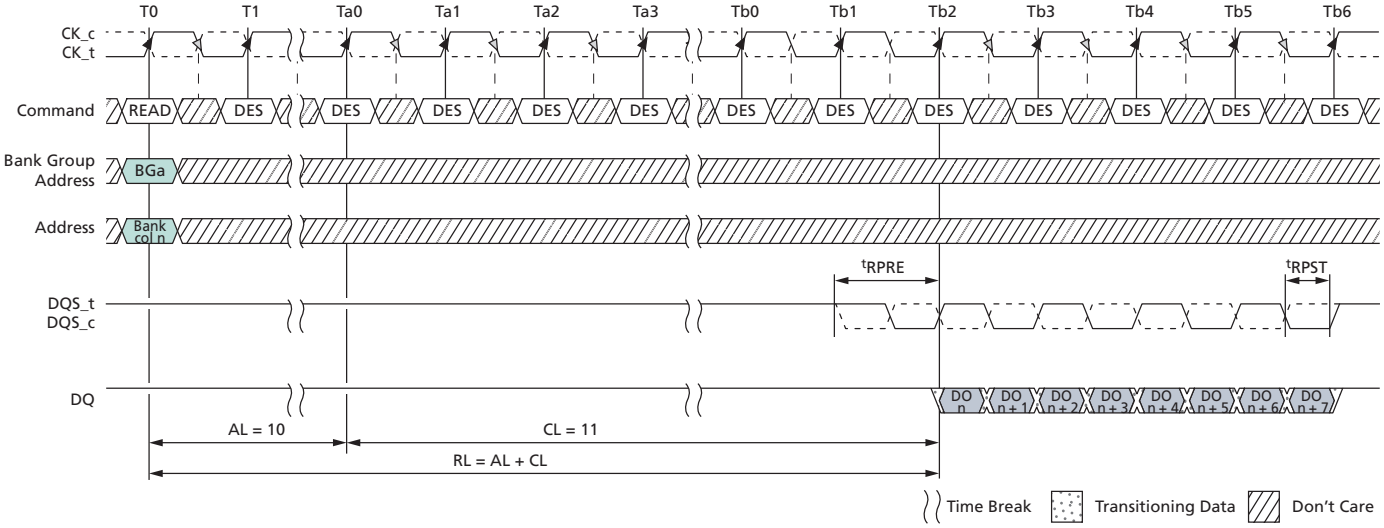
- READ command with A10 = 0 (RD) performs standard read, bank remains active after READ burst.
- READ command with A10 = 1 (RDA) performs read with auto precharge, bank goes in to precharge after READ burst.

**Figure 120: READ Burst Operation, RL = 11 (AL = 0, CL = 11, BL8)**




Notes:
1. BL8, RL = 0, AL = 0, CL = 11, Preamble = 1$^{t}$CK.
2. DO *n* = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ command at T0.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

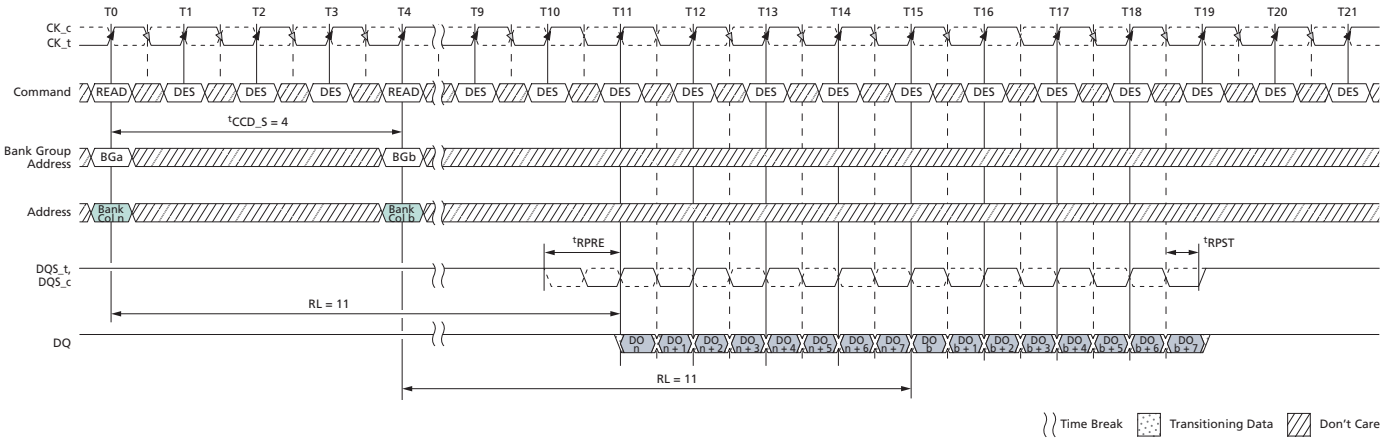
**Figure 121: READ Burst Operation, RL = 21 (AL = 10, CL = 11, BL8)**




Notes:
1. BL8, RL = 21, AL = (CL - 1), CL = 11, Preamble = 1$^{t}$CK.
2. DO *n* = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ command at T0.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

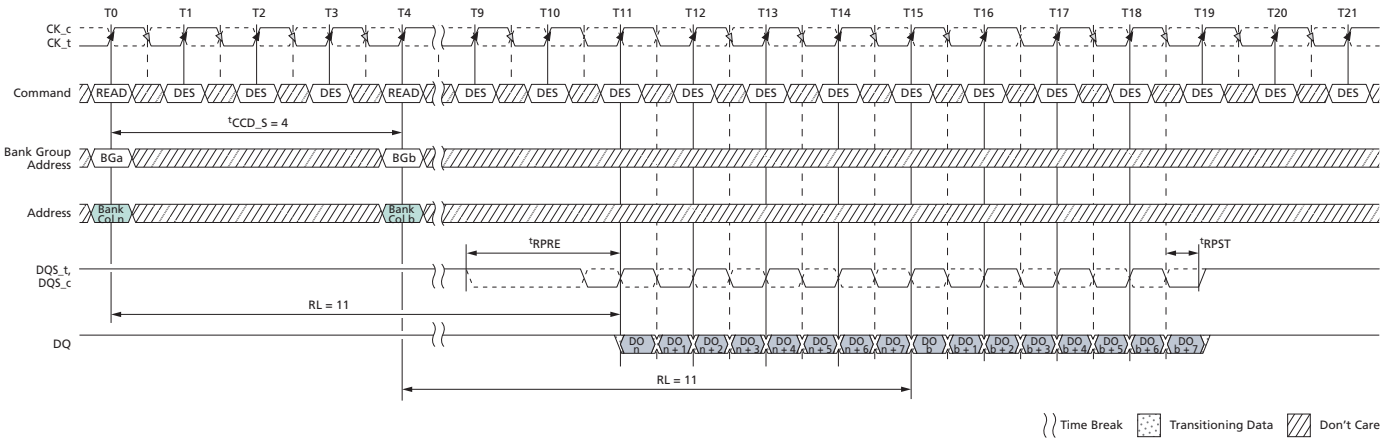
## READ Operation Followed by Another READ Operation

### Figure 122: Consecutive READ (BL8) with 1$^{t}$CK Preamble in Different Bank Group



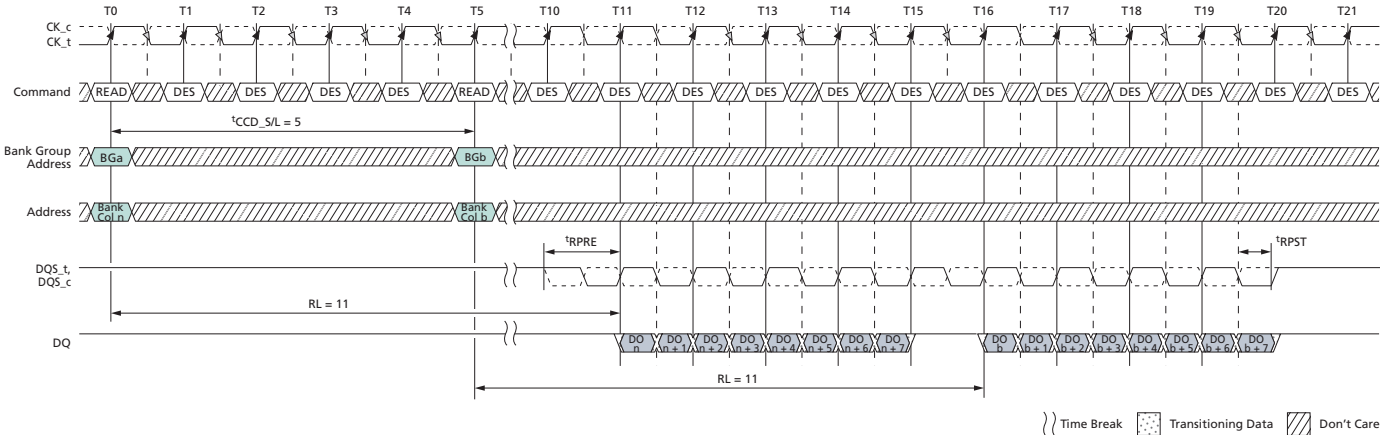

Notes:
1. BL8, AL = 0, CL = 11, Preamble = 1$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

### Figure 123: Consecutive READ (BL8) with 2$^{t}$CK Preamble in Different Bank Group



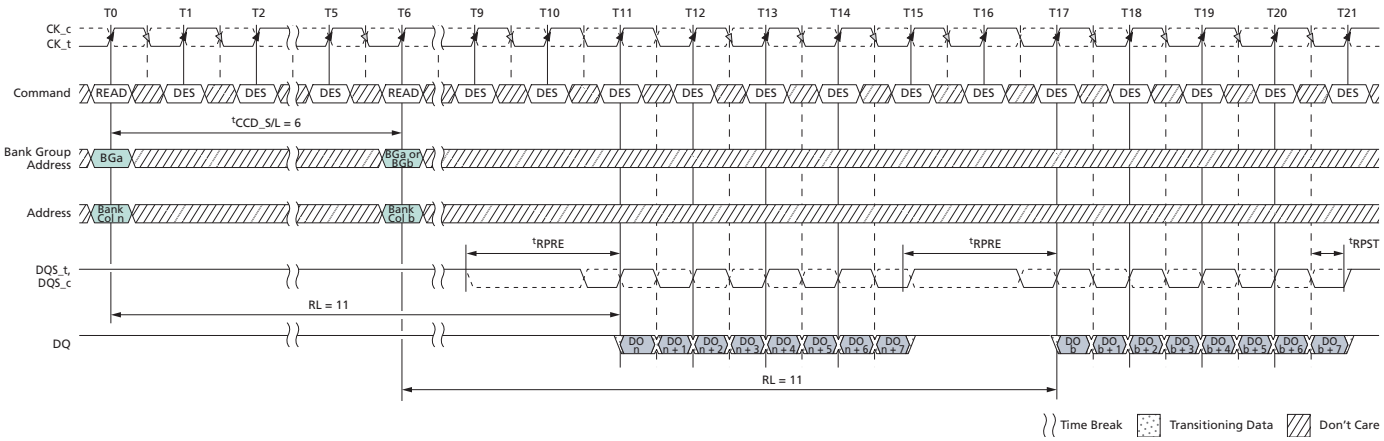

Notes:
1. BL8, AL = 0, CL = 11, Preamble = 2$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

**Figure 124: Nonconsecutive READ (BL8) with 1tCK Preamble in Same or Different Bank Group**



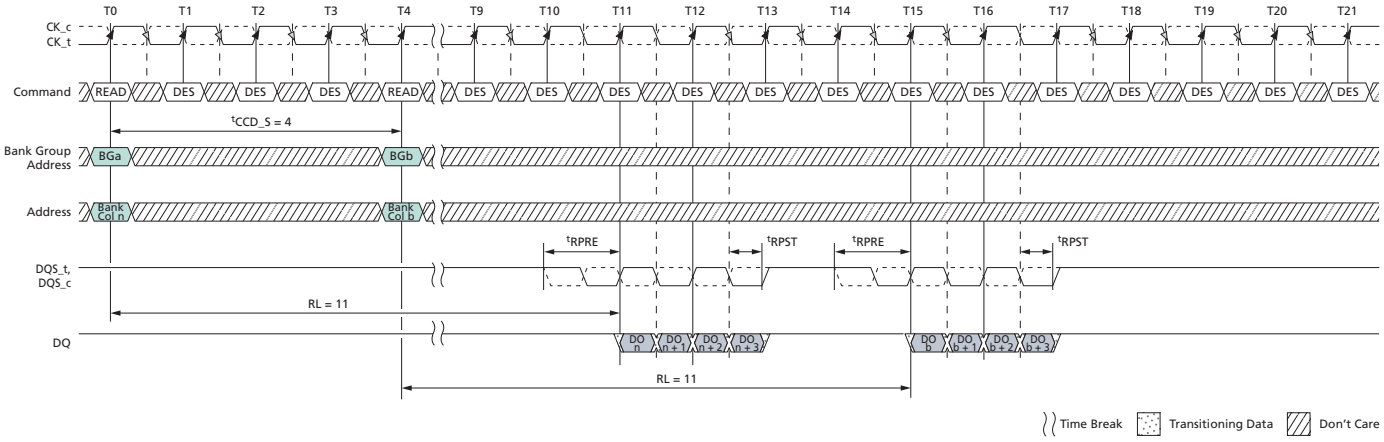

Notes:
1. BL8, AL = 0, CL = 11, Preamble = 1tCK, tCCD_S/L = 5.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and T5.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

**Figure 125: Nonconsecutive READ (BL8) with 2tCK Preamble in Same or Different Bank Group**



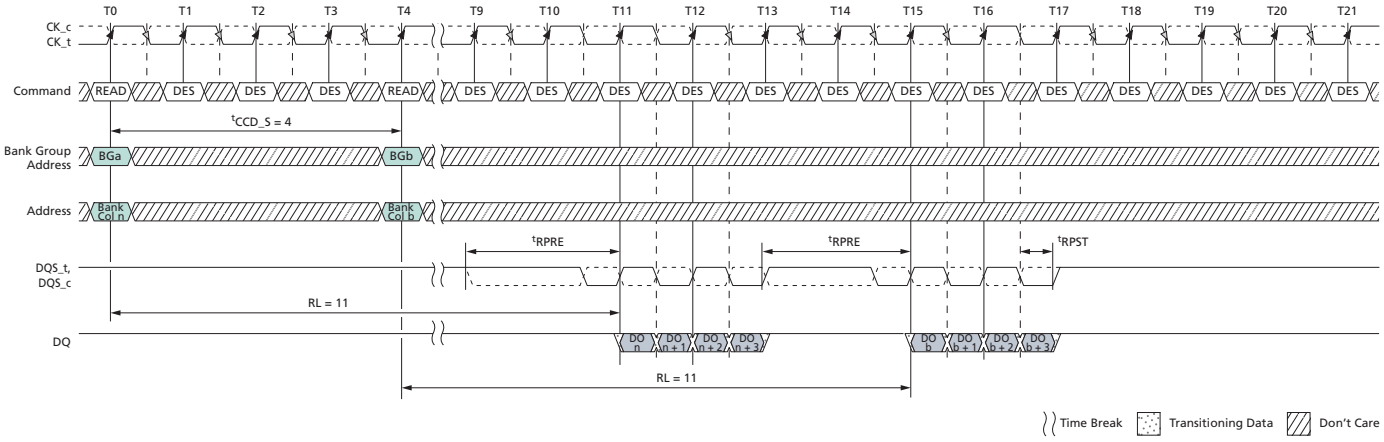

Notes:
1. BL8, AL = 0, CL = 11, Preamble = 2tCK, tCCD_S/L = 6.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[A1:0 = 00] or MR0[A1:0 = 01] and A12 = 1 during READ commands at T0 and T6.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.
6. 6 tCCD_S/L = 5 isn't allowed in 2tCK preamble mode.

**Figure 126: READ (BC4) to READ (BC4) with 1$^{t}$CK Preamble in Different Bank Group**



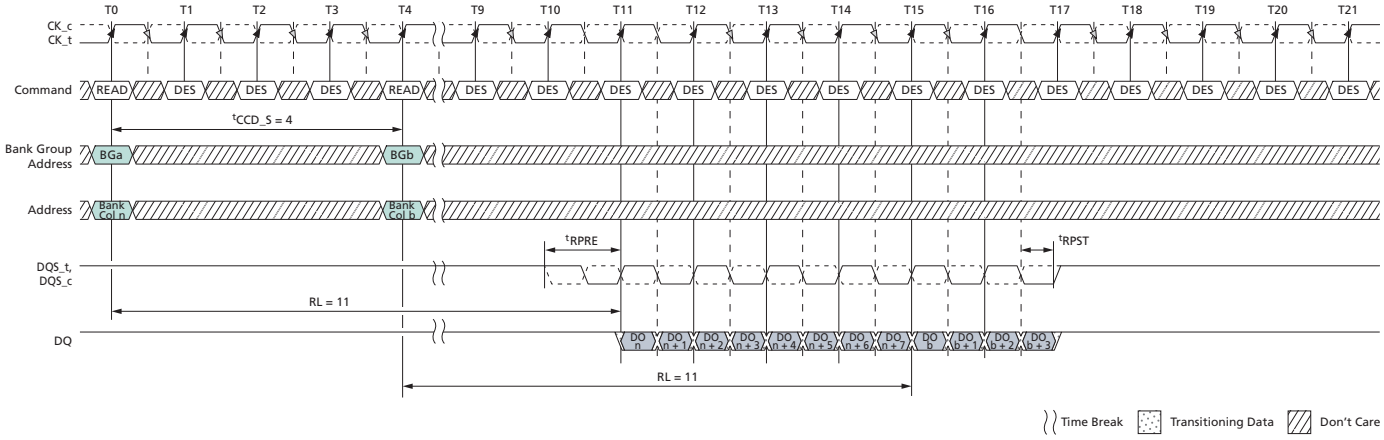

Notes:
1. BL8, AL = 0, CL = 11, Preamble = 1$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by either MR0[1:0] = 10 or MR0[1:0] = 01 and A12 = 0 during READ commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

**Figure 127: READ (BC4) to READ (BC4) with 2$^{t}$CK Preamble in Different Bank Group**



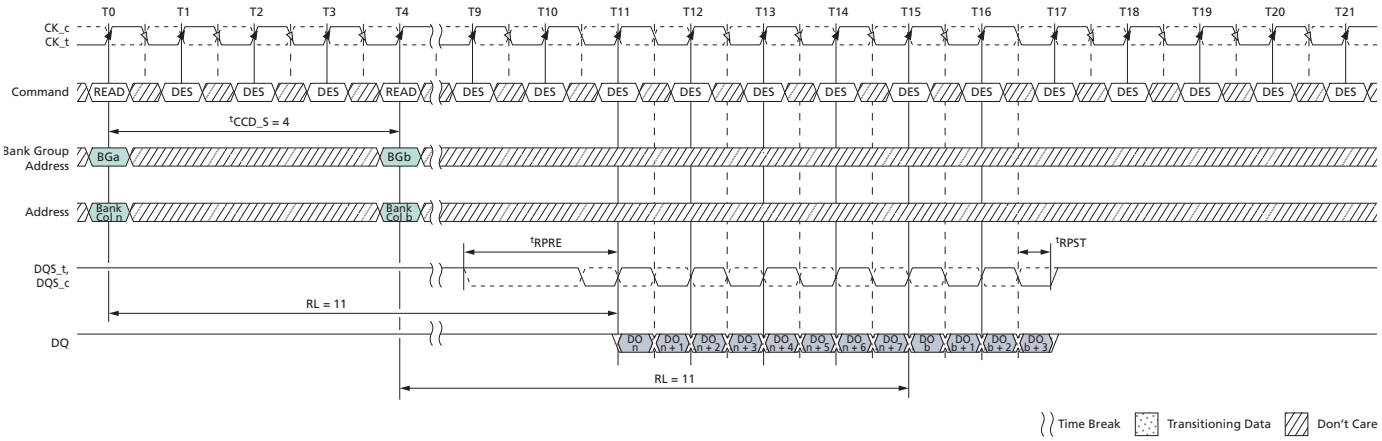

Notes:
1. BL8, AL = 0, CL = 11, Preamble = 2$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by either MR0[1:0] = 10 or MR0[1:0] = 01 and A12 = 0 during READ commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

**Figure 128: READ (BL8) to READ (BC4) OTF with 1$^{t}$CK Preamble in Different Bank Group**



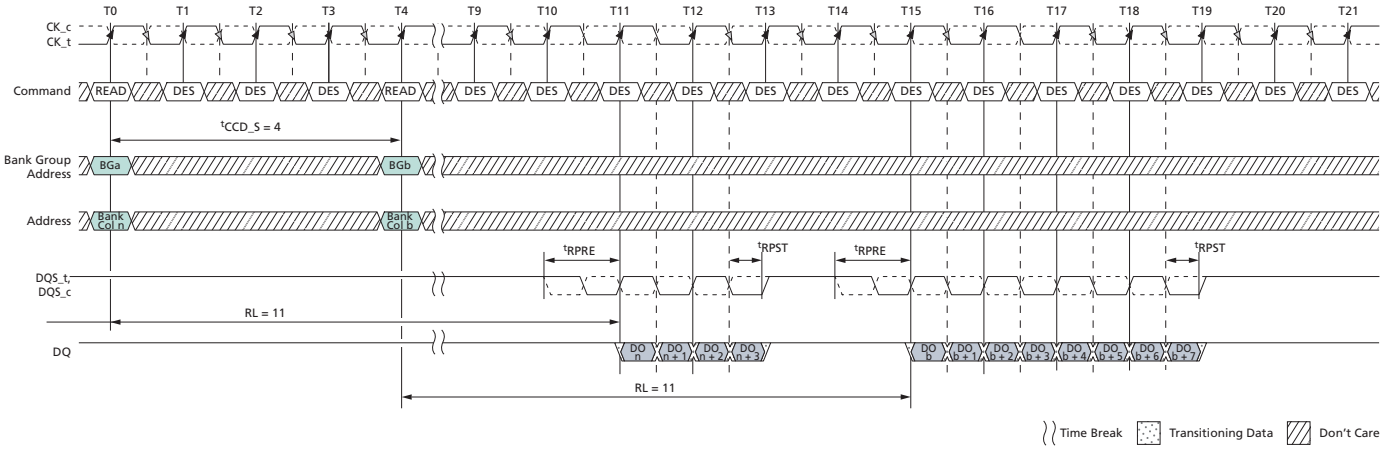

Notes:
1. BL = 8, AL = 0, CL = 11, Preamble = 1$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T0. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during READ commands at T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

**Figure 129: READ (BL8) to READ (BC4) OTF with 2$^{t}$CK Preamble in Different Bank Group**



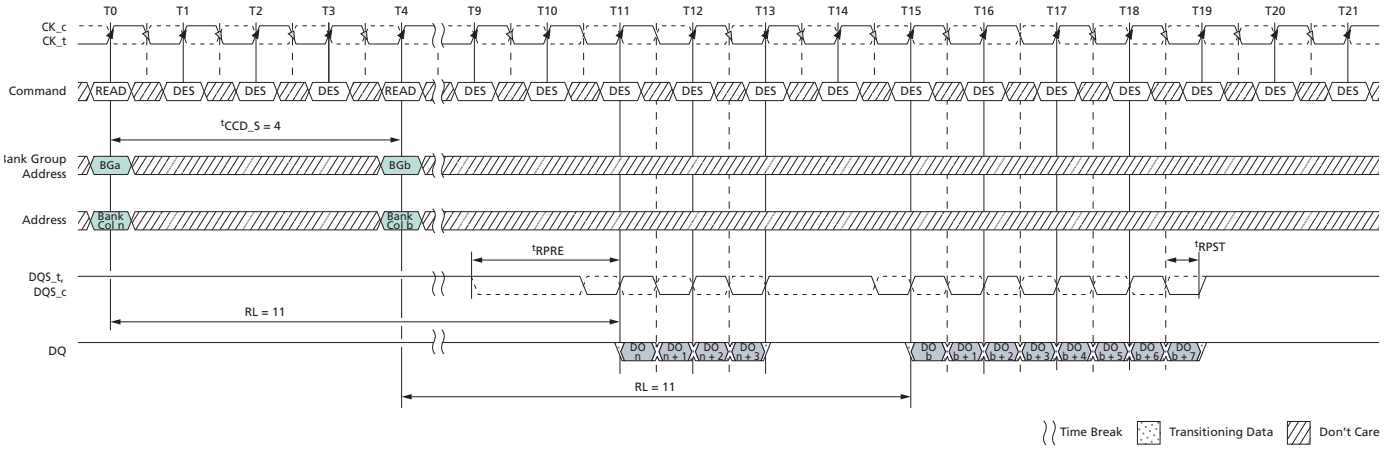

Notes:
1. BL = 8, AL =0, CL = 11, Preamble = 2$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T0. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during READ commands at T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

### Figure 130: READ (BC4) to READ (BL8) OTF with 1$^{t}$CK Preamble in Different Bank Group




Notes:
1. BL = 8, AL =0, CL = 11, Preamble = 1$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during READ commands at T0. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

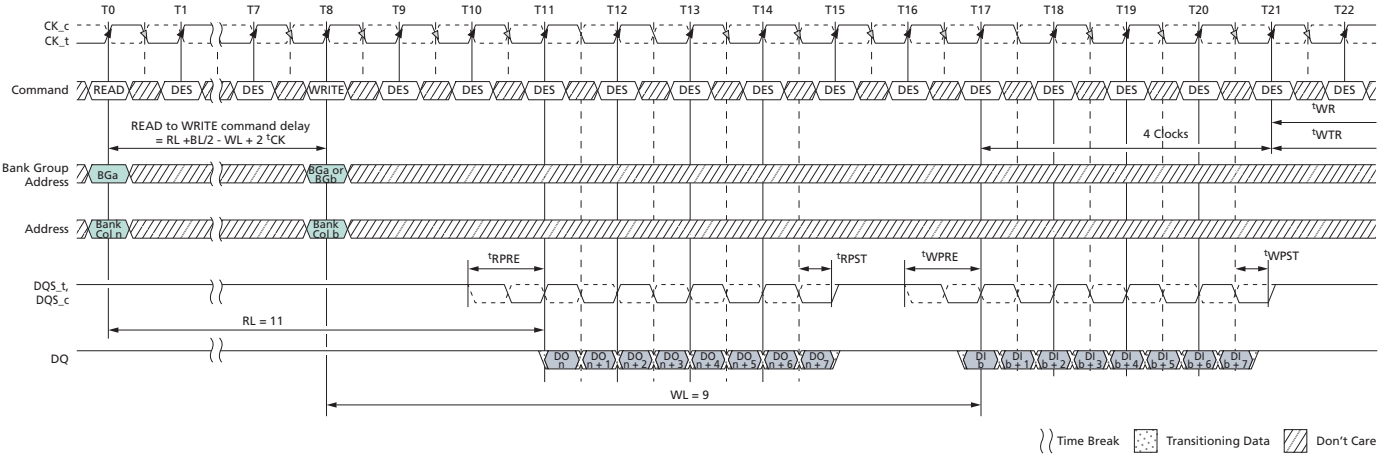
### Figure 131: READ (BC4) to READ (BL8) OTF with 2$^{t}$CK Preamble in Different Bank Group




Notes:
1. BL = 8, AL = 0, CL = 11, Preamble = 2$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during READ commands at T0. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

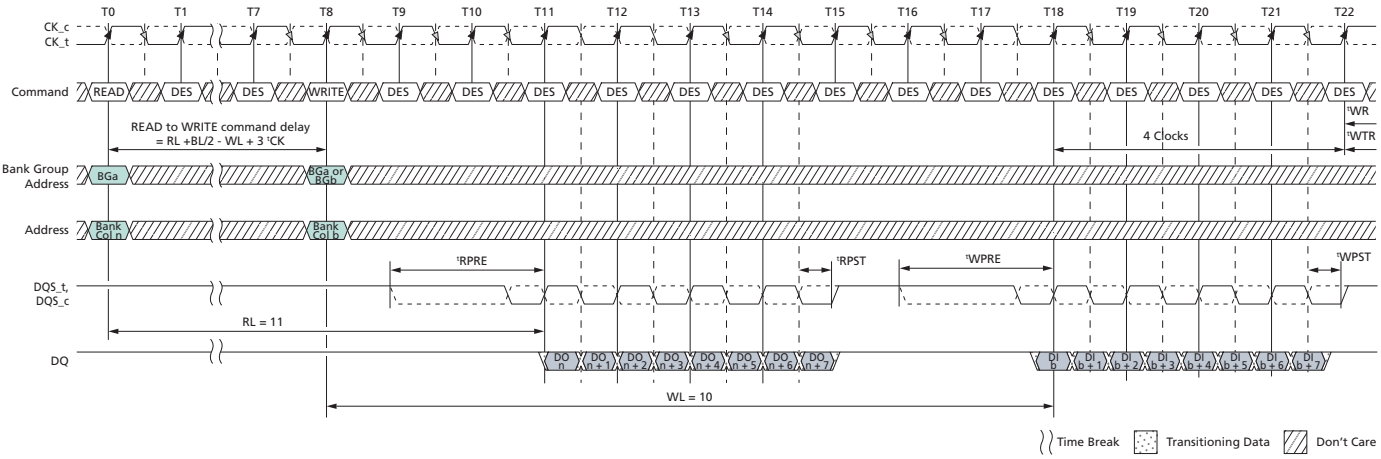
## READ Operation Followed by WRITE Operation

### Figure 132: READ (BL8) to WRITE (BL8) with 1$^{t}$CK Preamble in Same or Different Bank Group




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 1$^{t}$CK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1$^{t}$CK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and WRITE commands at T8.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

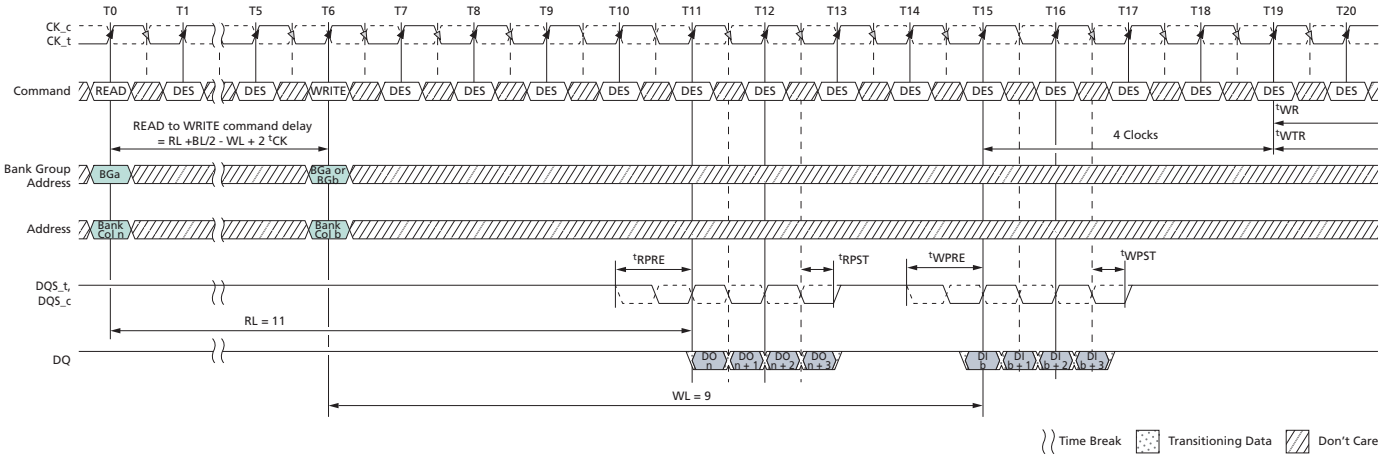
### Figure 133: READ (BL8) to WRITE (BL8) with 2$^{t}$CK Preamble in Same or Different Bank Group




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 2$^{t}$CK, WL = 10 (CWL = 9+1 [see Note 5], AL = 0), WRITE preamble = 2$^{t}$CK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

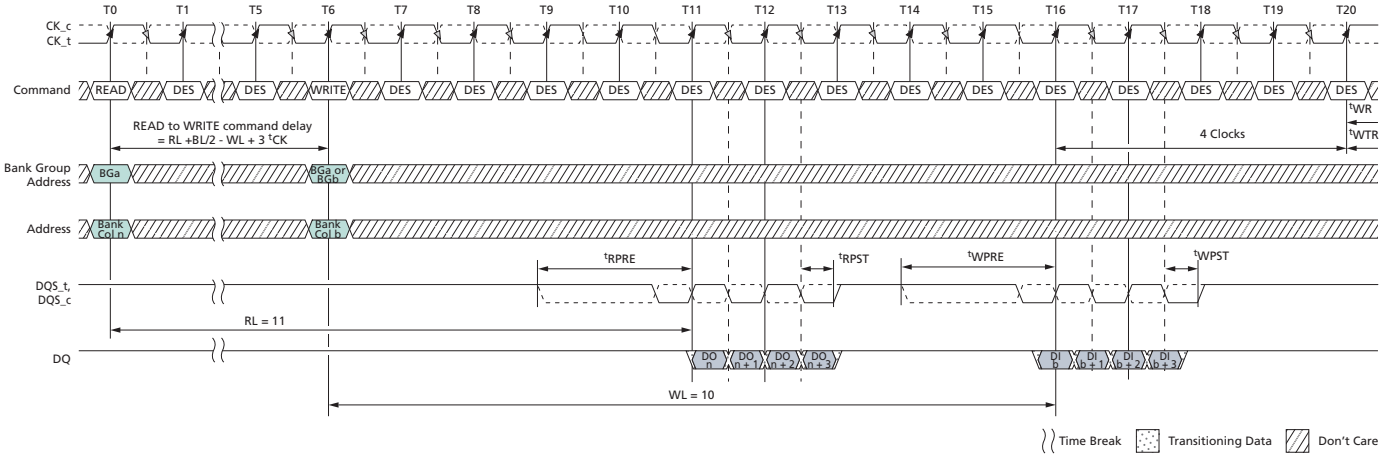
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and WRITE commands at T8.
5. When operating in 2$^{t}$CK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

**Figure 134: READ (BC4) OTF to WRITE (BC4) OTF with 1$^{t}$CK Preamble in Same or Different Bank Group**



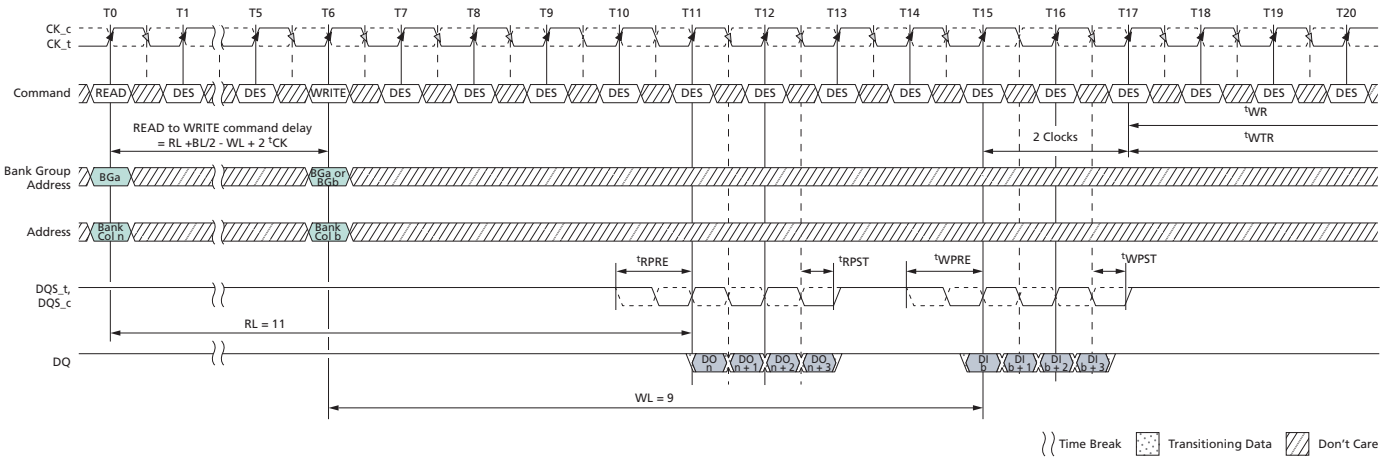

Notes:
1. BC = 4, RL = 11 (CL = 11, AL = 0), READ preamble = 1$^{t}$CK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1$^{t}$CK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 (OTF) setting activated by MR0[1:0] = 01 and A12 = 0 during READ commands at T0 and WRITE commands at T6.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

### Figure 135: READ (BC4) OTF to WRITE (BC4) OTF with 2tCK Preamble in Same or Different Bank Group




Notes:
1. BC = 4, RL = 11 (CL = 11, AL = 0), READ preamble = 2tCK, WL = 10 (CWL = 9 + 1 [see Note 5], AL = 0), WRITE preamble = 2tCK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 (OTF) setting activated by MR0[1:0] = 01 and A12 = 0 during READ commands at T0 and WRITE commands at T6.
5. When operating in 2tCK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

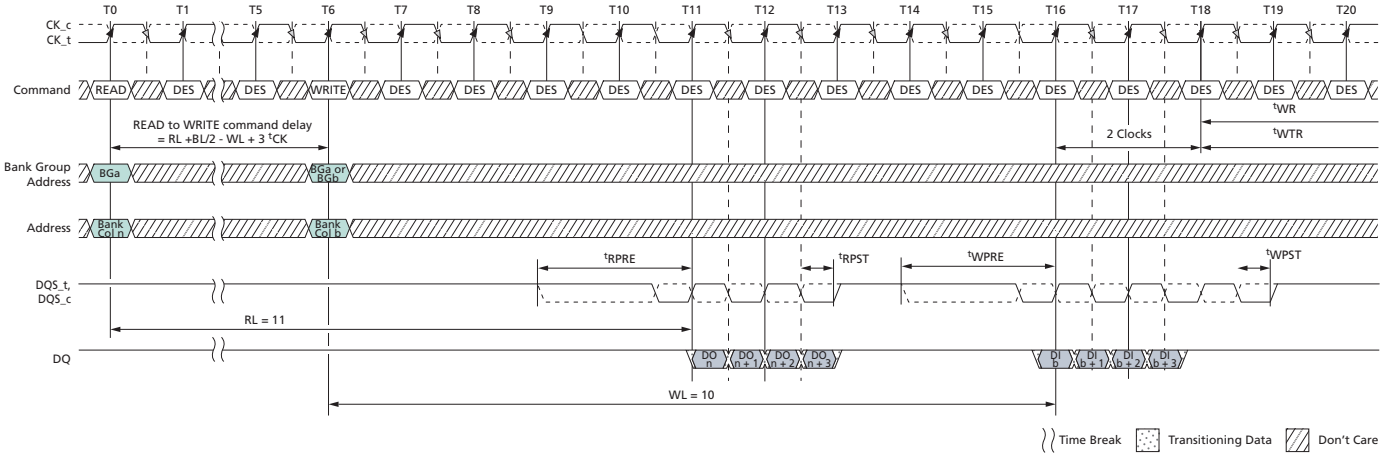
### Figure 136: READ (BC4) Fixed to WRITE (BC4) Fixed with 1tCK Preamble in Same or Different Bank Group




Notes:
1. BC = 4, RL = 11 (CL = 11, AL = 0), READ preamble = 1tCK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1tCK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.

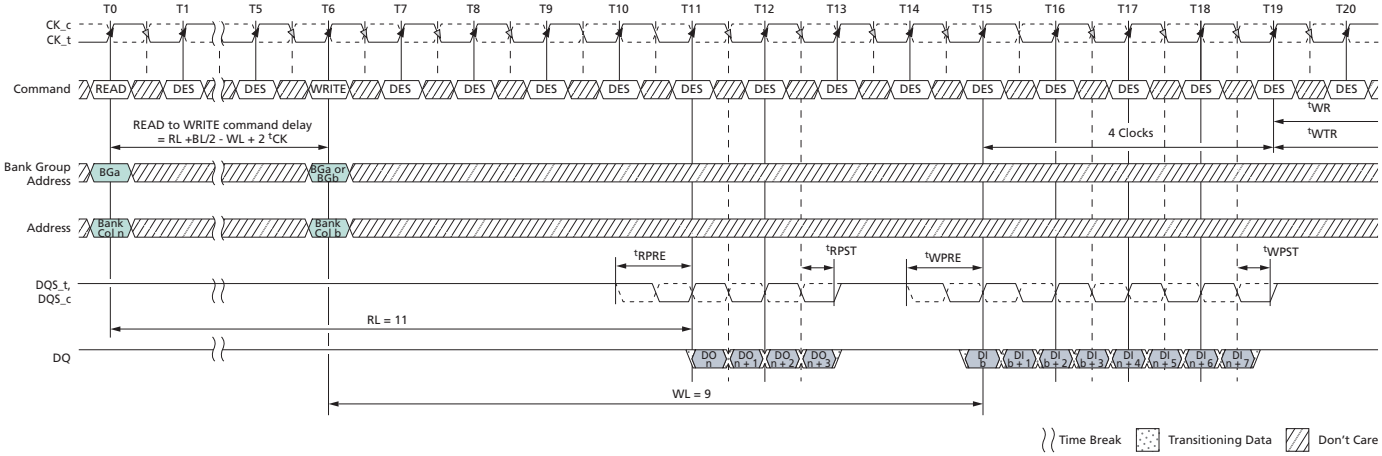
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 (fixed) setting activated by MR0[1:0] = 01.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

**Figure 137: READ (BC4) Fixed to WRITE (BC4) Fixed with 2$^{t}$CK Preamble in Same or Different Bank Group**



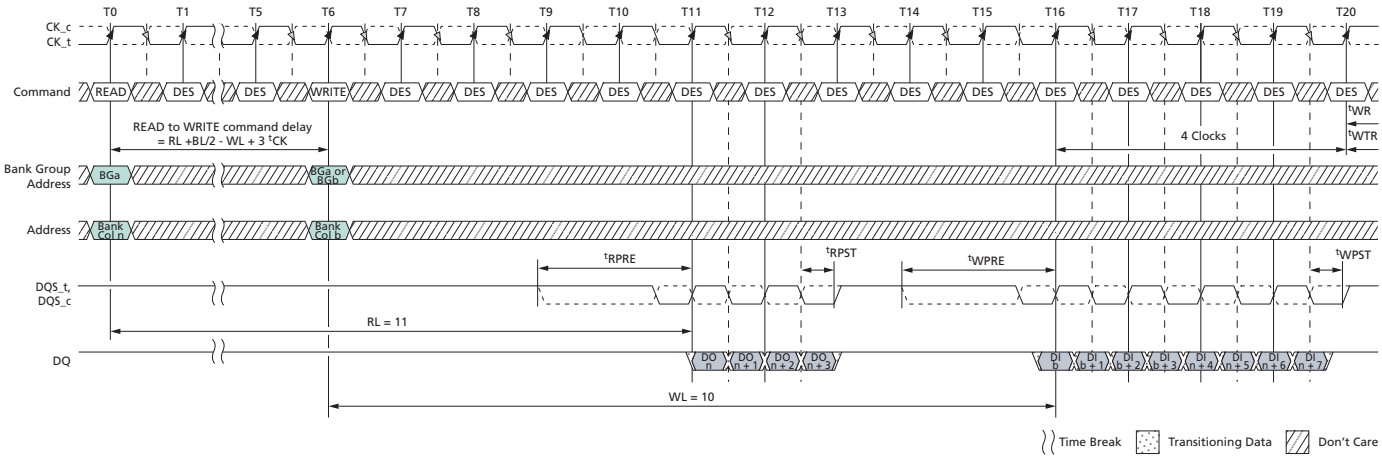

Notes:
1. BC = 4, RL = 11 (CL = 11, AL = 0), READ preamble = 2$^{t}$CK, WL = 9 (CWL = 9 + 1 [see Note 5], AL = 0), WRITE preamble = 2$^{t}$CK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 (fixed) setting activated by MR0[1:0] = 10.
5. When operating in 2$^{t}$CK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

**Figure 138: READ (BC4) to WRITE (BL8) OTF with 1tCK Preamble in Same or Different Bank Group**




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 1tCK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1tCK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T0. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T6.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

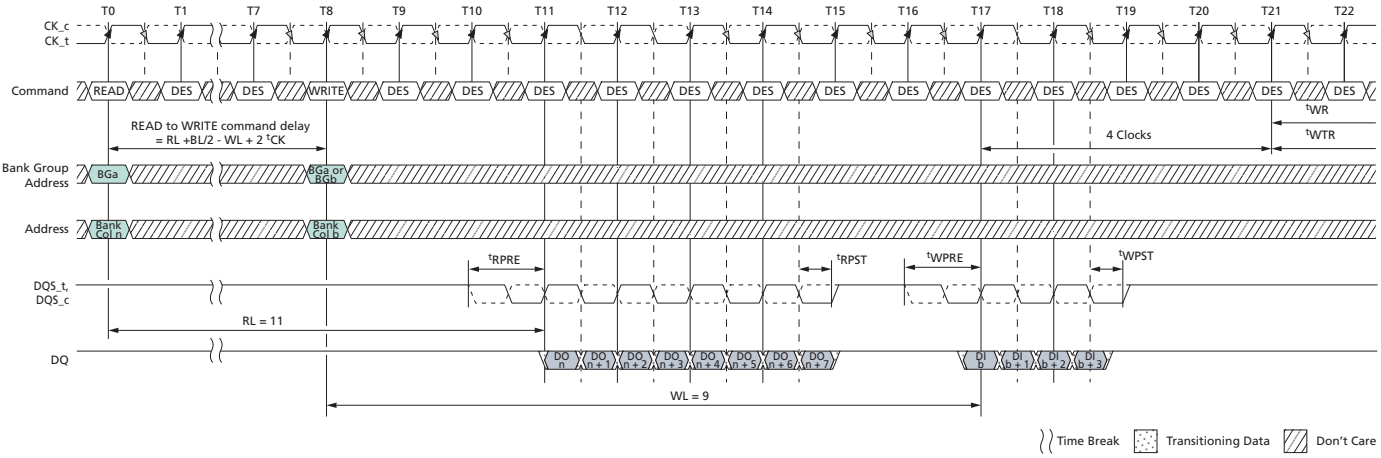
**Figure 139: READ (BC4) to WRITE (BL8) OTF with 2tCK Preamble in Same or Different Bank Group**




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 2tCK, WL = 10 (CWL = 9 + 1 [see Note 5], AL = 0), WRITE preamble = 2tCK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T0. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T6.

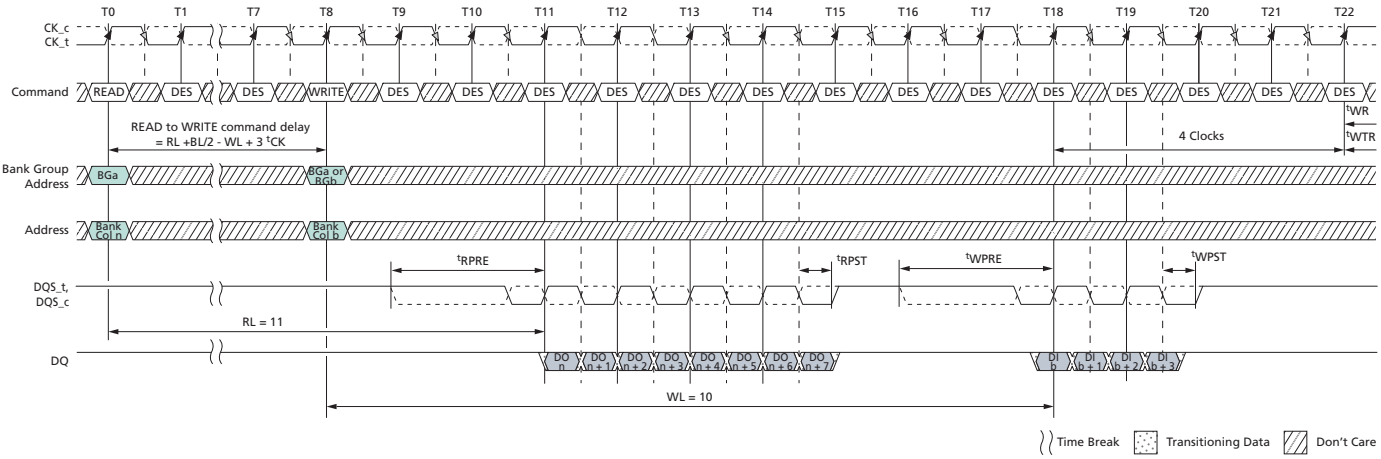
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

**Figure 140: READ (BL8) to WRITE (BC4) OTF with 1tCK Preamble in Same or Different Bank Group**




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 1tCK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1tCK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T0. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T8.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

**Figure 141: READ (BL8) to WRITE (BC4) OTF with 2tCK Preamble in Same or Different Bank Group**




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 2tCK, WL = 10 (CWL = 9 + 1 [see Note 5], AL = 0), WRITE preamble = 2tCK.
2. DO *n* = data-out from column *n*; DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

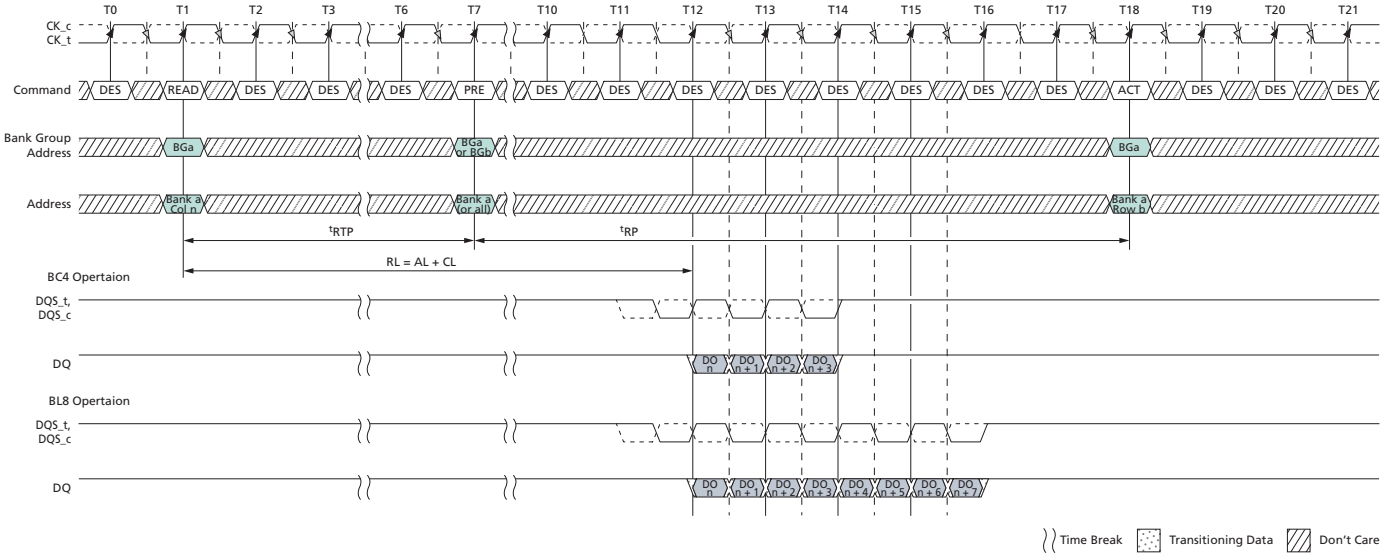
4. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during READ commands at T0. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T8.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

## READ Operation Followed by PRECHARGE Operation

The minimum external READ command to PRECHARGE command spacing to the same bank is equal to AL + $^{t}$RTP with $^{t}$RTP being the internal READ command to PRECHARGE command delay. Note that the minimum ACT to PRE timing, $^{t}$RAS, must be satisfied as well. The minimum value for the internal READ command to PRECHARGE command delay is given by $^{t}$RTP (MIN) = MAX (4 × *n*CK, 7.5ns). A new bank ACTIVATE command may be issued to the same bank if the following two conditions are satisfied simultaneously:

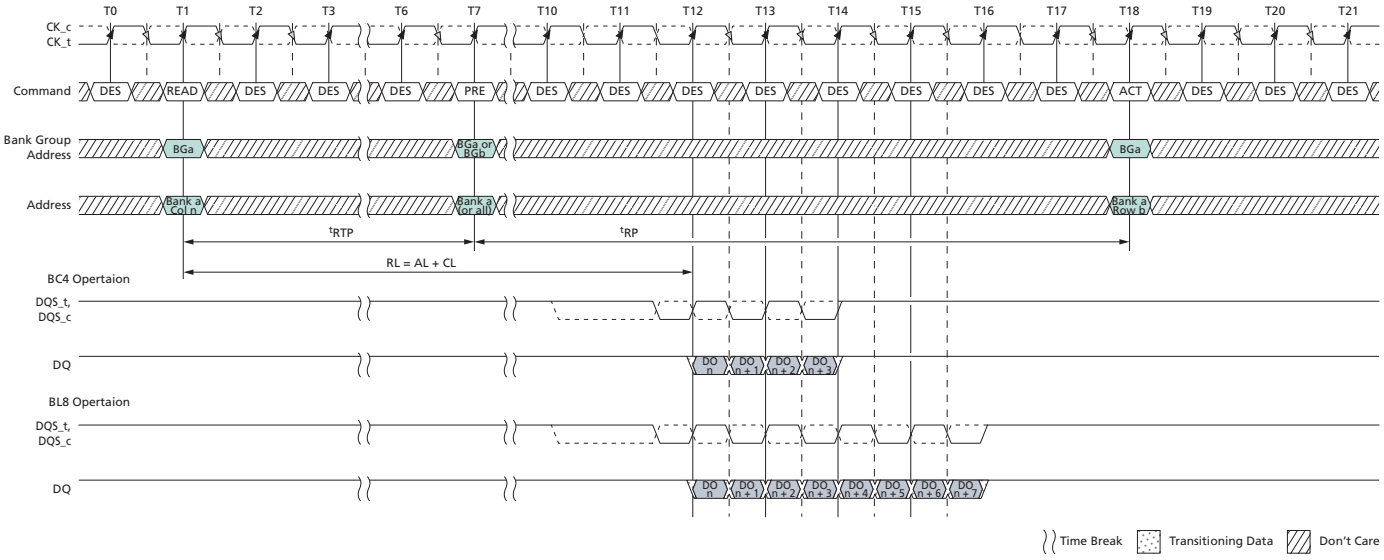
- The minimum RAS precharge time ($^{t}$RP [MIN]) has been satisfied from the clock at which the precharge begins.
- The minimum RAS cycle time ($^{t}$RC [MIN]) from the previous bank activation has been satisfied.

**Figure 142: READ to PRECHARGE with 1$^{t}$CK Preamble**



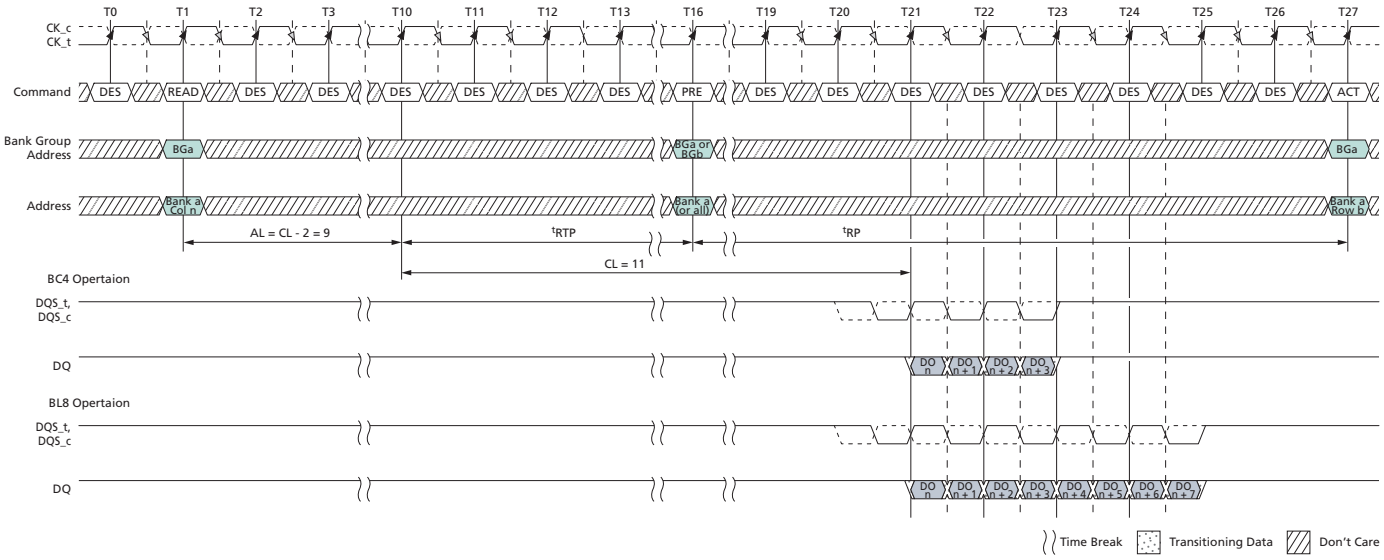

Notes:
1. RL = 11 (CL = 11, AL = 0 ), Preamble = 1$^{t}$CK, $^{t}$RTP = 6, $^{t}$RP = 11.
2. DO *n* = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. The example assumes that $^{t}$RAS (MIN) is satisfied at the PRECHARGE command time (T7) and that $^{t}$RC (MIN) is satisfied at the next ACTIVATE command time (T18).
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

### Figure 143: READ to PRECHARGE with 2tCK Preamble




Notes:
1. RL = 11 (CL = 11, AL = 0 ), Preamble = 2tCK, tRTP = 6, tRP = 11.
2. DO *n* = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. The example assumes that tRAS (MIN) is satisfied at the PRECHARGE command time (T7) and that tRC (MIN) is satisfied at the next ACTIVATE command time (T18).
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

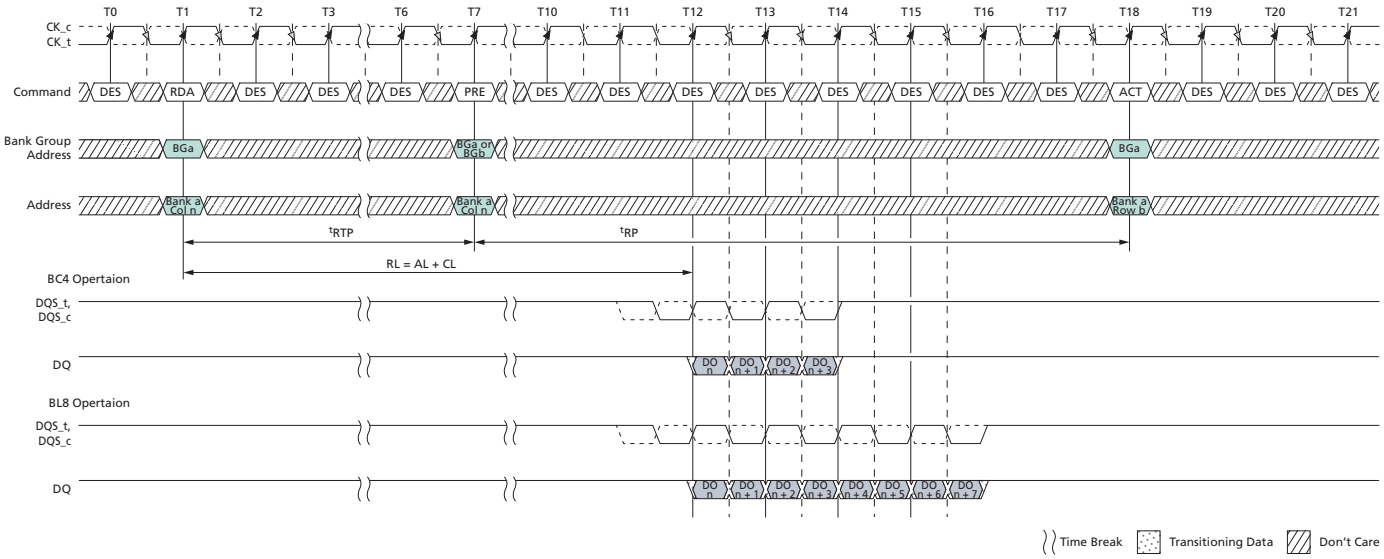
### Figure 144: READ to PRECHARGE with Additive Latency and 1tCK Preamble




Notes:
1. RL =20 (CL = 11, AL = CL - 2), Preamble = 1tCK, tRTP = 6, tRP = 11.
2. DO *n* = data-out from column *n*.

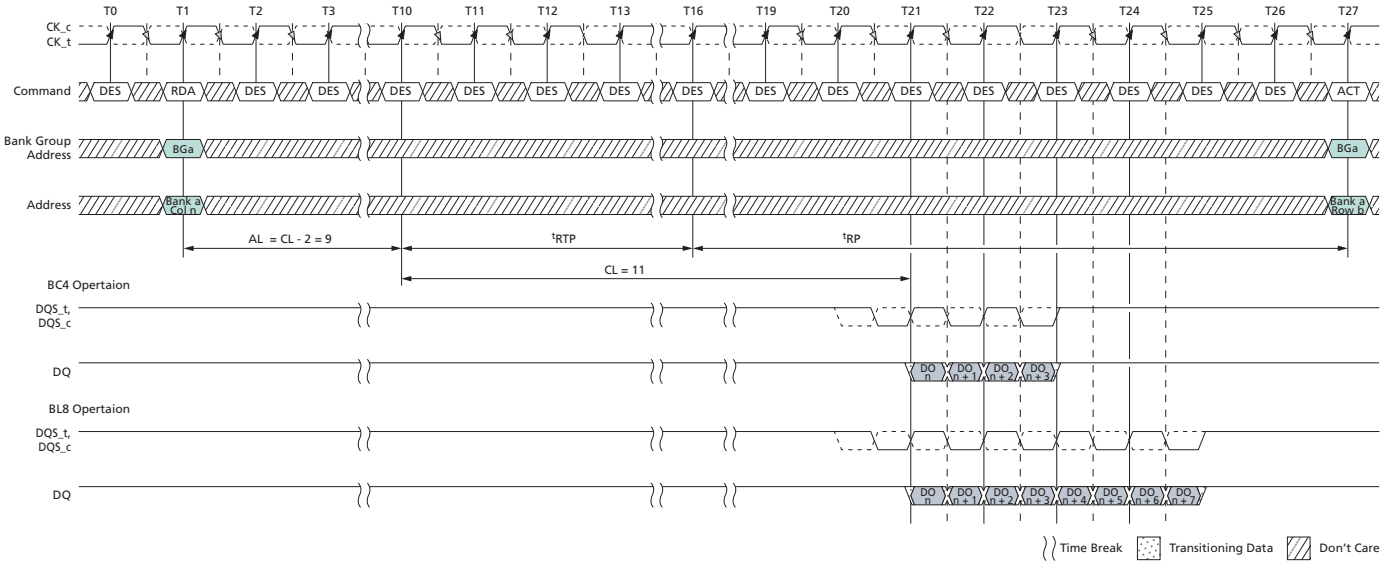
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. The example assumes that $^{t}$RAS (MIN) is satisfied at the PRECHARGE command time (T16) and that $^{t}$RC (MIN) is satisfied at the next ACTIVATE command time (T27).
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

**Figure 145: READ with Auto Precharge and 1$^{t}$CK Preamble**




Notes:
1. RL = 11 (CL = 11, AL = 0 ), Preamble = 1$^{t}$CK, $^{t}$RTP = 6, $^{t}$RP = 11.
2. DO *n* = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. $^{t}$RTP = 6 setting activated by MR0[A11:9 = 001].
5. The example assumes that $^{t}$RC (MIN) is satisfied at the next ACTIVATE command time (T18).
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

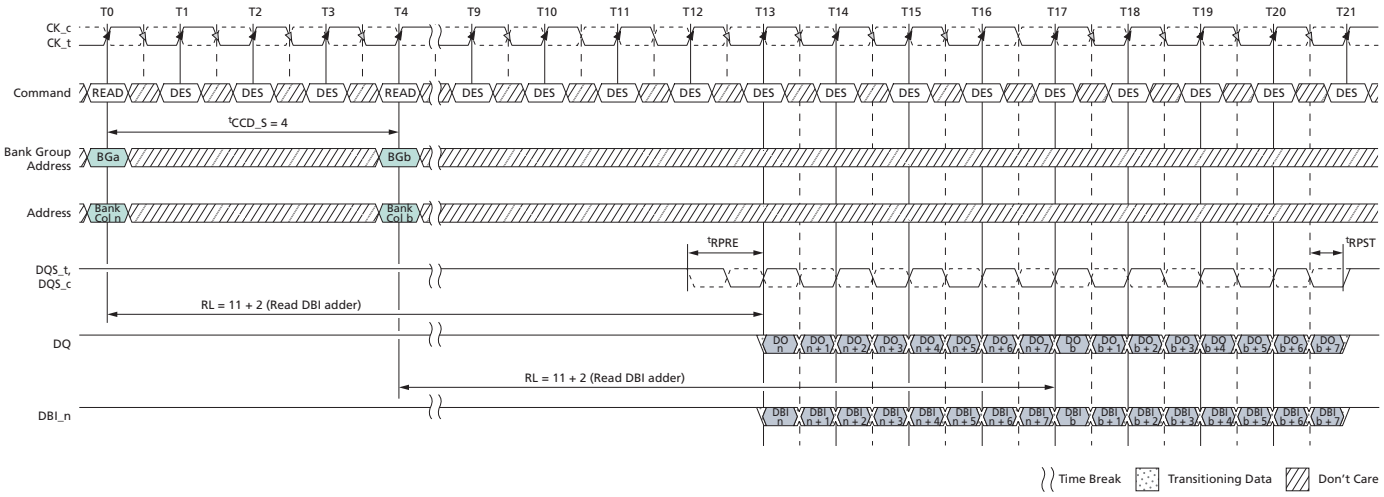
### Figure 146: READ with Auto Precharge, Additive Latency, and 1tCK Preamble




Notes:
1. RL = 20 (CL = 11, AL = CL - 2), Preamble = 1tCK, tRTP = 6, tRP = 11.
2. DO *n* = data-out from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. tRTP = 6 setting activated by MR0[11:9] = 001.
5. The example assumes that tRC (MIN) is satisfied at the next ACTIVATE command time (T27).
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

## READ Operation with Read Data Bus Inversion (DBI)

### Figure 147: Consecutive READ (BL8) with 1tCK Preamble and DBI in Different Bank Group

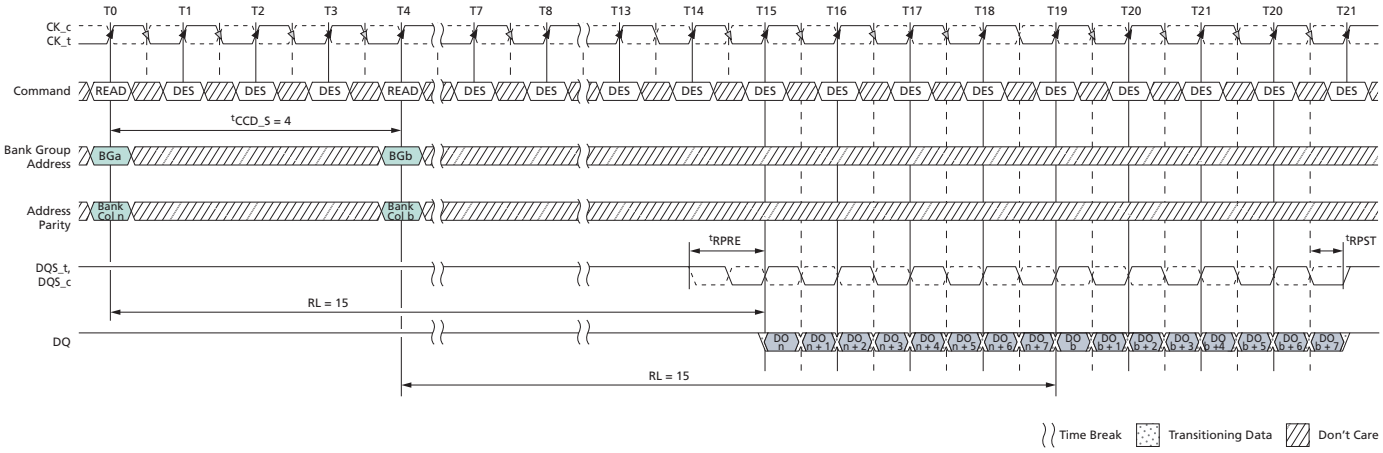



Notes:
1. BL = 8, AL = 0, CL = 11, Preamble = 1tCK, RL = 11 + 2 (Read DBI adder).

2. DO *n* (or *b*) = data-out from column *n* (or *b*); DBI *n* (or *b*) = data bus inversion from column *n* (or *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Enable.

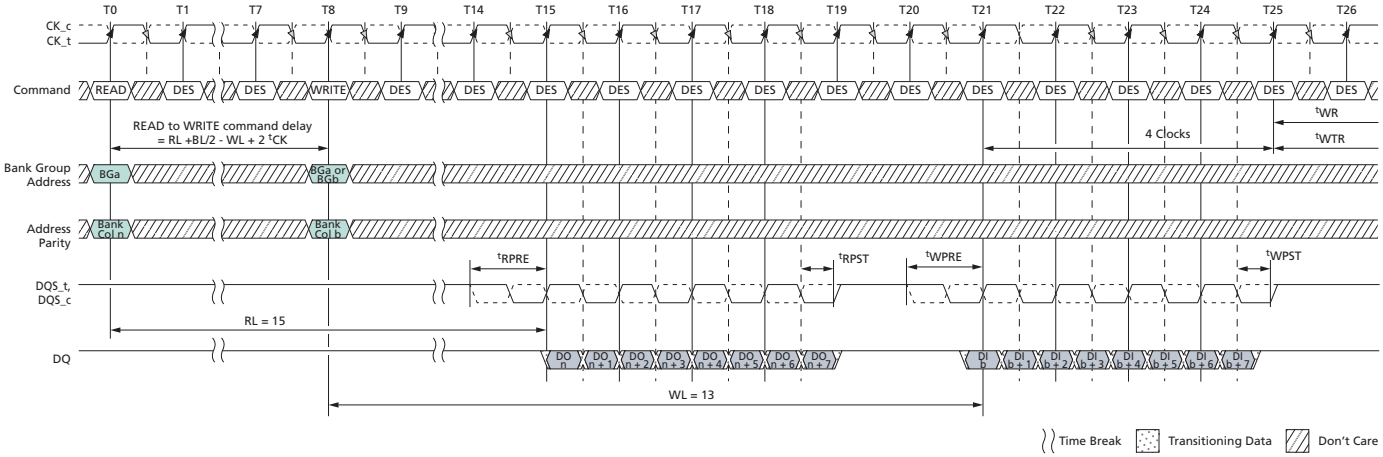
## READ Operation with Command/Address Parity (CA Parity)

### Figure 148: Consecutive READ (BL8) with 1$^{t}$CK Preamble and CA Parity in Different Bank Group




Notes:
1. BL = 8, AL = 0, CL = 11, PL = 4, (RL = CL + AL + PL = 15), Preamble = 1$^{t}$CK.
2. DO *n* (or *b*) = data-out from column *n* (or *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[A1:A0 = 00] or MR0[A1:A0 = 01] and A12 = 1 during READ commands at T0 and T4.
5. CA parity = Enable, CS to CA latency = Disable, Read DBI = Disable.

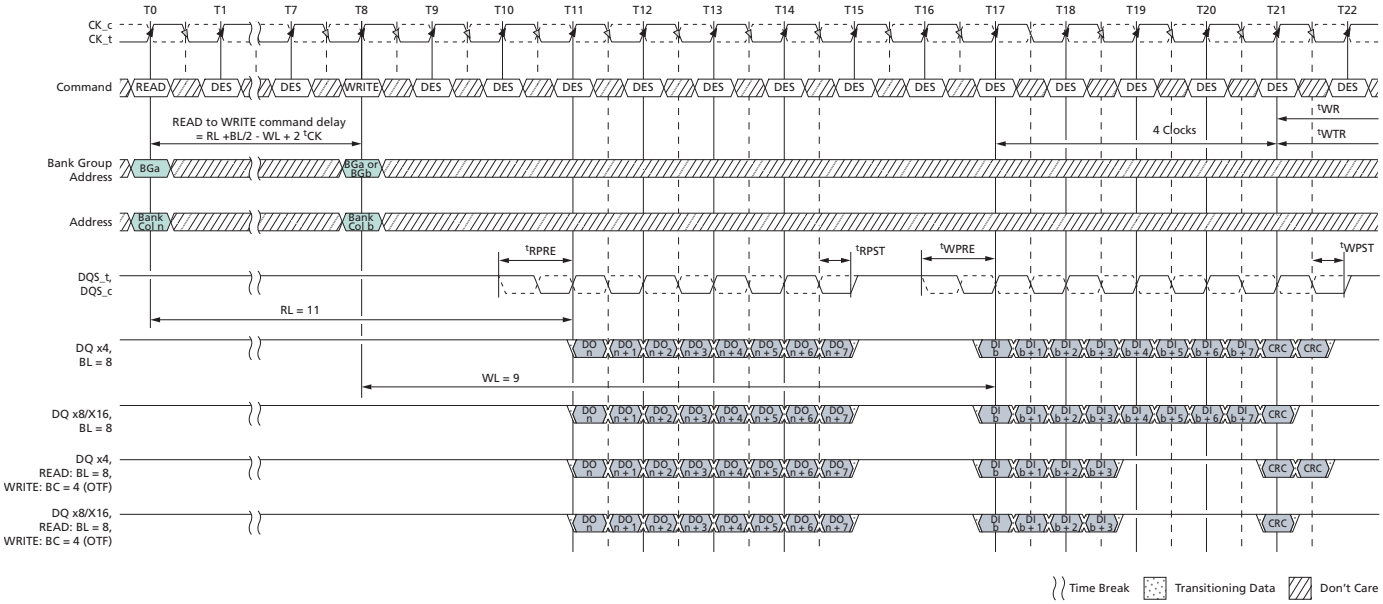
**Figure 149: READ (BL8) to WRITE (BL8) with 1tCK Preamble and CA Parity in Same or Different Bank Group**




Notes:
1. BL = 8, AL = 0, CL = 11, PL = 4, (RL = CL + AL + PL = 15), READ preamble = 1tCK, CWL = 9, AL = 0, PL = 4, (WL = CL + AL + PL = 13), WRITE preamble = 1tCK.
2. DO *n* = data-out from column *n*, DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and WRITE command at T8.
5. CA parity = Enable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.

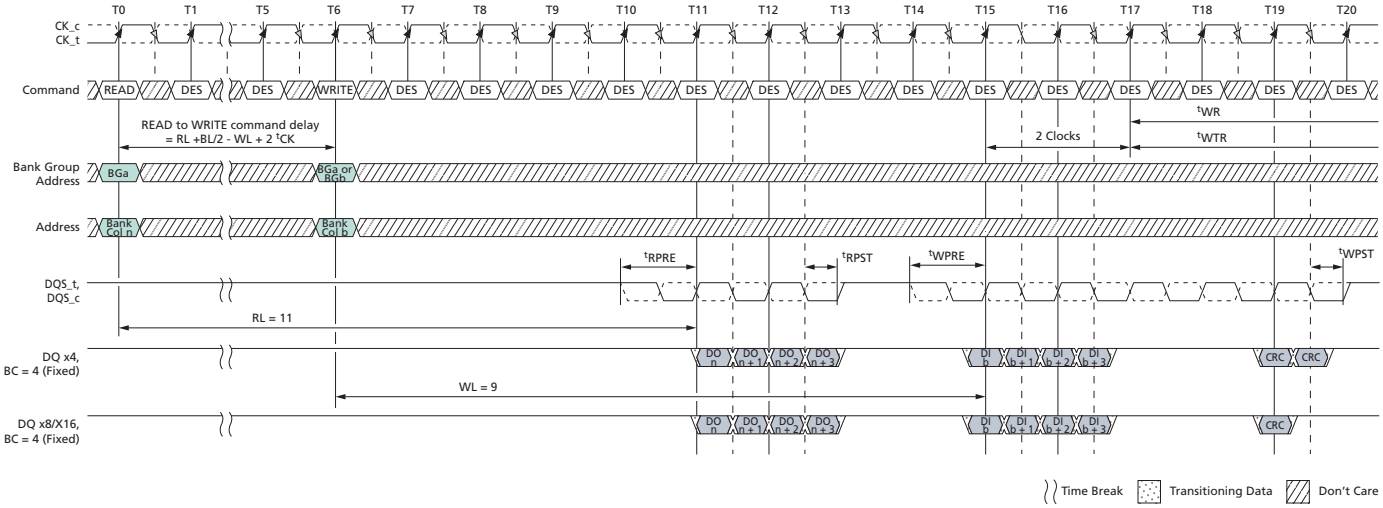
## READ Followed by WRITE with CRC Enabled

### Figure 150: READ (BL8) to WRITE (BL8 or BC4: OTF) with 1tCK Preamble and Write CRC in Same or Different Bank Group




Notes:
1. BL = 8 (or BC = 4: OTF for Write), RL = 11 (CL = 11, AL = 0), READ preamble = 1tCK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1tCK.
2. DO *n* = data-out from column *n*, DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T0 and WRITE commands at T8.
5. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T8.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Enable.

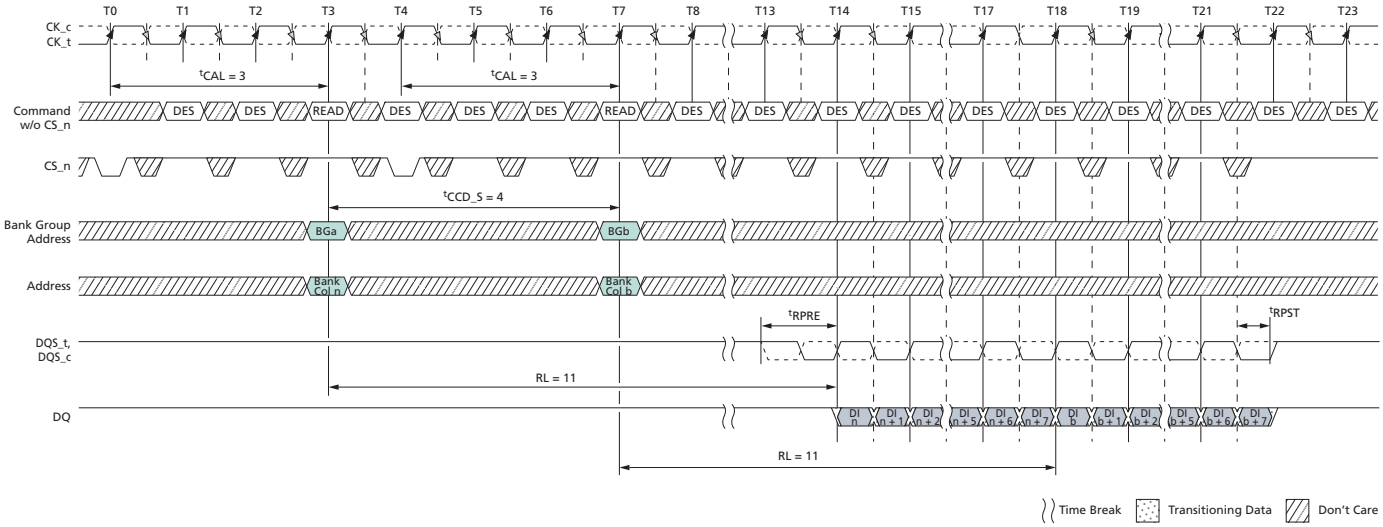
**Figure 151: READ (BC4: Fixed) to WRITE (BC4: Fixed) with 1tCK Preamble and Write CRC in Same or Different Bank Group**




Notes:
1. BC = 4 (Fixed), RL = 11 (CL = 11, AL = 0), READ preamble = 1tCK, WL = 9 (CWL = 9, AL = 0), WRITE preamble = 1tCK.
2. DO *n* = data-out from column *n*, DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Enable.

## READ Operation with Command/Address Latency (CAL) Enabled

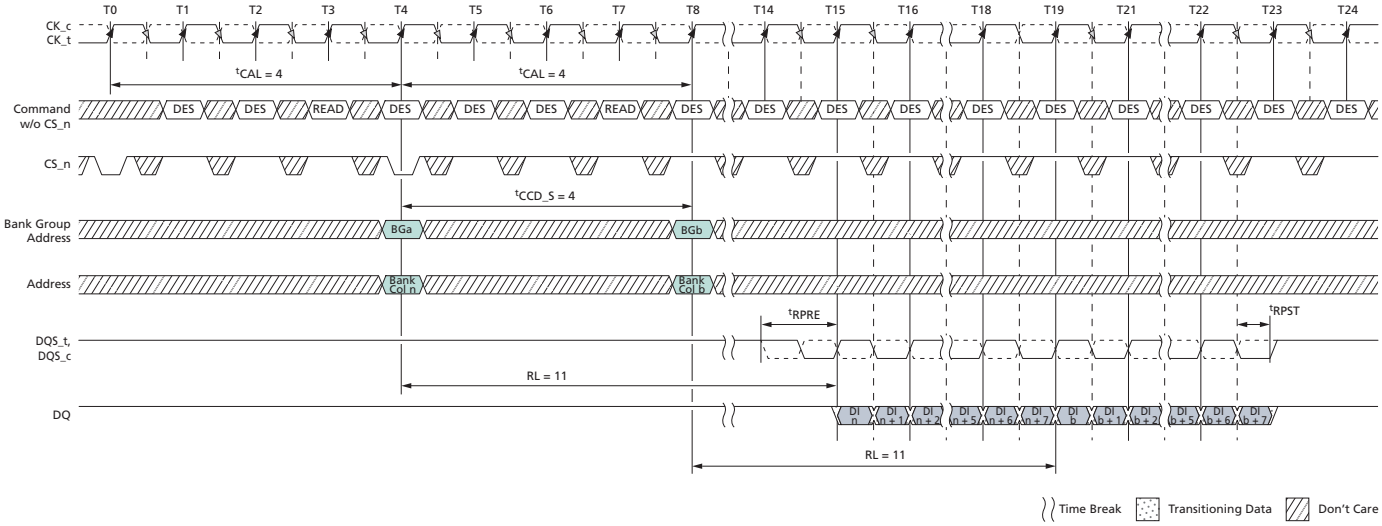
**Figure 152: Consecutive READ (BL8) with CAL (3tCK) and 1tCK Preamble in Different Bank Group**




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 1tCK.

2. DI *n* (or *b*) = data-in from column *n* (or *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T3 and T7.
5. CA parity = Disable, CS to CA latency = Enable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. Enabling CAL mode does not impact ODT control timings. The same timing relationship relative to the command/address bus as when CAL is disabled should be maintained.

**Figure 153: Consecutive READ (BL8) with CAL (4$^{t}$CK) and 1$^{t}$CK Preamble in Different Bank Group**




Notes:
1. BL = 8, RL = 11 (CL = 11, AL = 0), READ preamble = 1$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during READ commands at T3 and T8.
5. CA parity = Disable, CS to CA latency = Enable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. Enabling CAL mode does not impact ODT control timings. The same timing relationship relative to the command/address bus as when CAL is disabled should be maintained.

# WRITE Operation

## Write Timing Definitions

The write timings shown in the following figures are applicable in normal operation mode, that is, when the DLL is enabled and locked.

## Write Timing – Clock-to-Data Strobe Relationship

The clock-to-data strobe relationship is shown below and is applicable in normal operation mode, that is, when the DLL is enabled and locked.

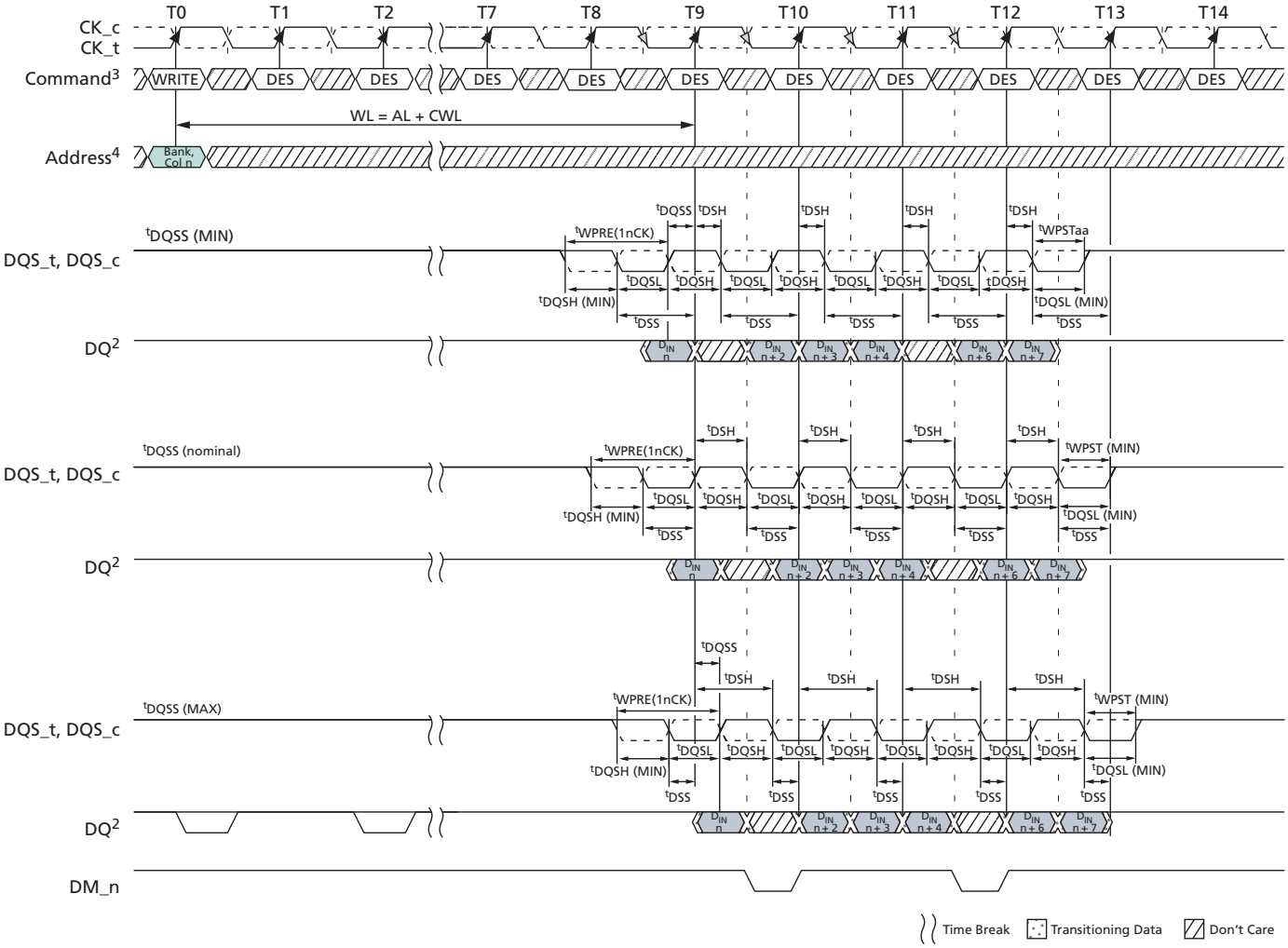
Rising data strobe edge parameters:

- $^{t}$DQSS (MIN) to $^{t}$DQSS (MAX) describes the allowed range for a rising data strobe edge relative to CK.
- $^{t}$DQSS is the actual position of a rising strobe edge relative to CK.
- $^{t}$DQSH describes the data strobe high pulse width.
- $^{t}$WPST strobe going to HIGH, nondrive level (shown in the postamble section of the graphic below).

Falling data strobe edge parameters:

- $^{t}$DQSL describes the data strobe low pulse width.
- $^{t}$WPRE strobe going to LOW, initial drive level (shown in the preamble section of the graphic below).

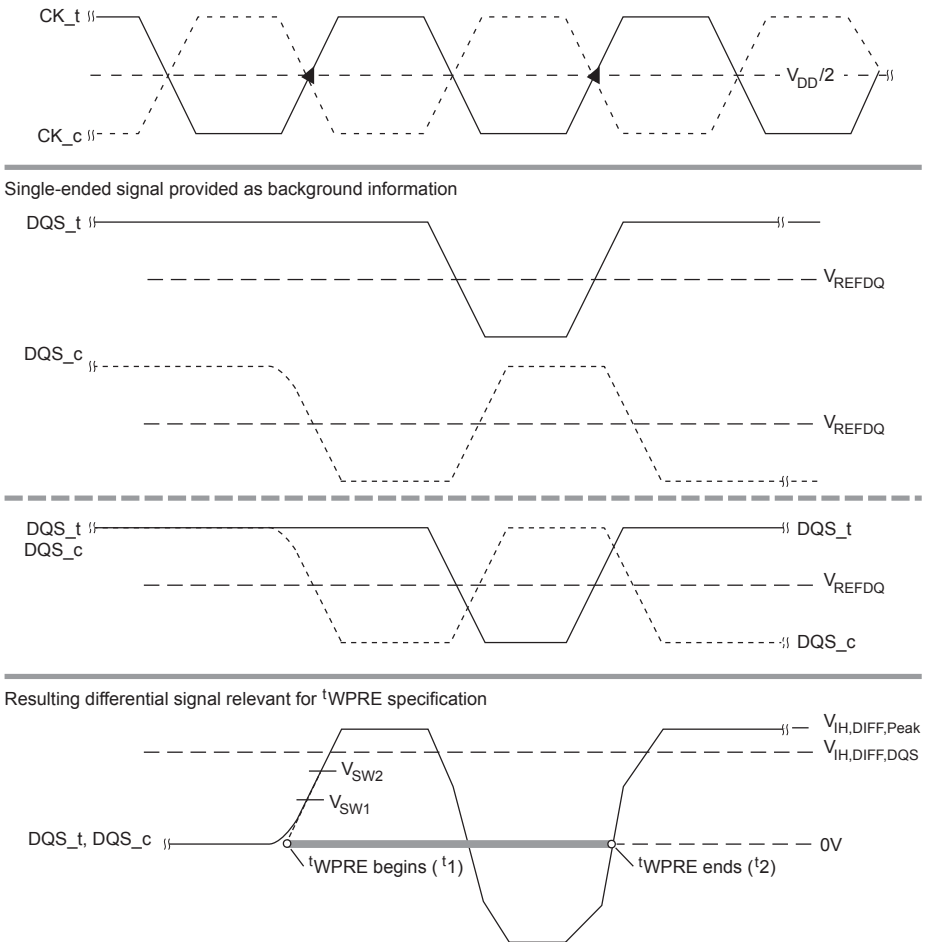
**Figure 154: Write Timing Definition**




Notes:
1. BL8, WL = 9 (AL = 0, CWL = 9).
2. $D_{IN}n$ = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. $^{t}$DQSS must be met at each rising clock edge.

## tWPRE Calculation

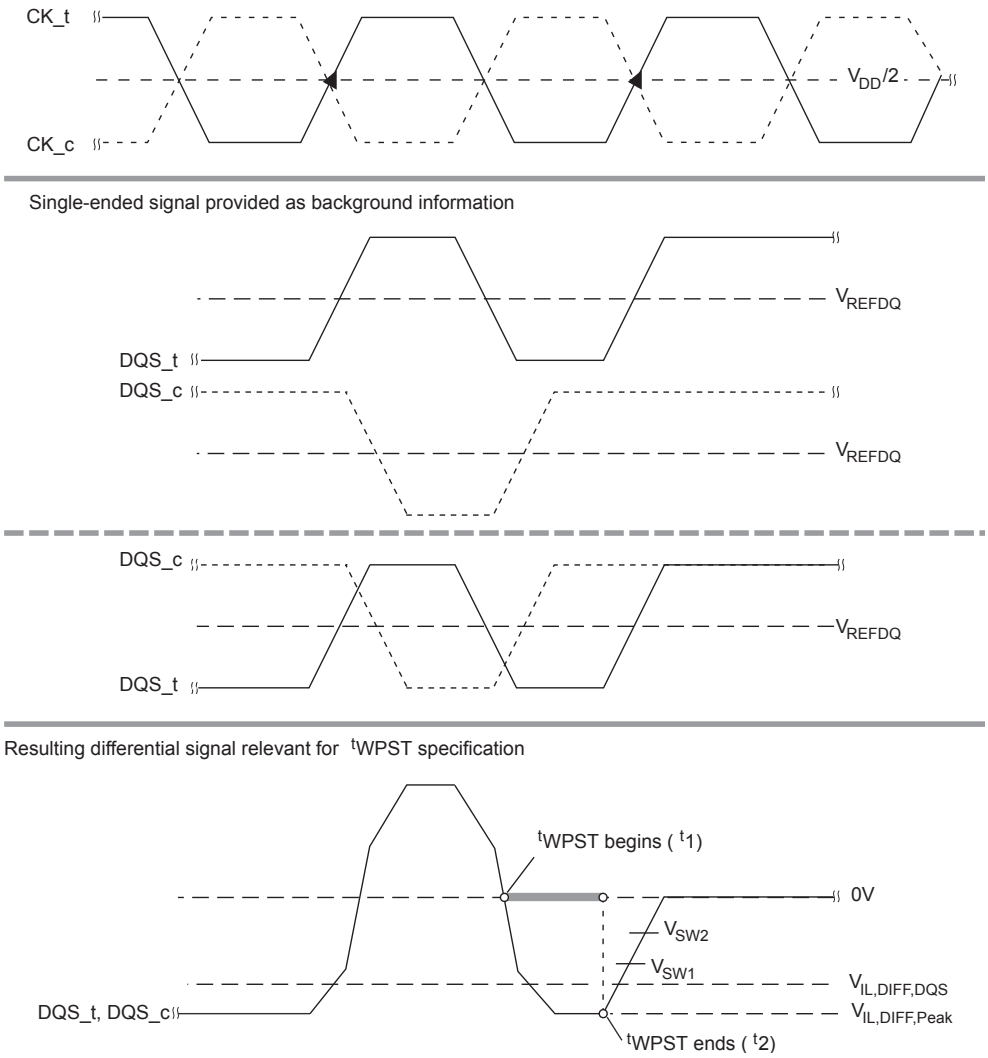
**Figure 155: tWPRE Method for Calculating Transitions and Endpoints**




Notes: 1. $V_{sw1} = (0.1) \times V_{IH,diff,DQS}$.
2. $V_{sw2} = (0.9) \times V_{IH,diff,DQS}$.

## tWPST Calculation

**Figure 156: tWPST Method for Calculating Transitions and Endpoints**

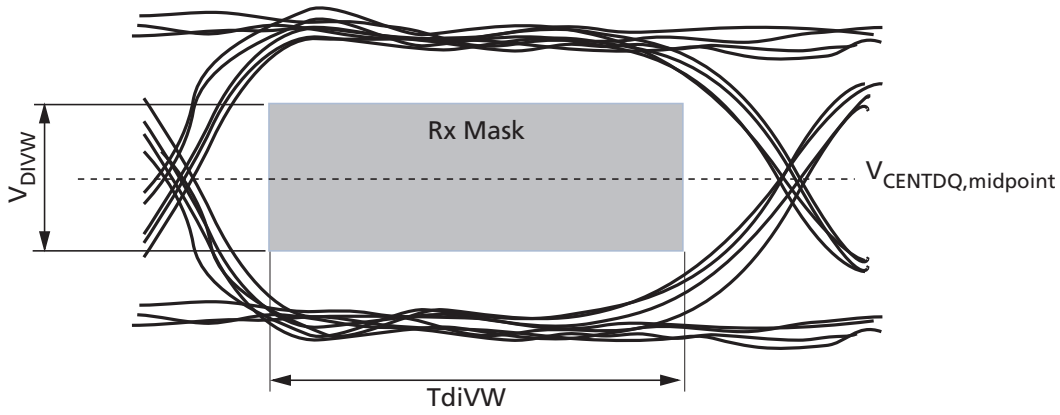



Notes: 1. $V_{sw1}$ =(0.9) × $V_{IL,diff,DQS}$.
2. $V_{sw2}$ = (0.1) × $V_{IL,diff,DQS}$.

## Write Timing – Data Strobe-to-Data Relationship

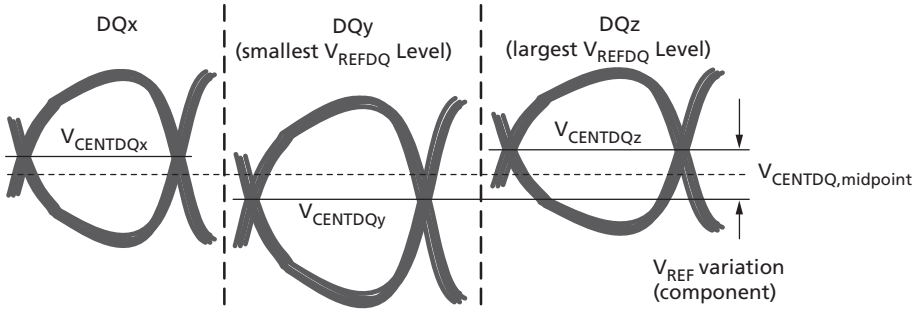
The DQ input receiver uses a compliance mask (Rx) for voltage and timing as shown in the figure below. The receiver mask (Rx mask) defines the area where the input signal must not encroach in order for the DRAM input receiver to be able to successfully capture a valid input signal. The Rx mask is not the valid data-eye. TdiVW and $V_{diVW}$ define the absolute maximum Rx mask.

**Figure 157: Rx Compliance Mask**



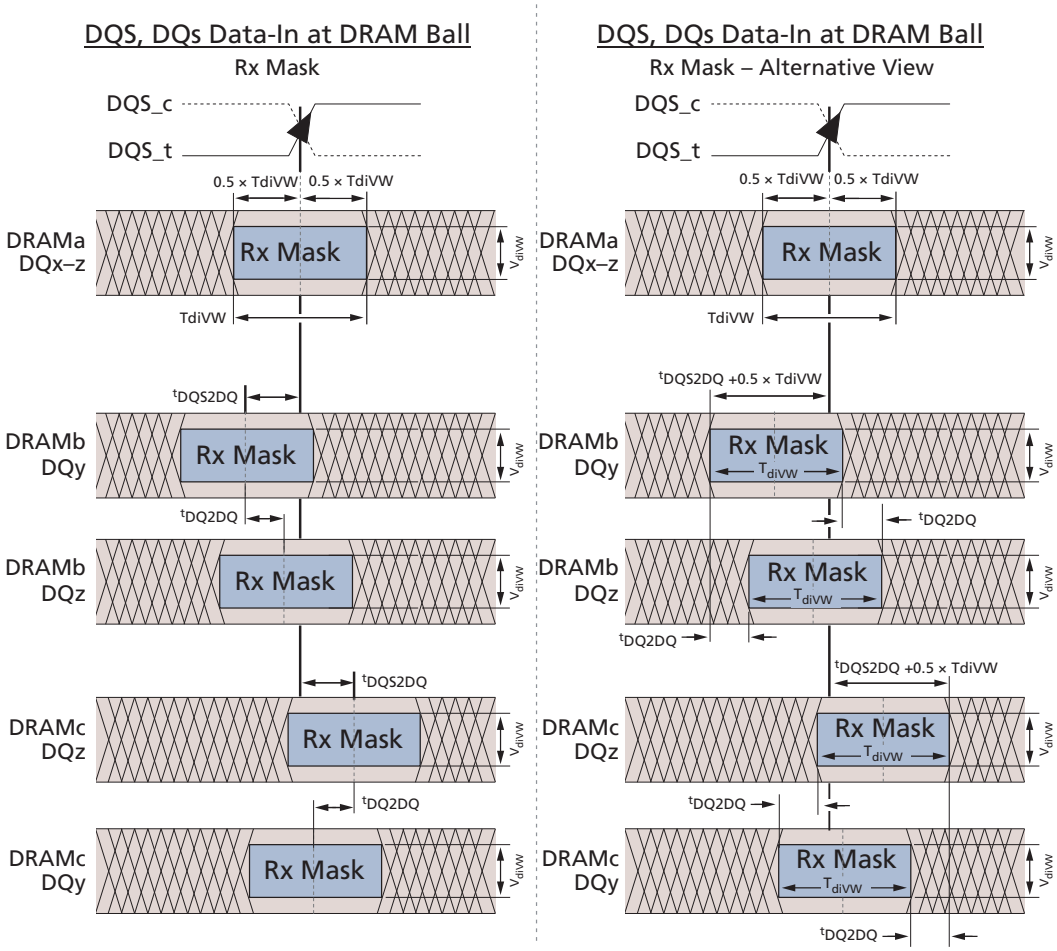

$V_{CENTDQ,midpoint}$ is defined as the midpoint between the largest $V_{REFDQ}$ voltage level and the smallest $V_{REFDQ}$ voltage level across all DQ pins for a given DRAM. Each DQ pin's $V_{REFDQ}$ is defined by the center (widest opening) of the cumulative data input eye as depicted in the following figure. This means a DRAM's level variation is accounted for within the DRAM Rx mask. The DRAM $V_{REFDQ}$ level will be set by the system to account for $R_{ON}$ and ODT settings.

**Figure 158: $V_{CENT\_DQ}$ $V_{REFDQ}$ Voltage Variation**




The following figure shows the Rx mask requirements both from a midpoint-to-mid-point reference (left side) and from an edge-to-edge reference. The intent is not to add any new requirement or specification between the two but rather how to convert the relationship between the two methodologies. The minimum data-eye shown in the composite view is not actually obtainable due to the minimum pulse width requirement.

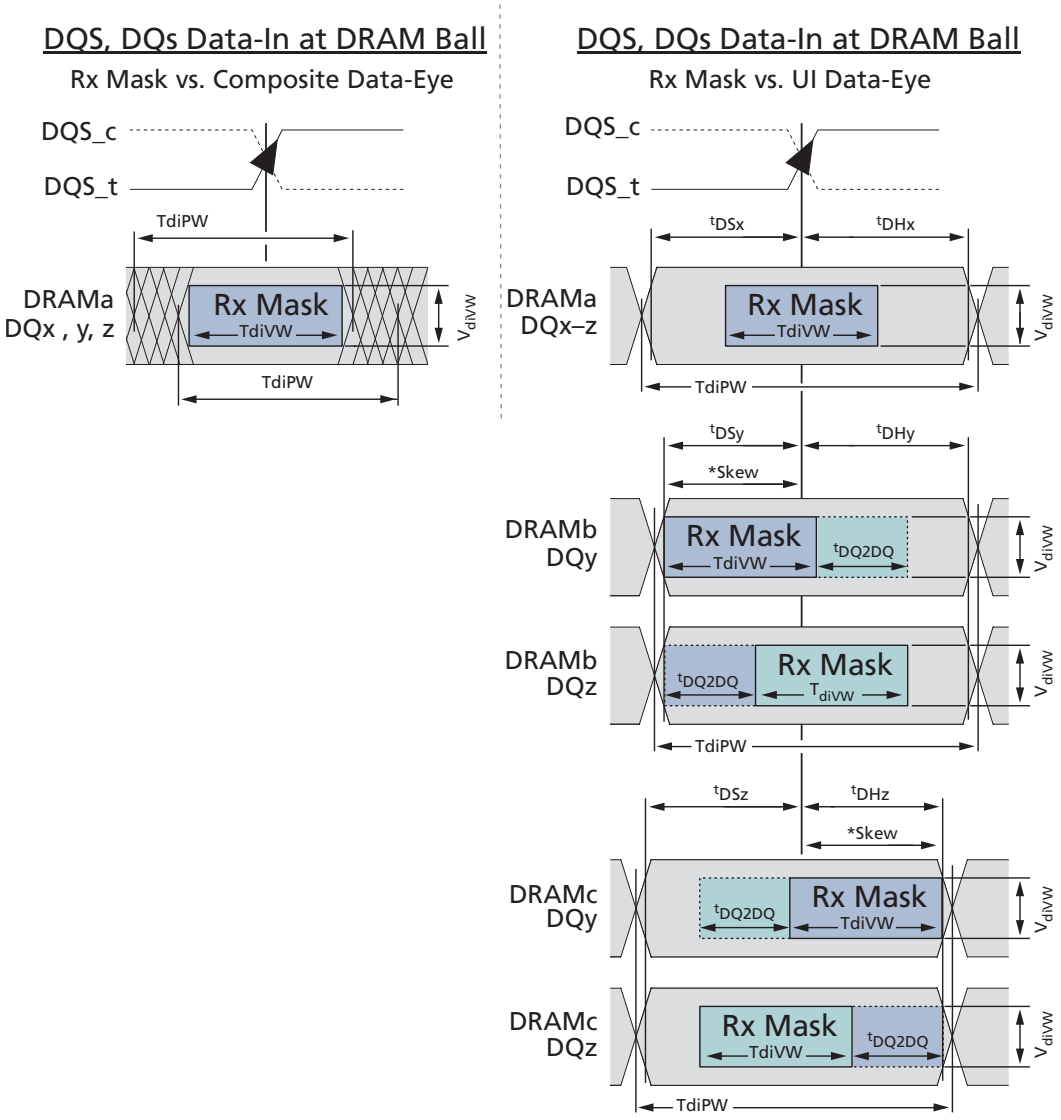
**Figure 159: Rx Mask DQ-to-DQS Timings**




Notes:
1. DQx represents an optimally centered mask.
   DQy represents earliest valid mask.
   DQz represents latest valid mask.
2. DRAMa represents a DRAM without any DQS/DQ skews.
   DRAMb represents a DRAM with early skews (negative $^{t}$DQS2DQ).
   DRAMc represents a DRAM with delayed skews (positive $^{t}$DQS2DQ).
3. This figure shows the skew allowed between DRAM-to-DRAM and between DQ-to-DQ for a DRAM. Signals assume data is center-aligned at DRAM latch.
   TdiPW is not shown; composite data-eyes shown would violate TdiPW.
   $V_{CENTDQ,midpoint}$ is not shown but is assumed to be midpoint of $V_{diVW}$.

The previous figure shows the basic Rx mask requirements. Converting the Rx mask requirements to a classical DQ-to-DQS relationship is shown in the following figure. It should become apparent that DRAM write training is required to take full advantage of the Rx mask.

**Figure 160: Rx Mask DQ-to-DQS DRAM-Based Timings**

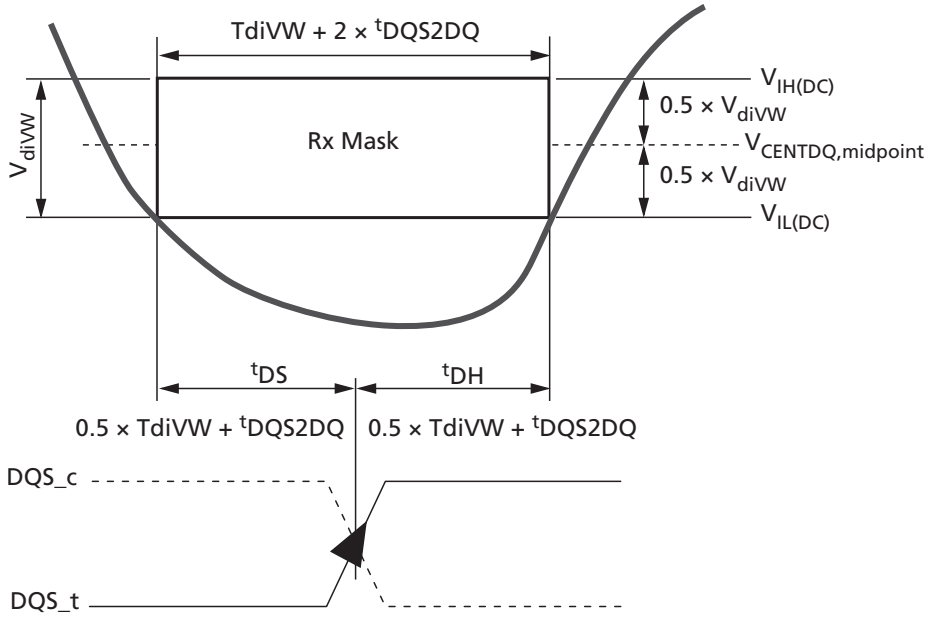



Notes:
1. DQx represents an optimally centered mask.
   DQy represents earliest valid mask.
   DQz represents latest valid mask.
2. *Skew = $^{t}$DQS2DQ + 0.5 × TdiVW
   DRAMa represents a DRAM without any DQS/DQ skews.
   DRAMb represents a DRAM with the earliest skews (negative $^{t}$DQS2DQ, $^{t}$DQSy > *Skew).
   DRAMc represents a DRAM with the latest skews (positive $^{t}$DQS2DQ, $^{t}$DQHz > *Skew).
3. $^{t}$DS/$^{t}$DH are traditional data-eye setup/hold edges at DC levels.
   $^{t}$DS and $^{t}$DH are not specified; $^{t}$DH and $^{t}$DS may be any value provided the pulse width and Rx mask limits are not violated.
   $^{t}$DH (MIN) > TdiVW + $^{t}$DS (MIN) + $^{t}$DQ2DQ.

The DDR4 SDRAM's input receivers are expected to capture the input data with an Rx mask of TdiVW provided the minimum pulse width is satisfied. The DRAM controller will have to train the data input buffer to utilize the Rx mask specifications to this

maximum benefit. If the DRAM controller does not train the data input buffers, then the worst case limits have to be used for the Rx mask (TdiVW + 2 × $^{t}$DQS2DQ), which will generally be the classical minimum ( $^{t}$DS and $^{t}$DH) and is required as well.

**Figure 161: Example of Data Input Requirements Without Training**




## WRITE Burst Operation

The following write timing diagrams are intended to help understand each write

parameter's meaning and are only examples. Each parameter will be defined in detail sep-arately. In these write timing diagrams, CK and DQS are shown aligned, and DQS and DQ are shown center-aligned for the purpose of illustration.

DDR4 WRITE command supports bursts of BL8 (fixed), BC4 (fixed), and BL8/BC4 on-the-fly (OTF); OTF uses address A12 to control OTF when OTF is enabled:

- A12 = 0, BC4 (BC4 = burst chop)
- A12 = 1, BL8

WRITE commands can issue precharge automatically with a WRITE with auto pre-charge (WRA) command, which is enabled by A10 HIGH.

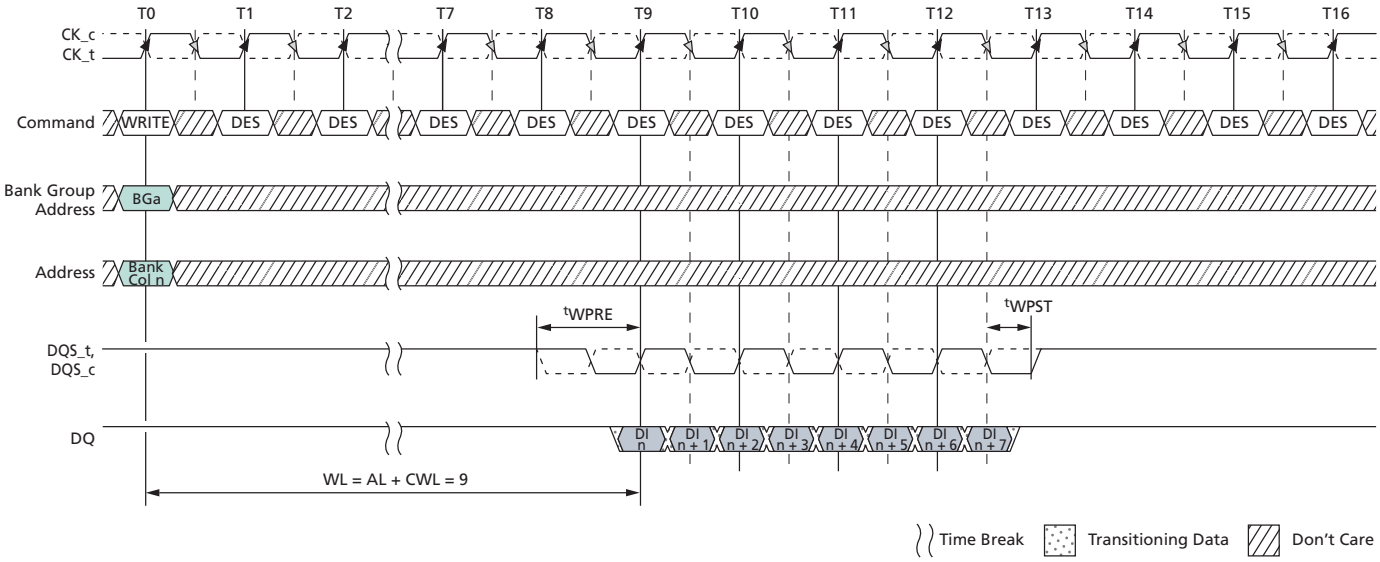
- WRITE command with A10 = 0 (WR) performs standard write, bank remains active after WRITE burst
- WRITE command with A10 = 1 (WRA) performs write with auto precharge, bank goes into precharge after WRITE burst

The DATA MASK (DM) function is supported for the x16 configurations only (the DM function is not supported on x4 devices). The DM function shares a common pin with the DBI_n and TDQS functions. The DM function only applies to WRITE operations and cannot be enabled at the same time the DBI function is enabled.

- If DM_n is sampled LOW on a given byte lane, the DRAM masks the write data received on the DQ inputs.

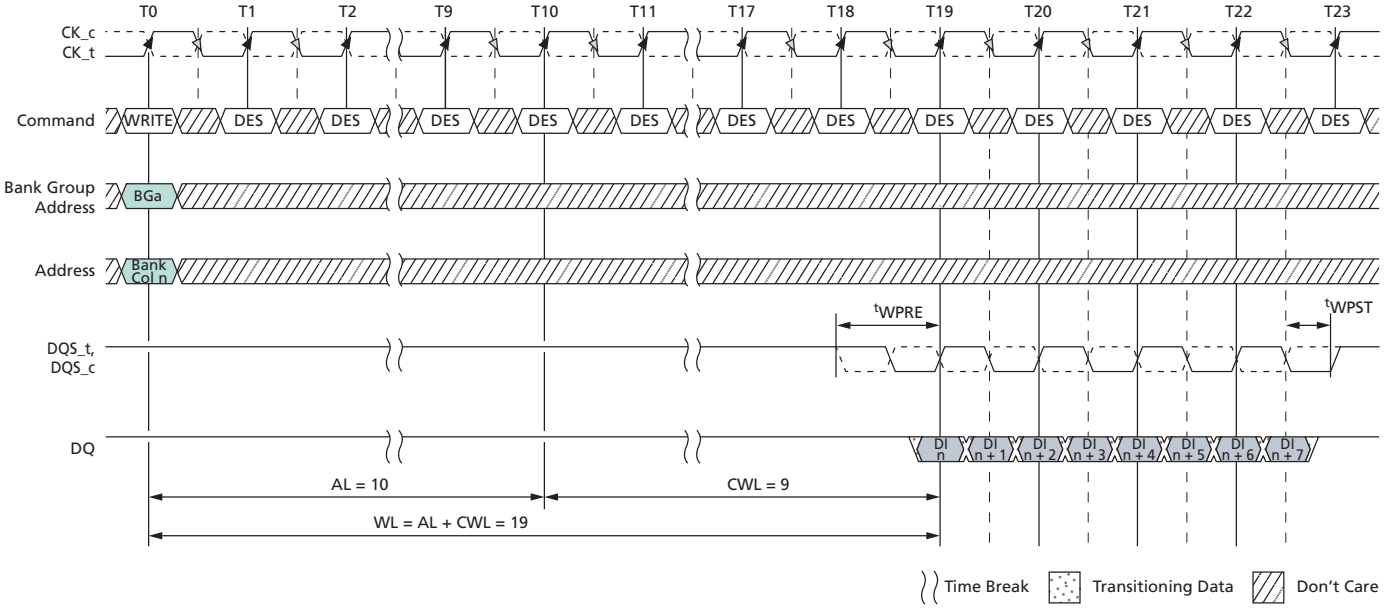
- If DM_n is sampled HIGH on a given byte lane, the DRAM does not mask the data and writes this data into the DRAM core.
- If CRC write is enabled, then DM enabled (via MRS) will be selected between write CRC nonpersistent mode (DM disabled) and write CRC persistent mode (DM enabled).

**Figure 162: WRITE Burst Operation, WL = 9 (AL = 0, CWL = 9, BL8)**




Notes:
1. BL8, WL = 0, AL = 0, CWL = 9, Preamble = 1$^{t}$CK.
2. DI *n* = Data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. CA parity = Disable, CS to CA Latency = Disable, Read DBI = Disable.

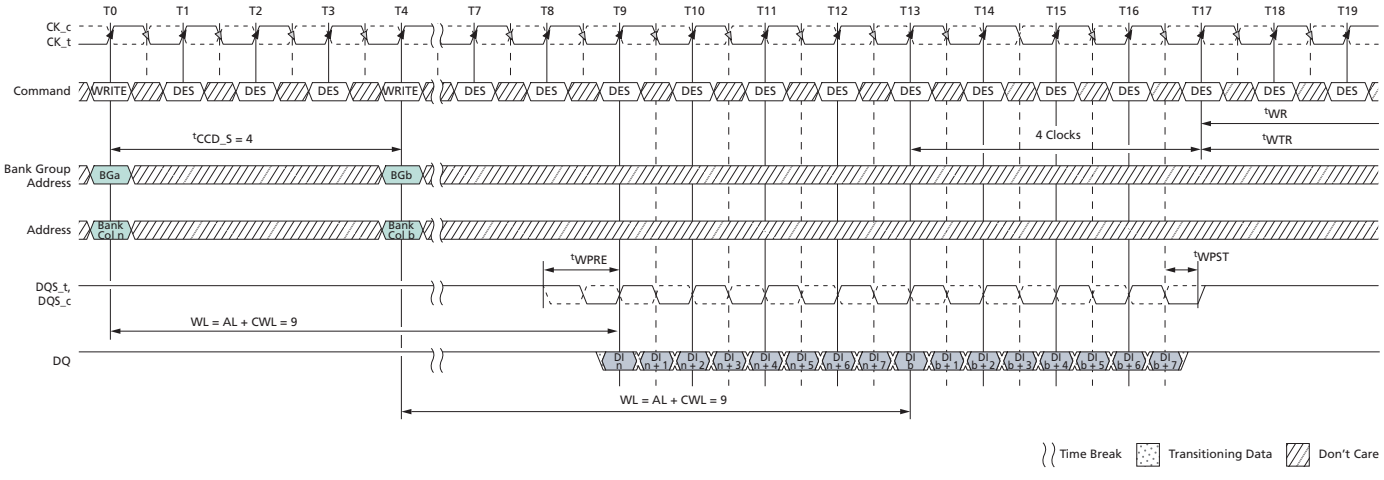
**Figure 163: WRITE Burst Operation, WL = 19 (AL = 10, CWL = 9, BL8)**




Notes:
1. BL8, WL = 19, AL = 10 (CL - 1), CWL = 9, Preamble = 1$^{t}$CK.
2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable.

## WRITE Operation Followed by Another WRITE Operation

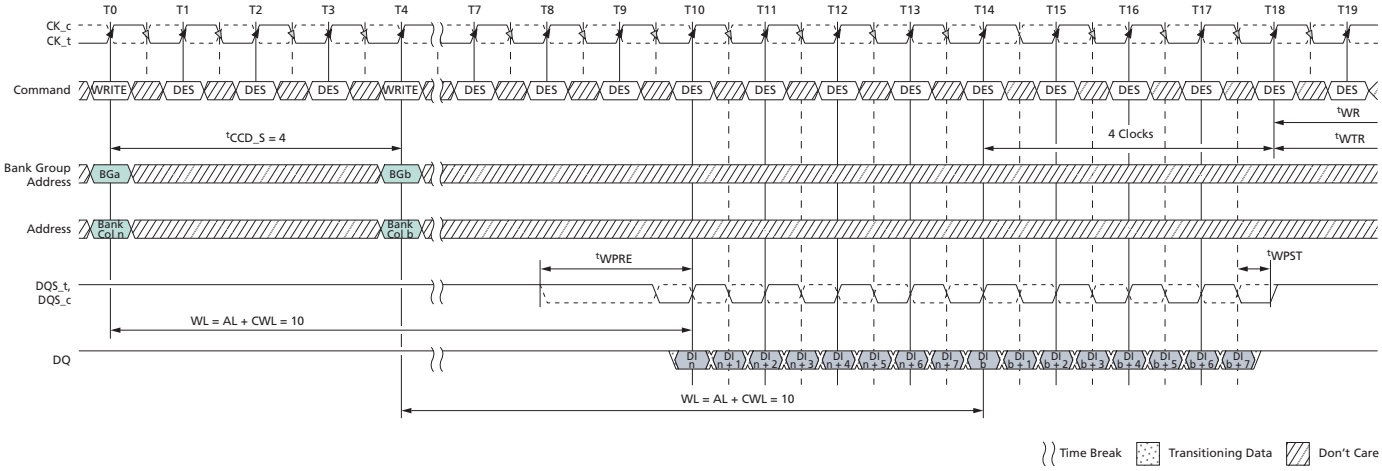
**Figure 164: Consecutive WRITE (BL8) with 1$^{t}$CK Preamble in Different Bank Group**




Notes:
1. BL8, AL = 0, CWL = 9, Preamble = 1$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).

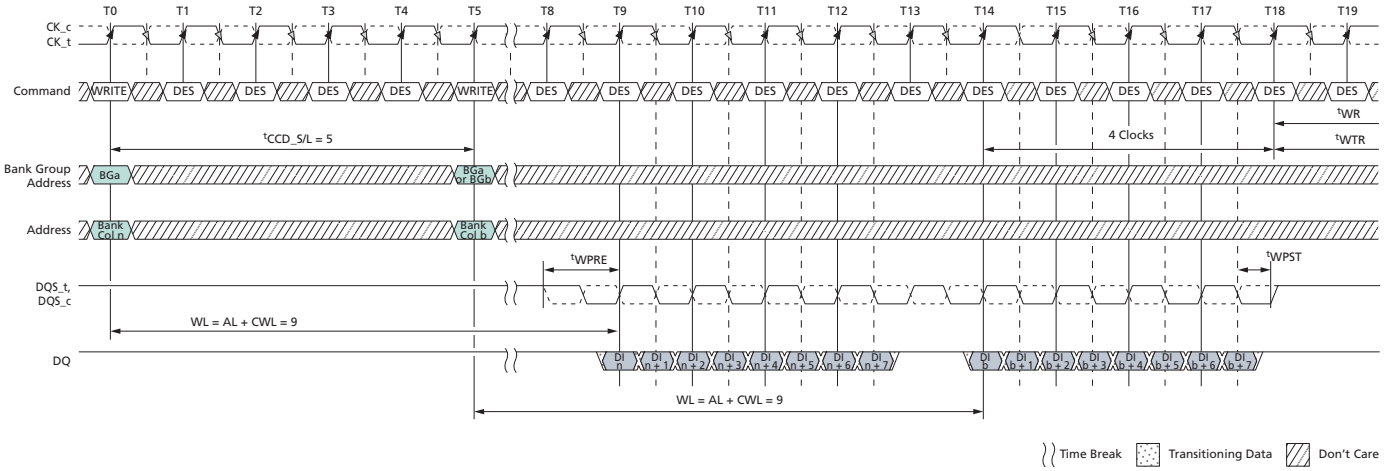
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T17.

**Figure 165: Consecutive WRITE (BL8) with 2$^{t}$CK Preamble in Different Bank Group**



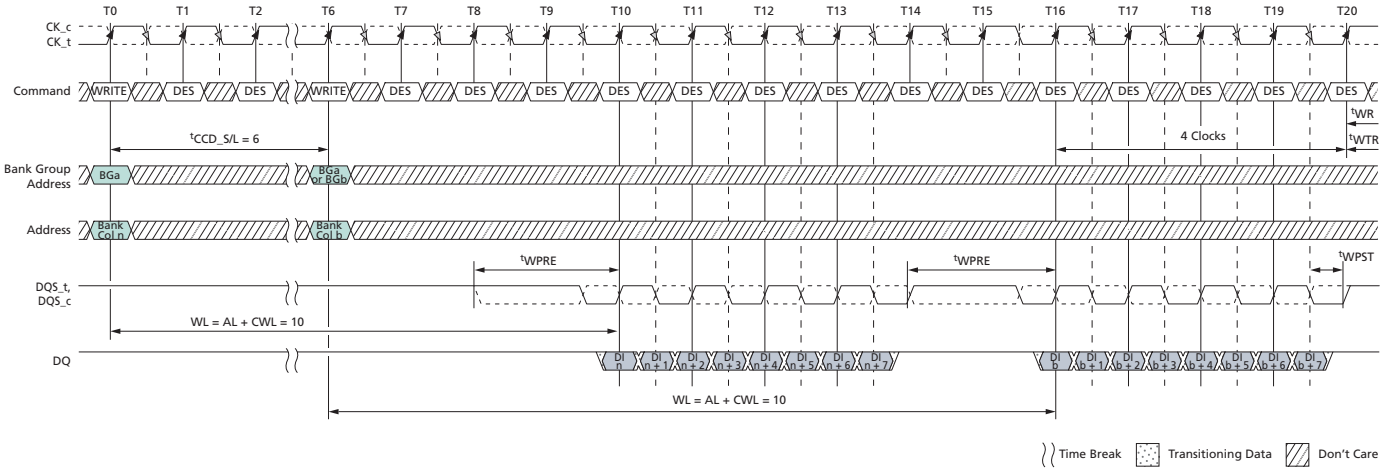

Notes:
1. BL8, AL = 0, CWL = 9 + 1 = 10 (see Note 7), Preamble = 2$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T17.
7. When operating in 2$^{t}$CK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range, which means CWL = 9 is not allowed when operating in 2$^{t}$CK WRITE preamble mode.

**Figure 166: Nonconsecutive WRITE (BL8) with 1tCK Preamble in Same or Different Bank Group**




Notes:
1. BL8, AL = 0, CWL = 9, Preamble = 1tCK, tCCD_S/L = 5tCK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T5.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write recovery time (tWR) and write timing parameter (tWTR) are referenced from the first rising clock edge after the last write data shown at T18.

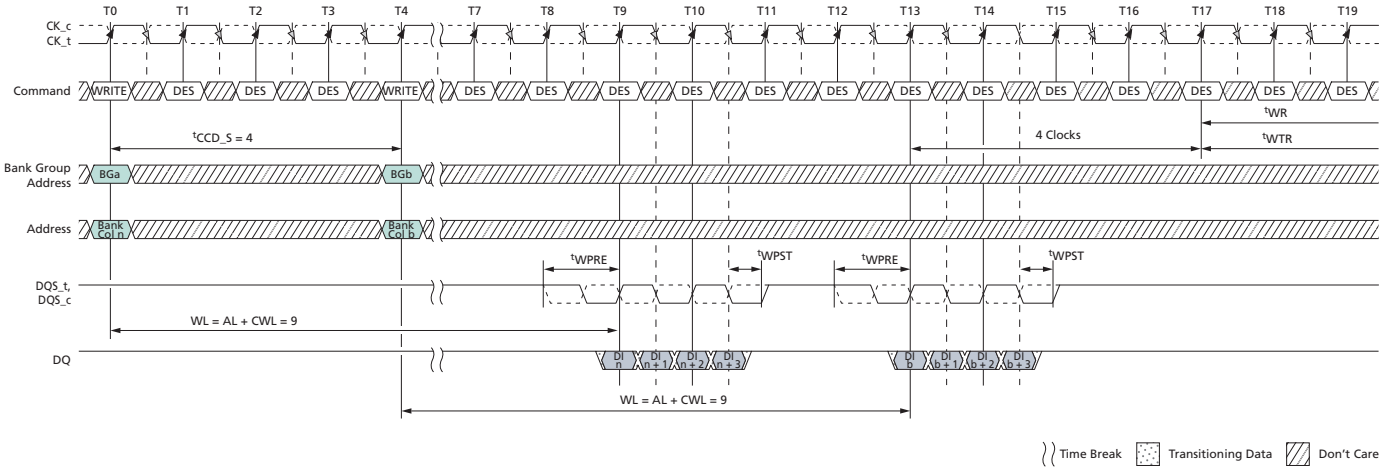
**Figure 167: Nonconsecutive WRITE (BL8) with 2tCK Preamble in Same or Different Bank Group**




Notes:
1. BL8, AL = 0, CWL = 9 + 1 = 10 (see Note 8), Preamble = 2tCK, tCCD_S/L = 6tCK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T6.

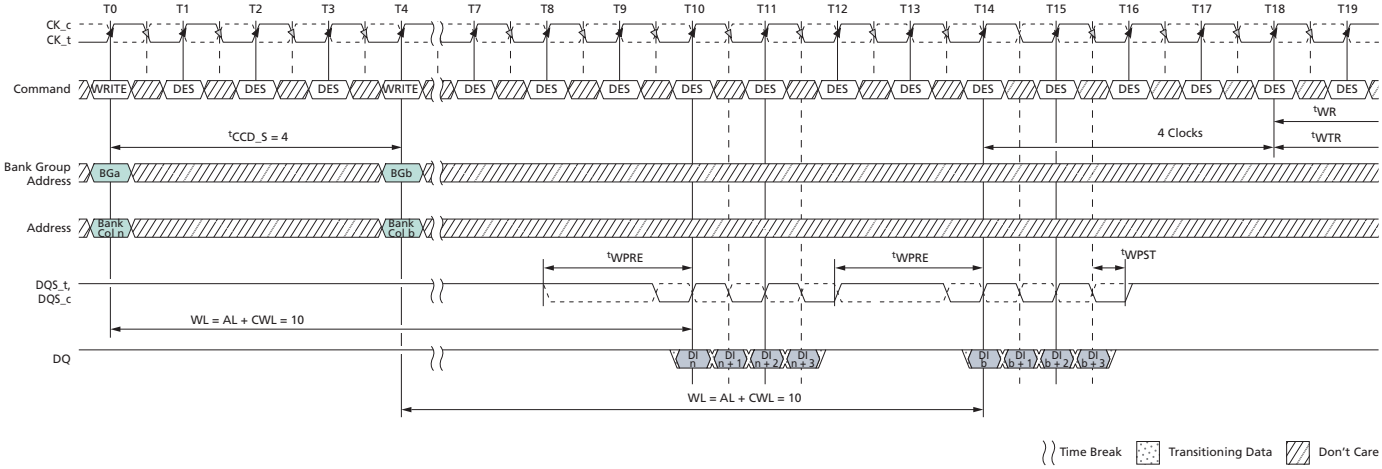
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. $^{t}$CCD_S/L = 5 isn't allowed in 2$^{t}$CK preamble mode.
7. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T20.
8. When operating in 2$^{t}$CK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range, which means CWL = 9 is not allowed when operating in 2$^{t}$CK WRITE preamble mode.

**Figure 168: WRITE (BC4) OTF to WRITE (BC4) OTF with 1$^{t}$CK Preamble in Different Bank Group**



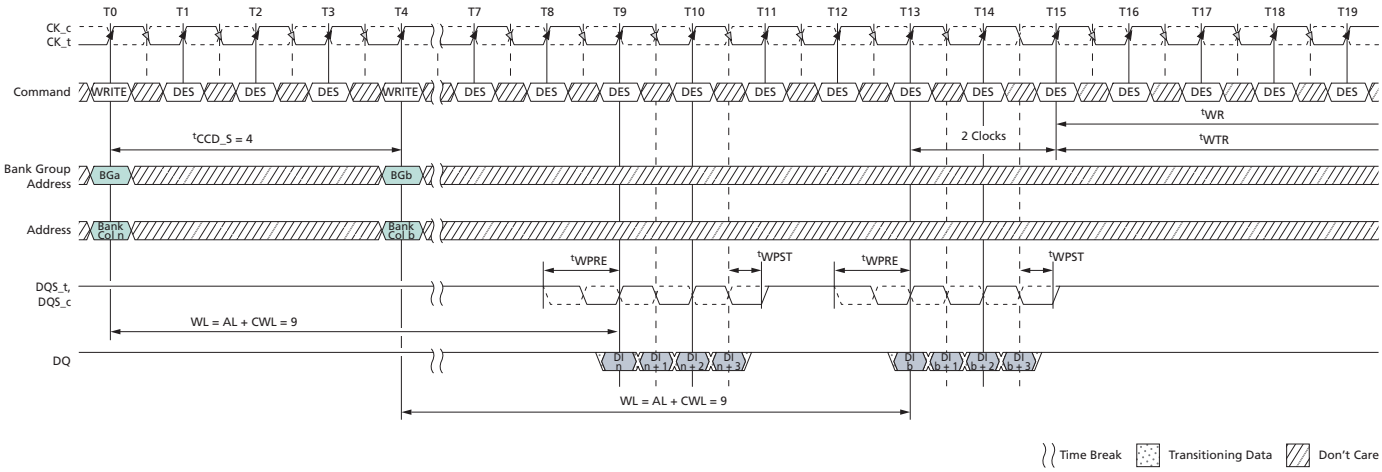

Notes:
1. BC4, AL = 0, CWL = 9, Preamble = 1$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T17.

**Figure 169: WRITE (BC4) OTF to WRITE (BC4) OTF with 2tCK Preamble in Different Bank Group**




Notes:
1. BC4, AL = 0, CWL = 9 + 1 = 10 (see Note 7), Preamble = 2tCK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T4.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write recovery time (tWR) and write timing parameter (tWTR) are referenced from the first rising clock edge after the last write data shown at T18.
7. When operating in 2tCK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable tCK range, which means CWL = 9 is not allowed when operating in 2tCK WRITE preamble mode.

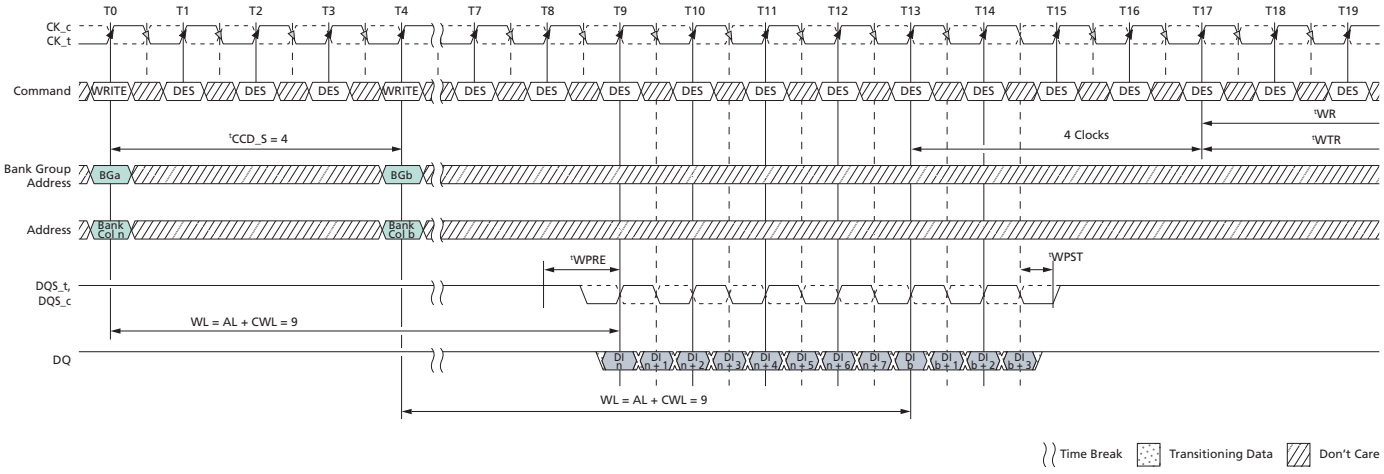
**Figure 170: WRITE (BC4) Fixed to WRITE (BC4) Fixed with 1tCK Preamble in Different Bank Group**




Notes:
1. BC4, AL = 0, CWL = 9, Preamble = 1tCK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).

3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 (fixed) setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T15.

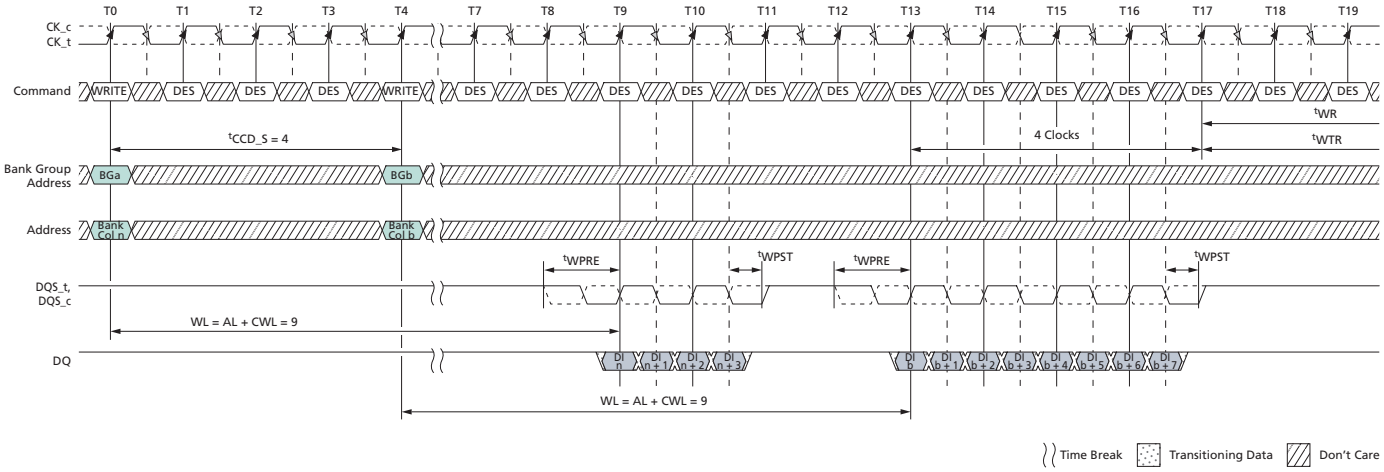
**Figure 171: WRITE (BL8) to WRITE (BC4) OTF with 1$^{t}$CK Preamble in Different Bank Group**




Notes:
1. BL = 8/BC = 4, AL = 0, CL = 9, Preamble = 1$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.

   BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T17.

### Figure 172: WRITE (BC4) OTF to WRITE (BL8) with 1$^{t}$CK Preamble in Different Bank Group

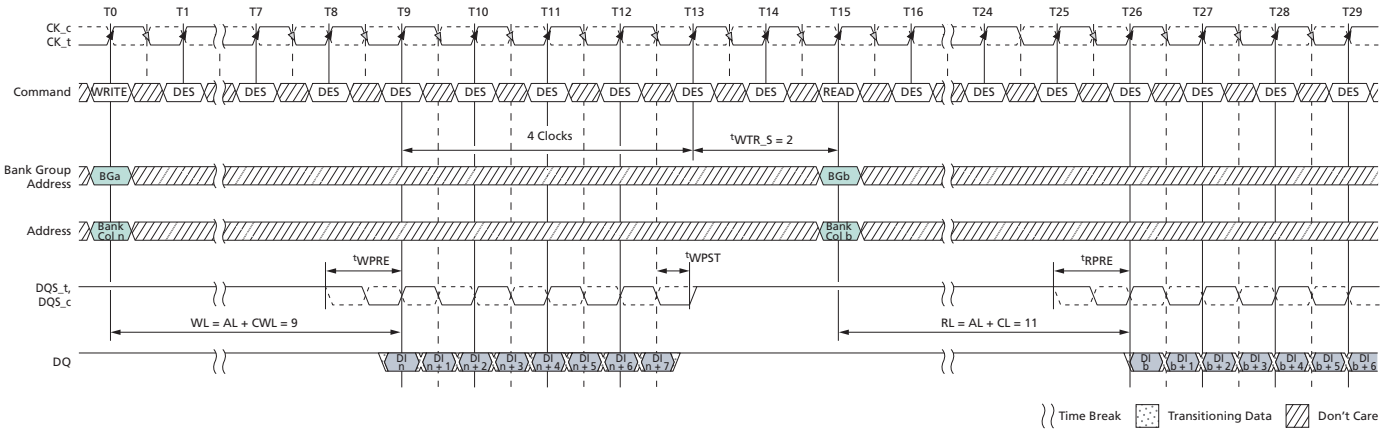



Notes:
1. BL = 8/BC = 4, AL = 0, CL = 9, Preamble = 1$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T0.

   BL8 setting activated by MR0[1:0] = 01 and A12 = 1 during WRITE command at T4.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T17.

## WRITE Operation Followed by READ Operation

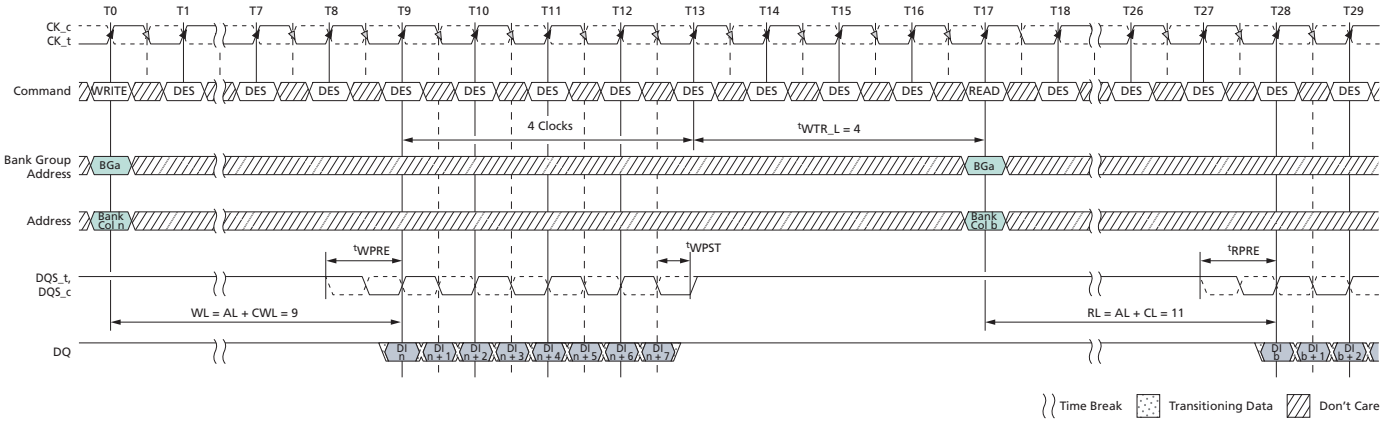
### Figure 173: WRITE (BL8) to READ (BL8) with 1$^{t}$CK Preamble in Different Bank Group




Notes:
1. BL = 8, WL = 9 (CWL = 9, AL = 0), CL = 11, READ preamble = 1$^{t}$CK, WRITE preamble = 1$^{t}$CK.
2. DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

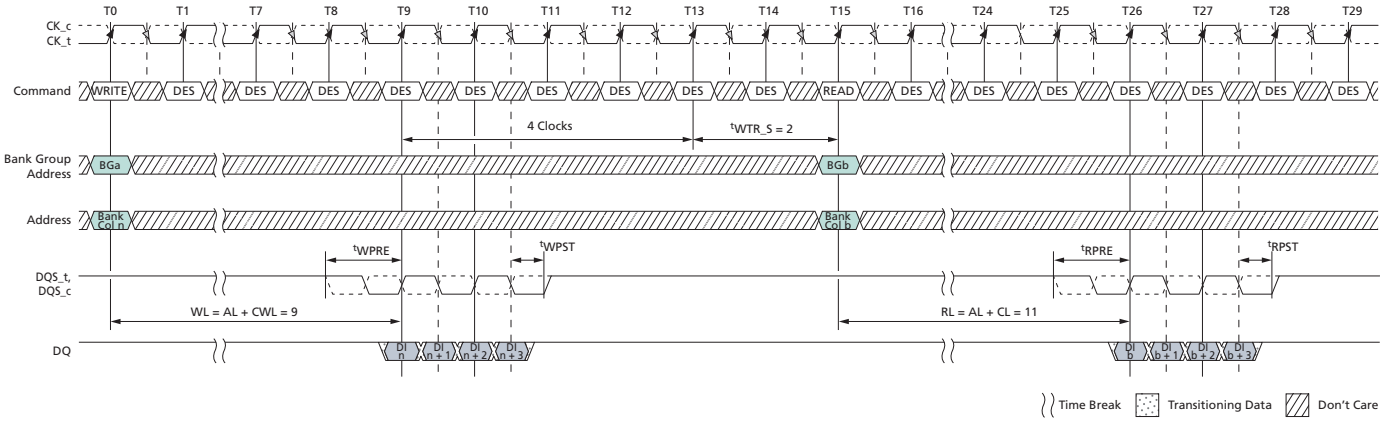
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0 and READ command at T15.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write timing parameter ($^{t}$WTR_S) is referenced from the first rising clock edge after the last write data shown at T13.

**Figure 174: WRITE (BL8) to READ (BL8) with 1$^{t}$CK Preamble in Same Bank Group**



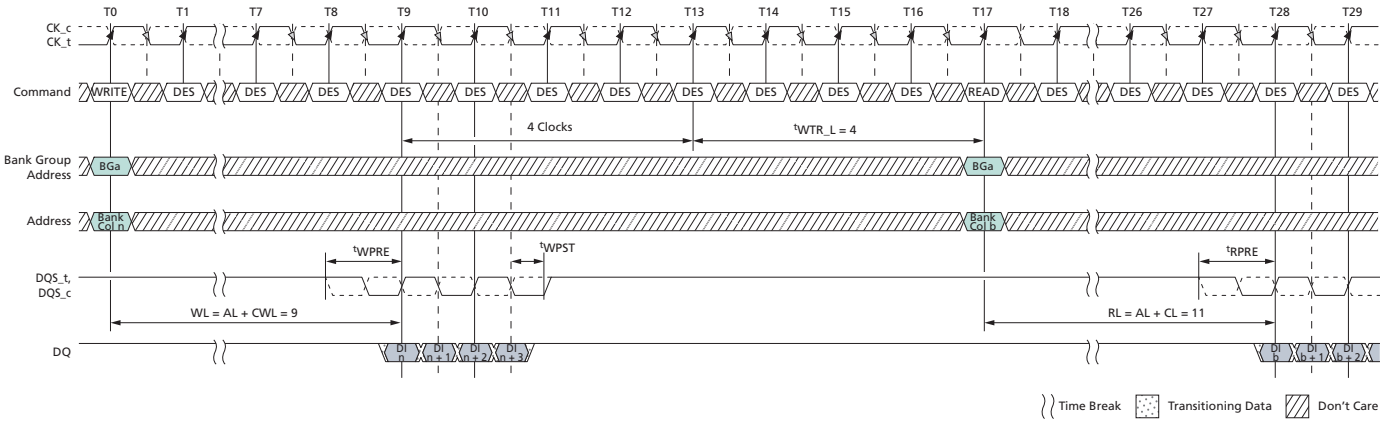

Notes:
1. BL = 8, WL = 9 (CWL = 9, AL = 0), CL = 11, READ preamble = 1$^{t}$CK, WRITE preamble = 1$^{t}$CK.
2. DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0 and READ command at T17.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write timing parameter ($^{t}$WTR_L) is referenced from the first rising clock edge after the last write data shown at T13.

**Figure 175: WRITE (BC4) OTF to READ (BC4) OTF with 1$^{t}$CK Preamble in Different Bank Group**




Notes:
1. BC = 4, WL = 9 (CWL = 9, AL = 0), CL = 11, READ preamble = 1$^{t}$CK, WRITE preamble = 1$^{t}$CK.
2. DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T0 and READ command at T15.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write timing parameter ($^{t}$WTR_S) is referenced from the first rising clock edge after the last write data shown at T13.

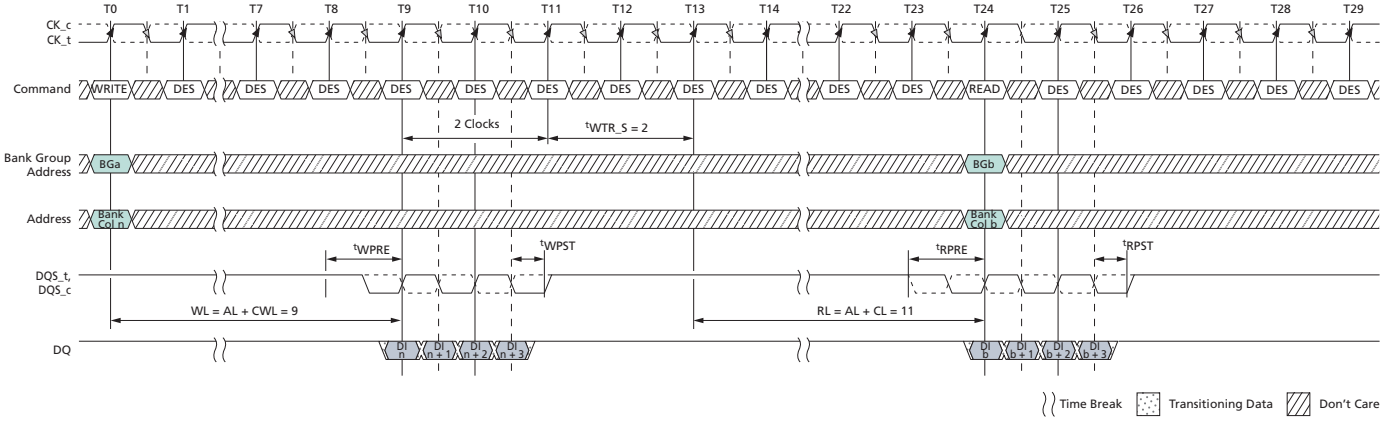
**Figure 176: WRITE (BC4) OTF to READ (BC4) OTF with 1$^{t}$CK Preamble in Same Bank Group**




Notes:
1. BC = 4, WL = 9 (CWL = 9, AL = 0), CL = 11, READ preamble = 1$^{t}$CK, WRITE preamble = 1$^{t}$CK.
2. DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T0 and READ command at T17.

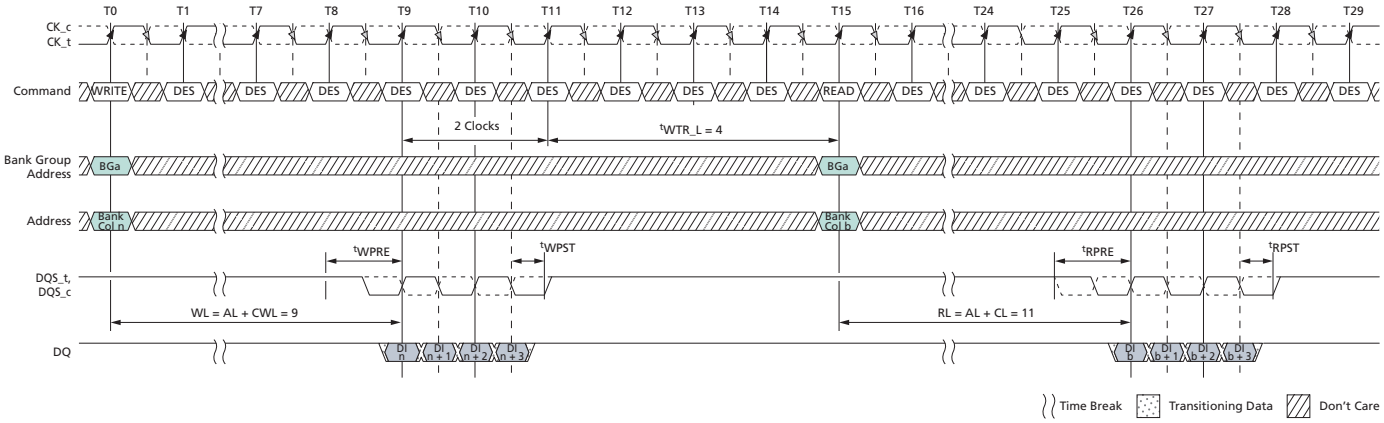
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write timing parameter ($^{t}$WTR_L) is referenced from the first rising clock edge after the last write data shown at T13.

**Figure 177: WRITE (BC4) Fixed to READ (BC4) Fixed with 1 $^{t}$CK Preamble in Different Bank Group**




Notes:
1. BC = 4, WL = 9 (CWL = 9, AL = 0), CL = 11, READ preamble = 1 $^{t}$CK, WRITE preamble = 1$^{t}$CK.
2. DI *b* = data-in from column *b*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write timing parameter ($^{t}$WTR_S) is referenced from the first rising clock edge after the last write data shown at T11.

**Figure 178: WRITE (BC4) Fixed to READ (BC4) Fixed with 1$^{t}$CK Preamble in Same Bank Group**



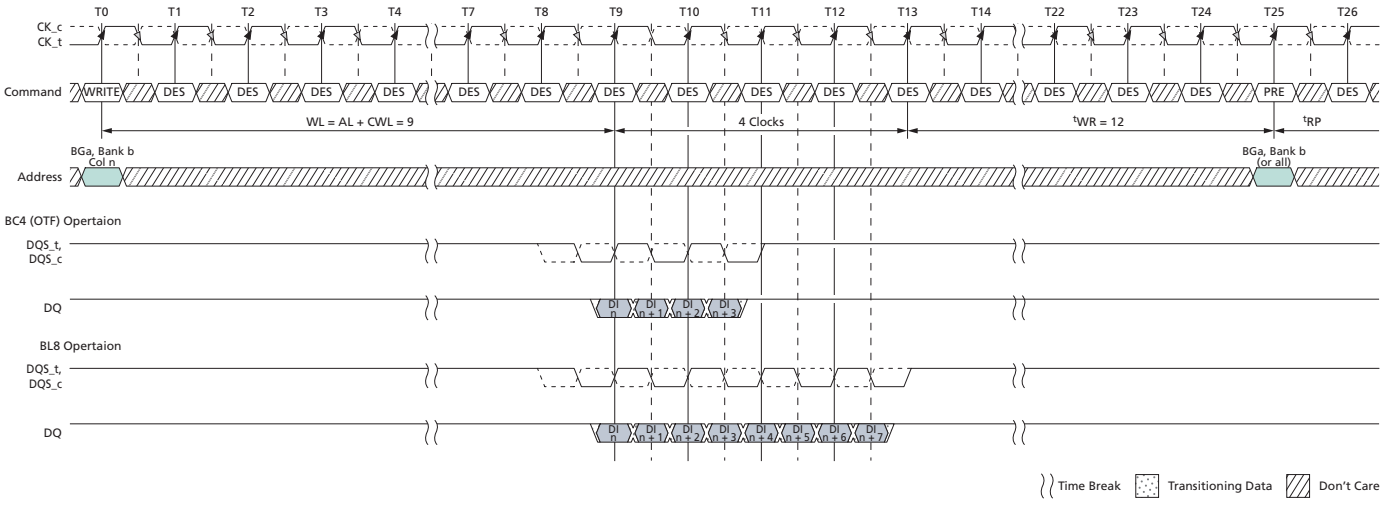

Notes:
1. BC = 4, WL = 9 (CWL = 9, AL = 0), C L = 11, READ preamble = 1$^{t}$CK, WRITE preamble = 1$^{t}$CK.
2. DI *b* = data-in from column *b*.

3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write DBI = Disable, Write CRC = Disable.
6. The write timing parameter ($^{t}$WTR_L) is referenced from the first rising clock edge after the last write data shown at T11.

## WRITE Operation Followed by PRECHARGE Operation

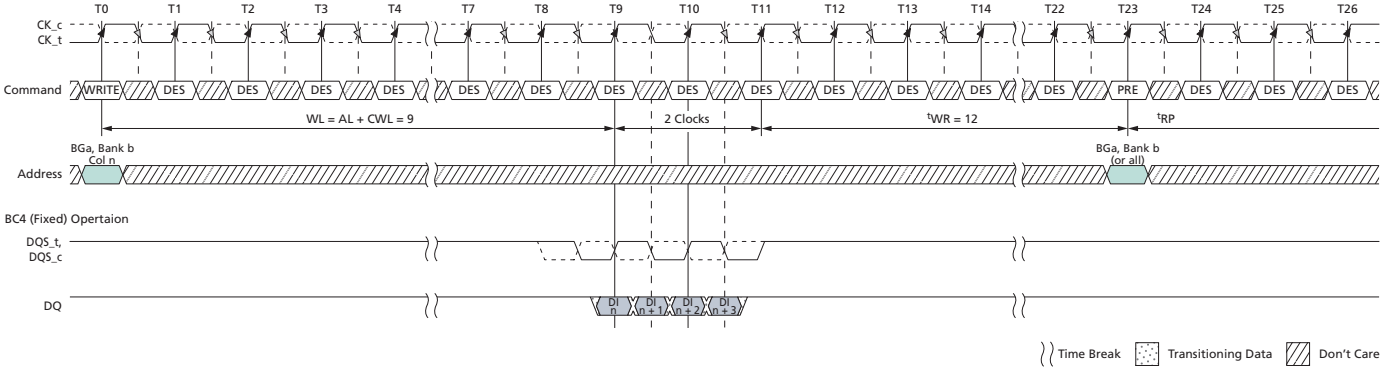
The minimum external WRITE command to PRECHARGE command spacing is equal to WL (AL + CWL) plus either 4$^{t}$CK (BL8/BC4-OTF) or 2$^{t}$CK (BC4-fixed) plus $^{t}$WR. The minimum ACT to PRE timing, $^{t}$RAS, must be satisfied as well.

**Figure 179: WRITE (BL8/BC4-OTF) to PRECHARGE with 1$^{t}$CK Preamble**



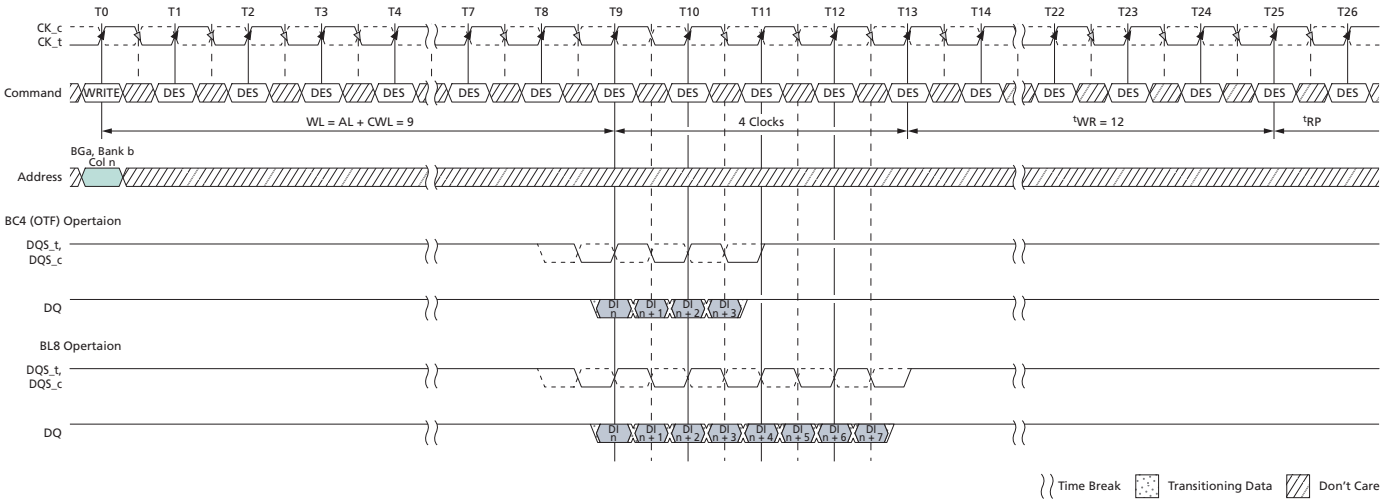

Notes:
1. BL = 8 with BC4-OTF, WL = 9 (CWL = 9, AL = 0 ), Preamble = 1$^{t}$CK, $^{t}$WR = 12.
2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T0. BL8 setting activated by MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, CRC = Disable.
6. The write recovery time ($^{t}$WR) is referenced from the first rising clock edge after the last write data shown at T13. $^{t}$WR specifies the last burst WRITE cycle until the PRECHARGE command can be issued to the same bank.

### Figure 180: WRITE (BC4-Fixed) to PRECHARGE with 1tCK Preamble




Notes:
1. BC4 = fixed, WL = 9 (CWL = 9, AL = 0 ), Preamble = 1tCK, tWR = 12.
2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, CRC = Disable.
6. The write recovery time (tWR) is referenced from the first rising clock edge after the last write data shown at T11. tWR specifies the last burst WRITE cycle until the PRECHARGE command can be issued to the same bank.

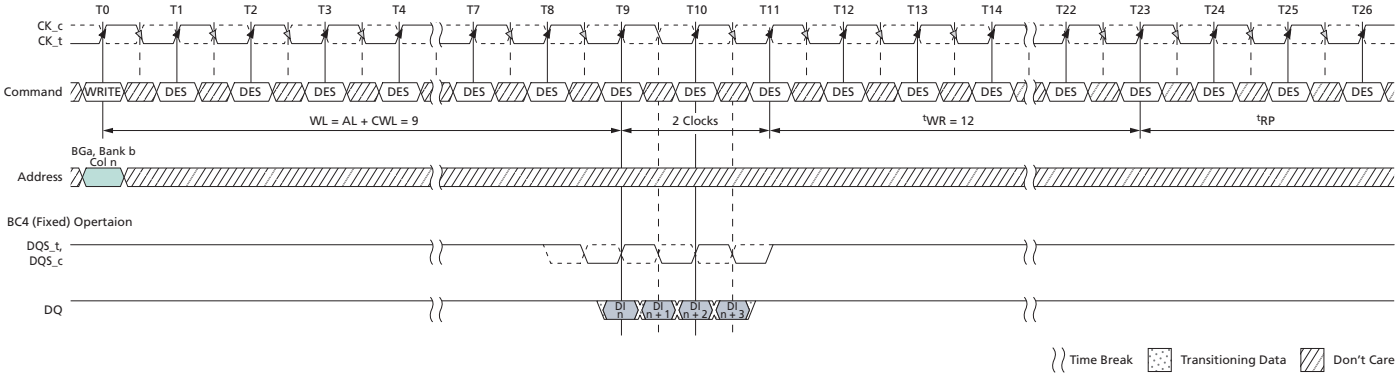
### Figure 181: WRITE (BL8/BC4-OTF) to Auto PRECHARGE with 1tCK Preamble




Notes:
1. BL = 8 with BC4-OTF, WL = 9 (CWL = 9, AL = 0 ), Preamble = 1tCK, tWR = 12.
2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T0. BL8 setting activated by MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, CRC = Disable.

6. The write recovery time ($^{t}$WR) is referenced from the first rising clock edge after the last write data shown at T13. $^{t}$WR specifies the last burst WRITE cycle until the PRECHARGE command can be issued to the same bank.

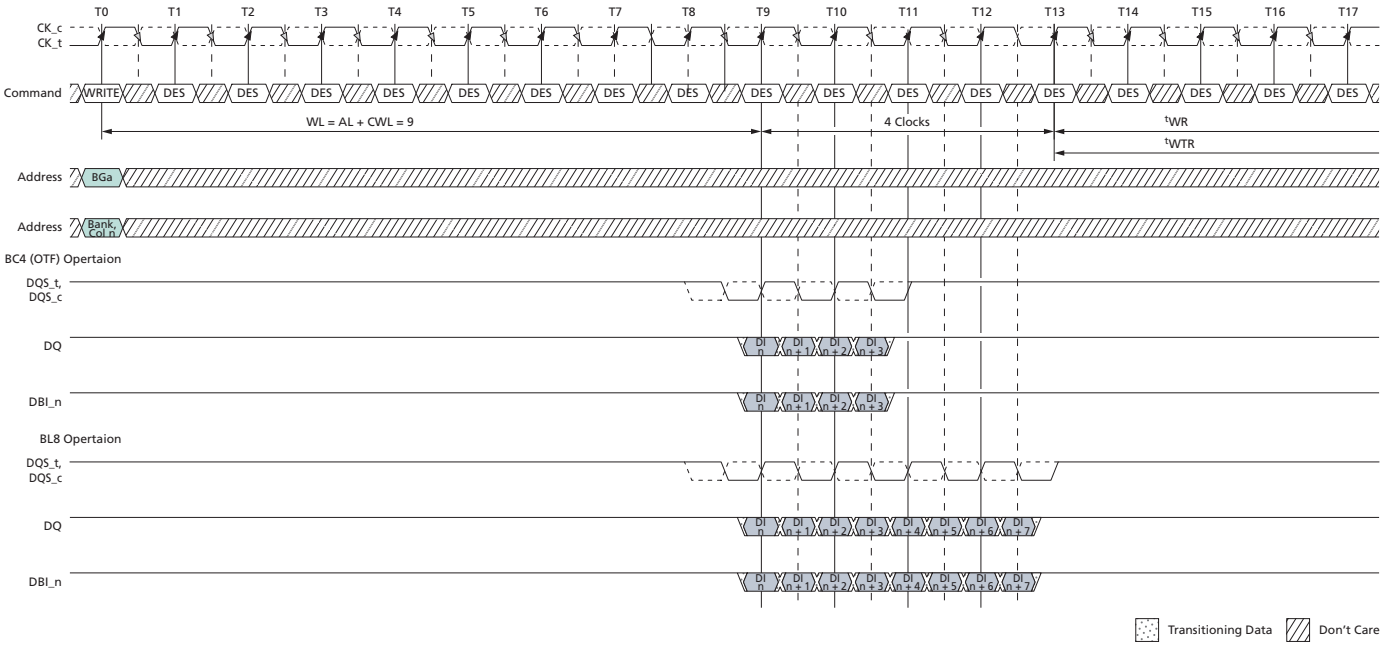
**Figure 182: WRITE (BC4-Fixed) to Auto PRECHARGE with 1$^{t}$CK Preamble**




Notes:
1. BC4 = fixed, WL = 9 (CWL = 9, AL = 0 ), Preamble = 1$^{t}$CK, $^{t}$WR = 12.
2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, CRC = Disable.
6. The write recovery time ($^{t}$WR) is referenced from the first rising clock edge after the last write data shown at T11. $^{t}$WR specifies the last burst WRITE cycle until the PRECHARGE command can be issued to the same bank.

## WRITE Operation with WRITE DBI Enabled

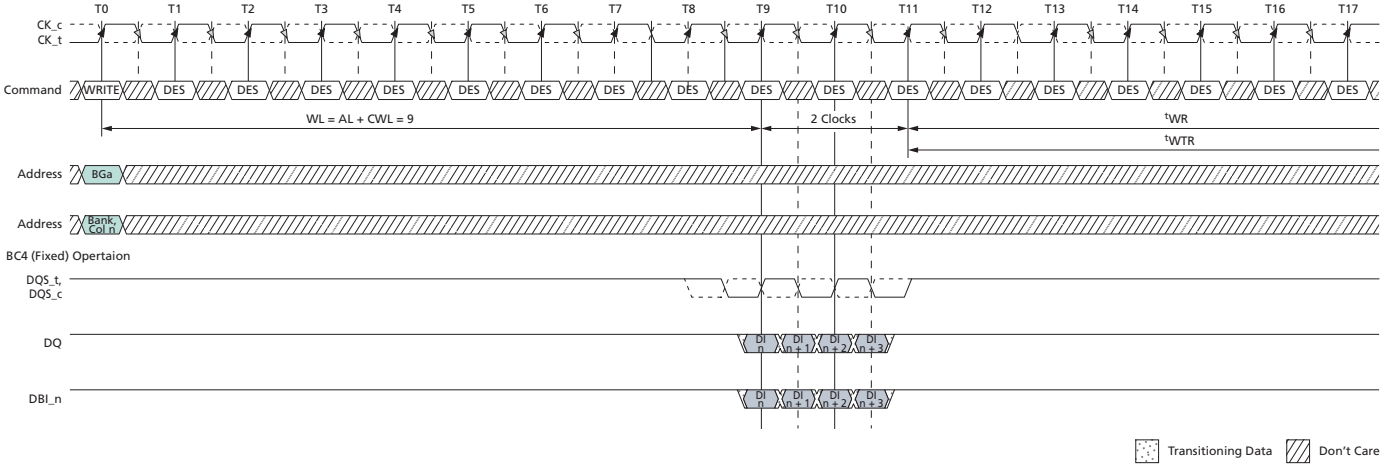
### Figure 183: WRITE (BL8/BC4-OTF) with 1tCK Preamble and DBI




Notes: 1. BL = 8 with BC4-OTF, WL = 9 (CWL = 9, AL = 0 ), Preamble = 1tCK.

2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE command at T0.
   BL8 setting activated by MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Enabled, Write CRC = Disabled.
6. The write recovery time (tWR_DBI) is referenced from the first rising clock edge after the last write data shown at T13.

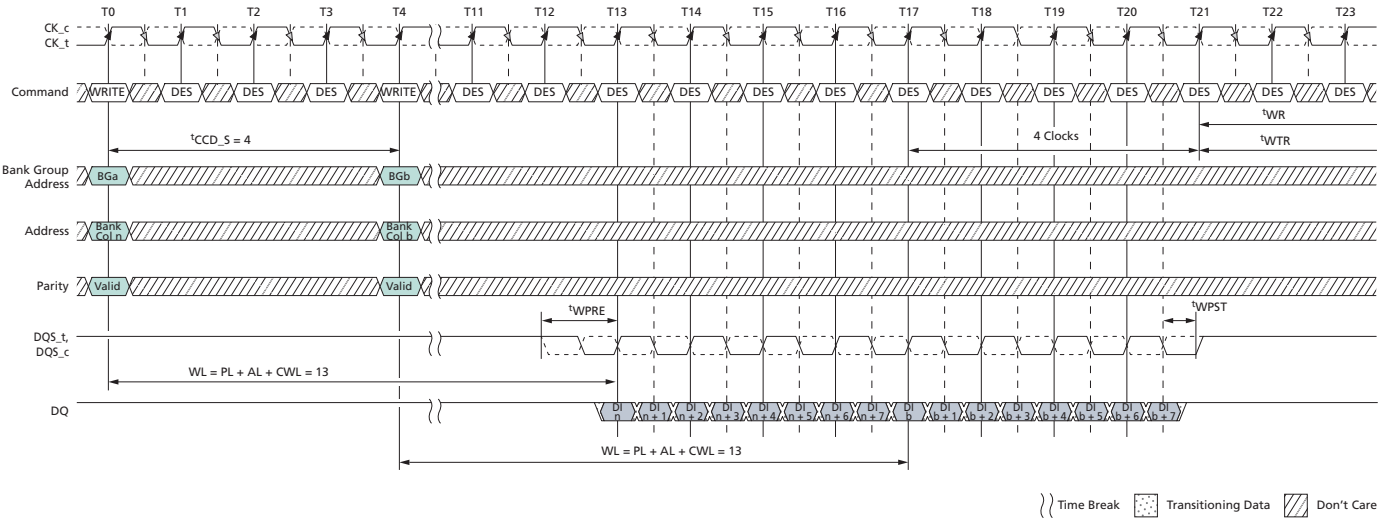
**Figure 184: WRITE (BC4-Fixed) with 1$^{t}$CK Preamble and DBI**




Notes:
1. BC4 = fixed, WL = 9 (CWL = 9, AL = 0 ), Preamble = 1$^{t}$CK.
2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10.
5. CA parity = Disable, CS to CA latency = Disable, Write DBI = Enabled, Write CRC = Disabled.

## WRITE Operation with CA Parity Enabled

### Figure 185: Consecutive Write (BL8) with 1tCK Preamble and CA Parity in Different Bank Group

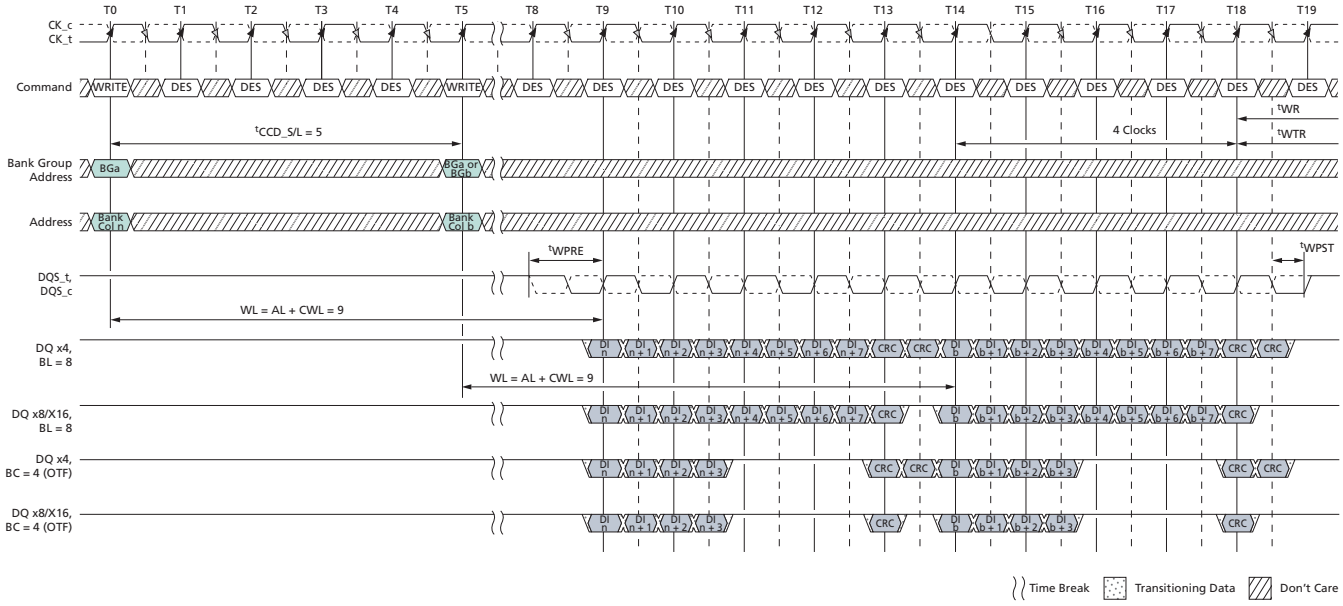



Notes: 1. BL = 8, WL = 9 (CWL = 13, AL = 0 ), Preamble = 1tCK.

2. DI *n* = data-in from column *n*.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T4.
5. CA parity = Enable, CS to CA latency = Disable, Write DBI = Enabled, Write CRC = Disable.
6. The write recovery time (tWR) and write timing parameter (tWTR) are referenced from the first rising clock edge after the last write data shown at T21.

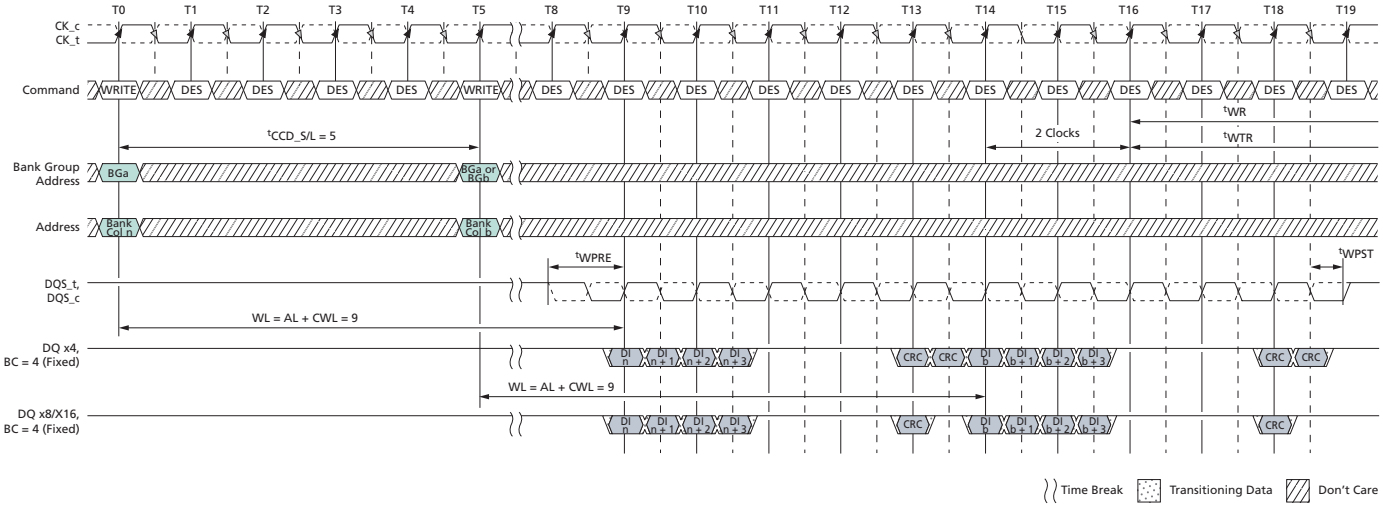
## WRITE Operation with Write CRC Enabled

### Figure 186: Consecutive WRITE (BL8/BC4-OTF) with 1tCK Preamble and Write CRC in Same or Different Bank Group



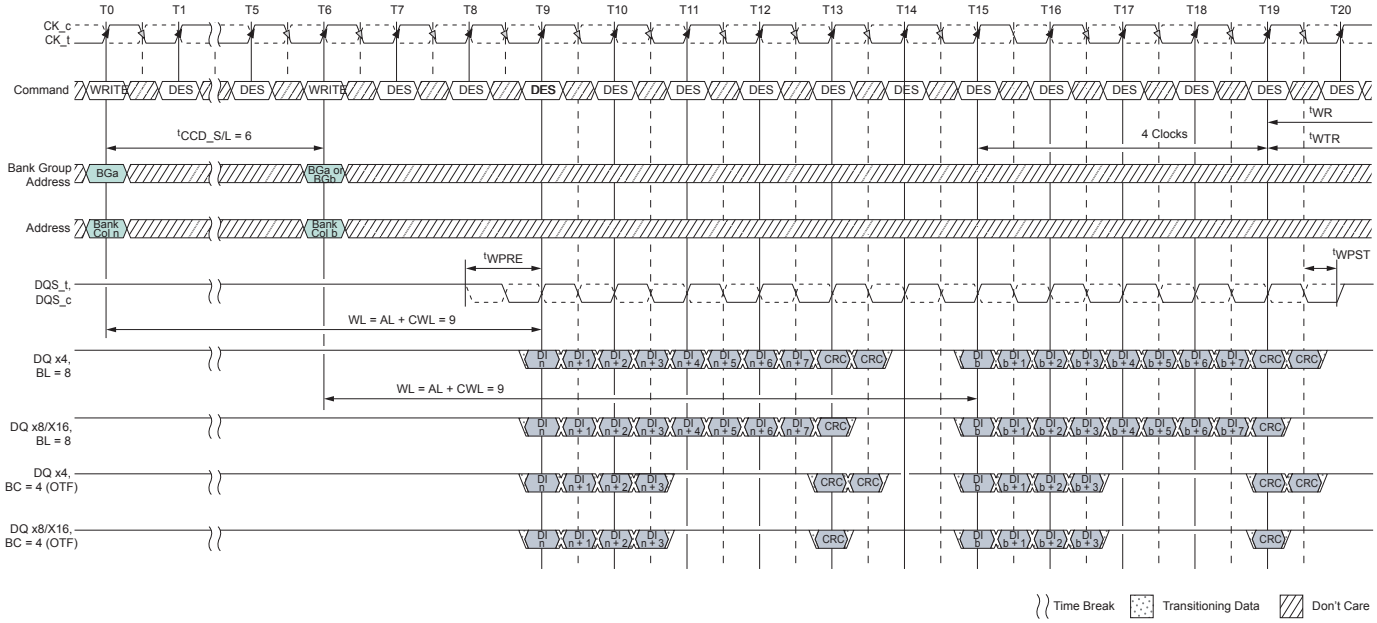

Notes:
1. BL8/BC4-OTF, AL = 0, CWL = 9, Preamble = 1tCK, tCCD_S/L = 5tCK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T5.
5. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T0 and T5.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Enable.
7. The write recovery time (tWR) and write timing parameter (tWTR) are referenced from the first rising clock edge after the last write data shown at T18.

**Figure 187: Consecutive WRITE (BC4-Fixed) with 1$^{t}$CK Preamble and Write CRC in Same or Different Bank Group**



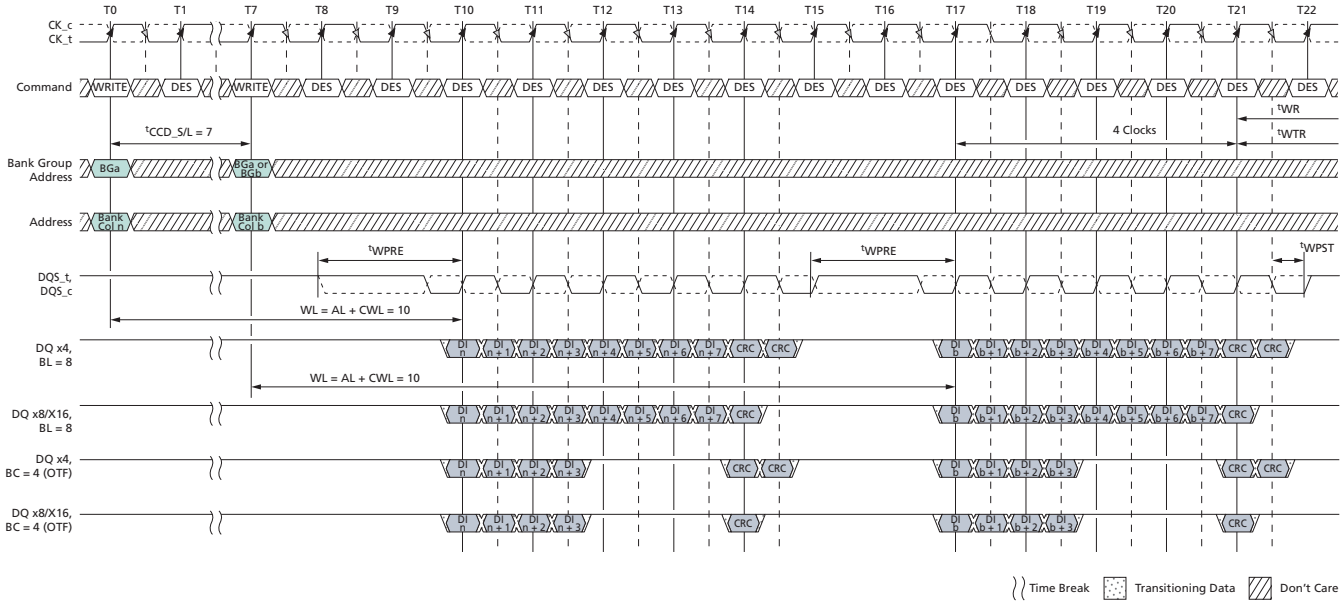

Notes:
1. BC4-fixed, AL = 0, CWL = 9, Preamble = 1$^{t}$CK, $^{t}$CCD_S/L = 5$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BC4 setting activated by MR0[1:0] = 10 during WRITE commands at T0 and T5.
5. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Enable, DM = Disable.
6. The write recovery time ($^{t}$WR) and write timing parameter ($^{t}$WTR) are referenced from the first rising clock edge after the last write data shown at T16.

**Figure 188: Nonconsecutive WRITE (BL8/BC4-OTF) with 1tCK Preamble and Write CRC in Same or Different Bank Group**



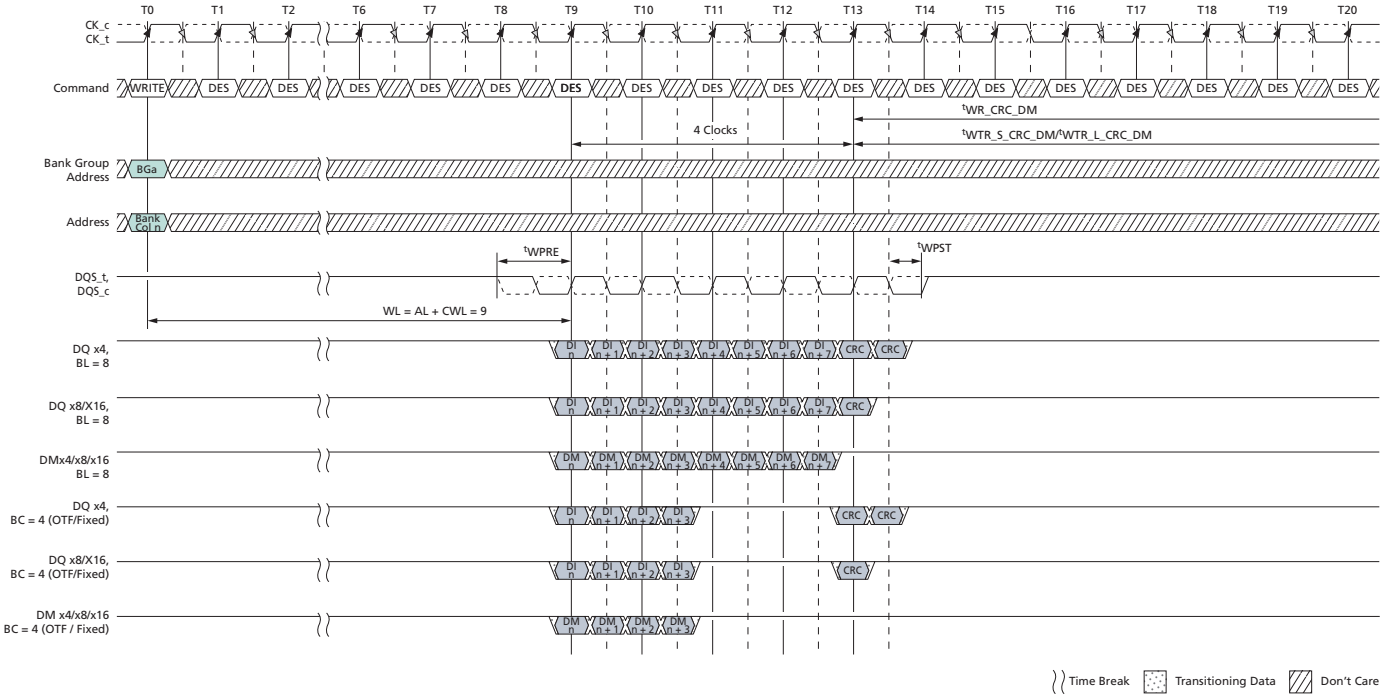

Notes:
1. BL8/BC4-OTF, AL = 0, CWL = 9, Preamble = 1tCK, tCCD_S/L = 6tCK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T6.
5. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T0 and T6.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Enable, DM = Disable.
7. The write recovery time (tWR) and write timing parameter (tWTR) are referenced from the first rising clock edge after the last write data shown at T19.

**Figure 189: Nonconsecutive WRITE (BL8/BC4-OTF) with 2tCK Preamble and Write CRC in Same or Different Bank Group**




Notes:
1. BL8/BC4-OTF, AL = 0, CWL = 9 + 1 = 10 (see Note 9), Preamble = 2tCK, tCCD_S/L = 7tCK (see Note 7).
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE commands at T0 and T7.
5. BC4 setting activated by MR0[1:0] = 01 and A12 = 0 during WRITE commands at T0 and T7.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Enable, DM = Disable.
7. tCCD_S/L = 6tCK is not allowed in 2tCK preamble mode if minimum tCCD_S/L allowed in 1tCK preamble mode would have been 6 clocks.
8. The write recovery time (tWR) and write timing parameter (tWTR) are referenced from the first rising clock edge after the last write data shown at T21.
9. When operating in 2tCK WRITE preamble mode, CWL may need to be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable tCK range. That means CWL = 9 is not allowed when operating in 2tCK WRITE preamble mode.

**Figure 190: WRITE (BL8/BC4-OTF/Fixed) with 1$^{t}$CK Preamble and Write CRC in Same or Different Bank Group**




Notes:
1. BL8/BC4, AL = 0, CWL = 9, Preamble = 1$^{t}$CK.
2. DI *n* (or *b*) = data-in from column *n* (or column *b*).
3. DES commands are shown for ease of illustration; other commands may be valid at these times.
4. BL8 setting activated by either MR0[1:0] = 00 or MR0[1:0] = 01 and A12 = 1 during WRITE command at T0.
5. BC4 setting activated by either MR0[1:0] = 10 or MR0[1:0] = 01 and A12 = 0 during WRITE command at T0.
6. CA parity = Disable, CS to CA latency = Disable, Read DBI = Disable, Write CRC = Enable, DM = Enable.
7. The write recovery time ($^{t}$WR_CRC_DM) and write timing parameter ($^{t}$WTR_S_CRC_DM/ $^{t}$WTR_L_CRC_DM) are referenced from the first rising clock edge after the last write data shown at T13.

# Write Timing Violations

## Motivation

Generally, if timing parameters are violated, a complete reset/initialization procedure has to be initiated to make sure that the device works properly. However, for certain minor violations, it is desirable that the device is guaranteed not to "hang up" and that errors are limited to that specific operation. A minor violation does not include a major timing violation (for example, when a DQS strobe misses in the $^{t}$DQSCK window).

For the following, it will be assumed that there are no timing violations with regard to the WRITE command itself (including ODT, and so on) and that it does satisfy all timing requirements not mentioned below.

## Data Setup and Hold Violations

If the data-to-strobe timing requirements ($^{t}$DS, $^{t}$DH) are violated, for any of the strobe edges associated with a WRITE burst, then wrong data might be written to the memory location addressed with this WRITE command.

In the example, the relevant strobe edges for WRITE Burst A are associated with the clock edges: T5, T5.5, T6, T6.5, T7, T7.5, T8, and T8.5.

Subsequent reads from that location might result in unpredictable read data; however, the device will work properly otherwise.

## Strobe-to-Strobe and Strobe-to-Clock Violations

If the strobe timing requirements ($^{t}$DQSH, $^{t}$DQSL, $^{t}$WPRE, $^{t}$WPST) or the strobe to clock timing requirements ($^{t}$DSS, $^{t}$DSH, $^{t}$DQSS) are violated, for any of the strobe edges associated with a WRITE burst, then wrong data might be written to the memory location addressed with the offending WRITE command. Subsequent reads from that location might result in unpredictable read data; however, the device will work properly other-wise with the following constraints:

- Both write CRC and data burst OTF are disabled; timing specifications other than $^{t}$DQSH, $^{t}$DQSL, $^{t}$WPRE, $^{t}$WPST, $^{t}$DSS, $^{t}$DSH, $^{t}$DQSS are not violated.
- The offending write strobe (and preamble) arrive no earlier or later than six DQS transition edges from the WRITE latency position.
- A READ command following an offending WRITE command from any open bank is allowed.
- One or more subsequent WR or a subsequent WRA (to same bank as offending WR) may be issued $^{t}$CCD_L later, but incorrect data could be written. Subsequent WR and WRA can be either offending or non-offending writes. Reads from these writes may provide incorrect data.
- One or more subsequent WR or a subsequent WRA (to a different bank group) may be issued $^{t}$CCD_S later, but incorrect data could be written. Subsequent WR and WRA can be either offending or non-offending writes. Reads from these writes may provide incorrect data.
- After one or more precharge commands (PRE or PREA) are issued to the device after an offending WRITE command and all banks are in precharged state (idle state), a subsequent, non-offending WR or WRA to any open bank will be able to write correct data.

## ZQ CALIBRATION Commands

A ZQ CALIBRATION command is used to calibrate DRAM $R_{ON}$ and ODT values. The device needs a longer time to calibrate the output driver and on-die termination circuits at initialization and a relatively smaller time to perform periodic calibrations.

The ZQCL command is used to perform the initial calibration during the power-up initialization sequence. This command may be issued at any time by the controller depending on the system environment. The ZQCL command triggers the calibration engine inside the DRAM and, after calibration is achieved, the calibrated values are transferred from the calibration engine to DRAM I/O, which is reflected as an updated out-put driver and ODT values.

The first ZQCL command issued after reset is allowed a timing period of $^{t}$ZQinit to per-form the full calibration and the transfer of values. All other ZQCL commands except the first ZQCL command issued after reset are allowed a timing period of $^{t}$ZQoper.

The ZQCS command is used to perform periodic calibrations to account for voltage and temperature variations. A shorter timing window is provided to perform the calibration and transfer of values as defined by timing parameter $^{t}$ZQCS. One ZQCS command can effectively correct a minimum of 0.5% (ZQ correction) of $R_{ON}$ and $R_{TT}$ impedance error
within 64 *n*CK for all speed bins assuming the maximum sensitivities specified in the Output Driver and ODT Voltage and Temperature Sensitivity tables. The appropriate interval between ZQCS commands can be determined from these tables and other application-specific parameters. One method for calculating the interval between ZQCS
commands, given the temperature ($T_{drift\_rate}$) and voltage ($V_{drift\_rate}$) drift rates that the device is subjected to in the application, is illustrated. The interval could be defined by the following formula:

$$\frac{ZQ_{correction}}{(T_{sense} \times T_{drift\_rate}) + (V_{sense} \times T_{drift\_rate})}$$

Where $T_{sense}$ = MAX($dR_{TT}dT$, $dR_{ON}dTM$) and $V_{sense}$ = MAX($dR_{TT}dV$, $dR_{ON}dVM$) define the temperature and voltage sensitivities.

For example, if $T_{sens}$ = 1.5%/°C, $V_{sens}$ = 0.15%/mV, $T_{driftrate}$ = 1 °C/sec and $V_{driftrate}$ = 15 mV/sec, then the interval between ZQCS commands is calculated as:

$$\frac{0.5}{(1.5 \times 1) + (0.15 \times 15)} = 0.133 \approx 128ms$$

No other activities should be performed on the DRAM channel by the controller for the duration of $^{t}$ZQinit, $^{t}$ZQoper, or $^{t}$ZQCS. The quiet time on the DRAM channel allows accurate calibration of output driver and on-die termination values. After DRAM calibration is achieved, the device should disable the ZQ current consumption path to reduce power.

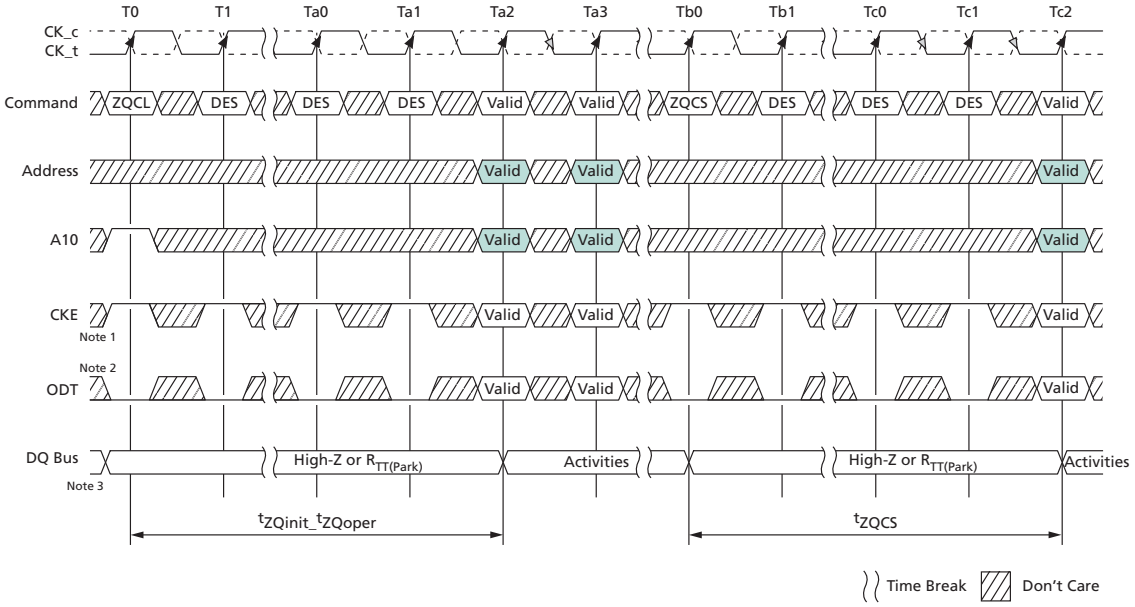
All banks must be precharged and $^{t}$RP met before ZQCL or ZQCS commands are issued by the controller.

ZQ CALIBRATION commands can also be issued in parallel to DLL lock time when coming out of self refresh. Upon self refresh exit, the device will not perform an I/O calibration

without an explicit ZQ CALIBRATION command. The earliest possible time for a ZQ CALIBRATION command (short or long) after self refresh exit is $^{t}$XS, $^{t}$XS_Abort, or $^{t}$XS_FAST depending on operation mode.

In systems that share the ZQ resistor between devices, the controller must not allow any overlap of $^{t}$ZQoper, $^{t}$ZQinit, or $^{t}$ZQCS between the devices.

**Figure 191: ZQ Calibration Timing**



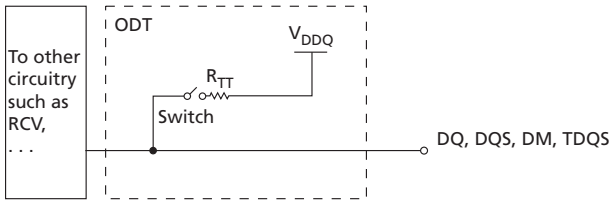

Notes:
1. CKE must be continuously registered HIGH during the calibration procedure.
2. During ZQ calibration, the ODT signal must be held LOW and DRAM continues to provide RTT_PARK.
3. All devices connected to the DQ bus should be High-Z during the calibration procedure.

## On-Die Termination

The on-die termination (ODT) feature enables the device to change termination resistance via the ODT control pin, WRITE command, or default parking value with MR setting. For the x16 configuration, ODT is applied to each UDQ, LDQ, UDQS, LDQS, UDM_n/UDBI_n, and LDM_n/LDBI_n signal. The ODT feature is designed to improve the signal integrity of the memory channel by allowing the DRAM controller to independently change termination re-sistance for any or all DRAM devices. If DBI read mode is enabled while the DRAM is in standby, either DM mode or DBI write mode must also be enabled if $R_{TT(NOM)}$ or
$R_{TT(Park)}$ is desired. More details about ODT control modes and ODT timing modes can be found further along in this document.

The ODT feature is turned off and not supported in self refresh mode.

**Figure 192: Functional Representation of ODT**




The switch is enabled by the internal ODT control logic, which uses the external ODT pin and other control information. The value of $R_{TT}$ is determined by the settings of mode register bits (see Mode Register). The ODT pin will be ignored if the mode register
MR1 is programmed to disable $R_{TT(NOM)}$ [MR1[10,9,8] = 0,0,0] and in self refresh mode.

## ODT Mode Register and ODT State Table

The ODT mode of the DDR4 device has four states: data termination disable, $R_{TT(NOM)}$, $R_{TT(WR)}$, and $R_{TT(Park)}$. The ODT mode is enabled if any of MR1[10:8] ($R_{TT(NOM)}$), MR2[11:9] ($R_{TT(WR)}$), or MR5[8:6] ($R_{TT(Park)}$) are non-zero. When enabled, the value of $R_{TT}$ is determined by the settings of these bits.

$R_{TT}$ control of each $R_{TT}$ condition is possible with a WR or RD command and ODT pin.

- $R_{TT(WR)}$: The DRAM (rank) that is being written to provide termination regardless of ODT pin status (either HIGH or LOW).
- $R_{TT(NOM)}$: DRAM turns ON $R_{TT(NOM)}$ if it sees ODT asserted HIGH (except when ODT is disabled by MR1).
- $R_{TT(Park)}$: Default parked value set via MR5 to be enabled and $R_{TT(NOM)}$ is not turned on.
- The Termination State Table that follows shows various interactions.

The $R_{TT}$ values have the following priority:

- Data termination disable
- $R_{TT(WR)}$
- $R_{TT(NOM)}$
- $R_{TT(Park)}$

**Table 60: Termination State Table**

| Case | $R_{TT(Park)}$ | $R_{TT(NOM)}$[1] | $R_{TT(WR)}$[2] | ODT Pin | ODT READS[3] | ODT Stand-by[7] | ODT WRITES |
|---|---|---|---|---|---|---|---|
| A[4] | Disabled | Disabled | Disabled | Don't Care | Off (High-Z) | Off (High-Z) | Off (High-Z) |
| | | | Enabled | Don't Care | Off (High-Z) | Off (High-Z) | $R_{TT(WR)}$ |
| B[5] | Enabled | Disabled | Disabled | Don't Care | Off (High-Z) | $R_{TT(Park)}$ | $R_{TT(Park)}$ |
| | | | Enabled | Don't Care | Off (High-Z) | $R_{TT(Park)}$ | $R_{TT(WR)}$ |
| C[6] | Disabled | Enabled | Disabled | Low | Off (High-Z) | Off (High-Z) | Off (High-Z) |
| | | | | High | Off (High-Z) | $R_{TT(NOM)}$ | $R_{TT(NOM)}$ |
| | | | Enabled | Low | Off (High-Z) | Off (High-Z) | $R_{TT(WR)}$ |
| | | | | High | Off (High-Z) | $R_{TT(NOM)}$ | $R_{TT(WR)}$ |
| D[6] | Enabled | Enabled | Disabled | Low | Off (High-Z) | $R_{TT(Park)}$ | $R_{TT(Park)}$ |
| | | | | High | Off (High-Z) | $R_{TT(NOM)}$ | $R_{TT(NOM)}$ |
| | | | Enabled | Low | Off (High-Z) | $R_{TT(Park)}$ | $R_{TT(WR)}$ |
| | | | | High | Off (High-Z) | $R_{TT(NOM)}$ | $R_{TT(WR)}$ |

Notes:
1. If $R_{TT(NOM)}$ MR is disabled, power to the ODT receiver will be turned off to save power.
2. If $R_{TT(WR)}$ is enabled, $R_{TT(WR)}$ will be activated by a WRITE command for a defined period time independent of the ODT pin and MR setting of $R_{TT(Park)}$/$R_{TT(NOM)}$. This is described in the Dynamic ODT section.
3. When a READ command is executed, the DRAM termination state will be High-Z for a defined period independent of the ODT pin and MR setting of $R_{TT(Park)}$/$R_{TT(NOM)}$. This is described in the ODT During Read section.
4. Case A is generally best for single-rank memories.
5. Case B is generally best for dual-rank, single-slotted memories.
6. Case C and Case D are generally best for multi-slotted memories.
7. The ODT feature is turned off and not supported in self refresh mode.

## ODT Read Disable State Table

Upon receiving a READ command, the DRAM driving data disables ODT after RL - (2 or 3) clock cycles, where 2 = 1$^t$CK preamble mode and 3 = 2$^t$CK preamble mode. ODT stays off for a duration of BL/2 + (2 or 3) + (0 or 1) clock cycles, where 2 = 1$^t$CK preamble mode, 3 = 2$^t$CK preamble mode, 0 = CRC disabled, and 1 = CRC enabled.

**Table 61: Read Termination Disable Window**

| Preamble | CRC | Start ODT Disable After Read | Duration of ODT Disable |
|---|---|---|---|
| 1$^t$CK | Disabled | RL - 2 | BL/2 + 2 |
| | Enabled | RL - 2 | BL/2 + 3 |
| 2$^t$CK | Disabled | RL - 3 | BL/2 + 3 |
| | Enabled | RL - 3 | BL/2 + 4 |

## Synchronous ODT Mode

Synchronous ODT mode is selected whenever the DLL is turned on and locked. Based on the power-down definition, these modes include the following:

- Any bank active with CKE HIGH
- Refresh with CKE HIGH
- Idle mode with CKE HIGH
- Active power-down mode
- Precharge power-down mode

In synchronous ODT mode, $R_{TT(NOM)}$ will be turned on DODTLon clock cycles after ODT is sampled HIGH by a rising clock edge and turned off DODTLoff clock cycles after ODT is registered LOW by a rising clock edge. The ODT latency is determined by the programmed values for: CAS WRITE latency (CWL), additive latency (AL), and parity latency (PL), as well as the programmed state of the preamble.

### ODT Latency and Posted ODT

The ODT latencies for synchronous ODT mode are summarized in the table below. For details, refer to the latency definitions.

**Table 62: ODT Latency at DDR4-1600/-1866/-2133/-2400/-2666/-3200**

Applicable when write CRC is disabled

| Symbol | Parameter | 1$^t$CK Preamble | 2$^t$CK Preamble | Unit |
|---|---|---|---|---|
| DODTLon | Direct ODT turn-on latency | CWL + AL + PL - 2 | CWL + AL + PL - 3 | $^t$CK |
| DODTLoff | Direct ODT turn-off latency | CWL + AL + PL - 2 | CWL + AL + PL - 3 | |
| RODTLoff | READ command to internal ODT turn-off latency | CL + AL + PL - 2 | CL + AL + PL - 3 | |
| RODTLon4 | READ command to $R_{TT(Park)}$ turn-on latency in BC4-fixed | RODTLoff + 4 | RODTLoff + 5 | |
| RODTLon8 | READ command to $R_{TT(Park)}$ turn-on latency in BL8/BC4-OTF | RODTLoff + 6 | RODTLoff + 7 | |
| ODTH4 | ODT Assertion time, BC4 mode | 4 | 5 | |
| ODTH8 | ODT Assertion time, BL8 mode | 6 | 7 | |

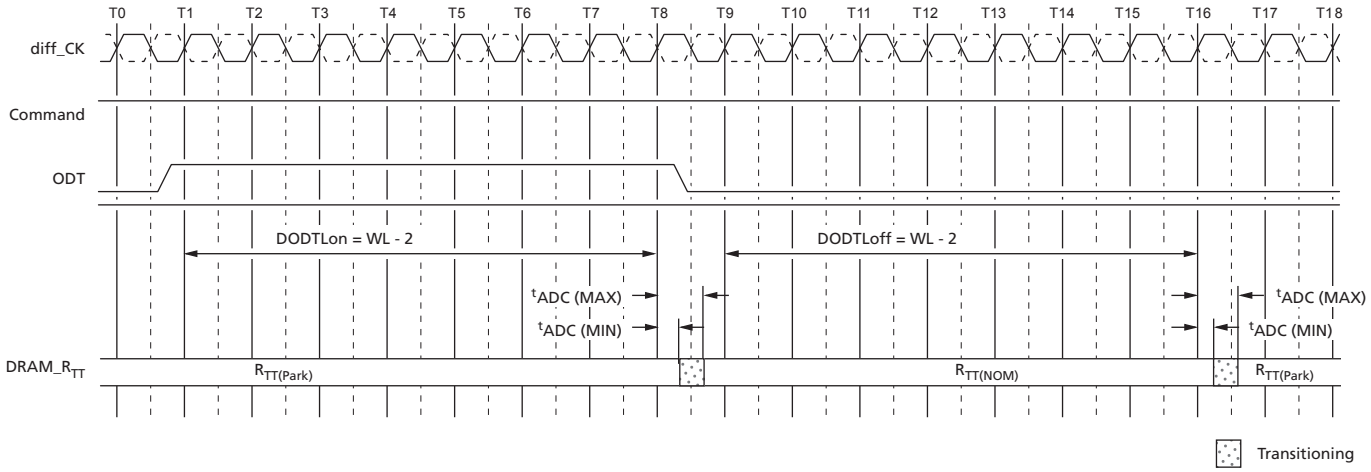
### Timing Parameters

In synchronous ODT mode, the following parameters apply:

- DODTLon, DODTLoff, RODTLoff, RODTLon4, RODTLon8, and $^t$ADC (MIN) / (MAX).
- $^t$ADC (MIN) and $^t$ADC (MAX) are minimum and maximum $R_{TT}$ change timing skew between different termination values. These timing parameters apply to both the synchronous ODT mode and the data termination disable mode.

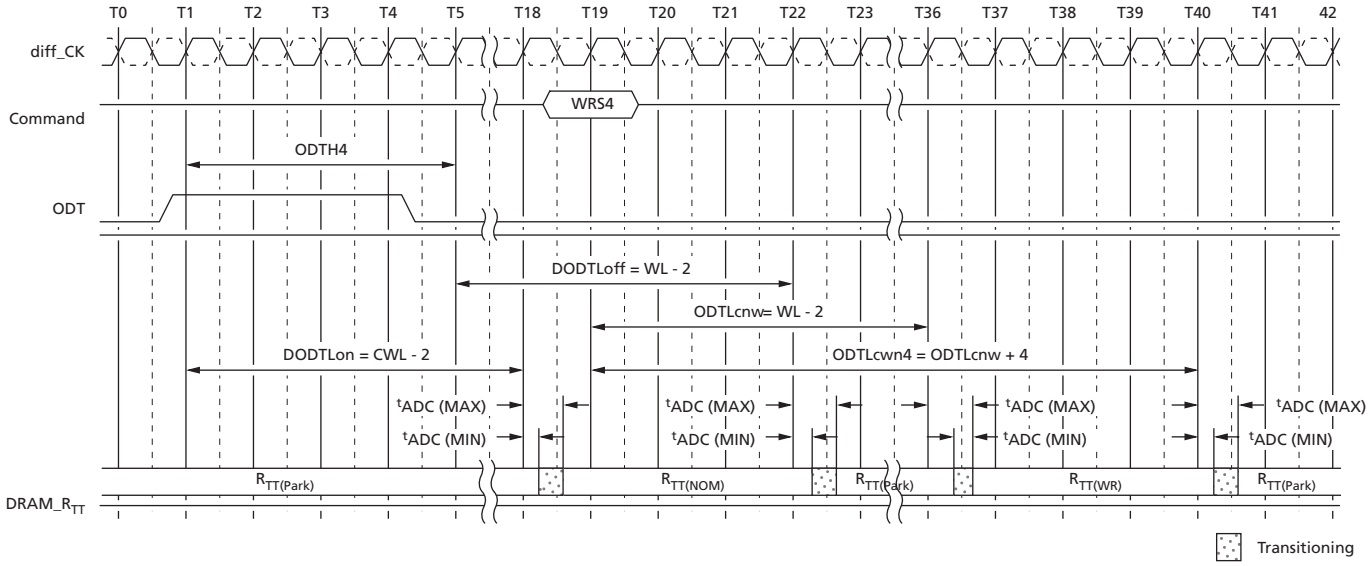
When ODT is asserted, it must remain HIGH until minimum ODTH4 (BC = 4) or ODTH8 (BL = 8) is satisfied. If write CRC mode or 2$^t$CK preamble mode is enabled, ODTH should be adjusted to account for it. ODTH*x* is measured from ODT first registered HIGH to ODT first registered LOW or from the registration of a WRITE command.

**Figure 193: Synchronous ODT Timing with BL8**




Notes:
1. Example for CWL = 9, AL = 0, PL = 0; DODTLon = AL + PL + CWL - 2 = 7; DODTLoff = AL + PL + CWL - 2 = 7.
2. ODT must be held HIGH for at least ODTH8 after assertion (T1).

**Figure 194: Synchronous ODT with BC4**



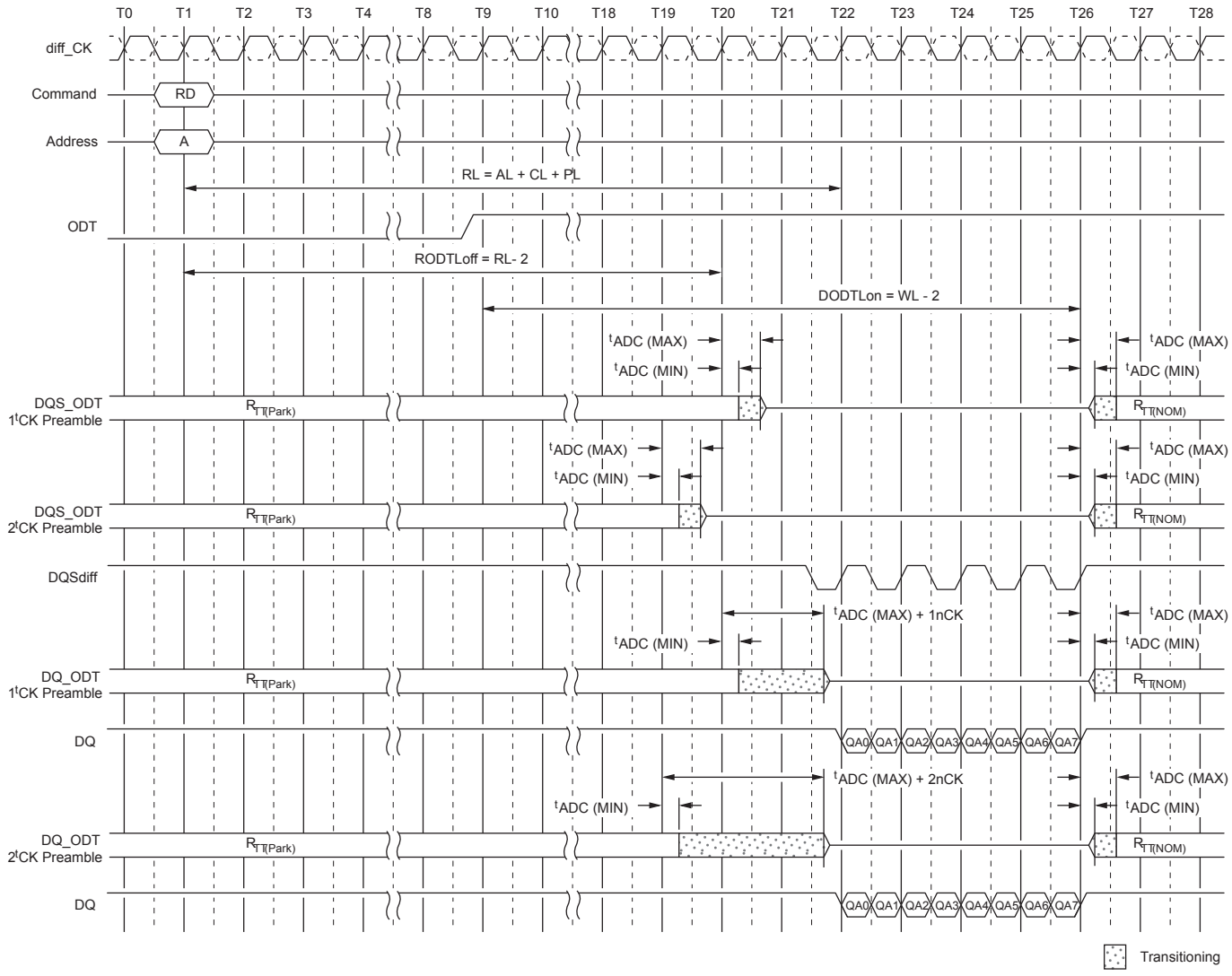

Notes:
1. Example for CWL = 9, AL = 10, PL = 0; DODTLon/off = AL + PL+ CWL - 2 = 17; ODTcnw = AL + PL+ CWL - 2 = 17.
2. ODT must be held HIGH for at least ODTH4 after assertion (T1).

## ODT During Reads

Because the DRAM cannot terminate with $R_{TT}$ and drive with $R_{ON}$ at the same time, $R_{TT}$ may nominally not be enabled until the end of the postamble as shown in the example below. At cycle T26 the device turns on the termination when it stops driving, which is determined by $^{t}$HZ. If the DRAM stops driving early (that is, $^{t}$HZ is early), then $^{t}$ADC (MIN) timing may apply. If the DRAM stops driving late (that is, $^{t}$HZ is late), then the DRAM complies with $^{t}$ADC (MAX) timing.

Using CL = 11 as an example for the figure below: PL = 0, AL = CL - 1 = 10, RL = PL + AL + CL = 21, CWL= 9; RODTLoff = RL - 2 = 19, DODTLon = PL + AL + CWL - 2 = 17, 1$^{t}$CK preamble.

**Figure 195: ODT During Reads**



# Dynamic ODT

In certain application cases and to further enhance signal integrity on the data bus, it is desirable that the termination strength of the device can be changed without issuing an MRS command. This requirement is supported by the dynamic ODT feature.

## Functional Description

Dynamic ODT mode is enabled if bit A9 or A10 of MR2 is set to 1.

- Three $R_{TT}$ values are available: $R_{TT(NOM)}$, $R_{TT(WR)}$, and $R_{TT(Park)}$.
  - The value for $R_{TT(NOM)}$ is preselected via bits MR1[10:8].
  - The value for $R_{TT(WR)}$ is preselected via bits MR2[11:9].
  - The value for $R_{TT(Park)}$ is preselected via bits MR5[8:6].
- During operation without WRITE commands, the termination is controlled as follows:
  - Nominal termination strength $R_{TT(NOM)}$ or $R_{TT(Park)}$ is selected.
  - $R_{TT(NOM)}$ on/off timing is controlled via ODT pin and latencies DODTLon and DODTLoff, and $R_{TT(Park)}$ is on when ODT is LOW.
- When a WRITE command (WR, WRA, WRS4, WRS8, WRAS4, and WRAS8) is registered, and if dynamic ODT is enabled, the termination is controlled as follows:
  - Latency ODTLcnw after the WRITE command, termination strength $R_{TT(WR)}$ is selected.
  - Latency ODTLcwn8 (for BL8, fixed by MRS or selected OTF) or ODTLcwn4 (for BC4, fixed by MRS or selected OTF) after the WRITE command, termination strength $R_{TT(WR)}$ is de-selected.

One or two clocks will be added into or subtracted from ODTLcwn8 and ODTLcwn4, depending on write CRC mode and/or 2$^{t}$CK preamble enablement.

The following table shows latencies and timing parameters relevant to the on-die termination control in dynamic ODT mode. The dynamic ODT feature is not supported in DLL-off mode. An MRS command must be used to set $R_{TT(WR)}$ to disable dynamic ODT externally (MR2[11:9] = 000).

**Table 63: Dynamic ODT Latencies and Timing (1$^{t}$CK Preamble Mode and CRC Disabled)**

| Name and Description | Abbr. | Defined from | Defined to | 1600/1866/2133/2400 | 2666 | 2933/3200 | Unit |
|---|---|---|---|---|---|---|---|
| ODT latency for change from $R_{TT(Park)}$/$R_{TT(NOM)}$ to $R_{TT(WR)}$ | ODTLcnw | Registering external WRITE command | Change $R_{TT}$ strength from $R_{TT(Park)}$/$R_{TT(NOM)}$ to $R_{TT(WR)}$ | ODTLcnw = WL - 2 | | | $^{t}$CK |
| ODT latency for change from $R_{TT(WR)}$ to $R_{TT(Park)}$/$R_{TT(NOM)}$ (BC = 4) | ODTLcwn4 | Registering external WRITE command | Change $R_{TT}$ strength from $R_{TT(WR)}$ to $R_{TT(Park)}$/$R_{TT(NOM)}$ | ODTLcwn4 = 4 + ODTLcnw | | | $^{t}$CK |
| ODT latency for change from $R_{TT(WR)}$ to $R_{TT(Park)}$/$R_{TT(NOM)}$ (BL = 8) | ODTLcwn8 | Registering external WRITE command | Change $R_{TT}$ strength from $R_{TT(NOM)}$ to $R_{TT(WR)}$ | ODTLcwn8 = 6 + ODTLcnw | | | $^{t}$CK (AVG) |

**Table 63: Dynamic ODT Latencies and Timing (1tCK Preamble Mode and CRC Disabled) (Continued)**

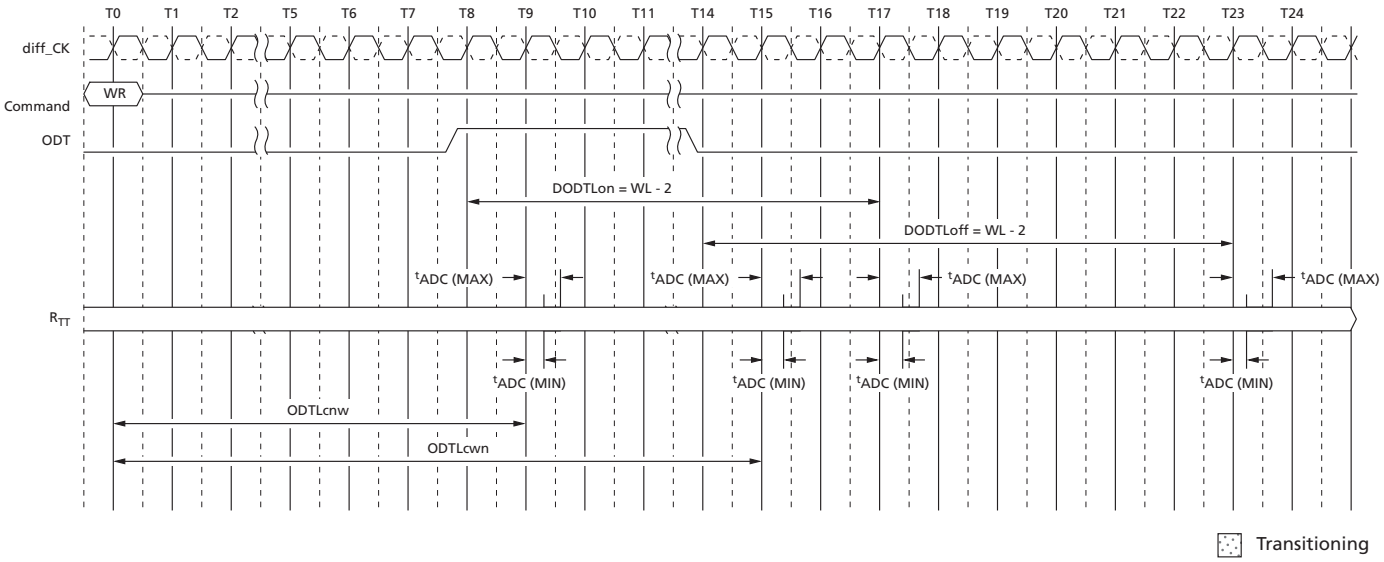
| Name and Description | Abbr. | Defined from | Defined to | 1600/1866/2133/2400 | 2666 | 2933/3200 | Unit |
|---|---|---|---|---|---|---|---|
| $R_{TT}$ change skew | tADC | ODTLcnw<br>ODTLcwn | $R_{TT}$ valid | tADC (MIN) = 0.30<br>tADC (MAX) = 0.70 | tADC (MIN) = 0.28<br>tADC (MAX) = 0.72 | tADC (MIN) = 0.26<br>tADC (MAX) = 0.74 | tCK (AVG) |

**Table 64: Dynamic ODT Latencies and Timing with Preamble Mode and CRC Mode Matrix**

| Symbol | 1tCK Parameter | | 2tCK Parameter | | Unit |
|---|---|---|---|---|---|
| | CRC Off | CRC On | CRC Off | CRC On | |
| ODTLcnw[1] | WL - 2 | WL - 2 | WL - 3 | WL - 3 | tCK |
| ODTLcwn4 | ODTLcnw + 4 | ODTLcnw + 7 | ODTLcnw + 5 | ODTLcnw + 8 | |
| ODTLcwn8 | ODTLcnw + 6 | ODTLcnw + 7 | ODTLcnw + 7 | ODTLcnw + 8 | |

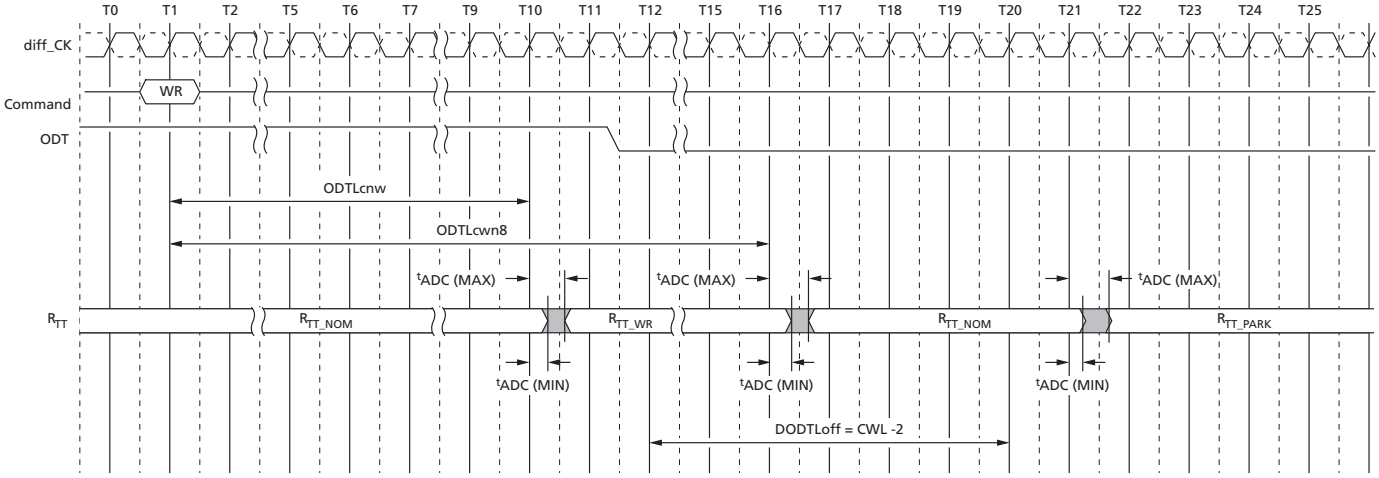
Note: 1. ODTLcnw = WL - 2 (1tCK preamble) or WL - 3 (2tCK preamble).

**Figure 196: Dynamic ODT (1t CK Preamble; CL = 14, CWL = 11, BL = 8, AL = 0, CRC Disabled)**




Notes: 1. ODTLcnw = WL - 2 (1tCK preamble) or WL - 3 (2tCK preamble).
2. If BC4, then ODTLcwn = WL + 4 if CRC disabled or WL + 5 if CRC enabled; If BL8, then ODTLcwn = WL + 6 if CRC disabled or WL + 7 if CRC enabled.

**Figure 197: Dynamic ODT Overlapped with $R_{TT(NOM)}$ (CL = 14, CWL = 11, BL = 8, AL = 0, CRC Disabled)**




Note: 1. Behavior with WR command issued while ODT is registered HIGH.

## Asynchronous ODT Mode

Asynchronous ODT mode is selected when the DRAM runs in DLL-off mode. In asynchronous ODT timing mode, the internal ODT command is *not* delayed by either additive latency (AL) or the parity latency (PL) relative to the external ODT signal ($R_{TT(NOM)}$). In asynchronous ODT mode, two timing parameters apply: $^{t}$AONAS (MIN/MAX), and $^{t}$AOFAS (MIN/MAX).

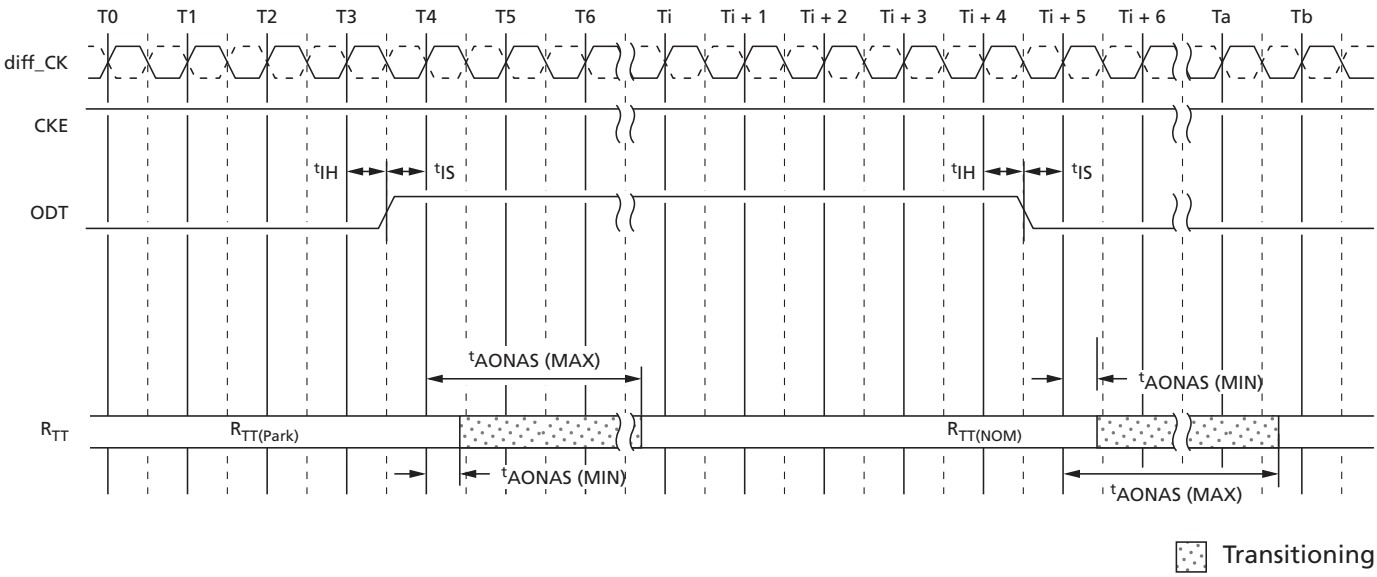
**$R_{TT(NOM)}$ Turn-on Time**

- Minimum $R_{TT(NOM)}$ turn-on time ($^{t}$AONAS [MIN]) is when the device termination circuit leaves $R_{TT(Park)}$ and ODT resistance begins to turn on.
- Maximum $R_{TT(NOM)}$ turn-on time ($^{t}$AONAS [MAX]) is when the ODT resistance has reached $R_{TT(NOM)}$.
- $^{t}$AONAS (MIN) and $^{t}$AONAS (MAX) are measured from ODT being sampled HIGH.

**$R_{TT(NOM)}$ Turn-off Time**

- Minimum $R_{TT(NOM)}$ turn-off time ($^{t}$AOFAS [MIN]) is when the device's termination circuit starts to leave $R_{TT(NOM)}$.
- Maximum $R_{TT(NOM)}$ turn-off time ($^{t}$AOFAS [MAX]) is when the on-die termination has reached $R_{TT(Park)}$.
- $^{t}$AOFAS (MIN) and $^{t}$AOFAS (MAX) are measured from ODT being sampled LOW.

**Figure 198: Asynchronous ODT Timings with DLL Off**



# Electrical Specifications

## Absolute Ratings

Stresses greater than those listed may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these or any other conditions outside those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may adversely affect reliability. Although "unlimited" row accesses to the same row is allowed within the refresh period; excessive row accesses to the same row over a long term can result in degraded operation.

**Table 65: Absolute Maximum Ratings**

| Symbol | Parameter | Min | Max | Unit | Notes |
|---|---|---|---|---|---|
| $V_{DD}$ | Voltage on $V_{DD}$ pin relative to $V_{SS}$ | –0.4 | 1.5 | V | 1 |
| $V_{DDQ}$ | Voltage on $V_{DDQ}$ pin relative to $V_{SS}$ | –0.4 | 1.5 | V | 1 |
| $V_{PP}$ | Voltage on $V_{PP}$ pin relative to $V_{SS}$ | –0.4 | 3.0 | V | 3 |
| $V_{IN}$, $V_{OUT}$ | Voltage on any pin relative to $V_{SS}$ | –0.4 | 1.5 | V | |
| $T_{STG}$ | Storage temperature | –55 | 150 | °C | 2 |

Notes:
1. $V_{DD}$ and $V_{DDQ}$ must be within 300mV of each other at all times, and $V_{REF}$ must not be greater than 0.6 × $V_{DDQ}$. When $V_{DD}$ and $V_{DDQ}$ are <500mV, $V_{REF}$ can be ≤300mV.
2. Storage temperature is the case surface temperature on the center/top side of the DRAM. For the measurement conditions, please refer to the JESD51-2 standard.
3. $V_{PP}$ must be equal to or greater than $V_{DD}$/$V_{DDQ}$ at all times when powered.

## DRAM Component Operating Temperature Range

Operating temperature, $T_{OPER}$, is the case surface temperature on the center/top side of the DRAM. For measurement conditions, refer to the JEDEC document JESD51-2.

**Table 66: Temperature Range**

| Symbol | Parameter | Min | Max | Unit | Notes |
|---|---|---|---|---|---|
| $T_{OPER}$ | Normal operating temperature range | -40 | 85 | °C | 1 |
| | Extended temperature range (optional) | >85 | 95 | °C | 2 |

Notes:
1. The normal temperature range specifies the temperatures at which all DRAM specifications will be supported. During operation, the DRAM case temperature must be maintained between 0°C to 85°C under all operating conditions for the commercial offering. The Industrial Temperature offering alow the case temperature to go below 0C to -40C.

2. Some applications require operation of the commercial, industrial, and automotive temperature DRAMs in the extended temperature range (between 85°C and 125°C case temperature). Full specifications are supported in this range, but the following additional conditions apply:

   - Refer to tREFI and tRFC parameters table for tREFI requirements when operating above 85°C.
   - If SELF REFRESH operation is required in the extended temperature range, it is mandatory to use either the manual self refresh mode with extended temperature range capability (MR2[6] = 0 and MR2 [7] = 1) or enable the optional auto self refresh mode (MR2 [6] = 1 and MR2 [7] = 1).

# Electrical Characteristics – AC and DC Operating Conditions

## Supply Operating Conditions

### Table 67: Recommended Supply Operating Conditions

| Symbol | Parameter | Rating | | | Unit | Notes |
|---|---|---|---|---|---|---|
| | | Min | Typ | Max | | |
| $V_{DD}$ | Supply voltage | 1.14 | 1.2 | 1.26 | V | 1, 2, 3, 4, 5 |
| $V_{DDQ}$ | Supply voltage for output | 1.14 | 1.2 | 1.26 | V | 1, 2, 6 |
| $V_{PP}$ | Wordline supply voltage | 2.375 | 2.5 | 2.750 | V | 7 |

Notes:
1. Under all conditions $V_{DDQ}$ must be less than or equal to $V_{DD}$.
2. $V_{DDQ}$ tracks with $V_{DD}$. AC parameters are measured with $V_{DD}$ and $V_{DDQ}$ tied together.
3. $V_{DD}$ slew rate between 300mV and 80% of $V_{DD,min}$ shall be between 0.004 V/ms and 600 V/ms, 20 MHz band-limited measurement.
4. $V_{DD}$ ramp time from 300mV to $V_{DD,min}$ shall be no longer than 200ms.
5. A stable valid $V_{DD}$ level is a set DC level (0 Hz to 250 KHz) and must be no less than $V_{DD,min}$ and no greater than $V_{DD,max}$. If the set DC level is altered anytime after initialization, the DLL reset and calibrations must be performed again after the new set DC level is final. AC noise of ±60mV (greater than 250 KHz) is allowed on $V_{DD}$ provided the noise doesn't alter $V_{DD}$ to less than $V_{DD,min}$ or greater than $V_{DD,max}$.
6. A stable valid $V_{DDQ}$ level is a set DC level (0 Hz to 250 KHz) and must be no less than $V_{DDQ,min}$ and no greater than $V_{DDQ,max}$. If the set DC level is altered anytime after initialization, the DLL reset and calibrations must be performed again after the new set DC level is final. AC noise of ±60mV (greater than 250 KHz) is allowed on $V_{DDQ}$ provided the noise doesn't alter $V_{DDQ}$ to less than $V_{DDQ,min}$ or greater than $V_{DDQ,max}$.
7. A stable valid $V_{PP}$ level is a set DC level (0 Hz to 250 KHz) and must be no less than $V_{PP,min}$ and no greater than $V_{PP,max}$. If the set DC level is altered anytime after initialization, the DLL reset and calibrations must be performed again after the new set DC level is final. AC noise of ±120mV (greater than 250 KHz) is allowed on $V_{PP}$ provided the noise doesn't alter $V_{PP}$ to less than $V_{PP,min}$ or greater than $V_{PP,max}$.

### Table 68: $V_{DD}$ Slew Rate

| Symbol | Min | Max | Unit | Notes |
|---|---|---|---|---|
| $V_{DD\_sl}$ | 0.004 | 600 | V/ms | 1, 2 |
| $V_{DD\_on}$ | – | 200 | ms | 3 |

Notes:
1. Measurement made between 300mV and 80% $V_{DD}$ (minimum level).
2. The DC bandwidth is limited to 20 MHz.
3. Maximum time to ramp $V_{DD}$ from 300 mV to $V_{DD}$ minimum.

## Leakages

### Table 69: Leakages

| Condition | Symbol | Min | Max | Unit | Notes |
|---|---|---|---|---|---|
| Input leakage (excluding ZQ and TEN) | $I_{IN}$ | –2 | 2 | µA | 1 |
| ZQ leakage | $I_{ZQ}$ | –50 | 10 | µA | 1 |
| TEN leakage | $I_{TEN}$ | –6 | 10 | µA | 1, 2 |
| $V_{REFCA}$ leakage | $I_{VREFCA}$ | –2 | 2 | µA | 3 |
| Output leakage: $V_{OUT} = V_{DDQ}$ | $I_{OZpd}$ | – | 10 | µA | 4 |
| Output leakage: $V_{OUT} = V_{SSQ}$ | $I_{OZpu}$ | –50 | – | µA | 4, 5 |

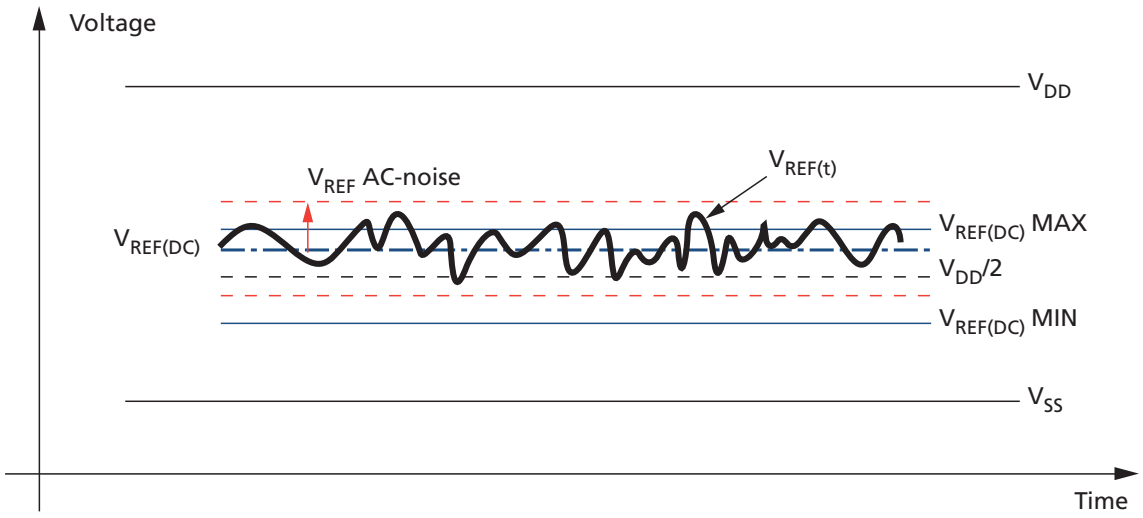
Notes:
1. Input under test $0V < V_{IN} < 1.1V$.
2. Additional leakage due to weak pull-down.
3. $V_{REFCA} = V_{DD}/2$, $V_{DD}$ at valid level after initialization.
4. DQs are disabled.
5. ODT is disabled with the ODT input HIGH.

## $V_{REFCA}$ Supply

$V_{REFCA}$ is to be supplied to the DRAM and equal to $V_{DD}/2$. The $V_{REFCA}$ is a reference supply input and therefore does not draw biasing current.

The DC-tolerance limits and AC-noise limits for the reference voltages $V_{REFCA}$ are illustrated in the figure below. The figure shows a valid reference voltage $V_{REF(t)}$ as a function of time ($V_{REF}$ stands for $V_{REFCA}$). $V_{REF(DC)}$ is the linear average of $V_{REF(t)}$ over a very long period of time (1 second). This average has to meet the MIN/MAX requirements. Furthermore, $V_{REF(t)}$ may temporarily deviate from $V_{REF(DC)}$ by no more than ±1% $V_{DD}$ for the AC-noise limit.

### Figure 199: $V_{REFDQ}$ Voltage Range



The voltage levels for setup and hold time measurements are dependent on $V_{REF}$. $V_{REF}$ is understood as $V_{REF(DC)}$, as defined in the above figure. This clarifies that DC-variations of $V_{REF}$ affect the absolute voltage a signal has to reach to achieve a valid HIGH or LOW level, and therefore, the time to which setup and hold is measured. System timing and voltage budgets need to account for $V_{REF(DC)}$ deviations from the optimum position within the data-eye of the input signals. This also clarifies that the DRAM setup/hold specification and derating values need to include time and voltage associated with $V_{REF}$ AC-noise. Timing and voltage effects due to AC-noise on $V_{REF}$ up to the specified limit (±1% of $V_{DD}$) are included in DRAM timings and their associated deratings.

## $V_{REFDQ}$ Supply and Calibration Ranges

The device internally generates its own $V_{REFDQ}$. DRAM internal $V_{REFDQ}$ specification parameters: voltage range, step size, $V_{REF}$ step time, $V_{REF}$ full step time, and $V_{REF}$ valid level are used to help provide estimated values for the internal $V_{REFDQ}$ and are not pass/fail limits. The voltage operating range specifies the minimum required range for DDR4 SDRAM devices. The minimum range is defined by $V_{REFDQ,min}$ and $V_{REFDQ,max}$. A calibration sequence should be performed by the DRAM controller to adjust $V_{REFDQ}$ and optimize the timing and voltage margin of the DRAM data input receivers.

**Table 70: $V_{REFDQ}$ Specification**

| Parameter | Symbol | Min | Typ | Max | Unit | Notes |
|---|---|---|---|---|---|---|
| Range 1 $V_{REFDQ}$ operating points | $V_{REFDQ}$ R1 | 60% | – | 92% | $V_{DDQ}$ | 1, 2 |
| Range 2 $V_{REFDQ}$ operating points | $V_{REFDQ}$ R2 | 45% | – | 77% | $V_{DDQ}$ | 1, 2 |
| $V_{REF}$ step size | $V_{REF,step}$ | 0.5% | 0.65% | 0.8% | $V_{DDQ}$ | 3 |
| $V_{REF}$ set tolerance | $V_{REF,set\_tol}$ | –1.625% | 0% | 1.625% | $V_{DDQ}$ | 4, 5, 6 |
| | | –0.15% | 0% | 0.15% | $V_{DDQ}$ | 4, 7, 8 |
| $V_{REF}$ step time | $V_{REF,time}$ | – | – | 150 | ns | 9, 10, 11 |
| $V_{REF}$ valid tolerance | $V_{REF\_val\_tol}$ | –0.15% | 0% | 0.15% | $V_{DDQ}$ | 12 |

Notes:
1. $V_{REF(DC)}$ voltage is referenced to $V_{DDQ(DC)}$. $V_{DDQ(DC)}$ is 1.2V.
2. DRAM range 1 or range 2 is set by the MRS6[6]6.
3. $V_{REF}$ step size increment/decrement range. $V_{REF}$ at DC level.
4. $V_{REF,new} = V_{REF,old} \pm n \times V_{REF,step}$; n = number of steps. If increment, use "+," if decrement, use "-."
5. For n >4, the minimum value of $V_{REF}$ setting tolerance = $V_{REF,new}$ - 1.625% × $V_{DDQ}$. The maximum value of $V_{REF}$ setting tolerance = $V_{REF,new}$ + 1.625% × $V_{DDQ}$.
6. Measured by recording the MIN and MAX values of the $V_{REF}$ output over the range, drawing a straight line between those points, and comparing all other $V_{REF}$ output settings to that line.
7. For n ≤4, the minimum value of $V_{REF}$ setting tolerance = $V_{REF,new}$ - 0.15% × $V_{DDQ}$. The maximum value of $V_{REF}$ setting tolerance = $V_{REF,new}$ + 0.15% × $V_{DDQ}$.
8. Measured by recording the MIN and MAX values of the $V_{REF}$ output across four consecutive steps (n = 4), drawing a straight line between those points, and comparing all $V_{REF}$ output settings to that line.
9. Time from MRS command to increment or decrement one step size for $V_{REF}$.
10. Time from MRS command to increment or decrement more than one step size up to the full range of $V_{REF}$.
11. If the $V_{REF}$ monitor is enabled, $V_{REF}$ must be derated by +10ns if DQ bus load is 0pF and an additional +15 ns/pF of DQ bus loading.

12. Only applicable for DRAM component-level test/characterization purposes. Not applicable for normal mode of operation. $V_{REF}$ valid qualifies the step times, which will be characterized at the component level.

## $V_{REFDQ}$ Ranges

MR6[6] selects range 1 (60% to 92.5% of $V_{DDQ}$) or range 2 (45% to 77.5% of $V_{DDQ}$), and MR6[5:0] sets the $V_{REFDQ}$ level, as listed in the following table. The values in MR6[6:0] will update the $V_{DDQ}$ range and level independent of MR6[7] setting. It is recommended MR6[7] be enabled when changing the settings in MR6[6:0], and it is highly recommended MR6[7] be enabled when changing the settings in MR6[6:0] multiple times during a calibration routine.

**Table 71: $V_{REFDQ}$ Range and Levels**

| MR6[5:0] | MR6[6] 0 = Range 1 | MR6[6] 1 = Range 2 | MR6[5:0] | MR6[6] 0 = Range 1 | MR6[6] 1 = Range 2 |
|---|---|---|---|---|---|
| 00 0000 | 60.00% | 45.00% | 01 1010 | 76.90% | 61.90% |
| 00 0001 | 60.65% | 45.65% | 01 1011 | 77.55% | 62.55% |
| 00 0010 | 61.30% | 46.30% | 01 1100 | 78.20% | 63.20% |
| 00 0011 | 61.95% | 46.95% | 01 1101 | 78.85% | 63.85% |
| 00 0100 | 62.60% | 47.60% | 01 1110 | 79.50% | 64.50% |
| 00 0101 | 63.25% | 48.25% | 01 1111 | 80.15% | 65.15% |
| 00 0110 | 63.90% | 48.90% | 10 0000 | 80.80% | 65.80% |
| 00 0111 | 64.55% | 49.55% | 10 0001 | 81.45% | 66.45% |
| 00 1000 | 65.20% | 50.20% | 10 0010 | 82.10% | 67.10% |
| 00 1001 | 65.85% | 50.85% | 10 0011 | 82.75% | 67.75% |
| 00 1010 | 66.50% | 51.50% | 10 0100 | 83.40% | 68.40% |
| 00 1011 | 67.15% | 52.15% | 10 0101 | 84.05% | 69.05% |
| 00 1100 | 67.80% | 52.80% | 10 0110 | 84.70% | 69.70% |
| 00 1101 | 68.45% | 53.45% | 10 0111 | 85.35% | 70.35% |
| 00 1110 | 69.10% | 54.10% | 10 1000 | 86.00% | 71.00% |
| 00 1111 | 69.75% | 54.75% | 10 1001 | 86.65% | 71.65% |
| 01 0000 | 70.40% | 55.40% | 10 1010 | 87.30% | 72.30% |
| 01 0001 | 71.05% | 56.05% | 10 1011 | 87.95% | 72.95% |
| 01 0010 | 71.70% | 56.70% | 10 1100 | 88.60% | 73.60% |
| 01 0011 | 72.35% | 57.35% | 10 1101 | 89.25% | 74.25% |
| 01 0100 | 73.00% | 58.00% | 10 1110 | 89.90% | 74.90% |
| 01 0101 | 73.65% | 58.65% | 10 1111 | 90.55% | 75.55% |
| 01 0110 | 74.30% | 59.30% | 11 0000 | 91.20% | 76.20% |
| 01 0111 | 74.95% | 59.95% | 11 0001 | 91.85% | 76.85% |
| 01 1000 | 75.60% | 60.60% | 11 0010 | 92.50% | 77.50% |
| 01 1001 | 76.25% | 61.25% | 11 0011 to 11 1111 are reserved | | |

# Electrical Characteristics – AC and DC Single-Ended Input Measurement Levels

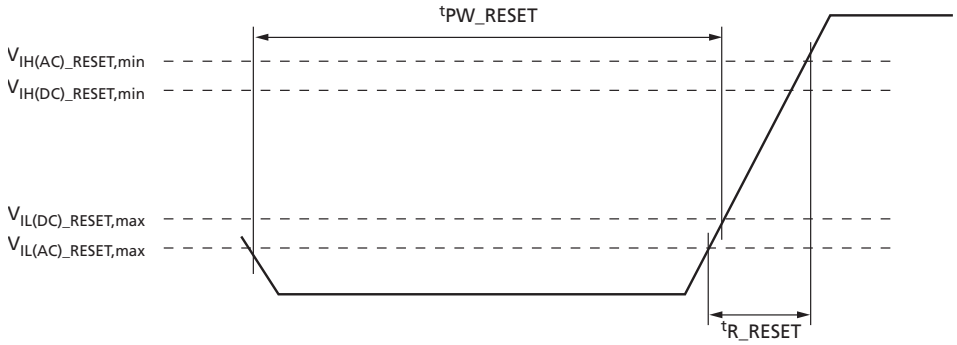
## RESET_n Input Levels

### Table 72: RESET_n Input Levels (CMOS)

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| AC input high voltage | $V_{IH(AC)\_RESET}$ | 0.8 × $V_{DD}$ | $V_{DD}$ | V | 1 |
| DC input high voltage | $V_{IH(DC)\_RESET}$ | 0.7 × $V_{DD}$ | $V_{DD}$ | V | 2 |
| DC input low voltage | $V_{IL(DC)\_RESET}$ | $V_{SS}$ | 0.3 × $V_{DD}$ | V | 3 |
| AC input low voltage | $V_{IL(AC)\_RESET}$ | $V_{SS}$ | 0.2 × $V_{DD}$ | V | 4 |
| Rising time | $^{t}$R_RESET | – | 1 | µs | 5 |
| RESET pulse width after power-up | $^{t}$PW_RESET_S | 1 | – | µs | 6, 7 |
| RESET pulse width during power-up | $^{t}$PW_RESET_L | 200 | – | µs | 6 |

Notes:
1. Overshoot should not exceed the $V_{IN}$ shown in the Absolute Maximum Ratings table.
2. After RESET_n is registered HIGH, the RESET_n level must be maintained above $V_{IH(DC)\_RESET}$, otherwise operation will be uncertain until it is reset by asserting RESET_n signal LOW.
3. After RESET_n is registered LOW, the RESET_n level must be maintained below $V_{IL(DC)\_RESET}$ during $^{t}$PW_RESET, otherwise the DRAM may not be reset.
4. Undershoot should not exceed the $V_{IN}$ shown in the Absolute Maximum Ratings table.
5. Slope reversal (ring-back) during this level transition from LOW to HIGH should be mitigated as much as possible.
6. RESET is destructive to data contents.
7. See RESET Procedure at Power Stable Condition figure.

### Figure 200: RESET_n Input Slew Rate Definition




## Command/Address Input Levels

### Table 73: Command and Address Input Levels: DDR4-1600 Through DDR4-2400

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| AC input high voltage | $V_{IH(AC)}$ | $V_{REF}$ + 100 | $V_{DD}$5 | mV | 1, 2, 3 |
| DC input high voltage | $V_{IH(DC)}$ | $V_{REF}$ + 75 | $V_{DD}$ | mV | 1, 2 |

**Table 73: Command and Address Input Levels: DDR4-1600 Through DDR4-2400 (Continued)**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| DC input low voltage | $V_{IL(DC)}$ | $V_{SS}$ | $V_{REF}$ - 75 | mV | 1, 2 |
| AC input low voltage | $V_{IL(AC)}$ | $V_{SS}$5 | $V_{REF}$ - 100 | mV | 1, 2, 3 |
| Reference voltage for CMD/ADDR inputs | $V_{REFFCA(DC)}$ | 0.49 × $V_{DD}$ | 0.51 × $V_{DD}$ | V | 4 |

Notes:
1. For input except RESET_n. $V_{REF} = V_{REFCA(DC)}$.
2. $V_{REF} = V_{REFCA(DC)}$.
3. Input signal must meet $V_{IL}/V_{IH(AC)}$ to meet $^{t}$IS timings and $V_{IL}/V_{IH(DC)}$ to meet $^{t}$IH timings.
4. The AC peak noise on $V_{REF}$ may not allow $V_{REF}$ to deviate from $V_{REFCA(DC)}$ by more than ±1% $V_{DD}$ (for reference: approximately ±12mV).
5. Refer to "Overshoot and Undershoot Specifications."

**Table 74: Command and Address Input Levels: DDR4-2666**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| AC input high voltage | $V_{IH(AC)}$ | $V_{REF}$ + 90 | $V_{DD}$5 | mV | 1, 2, 3 |
| DC input high voltage | $V_{IH(DC)}$ | $V_{REF}$ + 65 | $V_{DD}$ | mV | 1, 2 |
| DC input low voltage | $V_{IL(DC)}$ | $V_{SS}$ | $V_{REF}$ - 65 | mV | 1, 2 |
| AC input low voltage | $V_{IL(AC)}$ | $V_{SS}$5 | $V_{REF}$ - 90 | mV | 1, 2, 3 |
| Reference voltage for CMD/ADDR inputs | $V_{REFFCA(DC)}$ | 0.49 × $V_{DD}$ | 0.51 × $V_{DD}$ | V | 4 |

Notes:
1. For input except RESET_n. $V_{REF} = V_{REFCA(DC)}$.
2. $V_{REF} = V_{REFCA(DC)}$.
3. Input signal must meet $V_{IL}/V_{IH(AC)}$ to meet $^{t}$IS timings and $V_{IL}/V_{IH(DC)}$ to meet $^{t}$IH timings.
4. The AC peak noise on $V_{REF}$ may not allow $V_{REF}$ to deviate from $V_{REFCA(DC)}$ by more than ±1% $V_{DD}$ (for reference: approximately ±12mV).
5. Refer to "Overshoot and Undershoot Specifications."

**Table 75: Command and Address Input Levels: DDR4-2933 and DDR4-3200**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| AC input high voltage | $V_{IH(AC)}$ | $V_{REF}$ + 90 | $V_{DD}$5 | mV | 1, 2, 3 |
| DC input high voltage | $V_{IH(DC)}$ | $V_{REF}$ + 65 | $V_{DD}$ | mV | 1, 2 |
| DC input low voltage | $V_{IL(DC)}$ | $V_{SS}$ | $V_{REF}$ - 65 | mV | 1, 2 |
| AC input low voltage | $V_{IL(AC)}$ | $V_{SS}$5 | $V_{REF}$ - 90 | mV | 1, 2, 3 |
| Reference voltage for CMD/ADDR inputs | $V_{REFFCA(DC)}$ | 0.49 × $V_{DD}$ | 0.51 × $V_{DD}$ | V | 4 |

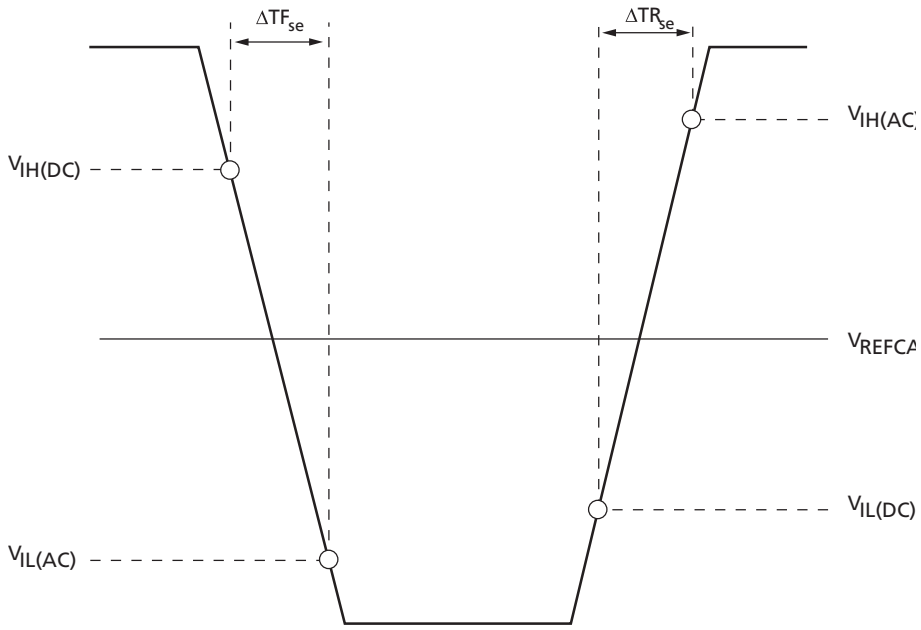
Notes:
1. For input except RESET_n. $V_{REF} = V_{REFCA(DC)}$.
2. $V_{REF} = V_{REFCA(DC)}$.
3. Input signal must meet $V_{IL}/V_{IH(AC)}$ to meet $^{t}$IS timings and $V_{IL}/V_{IH(DC)}$ to meet $^{t}$IH timings.
4. The AC peak noise on $V_{REF}$ may not allow $V_{REF}$ to deviate from $V_{REFCA(DC)}$ by more than ±1% $V_{DD}$ (for reference: approximately ±12mV).
5. Refer to "Overshoot and Undershoot Specifications."

**Table 76: Single-Ended Input Slew Rates**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| Single-ended input slew rate – CA | $SR_{CA}$ | 1.0 | 7.0 | V/ns | 1, 2, 3, 4 |

Notes:
1. For input except RESET_n.
2. $V_{REF} = V_{REFCA(DC)}$.
3. $^{t}IS/^{t}IH$ timings assume $SR_{CA}$ = 1V/ns.
4. Measured between $V_{IH(AC)}$ and $V_{IL(AC)}$ for falling edges and between $V_{IL(AC)}$ and $V_{IH(AC)}$ for rising edges

**Figure 201: Single-Ended Input Slew Rate Definition**




## Command, Control, and Address Setup, Hold, and Derating

The total $^{t}IS$ (setup time) and $^{t}IH$ (hold time) required is calculated to account for slew rate variation by adding the data sheet $^{t}IS$ (base) values, the $V_{IL(AC)}/V_{IH(AC)}$ points, and $^{t}IH$ (base) values, the $V_{IL(DC)}/V_{IH(DC)}$ points; to the $\Delta^{t}IS$ and $\Delta^{t}IH$ derating values, respectively. The base values are derived with single-end signals at 1V/ns and differential clock at 2 V/ns. Example: $^{t}IS$ (total setup time) = $^{t}IS$ (base) + $\Delta^{t}IS$. For a valid transition, the input signal has to remain above/below $V_{IH(AC)}/V_{IL(AC)}$ for the time defined by $^{t}VAC$.

Although the total setup time for slow slew rates might be negative (for example, a valid input signal will not have reached $V_{IH(AC)}/V_{IL(AC)}$ at the time of the rising clock transition), a valid input signal is still required to complete the transition and to reach $V_{IH(AC)}/V_{IL(AC)}$. For slew rates that fall between the values listed in derating tables, the derating values may be obtained by linear interpolation.

Setup ($^{t}IS$) nominal slew rate for a rising signal is defined as the slew rate between the last crossing of $V_{IL(DC)max}$ and the first crossing of $V_{IH(AC)min}$ that does not ring back be-low $V_{IH(DC)min}$. Setup ($^{t}IS$) nominal slew rate for a falling signal is defined as the slew

rate between the last crossing of $V_{IH(DC)min}$ and the first crossing of $V_{IL(AC)max}$ that does not ring back above $V_{IL(DC)max}$.

Hold ($^{t}$IH) nominal slew rate for a rising signal is defined as the slew rate between the last crossing of $V_{IL(DC)max}$ and the first crossing of $V_{IH(AC)min}$ that does not ring back below $V_{IH(DC)min}$. Hold ($^{t}$IH) nominal slew rate for a falling signal is defined as the slew rate between the last crossing of $V_{IH(DC)min}$ and the first crossing of $V_{IL(AC)min}$ that does not ring back above $V_{IL(DC)max}$.

**Table 77: Command and Address Setup and Hold Values Referenced – AC/DC-Based**

| Symbol | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Reference |
|---|---|---|---|---|---|---|---|---|---|
| $^{t}$IS(base, AC100) | 115 | 100 | 80 | 62 | – | – | – | ps | $V_{IH(AC)}/V_{IL(AC)}$ |
| $^{t}$IH(base, DC75) | 140 | 125 | 105 | 87 | – | – | – | ps | $V_{IH(DC)}/V_{IL(DC)}$ |
| $^{t}$IS(base, AC90) | – | – | – | – | 55 | 48 | 40 | ps | $V_{IH(AC)}/V_{IL(AC)}$ |
| $^{t}$IH(base, DC65) | – | – | – | – | 80 | 73 | 65 | ps | $V_{IH(DC)}/V_{IL(DC)}$ |
| $^{t}$IS/$^{t}$IH(Vref) | 215 | 200 | 180 | 162 | 145 | 138 | 130 | ps | $V_{IH(DC)}/V_{IL(DC)}$ |

**Table 78: Derating Values for $^{t}$IS/$^{t}$IH – AC100DC75-Based**

| $\Delta^{t}$IS with AC100 Threshold, $\Delta^{t}$IH with DC75 Threshold Derating (ps) – AC/DC-Based | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CMD/ ADDR Slew Rate V/ns | CK, CK# Differential Slew Rate | | | | | | | | | | | | | | | |
| | 10.0 V/ns | | 8.0 V/ns | | 6.0 V/ns | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.5 V/ns | | 1.0 V/ns | |
| | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IH | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH |
| 7.0 | 76 | 54 | 76 | 55 | 77 | 56 | 79 | 58 | 82 | 60 | 86 | 64 | 94 | 73 | 111 | 89 |
| 6.0 | 73 | 53 | 74 | 53 | 75 | 54 | 77 | 56 | 79 | 58 | 83 | 63 | 92 | 71 | 108 | 88 |
| 5.0 | 70 | 50 | 71 | 51 | 72 | 52 | 74 | 54 | 76 | 56 | 80 | 60 | 88 | 68 | 105 | 85 |
| 4.0 | 65 | 46 | 66 | 47 | 67 | 48 | 69 | 50 | 71 | 52 | 75 | 56 | 83 | 65 | 100 | 81 |
| 3.0 | 57 | 40 | 57 | 41 | 58 | 42 | 60 | 44 | 63 | 46 | 67 | 50 | 75 | 58 | 92 | 75 |
| 2.0 | 40 | 28 | 41 | 28 | 42 | 29 | 44 | 31 | 46 | 33 | 50 | 38 | 58 | 46 | 75 | 63 |
| 1.5 | 23 | 15 | 24 | 16 | 25 | 17 | 27 | 19 | 29 | 21 | 33 | 25 | 42 | 33 | 58 | 50 |
| **1.0** | –10 | –10 | –9 | –9 | –8 | –8 | –6 | –6 | –4 | –4 | **0** | **0** | 8 | 8 | 25 | 25 |
| 0.9 | –17 | –14 | –16 | –14 | –15 | –13 | –13 | –10 | –11 | –8 | –7 | –4 | 1 | 4 | 18 | 21 |
| 0.8 | –26 | –19 | –25 | –19 | –24 | –18 | –22 | –16 | –20 | –14 | –16 | –9 | –7 | –1 | 9 | 16 |
| 0.7 | –37 | –26 | –36 | –25 | –35 | –24 | –33 | –22 | –31 | –20 | –27 | –16 | –18 | –8 | –2 | 9 |
| 0.6 | –52 | –35 | –51 | –34 | –50 | –33 | –48 | –31 | –46 | –29 | –42 | –25 | –33 | –17 | –17 | 0 |
| 0.5 | –73 | –48 | –72 | –47 | –71 | –46 | –69 | –44 | –67 | –42 | –63 | –38 | –54 | –29 | –38 | –13 |
| 0.4 | –104 | –66 | –103 | –66 | –102 | –65 | –100 | –63 | –98 | –60 | –94 | –56 | –85 | –48 | –69 | –31 |

**Table 79: Derating Values for $^{t}$IS/$^{t}$IH – AC90/DC65-Based**

| $\Delta^{t}$IS with AC90 Threshold, $\Delta^{t}$IH with DC65 Threshold Derating (ps) – AC/DC-Based | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CMD/ ADDR Slew Rate V/ns | CK, CK# Differential Slew Rate | | | | | | | | | | | | | | | |
| | 10.0 V/ns | | 8.0 V/ns | | 6.0 V/ns | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.5 V/ns | | 1.0 V/ns | |
| | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IH | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH |
| 7.0 | 68 | 47 | 69 | 47 | 70 | 48 | 72 | 50 | 73 | 52 | 77 | 56 | 85 | 63 | 100 | 78 |
| 6.0 | 66 | 45 | 67 | 46 | 68 | 47 | 69 | 49 | 71 | 50 | 75 | 54 | 83 | 62 | 98 | 77 |
| 5.0 | 63 | 43 | 64 | 44 | 65 | 45 | 66 | 46 | 68 | 48 | 72 | 52 | 80 | 60 | 95 | 75 |
| 4.0 | 59 | 40 | 59 | 40 | 60 | 41 | 62 | 43 | 64 | 45 | 68 | 49 | 75 | 56 | 90 | 71 |
| 3.0 | 51 | 34 | 52 | 35 | 53 | 36 | 54 | 38 | 56 | 40 | 60 | 43 | 68 | 51 | 83 | 66 |
| 2.0 | 36 | 24 | 37 | 24 | 38 | 25 | 39 | 27 | 41 | 29 | 45 | 33 | 53 | 40 | 68 | 55 |
| 1.5 | 21 | 13 | 22 | 13 | 23 | 14 | 24 | 16 | 26 | 18 | 30 | 22 | 38 | 29 | 53 | 44 |
| **1.0** | –9 | –9 | –8 | –8 | –8 | –8 | –6 | –6 | –4 | –4 | **0** | **0** | 8 | 8 | 23 | 23 |
| 0.9 | –15 | –13 | –15 | –12 | –14 | –11 | –12 | –9 | –10 | –7 | –6 | –4 | 1 | 4 | 16 | 19 |
| 0.8 | –23 | –17 | –23 | –17 | –22 | –16 | –20 | –14 | –18 | –12 | –14 | –8 | –7 | –1 | 8 | 14 |
| 0.7 | –34 | –23 | –33 | –22 | –32 | –21 | –30 | –20 | –28 | –18 | –25 | –14 | –17 | –6 | –2 | 9 |
| 0.6 | –47 | –31 | –47 | –30 | –46 | –29 | –44 | –27 | –42 | –25 | –38 | –22 | –31 | –14 | –16 | 1 |
| 0.5 | –67 | –42 | –66 | –41 | –65 | –40 | –63 | –38 | –61 | –36 | –58 | –33 | –50 | –25 | –35 | –10 |
| 0.4 | –95 | –58 | –95 | –57 | –94 | –56 | –92 | –54 | –90 | –53 | –86 | –49 | –79 | –41 | –64 | –26 |

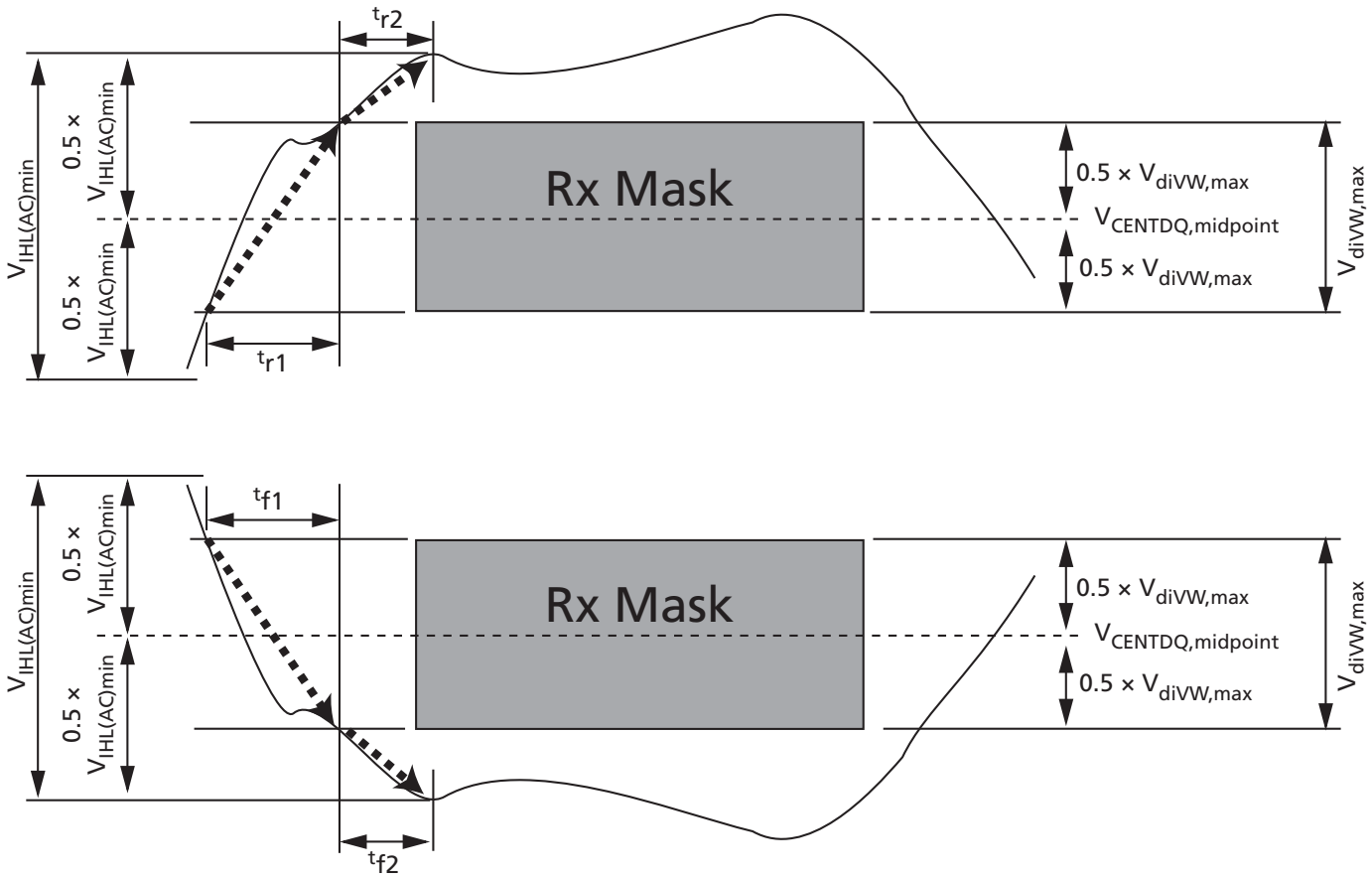
## Data Receiver Input Requirements

The following parameters apply to the data receiver Rx MASK operation detailed in the Write Timing section, Data Strobe-to-Data Relationship.

The rising edge slew rates are defined by srr1 and srr2. The slew rate measurement points for a rising edge are shown in the figure below. A LOW-to-HIGH transition time, tr1, is measured from $0.5 \times V_{diVW,max}$ below $V_{CENTDQ,midpoint}$ to the last transition through $0.5 \times V_{diVW,max}$ above $V_{CENTDQ,midpoint}$; tr2 is measured from the last transition through $0.5 \times V_{diVW,max}$ above $V_{CENTDQ,midpoint}$ to the first transition through the $0.5 \times V_{IHL(AC)min}$ above $V_{CENTDQ,midpoint}$.

The falling edge slew rates are defined by srf1 and srf2. The slew rate measurement points for a falling edge are shown in the figure below. A HIGH-to-LOW transition time, tf1, is measured from $0.5 \times V_{diVW,max}$ above $V_{CENTDQ,midpoint}$ to the last transition through $0.5 \times V_{diVW,max}$ below $V_{CENTDQ,midpoint}$; tf2 is measured from the last transition through $0.5 \times V_{diVW,max}$ below $V_{CENTDQ,midpoint}$ to the first transition through the $0.5 \times V_{IHL(AC)min}$ below $V_{CENTDQ,midpoint}$.

**Figure 202: DQ Slew Rate Definitions**




Notes:
1. Rising edge slew rate equation srr1 = $V_{diVW,max}/(^{t}r1)$.
2. Rising edge slew rate equation srr2 = $(V_{IHL(AC)min} - V_{diVW,max})/(2 \times {}^{t}r2)$.
3. Falling edge slew rate equation srf1 = $V_{diVW,max}/(^{t}f1)$.
4. Falling edge slew rate equation srf2 = $(V_{IHL(AC)min} - V_{diVW,max})/(2 \times {}^{t}f2)$.

**Table 80: DQ Input Receiver Specifications**

Note 1 applies to the entire table

| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400 | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | | |
| $V_{IN}$ Rx mask input peak-to-peak | $V_{diVW}$ | – | 136 | – | 130 | – | 120 | – | 115 | – | 110 | mV | 2, 3 |
| DQ Rx input timing window | TdiVW | – | 0.2 | – | 0.2 | – | 0.22 | – | 0.23 | – | 0.23 | UI | 2, 3 |
| DQ AC input swing peak-to-peak | $V_{IHL(AC)}$ | 186 | – | 160 | – | 150 | – | 145 | – | 140 | – | mV | 4, 5 |

**Table 80: DQ Input Receiver Specifications (Continued)**

Note 1 applies to the entire table

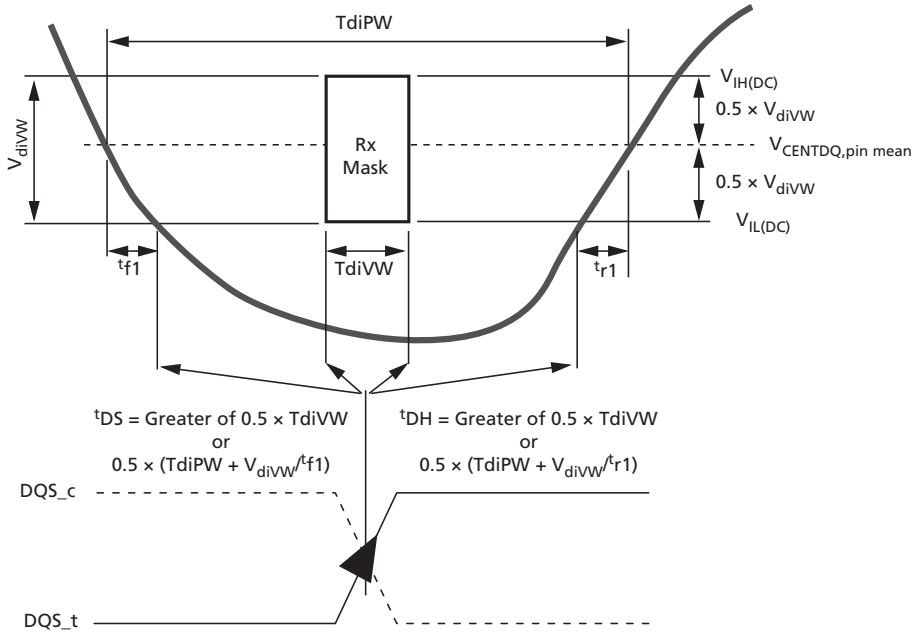
| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400 | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | | |
| DQ input pulse width | TdiPW | 0.58 | – | 0.58 | – | 0.58 | – | 0.58 | – | 0.58 | – | UI | 6 |
| DQS-to-DQ Rx mask offset | $^{t}$DQS2DQ | –0.17 | 0.17 | –0.17 | 0.17 | –0.19 | 0.19 | –0.22 | 0.22 | –0.22 | 0.22 | UI | 7 |
| DQ-to-DQ Rx mask offset | $^{t}$DQ2DQ | – | 0.1 | – | 0.1 | – | 0.105 | – | 0.115 | – | 0.125 | UI | 8 |
| Input slew rate over $V_{diVW}$ if $^{t}$CK ≥ 0.937ns | srr1, srf1 | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | V/ns | 9 |
| Input slew rate over $V_{diVW}$ if 0.937ns > $^{t}$CK ≥ 0.625ns | srr1, srf1 | – | – | 1.25 | 9 | 1.25 | 9 | 1.25 | 9 | 1.25 | 9 | V/ns | 9 |
| Rising input slew rate over 1/2 $V_{IHL(AC)}$ | srr2 | 0.2 × srr1 | 9 | 0.2 × srr1 | 9 | 0.2 × srr1 | 9 | 0.2 × srr1 | 9 | 0.2 × srr1 | 9 | V/ns | 10 |
| Falling input slew rate over 1/2 $V_{IHL(AC)}$ | srf2 | 0.2 × srf1 | 9 | 0.2 × srf1 | 9 | 0.2 × srf1 | 9 | 0.2 × srf1 | 9 | 0.2 × srf1 | 9 | V/ns | 10 |

Notes:
1. All Rx mask specifications must be satisfied for each UI. For example, if the minimum input pulse width is violated when satisfying TdiVW (MIN), $V_{diVW,max}$, and minimum slew rate limits, then either TdiVW (MIN) or minimum slew rates would have to be increased to the point where the minimum input pulse width would no longer be violated.
2. Data Rx mask voltage and timing total input valid window where $V_{diVW}$ is centered around $V_{CENTDQ,midpoint}$ after $V_{REFDQ}$ training is completed. The data Rx mask is applied per bit and should include voltage and temperature drift terms. The input buffer design specification is to achieve at least a BER =$1^{e-16}$ when the Rx mask is not violated.
3. Defined over the DQ internal $V_{REF}$ range 1.
4. Overshoot and undershoot specifications apply.
5. DQ input pulse signal swing into the receiver must meet or exceed $V_{IHL(AC)min}$. $V_{IHL(AC)min}$ is to be achieved on an UI basis when a rising and falling edge occur in the same UI (a valid TdiPW).
6. DQ minimum input pulse width defined at the $V_{CENTDQ,midpoint}$.
7. DQS-to-DQ Rx mask offset is skew between DQS and DQ within word ( x16 [for x16, the upper and lower bytes are treated as separate x8s]) at the SDRAM balls over process, voltage, and temperature.
8. DQ-to-DQ Rx mask offset is skew between DQs within word (x16) at the SDRAM balls for a given component over process, voltage, and temperature.
9. Input slew rate over $V_{diVW}$ mask centered at $V_{CENTDQ,midpoint}$. Slowest DQ slew rate to fastest DQ slew rate per transition edge must be within 1.7V/ns of each other.
10. Input slew rate between $V_{diVW}$ mask edge and $V_{IHL(AC)min}$ points.

The following figure shows the Rx mask relationship to the input timing specifications relative to system $^{t}$DS and $^{t}$DH. The classical definition for $^{t}$DS/$^{t}$DH required a DQ rising

and falling edges to not violate tDS and tDH relative to the DQS strobe at any time; however, with the Rx mask tDS and tDH can shift relative to the DQS strobe provided the input pulse width specification is satisfied and the Rx mask is not violated.

**Figure 203: Rx Mask Relative to tDS/tDH**




The following figure and table show an example of the worst case Rx mask required if the DQS and DQ pins do not have DRAM controller to DRAM write DQ training. The figure and table show that without DRAM write DQ training, the Rx mask would increase from 0.2UI to essentially 0.54UI. This would also be the minimum tDS and tDH required as well.

**Figure 204: Rx Mask Without Write Training**

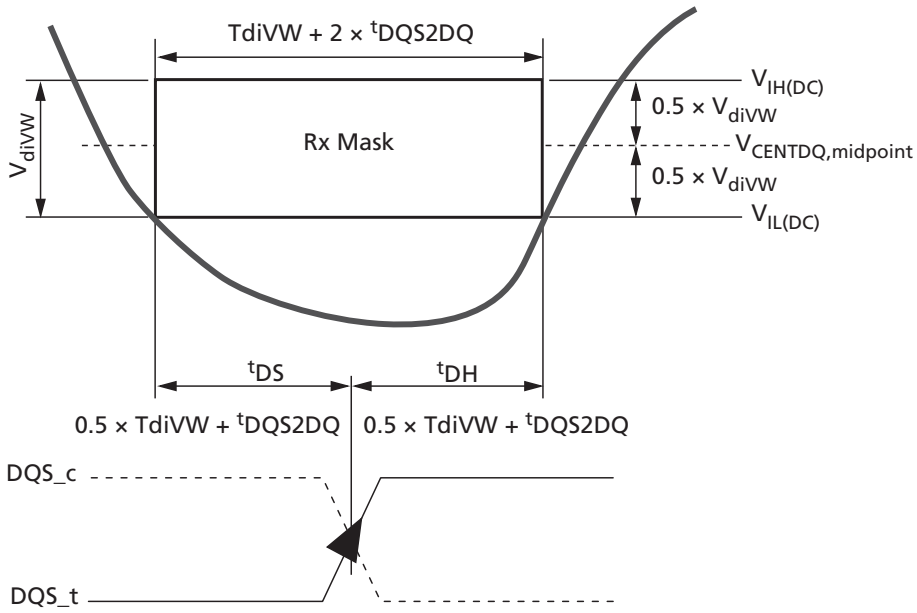



**Table 81: Rx Mask and $^{t}$DS/$^{t}$DH without Write Training**

| DDR4 | $V_{IHL(AC)}$ (mV) | TdiPW (UI) | $V_{diVW}$ (mV) | TdiVW (UI) | $^{t}$DQS2DQ (UI) | $^{t}$DQ2DQ (UI) | Rx Mask with Write Train (ps) | $^{t}$DS + $^{t}$DH (ps) |
|---|---|---|---|---|---|---|---|---|
| 1600 | 186 | 0.58 | 136 | 0.2 | ±0.17 | 0.1 | 125 | 338 |
| 1866 | 186 | 0.58 | 136 | 0.2 | ±0.17 | 0.1 | 107.1 | 289 |
| 2133 | 186 | 0.58 | 136 | 0.2 | ±0.17 | 0.1 | 94 | 253 |
| 2400 | 160 | 0.58 | 130 | 0.2 | ±0.17 | 0.1 | 83.3 | 225 |
| 2666 | 150 | 0.58 | 120 | 0.22 | ±0.19 | 0.105 | 82.5 | 225 |
| 2933 | 145 | 0.58 | 115 | 0.23 | ±0.22 | 0.115 | 78.4 | 228 |
| 3200 | 140 | 0.58 | 110 | 0.23 | ±0.22 | 0.125 | 71.8 | 209 |

Note: 1. $V_{IHL(AC)}$, $V_{diVW}$, and $V_{ILH(DC)}$ referenced to $V_{CENTDQ,midpoint}$.

## Connectivity Test (CT) Mode Input Levels

**Table 82: TEN Input Levels (CMOS)**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| TEN AC input high voltage | $V_{IH(AC)\_TEN}$ | 0.8 × $V_{DD}$ | $V_{DD}$ | V | 1 |
| TEN DC input high voltage | $V_{IH(DC)\_TEN}$ | 0.7 × $V_{DD}$ | $V_{DD}$ | V | |
| TEN DC input low voltage | $V_{IL(DC)\_TEN}$ | $V_{SS}$ | 0.3 × $V_{DD}$ | V | |
| TEN AC input low voltage | $V_{IL(AC)\_TEN}$ | $V_{SS}$ | 0.2 × $V_{DD}$ | V | 2 |
| TEN falling time | $^{t}$F_TEN | – | 1 0 | ns | |

**Table 82: TEN Input Levels (CMOS) (Continued)**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| TEN rising time | $^{t}$R_TEN | – | 1 0 | ns | |

Notes: 1. Overshoot should not exceed the $V_{IN}$ values in the Absolute Maximum Ratings table.
2. Undershoot should not exceed the $V_{IN}$ values in the Absolute Maximum Ratings table.

**Figure 205: TEN Input Slew Rate Definition**

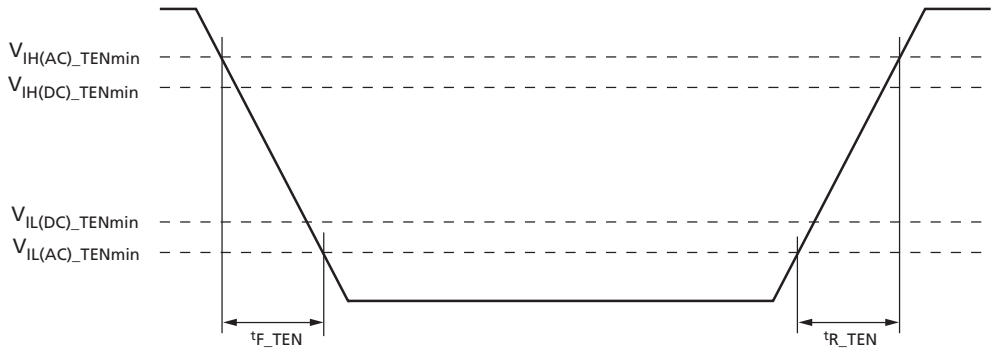



**Table 83: CT Type-A Input Levels**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| CTipA AC input high voltage | $V_{IH(AC)}$ | $V_{REF}$ + 200 | $V_{DD1}$[1] | V | 2, 3 |
| CTipA DC input high voltage | $V_{IH(DC)}$ | $V_{REF}$ + 150 | $V_{DD}$ | V | 2, 3 |
| CTipA DC input low voltage | $V_{IL(DC)}$ | $V_{SS}$ | $V_{REF}$ - 150 | V | 2, 3 |
| CTipA AC input low voltage | $V_{IL(AC)}$ | $V_{SS1}$[1] | $V_{REF}$ - 200 | V | 2, 3 |
| CTipA falling time | $^{t}$F_CTipA | – | 5 | ns | 2 |
| CTipA rising time | $^{t}$R_CTipA | – | 5 | ns | 2 |

Notes: 1. Refer to Overshoot and Undershoot Specifications.
2. CT Type-A inputs: CS_n, BG[1:0], BA[1:0], A[9:0], A10/AP, A11, A12/BC_n, A13, WE_n/A14, CAS_n/A15, RAS_n/A16, A17, CKE, ACT_n, ODT, CLK_t, CLK_C, PAR.
3. $V_{REFCA} = 0.5 \times V_{DD}$.

**Figure 206: CT Type-A Input Slew Rate Definition**

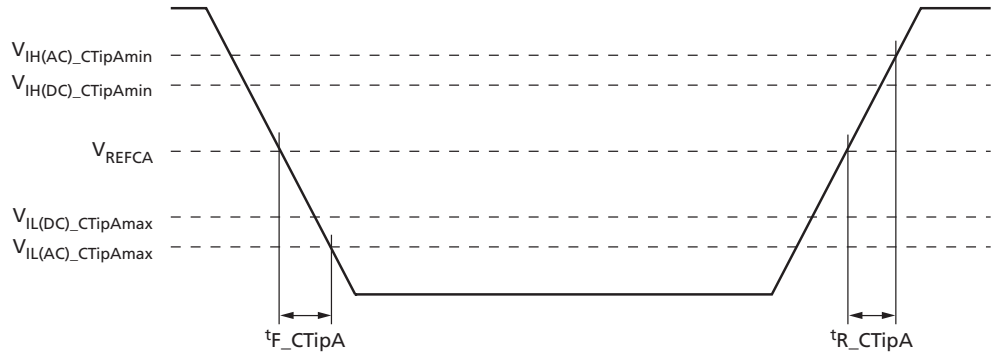


**Table 84: CT Type-B Input Levels**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| CTipB AC input high voltage | $V_{IH(AC)}$ | $V_{REF}$ + 300 | $V_{DD1}$[1] | V | 2, 3 |
| CTipB DC input high voltage | $V_{IH(DC)}$ | $V_{REF}$ + 200 | $V_{DD}$ | V | 2, 3 |
| CTipB DC input low voltage | $V_{IL(DC)}$ | $V_{SS}$ | $V_{REF}$ - 200 | V | 2, 3 |
| CTipB AC input low voltage | $V_{IL(AC)}$ | $V_{SS1}$[1] | $V_{REF}$ - 300 | V | 2, 3 |
| CTipB falling time | $^{t}$F_CTipB | – | 5 | ns | 2 |
| CTipB rising time | $^{t}$R_CTipB | – | 5 | ns | 2 |

Notes: 1. Refer to Overshoot and Undershoot Specifications.
2. CT Type-B inputs: DML_n/DBIL_n, DMU_n/DBIU_n and DM_n/DBI_n.
3. $V_{REFDQ}$ should be 0.5 × $V_{DD}$

**Figure 207: CT Type-B Input Slew Rate Definition**

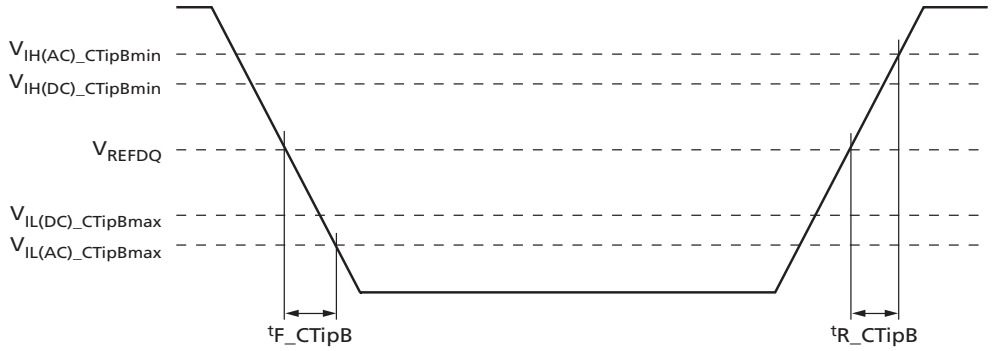



**Table 85: CT Type-C Input Levels (CMOS)**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| CTipC AC input high voltage | $V_{IH(AC)\_CTipC}$ | 0.8 × $V_{DD}$ | $V_{DD}$[1] | V | 2 |
| CTipC DC input high voltage | $V_{IH(DC)\_CTipC}$ | 0.7 × $V_{DD}$ | $V_{DD}$ | V | 2 |
| CTipC DC input low voltage | $V_{IL(DC)\_CTipC}$ | $V_{SS}$ | 0.3 × $V_{DD}$ | V | 2 |
| CTipC AC input low voltage | $V_{IL(AC)\_CTipC}$ | $V_{SS}$[1] | 0.2 × $V_{DD}$ | V | 2 |
| CTipC falling time | $^{t}$F_CTipC | – | 1 0 | ns | 2 |
| CTipC rising time | $^{t}$R_CTipC | – | 1 0 | ns | 2 |

Notes: 1. Refer to Overshoot and Undershoot Specifications.
2. CT Type-C inputs: Alert_n.

**Figure 208: CT Type-C Input Slew Rate Definition**

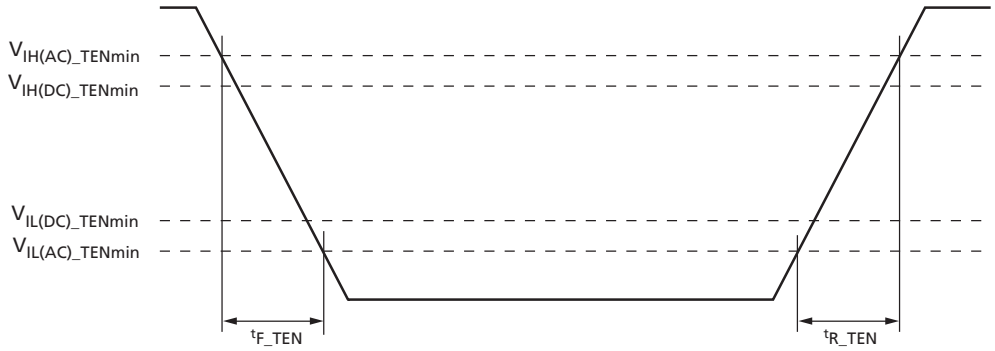
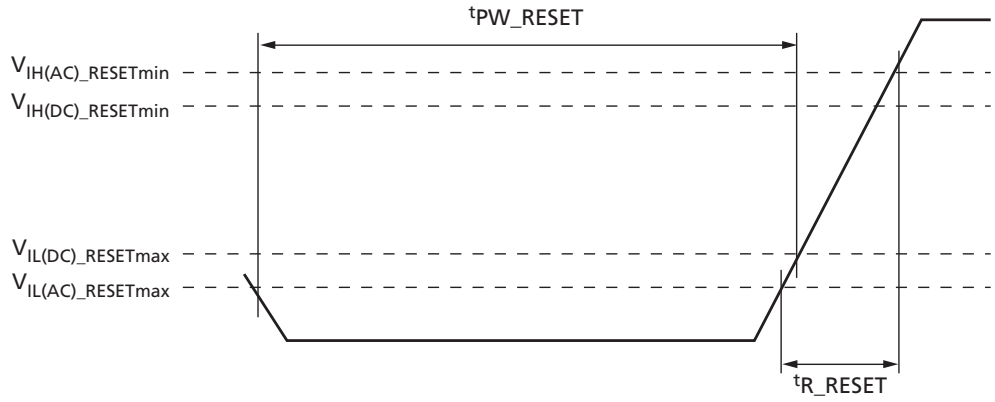



**Table 86: CT Type-D Input Levels**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| CTipD AC input high voltage | $V_{IH(AC)\_CTipD}$ | 0.8 × $V_{DD}$ | $V_{DD}$ | V | 4 |
| CTipD DC input high voltage | $V_{IH(DC)\_CTipD}$ | 0.7 × $V_{DD}$ | $V_{DD}$ | V | 2 |
| CTipD DC input low voltage | $V_{IL(DC)\_CTipD}$ | $V_{SS}$ | 0.3 × $V_{DD}$ | V | 1 |
| CTipD AC input low voltage | $V_{IL(AC)\_CTipD}$ | $V_{SS}$ | 0.2 × $V_{DD}$ | V | 5 |
| Rising time | $t_{R\_RESET}$ | – | 1 | µs | 3 |
| RESET pulse width - after power-up | $t_{PW\_RESET\_S}$ | 1 | – | µs | |
| RESET pulse width - during power-up | $t_{PW\_RESET\_L}$ | 200 | – | µs | |

Notes:
1. After RESET_n is registered LOW, the RESET_n level must be maintained below $V_{IL(DC)\_RESET}$ during $t_{PW\_RESET}$, otherwise, the DRAM may not be reset.
2. After RESET_n is registered HIGH, the RESET_n level must be maintained above $V_{IH(DC)\_RESET}$, otherwise, operation will be uncertain until it is reset by asserting RESET_n signal LOW.
3. Slope reversal (ring-back) during this level transition from LOW to HIGH should be mitigated as much as possible.
4. Overshoot should not exceed the $V_{IN}$ values in the Absolute Maximum Ratings table.
5. Undershoot should not exceed the $V_{IN}$ values in the Absolute Maximum Ratings table.
6. CT Type-D inputs: RESET_n; same requirements as in normal mode.

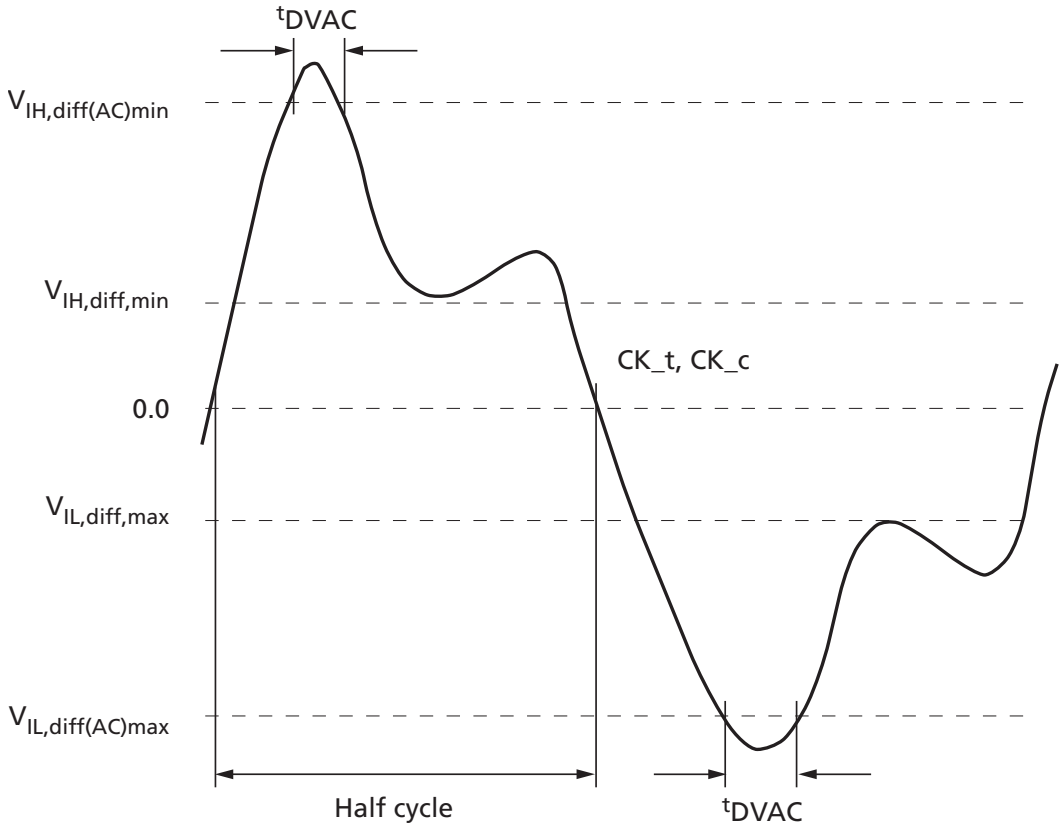
**Figure 209: CT Type-D Input Slew Rate Definition**



# Electrical Characteristics – AC and DC Differential Input Measurement Levels

## Differential Inputs

**Figure 210: Differential AC Swing and "Time Exceeding AC-Level" $^{t}$DVAC**




Notes: 1. Differential signal rising edge from $V_{IL,diff,max}$ to $V_{IH,diff(AC)min}$ must be monotonic slope.
2. Differential signal falling edge from $_{IH,diff,min}$ to $V_{IL,diff(AC)max}$ must be monotonic slope.

**Table 87: Differential Input Swing Requirements for CK_t, CK_c**

| Parameter | Sym-bol | DDR4-1600 / 1866 / 2133 | | DDR4-2400 / 2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Differential input high | $V_{IHdiff}$ | 150 | Note 3 | 135 | Note 3 | 125 | Note 3 | 110 | Note 3 | mV | 1 |
| Differential input low | $V_{ILdiff}$ | Note 3 | –150 | Note 3 | -135 | Note 3 | -125 | Note 3 | -110 | mV | 1 |
| Differential input high (AC) | $V_{IH-diff(AC)}$ | 2 × ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | 2 × ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | 2 × ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | 2 × ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | V | 2 |

**Table 87: Differential Input Swing Requirements for CK_t, CK_c (Continued)**

| Parameter | Symbol | DDR4-1600 / 1866 / 2133 | | DDR4-2400 / 2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Differential input low (AC) | $V_{IL-diff(AC)}$ | Note 3 | 2 × ($V_{IL(AC)}$ - $V_{REF}$) | Note 3 | 2 × ($V_{IL(AC)}$ - $V_{REF}$) | Note 3 | 2 × ($V_{IL(AC)}$ - $V_{REF}$) | Note 3 | 2 × ($V_{IL(AC)}$ - $V_{REF}$) | V | 2 |

Notes:
1. Used to define a differential signal slew-rate.
2. For CK_t, CK_c use $V_{IH(AC)}$ and $V_{IL(AC)}$ of ADD/CMD and $V_{REFCA}$.
3. These values are not defined; however, the differential signals (CK_t, CK_c) need to be within the respective limits, $V_{IH(DC)max}$ and $V_{IL(DC)min}$ for single-ended signals as well as the limitations for overshoot and undershoot.

**Table 88: Minimum Time AC Time $^{t}$DVAC for CK**

| Slew Rate (V/ns) | $^{t}$DVAC (ps) at $\lvert V_{IH,diff(AC)}$ to $V_{IL,diff(AC)}\rvert$ | |
|---|---|---|
| | 200mV | TBDmV |
| >4.0 | 120 | TBD |
| 4.0 | 115 | TBD |
| 3.0 | 110 | TBD |
| 2.0 | 105 | TBD |
| 1.9 | 100 | TBD |
| 1.6 | 95 | TBD |
| 1.4 | 90 | TBD |
| 1.2 | 85 | TBD |
| 1.0 | 80 | TBD |
| <1.0 | 80 | TBD |

Note: 1. Below $V_{IL(AC)}$.

## Single-Ended Requirements for CK Differential Signals

Each individual component of a differential signal (CK_t, CK_c) has to comply with certain requirements for single-ended signals. CK_t and CK_c have to reach approximately $V_{SEHmin}/V_{SEL,max}$, which are approximately equal to the AC levels $V_{IH(AC)}$ and $V_{IL(AC)}$ for ADD/CMD signals in every half-cycle. The applicable AC levels for ADD/CMD might differ per speed-bin, and so on. For example, if a value other than 100mV is used for ADD/CMD $V_{IH(AC)}$ and $V_{IL(AC)}$ signals, then these AC levels also apply for the single-ended signals CK_t and CK_c.

While ADD/CMD signal requirements are with respect to $V_{REFCA}$, the single-ended components of differential signals have a requirement with respect to $V_{DD}/2$; this is nominally the same. The transition of single-ended signals through the AC levels is used to measure setup time. For single-ended components of differential signals the requirement to reach $V_{SEL,max}/V_{SEH,min}$ has no bearing on timing, but adds a restriction on the common mode characteristics of these signals.

**Figure 211: Single-Ended Requirements for CK**

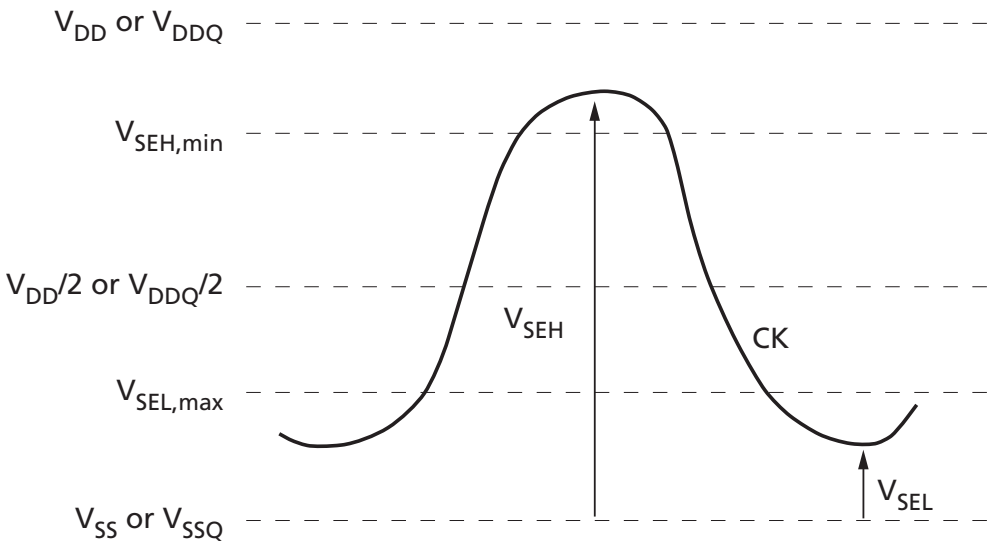



**Table 89: Single-Ended Requirements for CK**

| Parameter | Symbol | DDR4-1600 / 1866 / 2133 | | DDR4-2400 / 2666 | | DDR4-2933 / 3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | | | Min | Max | | |
| Single-ended high level for CK_t, CK_c | $V_{SEH}$ | $V_{DD}/2$ + 0.100 | Note 3 | $V_{DD}/2$ + 0.095 | Note 3 | $V_{DD}/2$ + 0.085 | Note 3 | V | 1, 2 |
| Single-ended low level for CK_t, CK_c | $V_{SEL}$ | Note 3 | $V_{DD}/2$ - 0.100 | Note 3 | $V_{DD}/2$ - 0.095 | Note 3 | $V_{DD}/2$ - 0.085 | V | 1, 2 |

Notes:
1. For CK_t, CK_c use $V_{IH(AC)}$ and $V_{IL(AC)}$ of ADD/CMD and $V_{REFCA}$.
2. ADDR/CMD $V_{IH(AC)}$ and $V_{IL(AC)}$ based on $V_{REFCA}$.
3. These values are not defined; however, the differential signal (CK_t, CK_c) need to be within the respective limits, $V_{IH(DC)max}$ and $V_{IL(DC)min}$ for single-ended signals as well as the limitations for overshoot and undershoot.

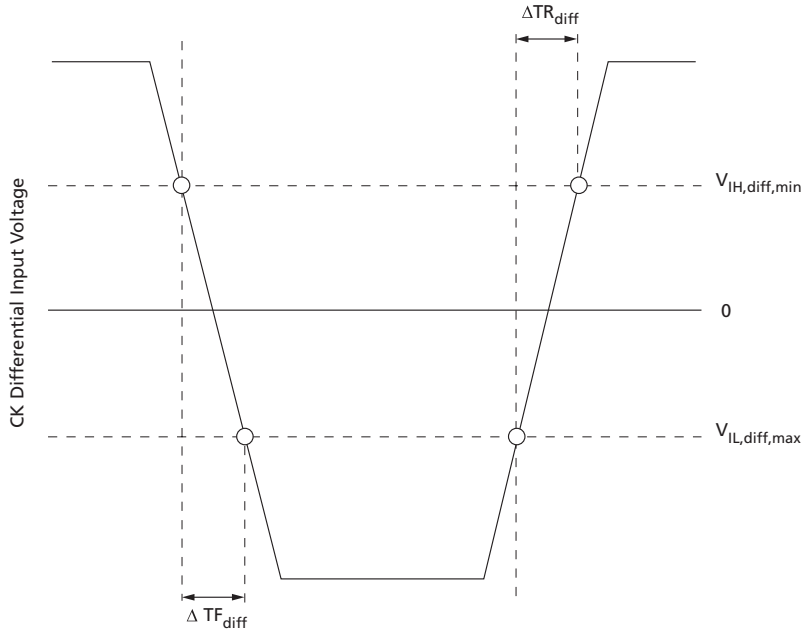
## Slew Rate Definitions for CK Differential Input Signals

**Table 90: CK Differential Input Slew Rate Definition**

| Description | Measured | | Defined by |
|---|---|---|---|
| | From | To | |
| Differential input slew rate for rising edge | $V_{IL,diff,max}$ | $V_{IH,diff,min}$ | $\lvert V_{IH,diff,min} - V_{IL,diff,max}\rvert / \Delta TR_{diff}$ |
| Differential input slew rate for falling edge | $V_{IH,diff,min}$ | $V_{IL,diff,max}$ | $\lvert V_{IH,diff,min} - V_{IL,diff,max}\rvert / \Delta TF_{diff}$ |

Note: 1. The differential signal CK_t, CK_c must be monotonic between these thresholds.

**Figure 212: Differential Input Slew Rate Definition for CK_t, CK_c**




## CK Differential Input Cross Point Voltage

To guarantee tight setup and hold times as well as output skew parameters with respect to clock and strobe, each cross point voltage of differential input signal CK_t, CK_c must meet the requirements shown below. The differential input cross point voltage $V_{IX(CK)}$ is measured from the actual cross point of true and complement signals to the midlevel between $V_{DD}$ and $V_{SS}$.

**Figure 213: $V_{IX(CK)}$ Definition**

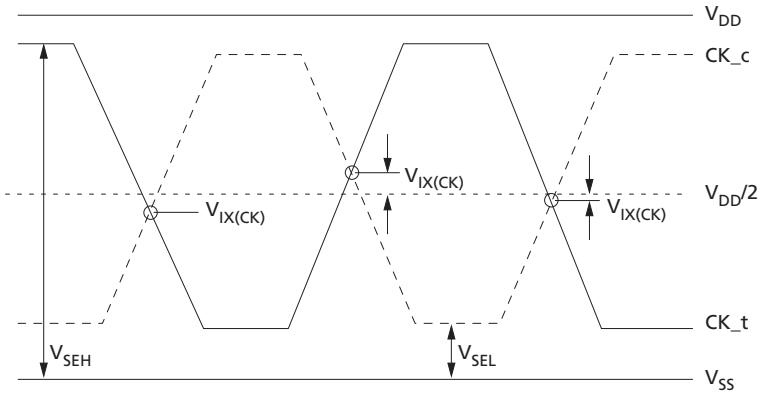


**Table 91: Cross Point Voltage For CK Differential Input Signals at DDR4-1600 through DDR4-2400**

| Parameter | Sym | Input Level | DDR4-1600, 1866, 2133, 2400 | |
|---|---|---|---|---|
| | | | Min | Max |
| Differential input cross point voltage relative to $V_{DD}/2$ for CK_t, CK_c | $V_{IX(CK)}$ | $V_{SEH} > V_{DD}/2 + 145mV$ | N/A | 120mV |
| | | $V_{DD}/2 + 100mV \le V_{SEH} \le V_{DD}/2 + 145mV$ | N/A | $(V_{SEH} - V_{DD}/2) - 25mV$ |
| | | $V_{DD}/2 - 145mV \le V_{SEL} \le V_{DD}/2 - 100mV$ | $-(V_{DD}/2 - V_{SEL}) + 25mV$ | N/A |
| | | $V_{SEL} < V_{DD}/2 - 145mV$ | –120mV | N/A |

**Table 92: Cross Point Voltage For CK Differential Input Signals at DDR4-2666 through DDR4-3200**

| Parameter | Sym | Input Level | DDR4-2666, 2933, 3200 | |
|---|---|---|---|---|
| | | | Min | Max |
| Differential input cross point voltage relative to $V_{DD}/2$ for CK_t, CK_c | $V_{IX(CK)}$ | $V_{SEH} > V_{DD}/2 + 145mV$ | N/A | 110mV |
| | | $V_{DD}/2 + 90mV \le V_{SEH} \le V_{DD}/2 + 145mV$ | N/A | $(V_{SEH} - V_{DD}/2) - 30mV$ |
| | | $V_{DD}/2 - 145mV \le V_{SEL} \le V_{DD}/2 - 90mV$ | $-(V_{DD}/2 - V_{SEL}) + 30mV$ | N/A |
| | | $V_{SEL} < V_{DD}/2 - 145mV$ | –110mV | N/A |

## DQS Differential Input Signal Definition and Swing Requirements

**Figure 214: Differential Input Signal Definition for DQS_t, DQS_c**

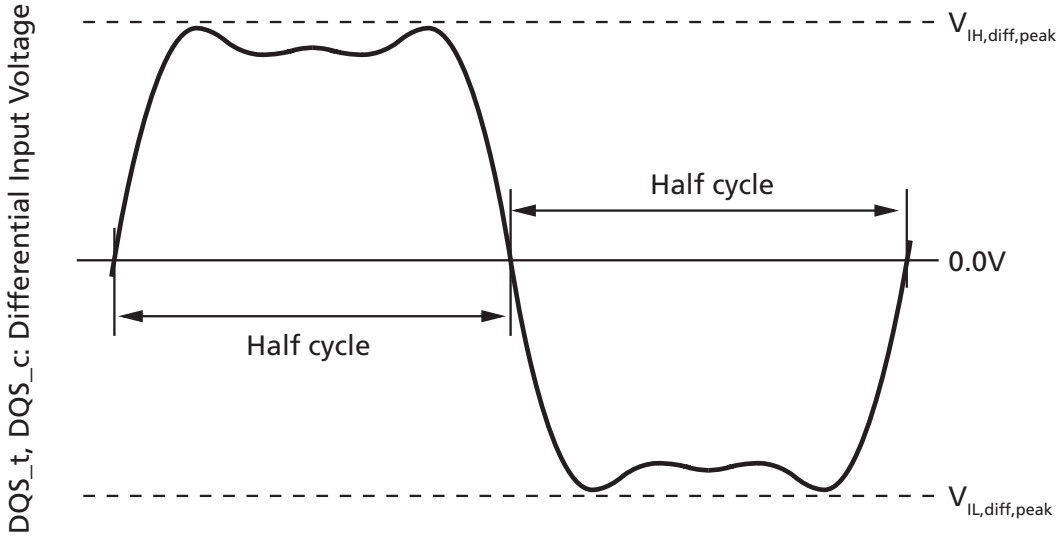



**Table 93: DDR4-1600 through DDR4-2400 Differential Input Swing Requirements for DQS_t, DQS_c**

| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| Peak differential input high voltage | $V_{IH,diff,peak}$ | 186 | $V_{DDQ}$ | 160 | $V_{DDQ}$ | mV | 1 , 2 |

**Table 93: DDR4-1600 through DDR4-2400 Differential Input Swing Requirements for DQS_t, DQS_c (Continued)**

| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| Peak differential input low voltage | $V_{IL,diff,peak}$ | $V_{SSQ}$ | –186 | $V_{SSQ}$ | –160 | mV | 1 , 2 |

Notes:
1. Minimum and maximum limits are relative to single-ended portion and can be exceeded within allowed overshoot and undershoot limits.
2. Minimum value point is used to determine differential signal slew-rate.

**Table 94: DDR4-2633 through DDR4-3200 Differential Input Swing Requirements for DQS_t, DQS_c**

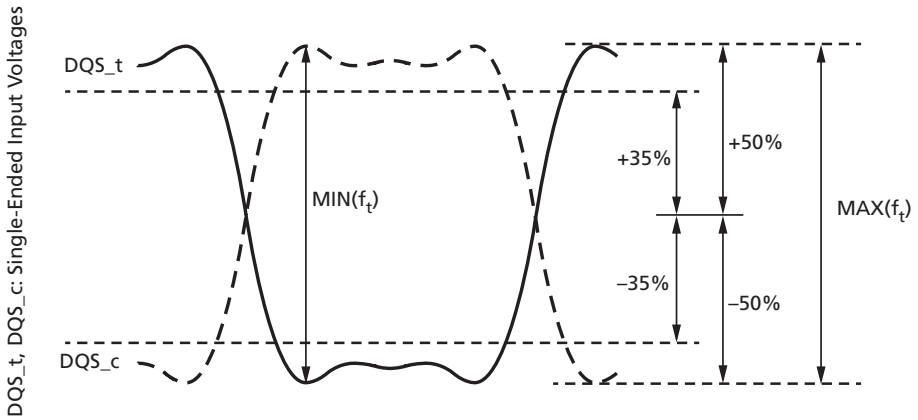
| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | | |
| Peak differential input high voltage | $V_{IH,diff,peak}$ | 150 | $V_{DDQ}$ | 145 | $V_{DDQ}$ | 140 | $V_{DDQ}$ | mV | 1 , 2 |
| Peak differential input low voltage | $V_{IL,diff,peak}$ | $V_{SSQ}$ | –150 | $V_{SSQ}$ | –145 | $V_{SSQ}$ | –140 | mV | 1 , 2 |

Notes:
1. Minimum and maximum limits are relative to single-ended portion and can be exceeded within allowed overshoot and undershoot limits.
2. Minimum value point is used to determine differential signal slew-rate.

The peak voltage of the DQS signals are calculated using the following equations:
$V_{IH,dif,Peak}$ voltage = MAX($f_t$)
$V_{IL,dif,Peak}$ voltage = MIN($f_t$)
($f_t$) = DQS_t, DQS_c.

The MAX(f(t)) or MIN(f(t)) used to determine the midpoint from which to reference the±35% window of the exempt non-monotonic signaling shall be the smallest peak voltage observed in all UIs.

**Figure 215: DQS_t, DQS_c Input Peak Voltage Calculation and Range of Exempt non-Monotonic Signaling**



## DQS Differential Input Cross Point Voltage

To achieve tight RxMask input requirements as well as output skew parameters with respect to strobe, the cross point voltage of differential input signals (DQS_t, DQS_c) must meet $V_{IX\_DQS,ratio}$ in the table below. The differential input cross point voltage $V_{IX\_DQS}$ ($V_{IX\_DQS\_FR}$ and $V_{IX\_DQS\_RF}$) is measured from the actual cross point of DQS_t, DQS_c relative to the $V_{DQS,mid}$ of the DQS_t and DQS_c signals.

$V_{DQS,mid}$ is the midpoint of the minimum levels achieved by the transitioning DQS_t and DQS_c signals, and noted by $V_{DQS\_trans}$. $V_{DQS\_trans}$ is the difference between the lowest horizontal tangent above $V_{DQS,mid}$ of the transitioning DQS signals and the highest horizontal tangent below $V_{DQS,mid}$ of the transitioning DQS signals. A non-monotonic transitioning signal's ledge is exempt or not used in determination of a horizontal tangent provided the said ledge occurs within ±35% of the midpoint of either $V_{IH.DIFF.Peak}$ voltage (DQS_t rising) or $V_{IL.DIFF.Peak}$ voltage (DQS_c rising), as shown in the figure below.

A secondary horizontal tangent resulting from a ring-back transition is also exempt in determination of a horizontal tangent. That is, a falling transition's horizontal tangent is derived from its negative slope to zero slope transition (point A in the figure below), and a ring-back's horizontal tangent is derived from its positive slope to zero slope transition (point B in the figure below) and is not a valid horizontal tangent; a rising transition's horizontal tangent is derived from its positive slope to zero slope transition (point C in the figure below), and a ring-back's horizontal tangent derived from its negative slope to zero slope transition (point D in the figure below) and is not a valid horizontal tangent.

**Figure 216: $V_{IXDQS}$ Definition**

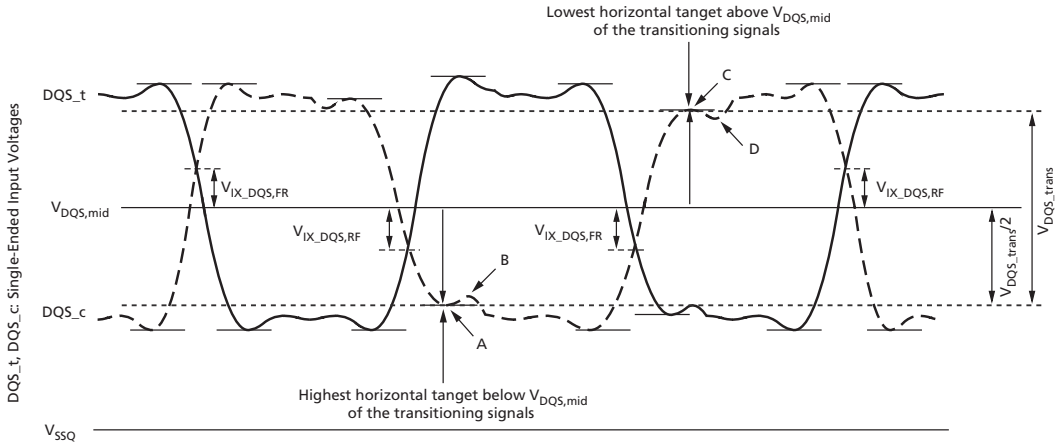



**Table 95: Cross Point Voltage For Differential Input Signals DQS**

| Parameter | Symbol | DDR4-1600, 1866, 2133, 2400, 2666, 2933, 3200 | | Unit | Notes |
|---|---|---|---|---|---|
| | | Min | Max | | |
| DQS_t and DQS_c crossing relative to the midpoint of the DQS_t and DQS_c signal swings | $V_{IX\_DQS,ratio}$ | – | 25 | % | 1, 2 |

**Table 95: Cross Point Voltage For Differential Input Signals DQS (Continued)**

| Parameter | Symbol | DDR4-1600, 1866, 2133, 2400, 2666, 2933, 3200 | | Unit | Notes |
|---|---|---|---|---|---|
| | | Min | Max | | |
| $V_{DQS,mid}$ to $V_{cent(midpoint)}$ offset | $V_{DQS,mid\_to\_Vcent}$ | – | Note 3 | mV | 2 |

Notes:
1. $V_{IX\_DQS,ratio}$ is DQS $V_{IX}$ crossing ($V_{IX\_DQS,FR}$ or $V_{IX\_DQS,RF}$) divided by $V_{DQS\_trans}$. $V_{DQS\_trans}$ is the difference between the lowest horizontal tangent above $V_{DQS,mid}$d of the transitioning DQS signals and the highest horizontal tangent below $V_{DQS,mid}$ of the transitioning DQS signals.
2. $V_{DQS,mid}$ will be similar to the $V_{REFDQ}$ internal setting value ($V_{cent(midpoint)}$ offset) obtained during $V_{REF}$ Training if the DQS and DQs drivers and paths are matched.
3. The maximum limit shall not exceed the smaller of $V_{IH,diff,DQS}$ minimum limit or 50mV.

## Slew Rate Definitions for DQS Differential Input Signals

**Table 96: DQS Differential Input Slew Rate Definition**

| Description | Measured | | Defined by |
|---|---|---|---|
| | From | To | |
| Differential input slew rate for rising edge | $V_{IL,diff,DQS}$ | $V_{IH,diff,DQS}$ | $\lvert V_{IH,diff,DQS} - V_{IL,diff,DQS}\rvert / \Delta TR_{diff}$ |
| Differential input slew rate for falling edge | $V_{IH,diff,DQS}$ | $V_{IL,diff,DQS}$ | $\lvert V_{IHdiffDQS} - V_{IL,diff,DQS}\rvert / \Delta TF_{diff}$ |

Note: 1. The differential signal DQS_t, DQS_c must be monotonic between these thresholds.

**Figure 217: Differential Input Slew Rate and Input Level Definition for DQS_t, DQS_c**

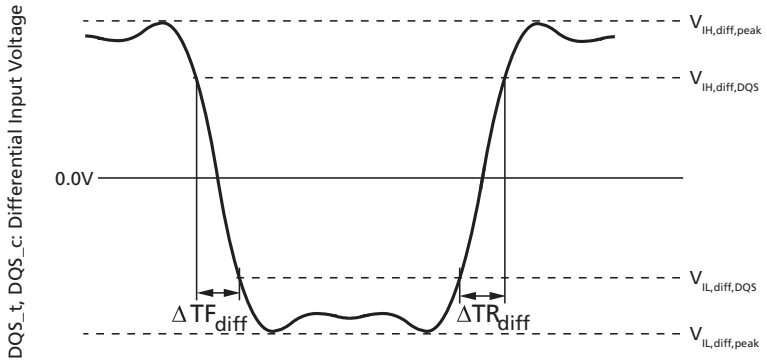



**Table 97: DDR4-1600 through DDR4-2400 Differential Input Slew Rate and Input Levels for DQS_t, DQS_c**

| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| Peak differential input high voltage | $V_{IH,diff,peak}$ | 186 | $V_{DDQ}$ | 160 | $V_{DDQ}$ | mV | 1 |
| Differential input high voltage | $V_{IH,diff,DQS}$ | 136 | – | 130 | – | mV | 2, 3 |
| Differential input low voltage | $V_{IL,diff,DQS}$ | – | –136 | – | –130 | mV | 2, 3 |

**Table 97: DDR4-1600 through DDR4-2400 Differential Input Slew Rate and Input Levels for DQS_t, DQS_c (Continued)**

| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| Peak differential input low voltage | $V_{IL,diff,peak}$ | $V_{SSQ}$ | –186 | $V_{SSQ}$ | –160 | mV | 1 |
| DQS differential input slew rate | SRIdiff | 3.0 | 18 | 3.0 | 18 | V/ns | 4, 5 |

Notes:
1. Minimum and maximum limits are relative to single-ended portion and can be exceeded within allowed overshoot and undershoot limits.
2. Differential signal rising edge from $V_{IL,diff,DQS}$ to $V_{IH,diff,DQS}$ must be monotonic slope.
3. Differential signal falling edge from $V_{IH,diff,DQS}$ to $V_{IL,diff,DQS}$ must be monotonic slope.
4. Differential input slew rate for rising edge from $V_{IL,diff,DQS}$ to $V_{IH,diff,DQS}$ is defined by $|V_{IL,diff,min} - V_{IH,diff,max}|/\Delta TR_{diff}$.
5. Differential input slew rate for falling edge from $V_{IH,diff,DQS}$ to $V_{IL,diff,DQS}$ is defined by $|V_{IL,diff,min} - V_{IH,diff,max}|/\Delta TF_{diff}$.

**Table 98: DDR4-2666 through DDR4-3200 Differential Input Slew Rate and Input Levels for DQS_t, DQS_c**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | | |
| Peak differential input high voltage | $V_{IH,diff,peak}$ | 150 | $V_{DDQ}$ | 145 | $V_{DDQ}$ | 140 | $V_{DDQ}$ | mV | 1 |
| Differential input high voltage | $V_{IH,diff,DQS}$ | 130 | – | 115 | – | 110 | – | mV | 2, 3 |
| Differential input low voltage | $V_{IL,diff,DQS}$ | – | –130 | – | –115 | – | –110 | mV | 2, 3 |
| Peak differential input low voltage | $V_{IL,diff,peak}$ | $V_{SSQ}$ | –150 | $V_{SSQ}$ | –145 | $V_{SSQ}$ | –140 | mV | 1 |
| DQS differential input slew rate | SRIdiff | 2.5 | 18 | 2.5 | 18 | 2.5 | 18 | V/ns | 4, 5 |

Notes:
1. Minimum and maximum limits are relative to single-ended portion and can be exceeded within allowed overshoot and undershoot limits.
2. Differential signal rising edge from $V_{IL,diff,DQS}$ to $V_{IH,diff,DQS}$ must be monotonic slope.
3. Differential signal falling edge from $V_{IH,diff,DQS}$ to $V_{IL,diff,DQS}$ must be monotonic slope.
4. Differential input slew rate for rising edge from $V_{IL,diff,DQS}$ to $V_{IH,diff,DQS}$ is defined by $|V_{IL,diff,min} - V_{IH,diff,max}|/\Delta TR_{diff}$.
5. Differential input slew rate for falling edge from $V_{IH,diff,DQS}$ to $V_{IL,diff,DQS}$ is defined by $|V_{IL,diff,min} - V_{IH,diff,max}|/\Delta TF_{diff}$.

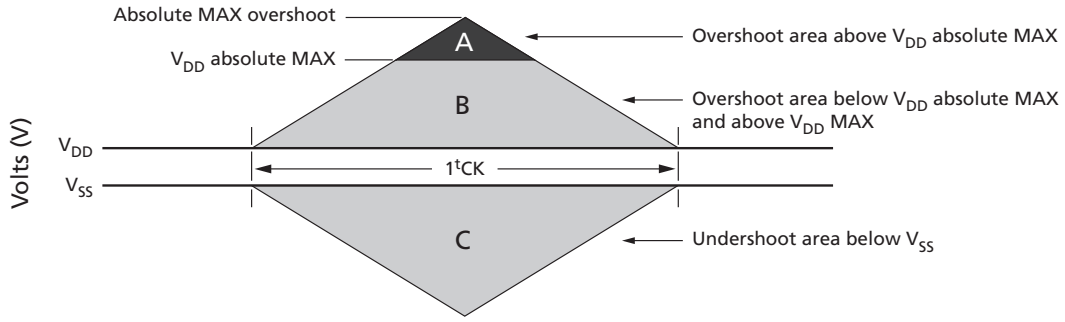
# Electrical Characteristics – Overshoot and Undershoot Specifications

## Address, Command, and Control Overshoot and Undershoot Specifications

**Table 99: ADDR, CMD, CNTL Overshoot and Undershoot/Specifications**

| Description | DDR4-1600 | DDR4-1866 | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|---|
| **Address and control pins (A[16:0], BG[0], BA[1:0], CS_n, RAS_n, CAS_n, WE_n, CKE, ODT, C2-0)** | | | | | | | | |
| Area A: Maximum peak amplitude above $V_{DD}$ absolute MAX | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | V |
| Area B: Amplitude allowed between $V_{DD}$ and $V_{DD}$ absolute MAX | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | V |
| Area C: Maximum peak amplitude allowed for undershoot below $V_{SS}$ | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | V |
| Area A maximum overshoot area per 1$^{t}$CK | 0.0083 | 0.0071 | 0.0062 | 0.0055 | 0.0055 | 0.0055 | 0.0055 | V/ns |
| Area B maximum overshoot area per 1$^{t}$CK | 0.2550 | 0.2185 | 0.1914 | 0.1699 | 0.1699 | 0.1699 | 0.1699 | V/ns |
| Area C maximum undershoot area per 1$^{t}$CK | 0.2644 | 0.2265 | 0.1984 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | V/ns |

**Figure 218: ADDR, CMD, CNTL Overshoot and Undershoot Definition**

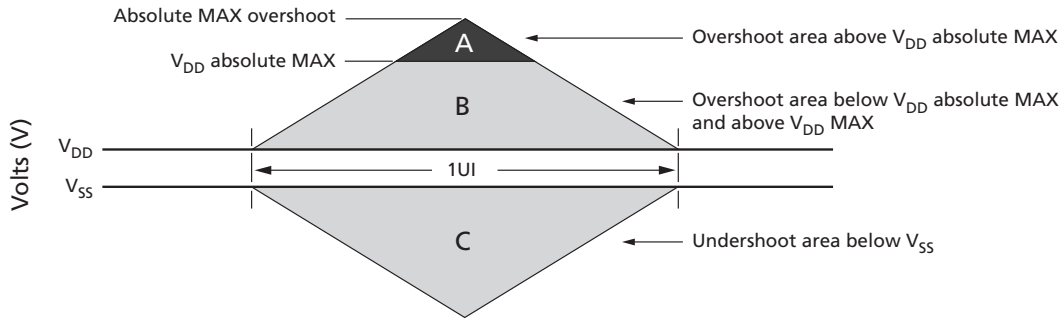


## Clock Overshoot and Undershoot Specifications

### Table 100: CK Overshoot and Undershoot/ Specifications

| Description | DDR4-1600 | DDR4-1866 | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|---|
| **CLK_t, CLK_n** | | | | | | | | |
| Area A: Maximum peak amplitude above $V_{DD}$ absolute MAX | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | V |
| Area B: Amplitude allowed between $V_{DD}$ and $V_{DD}$ absolute MAX | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | V |
| Area C: Maximum peak amplitude allowed for undershoot below $V_{SS}$ | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | V |
| Area A maximum overshoot area per 1UI | 0.0038 | 0.0032 | 0.0028 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | V/ns |
| Area B maximum overshoot area per 1UI | 0.1125 | 0.0964 | 0.0844 | 0.0750 | 0.0750 | 0.0750 | 0.0750 | V/ns |
| Area C maximum undershoot area per 1UI | 0.1144 | 0.0980 | 0.0858 | 0.0762 | 0.0762 | 0.0762 | 0.0762 | V/ns |

### Figure 219: CK Overshoot and Undershoot Definition

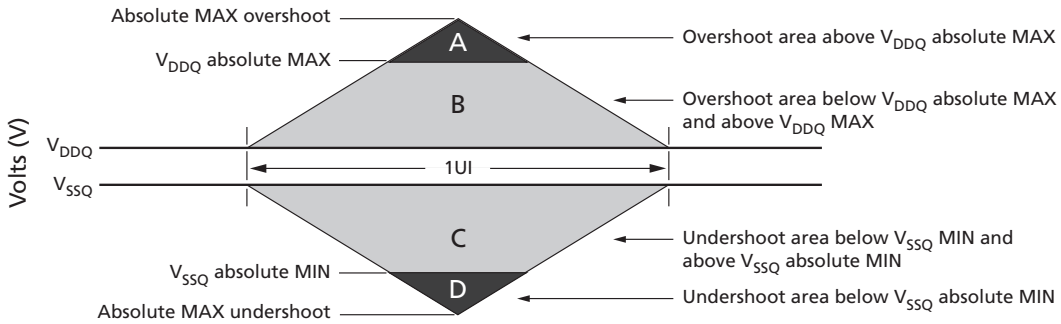


## Data, Strobe, and Mask Overshoot and Undershoot Specifications

### Table 101: Data, Strobe, and Mask Overshoot and Undershoot/ Specifications

| Description | DDR4-1600 | DDR4-1866 | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|---|
| **DQS_t, DQS_n, LDQS_t, LDQS_n, UDQS_t, UDQS_n, DQ[0:15], DM/DBI, UDM/UDBI, LDM/LDBI,** | | | | | | | | |
| Area A: Maximum peak amplitude above $V_{DDQ}$ absolute MAX | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | V |
| Area B: Amplitude allowed between $V_{DDQ}$ and $V_{DDQ}$ absolute MAX | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | V |
| Area C: Maximum peak amplitude allowed for undershoot below $V_{SSQ}$ | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | V |
| Area D: Maximum peak amplitude below $V_{SSQ}$ absolute MIN | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | V |
| Area A maximum overshoot area per 1UI | 0.0150 | 0.0129 | 0.0113 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | V/ns |
| Area B maximum overshoot area per 1UI | 0.1050 | 0.0900 | 0.0788 | 0.0700 | 0.0700 | 0.0700 | 0.0700 | V/ns |
| Area C maximum undershoot area per 1UI | 0.1050 | 0.0900 | 0.0788 | 0.0700 | 0.0700 | 0.0700 | 0.0700 | V/ns |
| Area D maximum undershoot area per 1UI | 0.0150 | 0.0129 | 0.0113 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | V/ns |

### Figure 220: Data, Strobe, and Mask Overshoot and Undershoot Definition




# Electrical Characteristics – AC and DC Output Measurement Levels

## Single-Ended Outputs

### Table 102: Single-Ended Output Levels

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | Unit |
|---|---|---|---|
| DC output high measurement level (for IV curve linearity) | $V_{OH(DC)}$ | 1.1 × $V_{DDQ}$ | V |
| DC output mid measurement level (for IV curve linearity) | $V_{OM(DC)}$ | 0.8 × $V_{DDQ}$ | V |
| DC output low measurement level (for IV curve linearity) | $V_{OL(DC)}$ | 0.5 × $V_{DDQ}$ | V |
| AC output high measurement level (for output slew rate) | $V_{OH(AC)}$ | (0.7 + 0.15) × $V_{DDQ}$ | V |

**Table 102: Single-Ended Output Levels (Continued)**

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | Unit |
|---|---|---|---|
| AC output low measurement level (for output slew rate) | $V_{OL(AC)}$ | (0.7 - 0.15) × $V_{DDQ}$ | V |

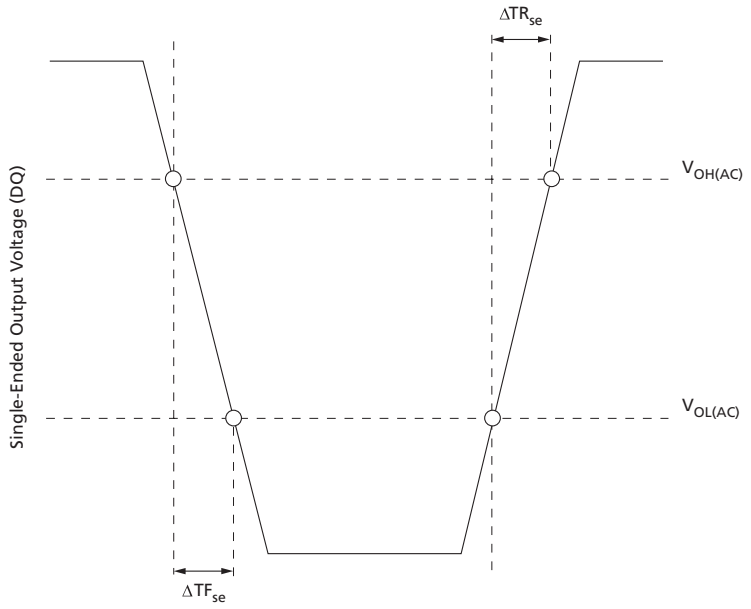
Note: 1. The swing of ±0.15 × $V_{DDQ}$ is based on approximately 50% of the static single-ended output peak-to-peak swing with a driver impedance of $R_{ZQ}/7$ and an effective test load of 50Ω to $V_{TT} = V_{DDQ}$.

Using the same reference load used for timing measurements, output slew rate for falling and rising edges is defined and measured between $V_{OL(AC)}$ and $V_{OH(AC)}$ for single-ended signals.

**Table 103: Single-Ended Output Slew Rate Definition**

| Description | Measured | | Defined by |
|---|---|---|---|
| | From | To | |
| Single-ended output slew rate for rising edge | $V_{OL(AC)}$ | $V_{OH(AC)}$ | $[V_{OH(AC)} - V_{OL(AC)}]/\Delta TR_{se}$ |
| Single-ended output slew rate for falling edge | $V_{OH(AC)}$ | $V_{OL(AC)}$ | $[V_{OH(AC)} - V_{OL(AC)}]/\Delta TF_{se}$ |

**Figure 221: Single-ended Output Slew Rate Definition**



### Table 104: Single-Ended Output Slew Rate

For $R_{ON} = R_{ZQ}/7$

| Parameter | Symbol | DDR4-1600/ 1866 / 2133 / 2400 | | DDR4-2666 | | DDR4-2933 / 3200 | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | |
| Single-ended output slew rate | $SRQ_{se}$ | 4 | 9 | 4 | 9 | 4 | 9 | V/ns |

Notes: 1. SR = slew rate; Q = query output; se = single-ended signals.
2. In two cases a maximum slew rate of 12V/ns applies for a single DQ signal within a byte lane:
   - Case 1 is defined for a single DQ signal within a byte lane that is switching into a certain direction (either from HIGH-to-LOW or LOW-to-HIGH) while all remaining DQ signals in the same byte lane are static (they stay at either HIGH or LOW).
   - Case 2 is defined for a single DQ signal within a byte lane that is switching into a certain direction (either from HIGH-to-LOW or LOW-to-HIGH) while all remaining DQ signals in the same byte lane are switching into the opposite direction (from LOW-to-HIGH or HIGH-to-LOW, respectively). For the remaining DQ signal switching into the opposite direction, the standard maximum limit of 9 V/ns applies.

## Differential Outputs

### Table 105: Differential Output Levels

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | Unit |
|---|---|---|---|
| AC differential output high measurement level (for output slew rate) | $V_{OH,diff(AC)}$ | $0.3 \times V_{DDQ}$ | V |
| AC differential output low measurement level (for output slew rate) | $V_{OL,diff(AC)}$ | $-0.3 \times V_{DDQ}$ | V |

Note: 1. The swing of $\pm 0.3 \times V_{DDQ}$ is based on approximately 50% of the static single-ended output peak-to-peak swing with a driver impedance of $R_{ZQ}/7$ and an effective test load of 50Ω to $V_{TT} = V_{DDQ}$ at each differential output.

Using the same reference load used for timing measurements, output slew rate for falling and rising edges is defined and measured between $V_{OL,diff(AC)}$ and $V_{OH,diff(AC)}$ for dif-ferential signals.

### Table 106: Differential Output Slew Rate Definition

| Description | Measured | | Defined by |
|---|---|---|---|
| | From | To | |
| Differential output slew rate for rising edge | $V_{OL,diff(AC)}$ | $V_{OH,diff(AC)}$ | $[V_{OH,diff(AC)} - V_{OL,diff(AC)}]/\Delta TR_{diff}$ |
| Differential output slew rate for falling edge | $V_{OH,diff(AC)}$ | $V_{OL,diff(AC)}$ | $[V_{OH,diff(AC)} - V_{OL,diff(AC)}]/\Delta TF_{diff}$ |

**Figure 222: Differential Output Slew Rate Definition**

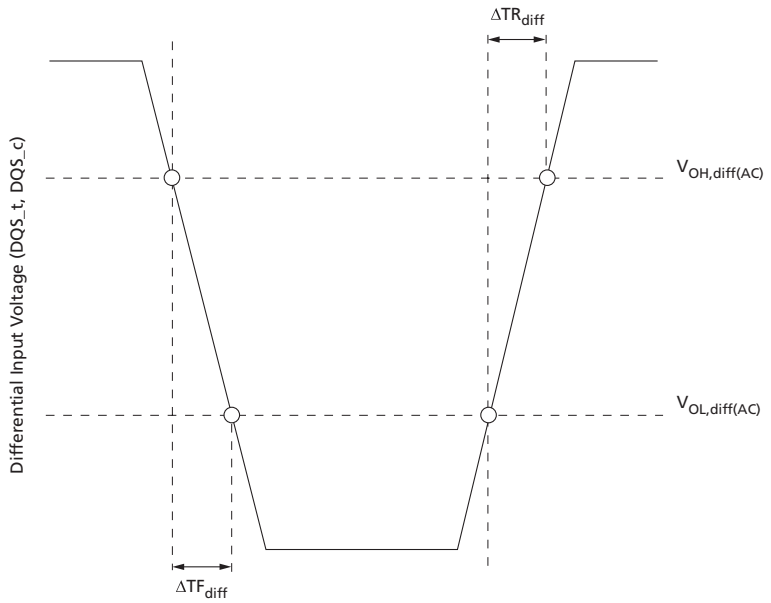



**Table 107: Differential Output Slew Rate**

For $R_{ON} = R_{ZQ}/7$

| Parameter | Symbol | DDR4-1600 / 1866 / 2133 / 2400 | | DDR4-2666 | | DDR4-2933 / 3200 | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | |
| Differential output slew rate | $SRQ_{diff}$ | 8 | 18 | 8 | 18 | 8 | 18 | V/ns |

Note: 1. SR = slew rate; Q = query output; diff = differential signals.

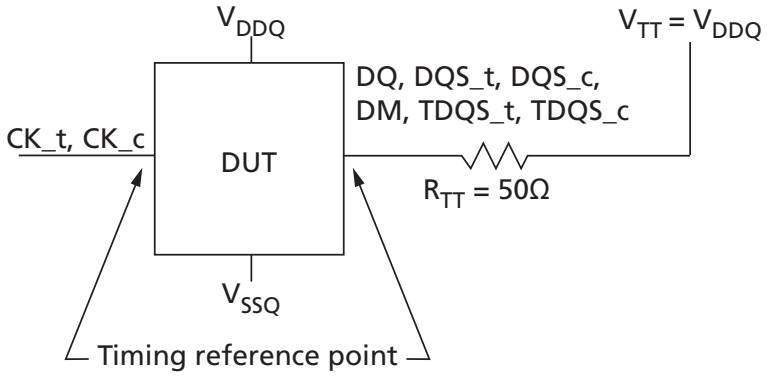
## Reference Load for AC Timing and Output Slew Rate

The effective reference load of 50Ω to $V_{TT} = V_{DDQ}$ and driver impedance of $R_{ZQ}/7$ for each output was used in defining the relevant AC timing parameters of the device as well as output slew rate measurements.

$R_{ON}$ nominal of DQ, DQS_t and DQS_c drivers uses 34 ohms to specify the relevant AC timing parameter values of the device. The maximum DC high level of output signal = $1.0 \times V_{DDQ}$, the minimum DC low level of output signal = $\{ 34 / ( 34 + 50 ) \} \times V_{DDQ} = 0.4 \times V_{DDQ}$.

The nominal reference level of an output signal can be approximated by the following: The center of maximum DC high and minimum DC low = $\{ ( 1 + 0.4 ) / 2 \} \times V_{DDQ} = 0.7 \times V_{DDQ}$. The actual reference level of output signal might vary with driver $R_{ON}$ and reference load tolerances. Thus, the actual reference level or midpoint of an output signal is at the widest part of the output signal's eye.

**Figure 223: Reference Load For AC Timing and Output Slew Rate**




## Connectivity Test Mode Output Levels

**Table 108: Connectivity Test Mode Output Levels**

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | Unit |
|---|---|---|---|
| DC output high measurement level (for IV curve linearity) | $V_{OH(DC)}$ | $1.1 \times V_{DDQ}$ | V |
| DC output mid measurement level (for IV curve linearity) | $V_{OM(DC)}$ | $0.8 \times V_{DDQ}$ | V |
| DC output low measurement level (for IV curve linearity) | $V_{OL(DC)}$ | $0.5 \times V_{DDQ}$ | V |
| DC output below measurement level (for IV curve linearity) | $V_{OB(DC)}$ | $0.2 \times V_{DDQ}$ | V |
| AC output high measurement level (for output slew rate) | $V_{OH(AC)}$ | $V_{TT} + (0.1 \times V_{DDQ})$ | V |
| AC output low measurement level (for output slew rate) | $V_{OL(AC)}$ | $V_{TT} - (0.1 \times V_{DDQ})$ | V |

Note: 1. Driver impedance of $R_{ZQ}/7$ and an effective test load of 50Ω to $V_{TT} = V_{DDQ}$.

**Figure 224: Connectivity Test Mode Reference Test Load**

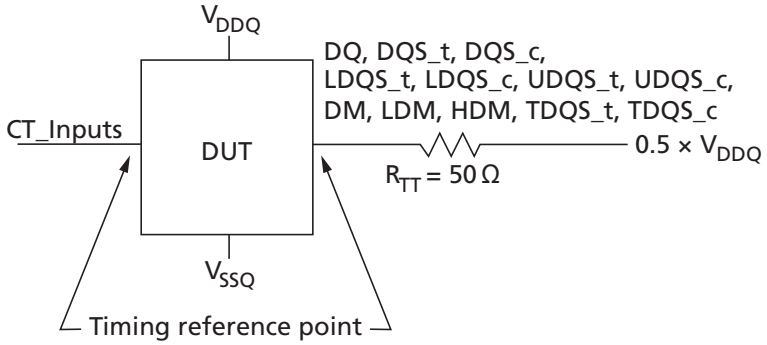


**Figure 225: Connectivity Test Mode Output Slew Rate Definition**

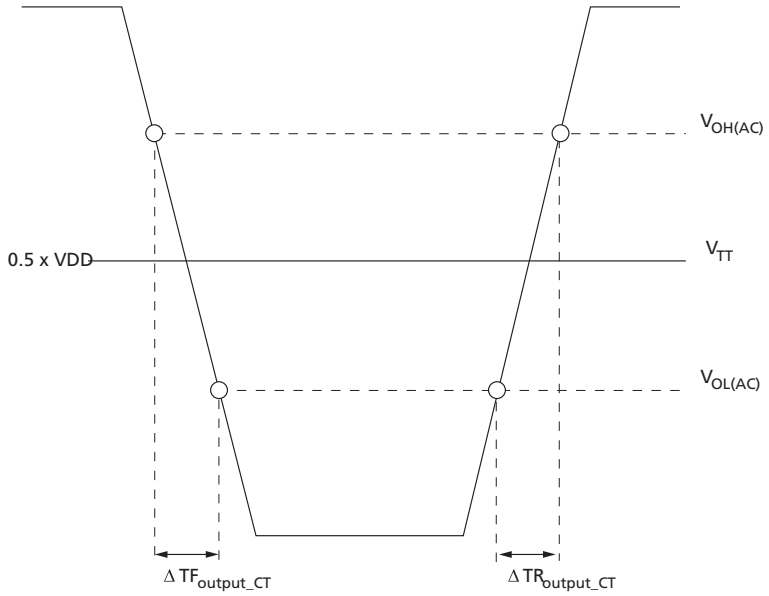



**Table 109: Connectivity Test Mode Output Slew Rate**

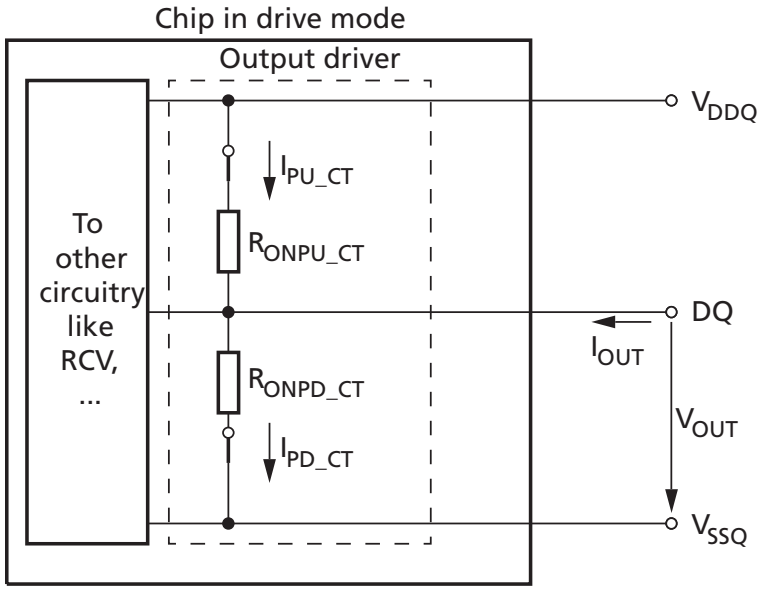
| Parameter | Symbol | DDR4-1600 / 1866 / 2133 / 2400 | | DDR4-2666 | | DDR4-2933 / 3200 | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | |
| Output signal falling time | TF_output_CT | – | 10 | – | 10 | – | 10 | ns/V |
| Output signal rising time | TR_output_CT | – | 10 | – | 10 | – | 10 | ns/V |

# Electrical Characteristics – AC and DC Output Driver Characteristics

## Connectivity Test Mode Output Driver Electrical Characteristics

The DDR4 driver supports special values during connectivity test mode. These $R_{ON}$ values are referenced in this section. A functional representation of the output buffer is shown in the figure below.

**Figure 226: Output Driver During Connectivity Test Mode**




The output driver impedance, $R_{ON}$, is determined by the value of the external reference resistor $R_{ZQ}$ as follows: $R_{ON} = R_{ZQ}/7$. This targets 34Ω with nominal $R_{ZQ} = 240Ω$; however, connectivity test mode uses uncalibrated drivers and only a maximum target is defined. Mismatch between pull up and pull down is undefined.

The individual pull-up and pull-down resistors ($R_{ONPu\_CT}$ and $R_{ONPd\_CT}$) are defined as follows:

$R_{ONPu\_CT}$ when $R_{ONPd\_CT}$ is off:

$$R_{ONPU\_CT} = \frac{V_{DDQ} - V_{OUT}}{|I_{OUT}|}$$

$R_{ONPD\_CT}$ when $R_{ONPU\_CT}$ is off:

$$R_{ONPD\_CT} = \frac{V_{OUT}}{|I_{OUT}|}$$

**Table 110: Output Driver Electrical Characteristics During Connectivity Test Mode**

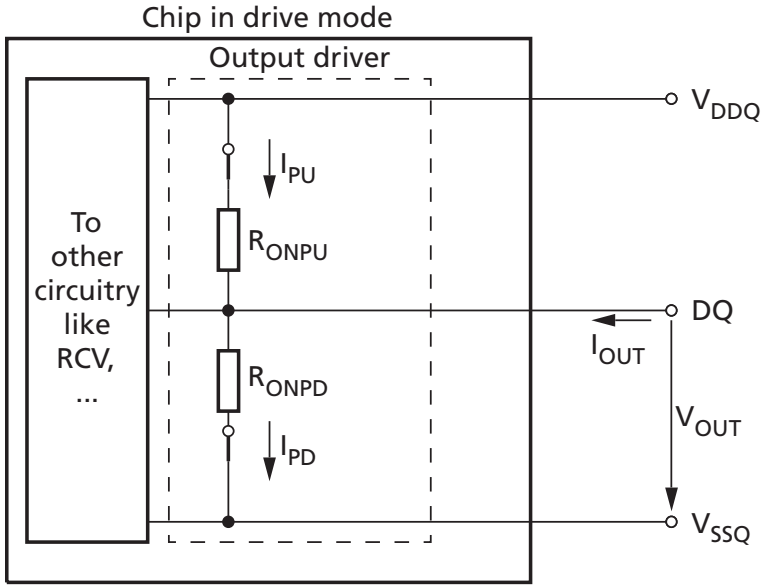
Assumes $R_{ZQ}$ = 240Ω; ZQ calibration not required

| $R_{ON,nom\_CT}$ | Resistor | $V_{OUT}$ | Min | Nom | Max | Unit |
|---|---|---|---|---|---|---|
| 34Ω | $R_{ONPD\_CT}$ | $V_{OB(DC)}$ = 0.2 × $V_{DDQ}$ | N/A | N/A | 1.9 | $R_{ZQ}$/7 |
| | | $V_{OL(DC)}$ = 0.5 × $V_{DDQ}$ | N/A | N/A | 2.0 | $R_{ZQ}$/7 |
| | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | N/A | N/A | 2.2 | $R_{ZQ}$/7 |
| | | $V_{OH(DC)}$ = 1.1 × $V_{DDQ}$ | N/A | N/A | 2.5 | $R_{ZQ}$/7 |
| | $R_{ONPU\_CT}$ | $V_{OB(DC)}$ = 0.2 × $V_{DDQ}$ | N/A | N/A | 1.9 | $R_{ZQ}$/7 |
| | | $V_{OL(DC)}$ = 0.5 × $V_{DDQ}$ | N/A | N/A | 2.0 | $R_{ZQ}$/7 |
| | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | N/A | N/A | 2.2 | $R_{ZQ}$/7 |
| | | $V_{OH(DC)}$ = 1.1 × $V_{DDQ}$ | N/A | N/A | 2.5 | $R_{ZQ}$/7 |

## Output Driver Electrical Characteristics

The DDR4 driver supports two $R_{ON}$ values. These $R_{ON}$ values are referred to as strong mode (low $R_{ON}$: 34Ω) and weak mode (high $R_{ON}$: 48Ω). A functional representation of the output buffer is shown in the figure below.

**Figure 227: Output Driver: Definition of Voltages and Currents**




The output driver impedance, $R_{ON}$, is determined by the value of the external reference resistor $R_{ZQ}$ as follows: $R_{ON(34)} = R_{ZQ}/7$, or $R_{ON(48)} = R_{ZQ}/5$. This provides either a nominal 34.3Ω ±10% or 48Ω ±10% with nominal $R_{ZQ}$ = 240Ω.

The individual pull-up and pull-down resistors ($R_{ONPu}$ and $R_{ONPd}$) are defined as follows:

$R_{ONPu}$ when $R_{ONPd}$ is off:

$$R_{ONPU} = \frac{V_{DDQ} - V_{OUT}}{|I_{OUT}|}$$

$R_{ONPD}$ when $R_{ONPU}$ is off:

$$R_{ONPD} = \frac{V_{OUT}}{|I_{OUT}|}$$

### Table 111: Strong Mode (34Ω) Output Driver Electrical Characteristics

Assumes $R_{ZQ}$ = 240Ω; Entire operating temperature range after proper ZQ calibration

| $R_{ON,nom}$ | Resistor | $V_{OUT}$ | Min | Nom | Max | Unit | Notes |
|---|---|---|---|---|---|---|---|
| 34Ω | $R_{ON34PD}$ | $V_{OL(DC)}$ = 0.5 × $V_{DDQ}$ | 0.73 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1, 2, 3 |
| | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | 0.83 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1, 2, 3 |
| | | $V_{OH(DC)}$ = 1.1 × $V_{DDQ}$ | 0.83 | 1.00 | 1.25 | $R_{ZQ}$/7 | 1, 2, 3 |
| | $R_{ON34PU}$ | $V_{OL(DC)}$ = 0.5 × $V_{DDQ}$ | 0.90 | 1.00 | 1.25 | $R_{ZQ}$/7 | 1, 2, 3 |
| | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | 0.90 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1, 2, 3 |
| | | $V_{OH(DC)}$ = 1.1 × $V_{DDQ}$ | 0.80 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1, 2, 3 |
| Mismatch between pull-up and pull-down, $MM_{PUPD}$ | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | 10 | – | 23 | % | 1, 2, 3, 4, 6, 7 |
| Mismatch between DQ to DQ within byte variation pull-up, $MM_{PUdd}$ | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | – | – | 10 | % | 1, 2, 3, 4, 5 |
| Mismatch between DQ to DQ within byte variation pull-down, $MM_{PDdd}$ | | $V_{OM(DC)}$ = 0.8 × $V_{DDQ}$ | - | – | 10 | % | 1, 2, 3, 4, 6, 7 |

Notes:
1. The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see following section on voltage and temperature sensitivity.
2. The tolerance limits are specified under the condition that $V_{DDQ}$ = $V_{DD}$ and that $V_{SSQ}$ = $V_{SS}$.
3. Alliance recommends calibrating pull-down and pull-up output driver impedances at 0.8 × $V_{DDQ}$. Other calibration schemes may be used to achieve the linearity specification shown above; for example, calibration at 0.5 × $V_{DDQ}$ and 1.1 $V_{DDQ}$.
4. DQ-to-DQ mismatch within byte variation for a given component including DQS_t and DQS_c (characterized).
5. Measurement definition for mismatch between pull-up and pull-down, $MM_{PUPD}$: Measure both $R_{ONPU}$ and $R_{ONPD}$ at 0.8 × $V_{DDQ}$ separately; $R_{ON,nom}$ is the nominal $R_{ON}$ value:

$$MM_{PUPD} = \frac{R_{ONPU} - R_{ONPD}}{R_{ON,nom}} \times 100$$

6. $R_{ON}$ variance range ratio to $R_{ON}$ nominal value in a given component, including DQS_t and DQS_c:

$$MM_{PUDD} = \frac{R_{ONPU,max} - R_{ONPU,min}}{R_{ON,nom}} \times 100$$

$$MM_{PDDD} = \frac{R_{ONPD,max} - R_{ONPD,min}}{R_{ON,nom}} \times 100$$

7. The lower and upper bytes of a x16 are each treated on a per byte basis.
8. The minimum values are derated by 9% when the device operates between –40°C and 0°C ($T_C$).

### Table 112: Weak Mode (48Ω) Output Driver Electrical Characteristics

Assumes $R_{ZQ} = 240\Omega$; Entire operating temperature range after proper ZQ calibration

| $R_{ON,nom}$ | Resistor | $V_{OUT}$ | Min | Nom | Max | Unit | Notes |
|---|---|---|---|---|---|---|---|
| 48Ω | $R_{ON48PD}$ | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.73 | 1.00 | 1.10 | $R_{ZQ}/5$ | 1, 2, 3 |
| | | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.83 | 1.00 | 1.10 | $R_{ZQ}/5$ | 1, 2, 3 |
| | | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.83 | 1.00 | 1.25 | $R_{ZQ}/5$ | 1, 2, 3 |
| | $R_{ON48PU}$ | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.90 | 1.00 | 1.25 | $R_{ZQ}/5$ | 1, 2, 3 |
| | | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.90 | 1.00 | 1.10 | $R_{ZQ}/5$ | 1, 2, 3 |
| | | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.80 | 1.00 | 1.10 | $R_{ZQ}/5$ | 1, 2, 3 |
| Mismatch between pull-up and pull-down, $MM_{PUPD}$ | | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 10 | – | 23 | % | 1, 2, 3, 4, 6, 7 |
| Mismatch between DQ to DQ within byte variation pull-up, $MM_{PUdd}$ | | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | – | – | 10 | % | 1, 2, 3, 4, 5 |
| Mismatch between DQ to DQ within byte variation pull-down, $MM_{PDdd}$ | | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | – | – | 10 | % | 1, 2, 3, 4, 6, 7 |

Notes:
1. The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see following section on voltage and temperature sensitivity.
2. The tolerance limits are specified under the condition that $V_{DDQ} = V_{DD}$ and that $V_{SSQ} = V_{SS}$.
3. Alliance recommends calibrating pull-down and pull-up output driver impedances at $0.8 \times V_{DDQ}$. Other calibration schemes may be used to achieve the linearity specification shown above; for example, calibration at $0.5 \times V_{DDQ}$ and $1.1\ V_{DDQ}$.
4. DQ-to-DQ mismatch within byte variation for a given component including DQS_t and DQS_c (characterized).
5. Measurement definition for mismatch between pull-up and pull-down, $MM_{PUPD}$: Measure both $R_{ONPU}$ and $R_{ONPD}$ at $0.8 \times V_{DDQ}$ separately; $R_{ON,nom}$ is the nominal $R_{ON}$ value:

$$MM_{PUPD} = \frac{R_{ONPU} - R_{ONPD}}{R_{ON,nom}} \times 100$$

6. $R_{ON}$ variance range ratio to $R_{ON}$ nominal value in a given component, including DQS_t and DQS_c:

$$MM_{PUDD} = \frac{R_{ONPU,max} - R_{ONPU,min}}{R_{ON,nom}} \times 100$$

$$MM_{PDDD} = \frac{R_{ONPD,max} - R_{ONPD,min}}{R_{ON,nom}} \times 100$$

7. The lower and upper bytes of a x16 are each treated on a per byte basis.
8. The minimum values are derated by 9% when the device operates between –40°C and 0°C ($T_C$).

## Output Driver Temperature and Voltage Sensitivity

If temperature and/or voltage change after calibration, the tolerance limits widen according to the equations and tables below.

$\Delta T = T - T(@calibration)$; $\Delta V = V_{DDQ} - V_{DDQ}(@ calibration)$; $V_{DD} = V_{DDQ}$

**Table 113: Output Driver Sensitivity Definitions**

| Symbol | Min | Max | Unit |
|---|---|---|---|
| $R_{ONPU}$@ $V_{OH(DC)}$ | 0.6 - $dR_{ON}dTH \times \lvert\Delta T\rvert$ - $dR_{ON}dVH \times \lvert\Delta V\rvert$ | 1.1 _ $dR_{ON}dTH \times \lvert\Delta T\rvert$ + $dR_{ON}dVH \times \lvert\Delta V\rvert$ | $R_{ZQ}/6$ |
| $R_{ON}$@ $V_{OM(DC)}$ | 0.9 - $dR_{ON}dTM \times \lvert\Delta T\rvert$ - $dR_{ON}dVM \times \lvert\Delta V\rvert$ | 1.1 + $dR_{ON}dTM \times \lvert\Delta T\rvert$ + $dR_{ON}dVM \times \lvert\Delta V\rvert$ | $R_{ZQ}/6$ |
| $R_{ONPD}$@ $V_{OL(DC)}$ | 0.6 - $dR_{ON}dTL \times \lvert\Delta T\rvert$ - $dR_{ON}dVL \times \lvert\Delta V\rvert$ | 1.1 + $dR_{ON}dTL \times \lvert\Delta T\rvert$ + $dR_{ON}dVL \times \lvert\Delta V\rvert$ | $R_{ZQ}/6$ |

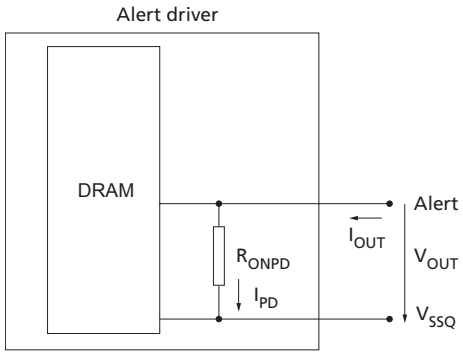
**Table 114: Output Driver Voltage and Temperature Sensitivity**

| Symbol | Voltage and Temperature Range | | Unit |
|---|---|---|---|
| | Min | Max | |
| $dR_{ON}dTM$ | 0 | 1.5 | %/°C |
| $dR_{ON}dVM$ | 0 | 0.15 | %/mV |
| $dR_{ON}dTL$ | 0 | 1.5 | %/°C |
| $dR_{ON}dVL$ | 0 | 0.15 | %/mV |
| $dR_{ON}dTH$ | 0 | 1.5 | %/°C |
| $dR_{ON}dVM$ | 0 | 0.15 | %/mV |

## Alert Driver

A functional representation of the alert output buffer is shown in the figure below. Output driver impedance, $R_{ON}$, is defined as follows.

**Figure 228: Alert Driver**




$R_{ONPD}$ when $R_{ONPU}$ is off:

$$R_{ONPD} = \frac{V_{OUT}}{|I_{OUT}|}$$

**Table 115: Alert Driver Voltage**

| $R_{ON,nom}$ | Register | $V_{OUT}$ | Min | Nom | Max | Unit |
|---|---|---|---|---|---|---|
| N/A | $R_{ONPD}$ | $V_{OL(DC)} = 0.1 \times V_{DDQ}$ | 0.3 | N/A | 1.2 | $R_{ZQ}/7$ |
| | | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.4 | N/A | 1.2 | $R_{ZQ}/7$ |
| | | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.4 | N/A | 1.4 | $R_{ZQ}/7$ |

Note: 1. $V_{DDQ}$ voltage is at $V_{DDQ(DC)}$.

# Electrical Characteristics – On-Die Termination Characteristics

## ODT Levels and I-V Characteristics

On-die termination (ODT) effective resistance settings are defined and can be selected by any or all of the following options:

- MR1[10:8] ($R_{TT(NOM)}$): Disable, 240 ohms, 120 ohms, 80 ohms, 60 ohms, 48 ohms, 40 ohms, and 34 ohms.
- MR2[11:9] ($R_{TT(WR)}$): Disable, 240 ohms,120 ohms, and 80 ohms.
- MR5[8:6] ($R_{TT(Park)}$): Disable, 240 ohms, 120 ohms, 80 ohms, 60 ohms, 48 ohms, 40 ohms, and 34 ohms.

ODT is applied to the following inputs:

- x16: DQ, LDM_n, UDM_n, LDQS_t, LDQS_c, UDQS_t, and UDQS_c inputs.

A functional representation of ODT is shown in the figure below.

**Figure 229: ODT Definition of Voltages and Currents**

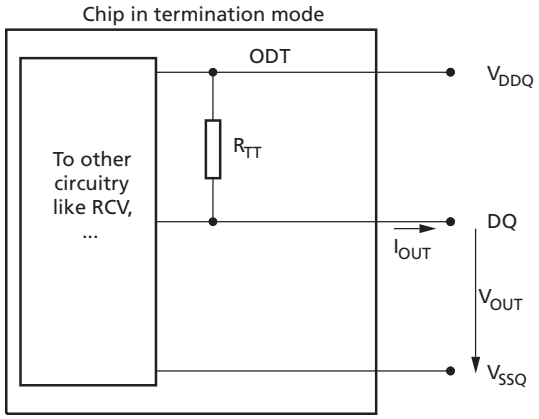



**Table 116: ODT DC Characteristics**

| $R_{TT}$ | $V_{OUT}$ | Min | Nom | Max | Unit | Notes |
|---|---|---|---|---|---|---|
| 240 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}$ | 1, 2, 3 |
| 120 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}/2$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}/2$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}/2$ | 1, 2, 3 |
| 80 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}/3$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}/3$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}/3$ | 1, 2, 3 |
| 60 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}/4$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}/4$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}/4$ | 1, 2, 3 |
| 48 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}/5$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}/5$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}/5$ | 1, 2, 3 |
| 40 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}/6$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}/6$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}/6$ | 1, 2, 3 |
| 34 ohm | $V_{OL(DC)} = 0.5 \times V_{DDQ}$ | 0.9 | 1 | 1.25 | $R_{ZQ}/7$ | 1, 2, 3 |
| | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0.9 | 1 | 1.1 | $R_{ZQ}/7$ | 1, 2, 3 |
| | $V_{OH(DC)} = 1.1 \times V_{DDQ}$ | 0.8 | 1 | 1.1 | $R_{ZQ}/7$ | 1, 2, 3 |
| DQ-to-DQ mismatch within byte | $V_{OM(DC)} = 0.8 \times V_{DDQ}$ | 0 | – | 10 | % | 1, 2, 4, 5, 6 |

Notes: 1. The tolerance limits are specified after calibration to 240 ohm ±1% resistor with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see ODT Temperature and Voltage Sensitivity.

2. Alliance recommends calibrating pull-up ODT resistors at 0.8 × $V_{DDQ}$. Other calibration schemes may be used to achieve the linearity specification shown here.
3. The tolerance limits are specified under the condition that $V_{DDQ} = V_{DD}$ and $V_{SSQ} = V_{SS}$.
4. The DQ-to-DQ mismatch within byte variation for a given component including DQS_t and DQS_c.
5. $R_{TT}$ variance range ratio to $R_{TT}$ nominal value in a given component, including DQS_t and DQS_c.

$$\text{DQ-to-DQ mismatch} = \frac{R_{TT(MAX)} - R_{TT(MIN)}}{R_{TT(NOM)}} \times 100$$

6. DQ-to-DQ mismatch for a x16 device is treated as two separate bytes.
7. For IT, AT, and UT devices, the minimum values are derated by 9% when the device operates between –40°C and 0°C (TC).

## ODT Temperature and Voltage Sensitivity

If temperature and/or voltage change after calibration, the tolerance limits widen according to the following equations and tables.

$\Delta T = T - T(@\ \text{calibration})$; $\Delta V = V_{DDQ} - V_{DDQ}(@\ \text{calibration})$; $V_{DD} = V_{DDQ}$

**Table 117: ODT Sensitivity Definitions**

| Parameter | Min | Max | Unit |
|---|---|---|---|
| $R_{TT}$@ | 0.9 - $dR_{TT}dT \times \lvert\Delta T\rvert$ - $dR_{TT}dV \times \lvert\Delta V\rvert$ | 1.6 + $dR_{TT}dTH \times \lvert\Delta T\rvert$ + $dR_{TT}dVH \times \lvert\Delta V\rvert$ | $R_{ZQ}/n$ |

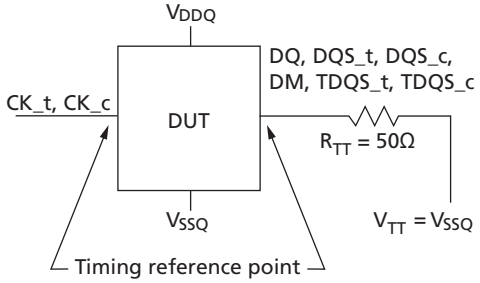
**Table 118: ODT Voltage and Temperature Sensitivity**

| Parameter | Min | Max | Unit |
|---|---|---|---|
| $dR_{TT}dT$ | 0 | 1.5 | %/°C |
| $dR_{TT}dV$ | 0 | 0.15 | %/mV |

## ODT Timing Definitions

The reference load for ODT timings is different than the reference load used for timing measurements.

**Figure 230: ODT Timing Reference Load**



## ODT Timing Definitions

Definitions for tADC, tAONAS, and tAOFAS are provided in the Table 129 (page 300) and shown in Figure 231 (page 294) and Figure 233 (page 295). Measurement reference settings are provided in the subsequent Table 120 (page 293).

The tADC for the dynamic ODT case and read disable ODT cases are represented by tADC of Direct ODT Control case.

**Table 119: ODT Timing Definitions**

| Parameter | Begin Point Definition | End Point Definition | Figure |
|---|---|---|---|
| tADC | Rising edge of CK_t, CK_c defined by the end point of DODTLoff | Extrapolated point at $V_{RTT,nom}$ | Figure 235 (page 301) |
| | Rising edge of CK_t, CK_c defined by the end point of DODTLon | Extrapolated point at $V_{SSQ}$ | Figure 235 (page 301) |
| | Rising edge of CK_t, CK_c defined by the end point of ODTLcnw | Extrapolated point at $V_{RTT,nom}$ | Figure 236 (page 301) |
| | Rising edge of CK_t, CK_c defined by the end point of ODTLcwn4 or ODTLcwn8 | Extrapolated point at $V_{SSQ}$ | Figure 236 (page 301) |
| tAONAS | Rising edge of CK_t, CK_c with ODT being first registered HIGH | Extrapolated point at $V_{SSQ}$ | Figure 237 (page 302) |
| tAOFAS | Rising edge of CK_t, CK_c with ODT being first registered LOW | Extrapolated point at $V_{RTT,nom}$ | Figure 237 (page 302) |

**Table 120: Reference Settings for ODT Timing Measurements**

| Measure Parameter | $R_{TT(Park)}$ | $R_{TT(NOM)}$ | $R_{TT(WR)}$ | VSW1 | VSW2 | Note |
|---|---|---|---|---|---|---|
| tADC | Disable | $R_{ZQ}/7$ (34Ω) | – | 0.20V | 0.40V | 1, 2, 4 |
| | – | $R_{ZQ}/7$ (34Ω) | High-Z | 0.20V | 0.40V | 1, 3, 5 |
| tAONAS | Disable | $R_{ZQ}/7$ (34Ω) | – | 0.20V | 0.40V | 1, 2, 6 |
| tAOFAS | Disable | $R_{ZQ}/7$ (34Ω) | – | 0.20V | 0.40V | 1, 2, 6 |

Notes:
1. MR settings are as follows: MR1 has A10 = 1, A9 = 1, A8 = 1 for $R_{TT(NOM)}$ setting; MR5 has A8 = 0, A7 = 0, A6 = 0 for $R_{TT(Park)}$ setting; and MR2 has A11 = 0, A10 = 1, A9 = 1 for $R_{TT(WR)}$ setting.
2. ODT state change is controlled by ODT pin.
3. ODT state change is controlled by a WRITE command.
4. Refer to Figure 231 (page 294).
5. Refer to Figure 232 (page 294).
6. Refer to Figure 233 (page 295).

**Figure 231: $^{t}$ADC Definition with Direct ODT Control**

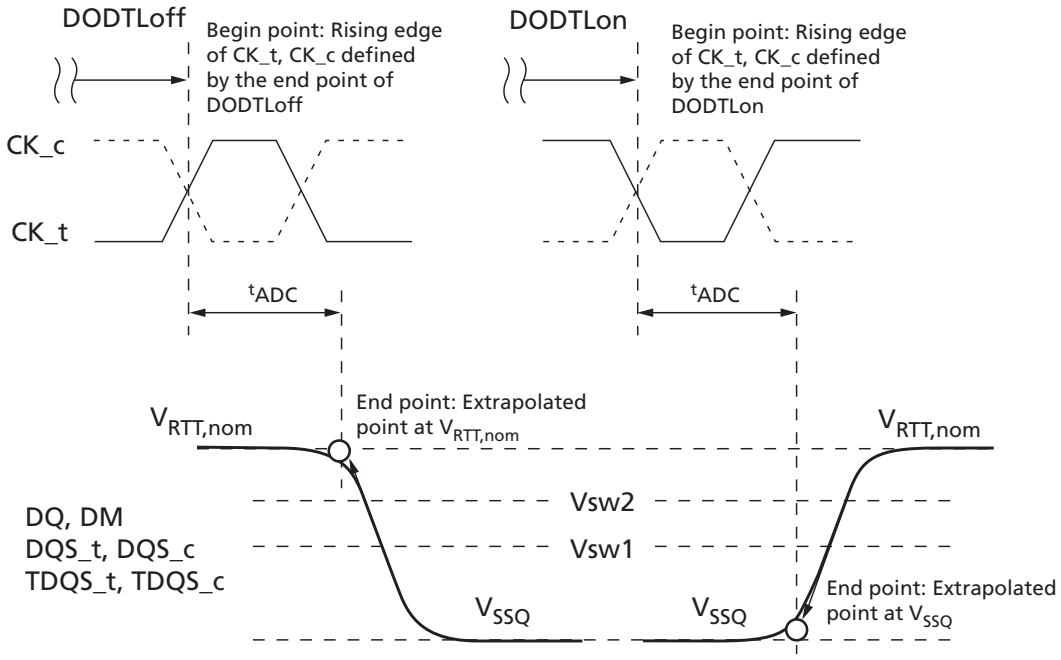



**Figure 232: $^{t}$ADC Definition with Dynamic ODT Control**

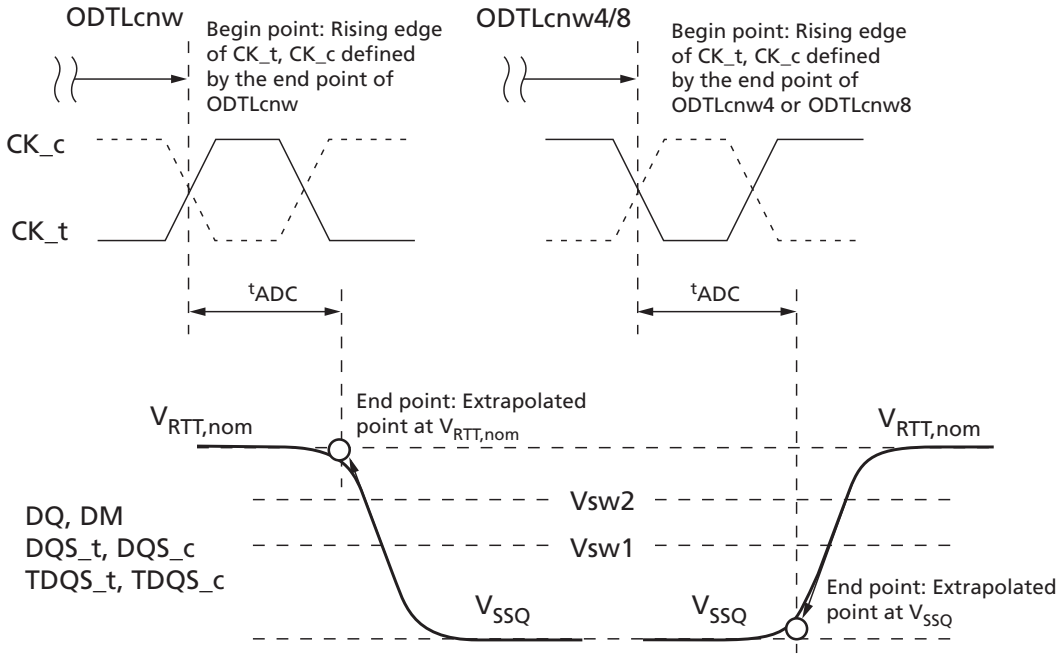
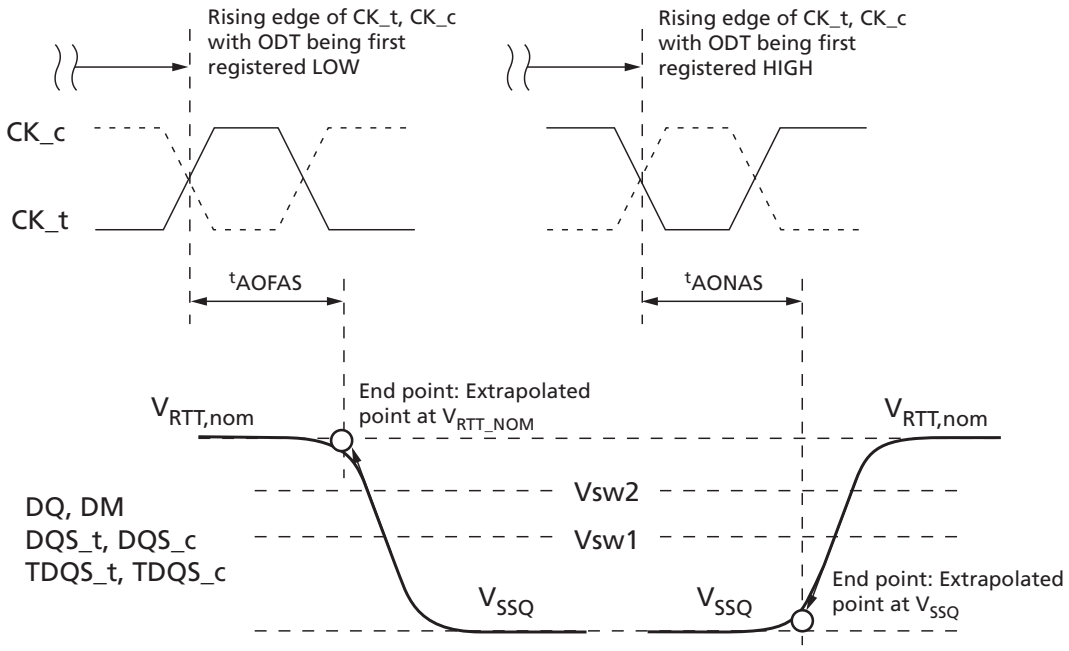


**Figure 233: $^{t}$AOFAS and $^{t}$AONAS Definitions**



## DRAM Package Electrical Specifications

**Table 121: DRAM Package Electrical Specifications for x16 Devices**

| Parameter | | Symbol | 1600/1866/2133/2400/2666 | | 2933 | | 3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | | |
| Input/output | Zpkg | $Z_{IO}$ | 45 | 85 | 45 | 85 | 45 | 85 | ohm | 1, 2, 4 |
| | Package delay | $Td_{IO}$ | 14 | 45 | 14 | 45 | 14 | 45 | ps | 1, 3, 4 |
| | Lpkg | $L_{IO}$ | – | 3.4 | – | 3.4 | – | 3.4 | nH | 11 |
| | Cpkg | $C_{IO}$ | – | 0.82 | – | 0.82 | – | 0.82 | pF | 11 |
| LDQS_t/LDQS_c/UDQS_t/UDQS_c | Zpkg | $Z_{IO\ DQS}$ | 45 | 85 | 45 | 85 | 45 | 85 | ohm | 1, 2 |
| | Package delay | $Td_{IO\ DQS}$ | 14 | 45 | 14 | 45 | 14 | 45 | ps | 1, 3 |
| | Lpkg | $L_{IO\ DQS}$ | – | 3.4 | – | 3.4 | – | 3.4 | nH | 11 |
| | Cpkg | $C_{IO\ DQS}$ | – | 0.82 | – | 0.82 | – | 0.82 | pF | 11 |
| LDQS_t/LDQS_c, UDQS_t/UDQS_c, | Delta Zpkg | $DZ_{IO\ DQS}$ | – | 10.5 | – | 10.5 | – | 10.5 | ohm | 1, 2, 6 |
| | Delta delay | $DTd_{IO\ DQS}$ | – | 5 | – | 5 | – | 5 | ps | 1, 3, 6 |
| Input CTRL pins | Zpkg | $Z_{I\ CTRL}$ | 50 | 90 | 50 | 90 | 50 | 90 | ohm | 1, 2, 8 |
| | Package delay | $Td_{I\ CTRL}$ | 14 | 42 | 14 | 42 | 14 | 42 | ps | 1, 3, 8 |
| | Lpkg | $L_{I\ CTRL}$ | – | 3.4 | – | 3.4 | – | 3.4 | nH | 11 |
| | Cpkg | $C_{I\ CTRL}$ | – | 0.7 | – | 0.7 | – | 0.7 | pF | 11 |
| Input CMD ADD pins | Zpkg | $Z_{I\ ADD\ CMD}$ | 50 | 90 | 50 | 90 | 50 | 90 | ohm | 1, 2, 7 |
| | Package delay | $Td_{I\ ADD\ CMD}$ | 14 | 52 | 14 | 52 | 14 | 52 | ps | 1, 3, 7 |
| | Lpkg | $L_{I\ ADD\ CMD}$ | – | 3.9 | – | 3.9 | – | 3.9 | nH | 11 |
| | Cpkg | $C_{I\ ADD\ CMD}$ | – | 0.86 | – | 0.86 | – | 0.86 | pF | 11 |
| CK_t, CK_c | Zpkg | $Z_{CK}$ | 50 | 90 | 50 | 90 | 50 | 90 | ohm | 1, 2 |
| | Package delay | $Td_{CK}$ | 14 | 42 | 14 | 42 | 14 | 42 | ps | 1, 3 |
| | Delta Zpkg | $DZ_{DCK}$ | – | 10.5 | – | 10.5 | – | 10.5 | ohm | 1, 2, 5 |
| | Delta delay | $DTd_{DCK}$ | – | 5 | – | 5 | – | 5 | ps | 1, 3, 5 |

**Table 121: DRAM Package Electrical Specifications for x16 Devices (Continued)**

| Parameter | | Symbol | 1600/1866/2133/2400/2666 | | 2933 | | 3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | | |
| Input CLK | Lpkg | $L_{I\ CLK}$ | – | 3.4 | – | 3.4 | – | 3.4 | nH | 11 |
| | Cpkg | $C_{I\ CLK}$ | – | 0.7 | – | 0.7 | – | 0.7 | pF | 11 |
| ZQ Zpkg | | $Z_{O\ ZQ}$ | – | 100 | – | 100 | – | 100 | ohm | 1, 2 |
| ZQ delay | | $Td_{O\ ZQ}$ | 20 | 90 | 20 | 90 | 20 | 90 | ps | 1, 3 |
| ALERT Zpkg | | $Z_{O\ ALERT}$ | 40 | 100 | 40 | 100 | 40 | 100 | ohm | 1, 2 |
| ALERT delay | | $Td_{O\ ALERT}$ | 20 | 55 | 20 | 55 | 20 | 55 | ps | 1, 3 |

Notes:
1. This parameter is not subject to a production test; it is verified by design and characterization and are provided for reference; system signal simulations should not use these values but use the Alliance package model. The package parasitic (L and C) are validated using package only samples. The capacitance is measured with $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ shorted with all other signal pins floating. The inductance is measured with $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ shorted and all other signal pins shorted at the die, not pin, side.
2. Package-only impedance (Zpkg) is calculated based on the Lpkg and Cpkg total for a given pin where: Zpkg (total per pin) = SQRT (Lpkg/Cpkg).
3. Package-only delay (Tpkg) is calculated based on Lpkg and Cpkg total for a given pin where: Tdpkg (total per pin) = SQRT (Lpkg × Cpkg).
4. $Z_{IO}$ and $Td_{IO}$ apply to DQ, DM, TDQS_t and TDQS_c.
5. Absolute value of ZCK_t, ZCK_c for impedance (Z) or absolute value of TdCK_t, TdCK_c for delay (Td).
6. Absolute value of ZIO (DQS_t), ZIO (DQS_c) for impedance (Z) or absolute value of TdIO (DQS_t), TdIO (DQS_c) for delay (Td).
7. $Z_{I\ ADD\ CMD}$ and $Td_{I\ ADD\ CMD}$ apply to A[17:0], BA[1:0], BG[1:0], RAS_n CAS_n, WE_n, ACT_n, and PAR.
8. $Z_{I\ CTRL}$ and $Td_{I\ CTRL}$ apply to ODT, CS_n, and CKE.
9. Package implementations will meet specification if the Zpkg and package delay fall within the ranges shown, and the maximum Lpkg and Cpkg do not exceed the maximum values shown.
10. It is assumed that Lpkg can be approximated as Lpkg = $Z_O$ × Td.
11. It is assumed that Cpkg can be approximated as Cpkg = $Td/Z_O$.

**Table 122: Pad Input/Output Capacitance**

| Parameter | Symbol | DDR4-1600, 1866, 2133 | | DDR4-2400, 2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Input/output capacitance: DQ, DM, DQS_t, DQS_c, TDQS_t, TDQS_c | $C_{IO}$ | 0.55 | 1.4 | 0.55 | 1.15 | 0.55 | 1.00 | 0.55 | 1.00 | pF | 1, 2, 3 |
| Input capacitance: CK_t and CK_c | $C_{CK}$ | 0.2 | 0.8 | 0.2 | 0.7 | 0.2 | 0.7 | 0.15 | 0.7 | pF | 2, 3 |
| Input capacitance delta: CK_t and CK_c | $C_{DCK}$ | - | 0.05 | - | 0.05 | - | 0.05 | - | 0.05 | pF | 2, 3, 6 |
| Input/output capacitance delta: DQS_t and DQS_c | $C_{DDQS}$ | - | 0.05 | - | 0.05 | - | 0.05 | - | 0.05 | pF | 2, 3, 5 |
| Input capacitance: CTRL, ADD, CMD input-only pins | $C_I$ | 0.2 | 0.8 | 0.2 | 0.7 | 0.2 | 0.6 | 0.15 | 0.55 | pF | 2, 3, 4 |
| Input capacitance delta: All CTRL input-only pins | $C_{DI\_CTRL}$ | –0.1 | 0.1 | –0.1 | 0.1 | –0.1 | 0.1 | –0.1 | 0.1 | pF | 2, 3, 8, 9 |
| Input capacitance delta: All ADD/CMD input-only pins | $C_{DI\_ADD\_CMD}$ | –0.1 | 0.1 | –0.1 | 0.1 | –0.1 | 0.1 | –0.1 | 0.1 | pF | 1, 2, 10, 11 |
| Input/output capacitance delta: DQ, DM, DQS_t, DQS_c, TDQS_t, TDQS_c | $C_{DIO}$ | –0.1 | 0.1 | –0.1 | 0.1 | –0.1 | 0.1 | –0.1 | 0.1 | pF | 1, 2, 3, 4 |
| Input/output capacitance: ALERT pin | $C_{ALERT}$ | 0.5 | 1.5 | 0.5 | 1.5 | 0.5 | 1.5 | 0.5 | 1.5 | pF | 2, 3 |
| Input/output capacitance: ZQ pin | $C_{ZQ}$ | – | 2.3 | – | 2.3 | – | 2.3 | – | 2.3 | pF | 2, 3, 12 |
| Input/output capacitance: TEN pin | $C_{TEN}$ | 0.2 | 2.3 | 0.2 | 2.3 | 0.2 | 2.3 | 0.15 | 2.3 | pF | 2, 3, 13 |

Notes:
1. Although the DM, TDQS_t, and TDQS_c pins have different functions, the loading matches DQ and DQS.
2. This parameter is not subject to a production test; it is verified by design and characterization and are provided for reference; system signal simulations should not use these values but use the Alliance package model. The capacitance, if and when, is measured ac-cording to the JEP147 specification, "Procedure for Measuring Input Capacitance Using a Vector Network Analyzer (VNA)," with $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ applied and all other pins floating (except the pin under test, CKE, RESET_n and ODT, as necessary). $V_{DD} = V_{DDQ} = 1.2V$, $V_{BIAS} = V_{DD}/2$ and on-die termination off. Measured data is rounded using industry standard half-rounded up methodology to the nearest hundredth of the MSB.
3. This parameter applies to monolithic die, obtained by de-embedding the package L and C parasitics.
4. $C_{DIO} = C_{IO}(DQ, DM) - 0.5 \times (C_{IO}(DQS\_t) + C_{IO}(DQS\_c))$.
5. Absolute value of $C_{IO}$ (DQS_t), $C_{IO}$ (DQS_c)
6. Absolute value of CCK_t, CCK_c
7. $C_I$ applies to ODT, CS_n, CKE, A[17:0], BA[1:0], BG[1:0], RAS_n, CAS_n, ACT_n, PAR and WE_n.
8. $C_{DI\_CTRL}$ applies to ODT, CS_n, and CKE.

9. $C_{DI\_CTRL} = C_I(CTRL) - 0.5 \times (C_I(CLK\_t) + C_I(CLK\_c))$.
10. $C_{DI\_ADD\_CMD}$ applies to A[17:0], BA1:0], BG[1:0], RAS_n, CAS_n, ACT_n, PAR and WE_n.
11. $C_{DI\_ADD\_CMD} = C_I(ADD\_CMD) - 0.5 \times (C_I(CLK\_t) + C_I(CLK\_c))$.
12. Maximum external load capacitance on ZQ pin: 5pF.
13. Only applicable if TEN pin does not have an internal pull-up.

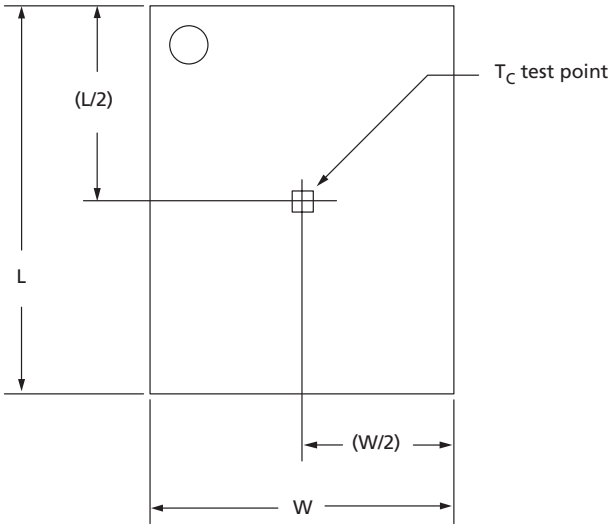
# Thermal Characteristics

### Table 123: Thermal Characteristics

| Parameter/Condition | | Symbol | Value | Units | Notes |
|---|---|---|---|---|---|
| Operating case temperature: Commercial | | $T_C$ | 0 to +85 | °C | 1, 2, 3 |
| | | $T_C$ | 0 to +95 | °C | 1, 2, 3, |
| 96-ball | Junction-to-case (TOP) | ΘJC | 4.1 | °C/W | 4 |
| | Junction-to-board | ΘJB | 12.3 | | |

Notes:
1. MAX operating case temperature. $T_C$ is measured in the center of the package.
2. A thermal solution must be designed to ensure the DRAM device does not exceed the maximum $T_C$ during operation.
3. Device functionality is not guaranteed if the DRAM device exceeds the maximum $T_C$ during operation.
4. The thermal resistance data is based off of typical number.

### Figure 234: Thermal Measurement Point



# Current Specifications – Measurement Conditions

## $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement Conditions

$I_{DD}$, $I_{PP}$, and $I_{DDQ}$ measurement conditions, such as test load and patterns, are defined in this section.

- $I_{DD}$ currents ($I_{DD0}$, $I_{DD1}$, $I_{DD2N}$, $I_{DD2NT}$, $I_{DD2P}$, $I_{DD2Q}$, $I_{DD3N}$, $I_{DD3P}$, $I_{DD4R}$, $I_{DD4W}$, $I_{DD5R}$, $I_{DD6N}$, $I_{DD6E}$, $I_{DD6R}$, $I_{DD6A}$, $I_{DD7}$, and $I_{DD8}$) are measured as time-averaged currents with all $V_{DD}$ balls of the device under test grouped together.
- $I_{PP}$ currents are $I_{PP3N}$ for standby cases ($I_{DD2N}$, $I_{DD2NT}$, $I_{DD2P}$, $I_{DD2Q}$, $I_{DD3N}$, $I_{DD3P}$, $I_{DD8}$), $I_{PP0}$ for active cases ($I_{DD0}$,$I_{DD1}$, $I_{DD4R}$, $I_{DD4W}$), $I_{PP5R}$ for the distributed refresh case ($I_{DD5R}$), $I_{PP6x}$ for self refresh cases ($I_{DD6N}$, $I_{DD6E}$, $I_{DD6R}$, $I_{DD6A}$) and $I_{PP7}$ for the operating bank interleave read case ($I_{DD7}$). These have the same definitions as the $I_{DD}$ currents referenced but are measured on the $V_{PP}$ supply.
- $I_{DDQ}$ currents are measured as time-averaged currents with $V_{DDQ}$ balls of the device under test grouped together. Alliance does not specify $I_{DDQ}$ currents.
- $I_{PP}$ and $I_{DDQ}$ currents are not included in $I_{DD}$ currents, $I_{DD}$ and $I_{DDQ}$ currents are not included in $I_{PP}$ currents, and $I_{DD}$ and $I_{PP}$ currents are not included in $I_{DDQ}$ currents.

**Note:** $I_{DDQ}$ values cannot be directly used to calculate the I/O power of the device. They can be used to support correlation of simulated I/O power to actual I/O power. In DRAM module application, $I_{DDQ}$ cannot be measured separately because $V_{DD}$ and $V_{DDQ}$ are using a merged-power layer in the module PCB.

The following definitions apply for $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ measurements.

- "0" and "LOW" are defined as $V_{IN} \leq V_{IL(AC)max}$
- "1" and "HIGH" are defined as $V_{IN} \geq V_{IH(AC)min}$
- "Midlevel" is defined as inputs $V_{REF} = V_{DD}/2$
- Timings used for $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ measurement-loop patterns are provided in the Current Test Definition and Patterns section.
- Basic $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ measurement conditions are described in the Current Test Definition and Patterns section.
- Detailed $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ measurement-loop patterns are described in the Current Test Definition and Patterns section.
- Current measurements are done after properly initializing the device. This includes, but is not limited to, setting:
  $R_{ON} = R_{ZQ}/7$ (34 ohm in MR1);
  Qoff = 0B (output buffer enabled in MR1);
  $R_{TT(NOM)} = R_{ZQ}/6$ (40 ohm in MR1);
  $R_{TT(WR)} = R_{ZQ}/2$ (120 ohm in MR2);
  $R_{TT(Park)}$ = disabled;
  TDQS feature disabled in MR1; CRC disabled in MR2; CA parity feature disabled in MR3; Gear-down mode disabled in MR3; Read/Write DBI disabled in MR5; DM disabled in MR5
- Define D = {CS_n, RAS_n, CAS_n, WE_n}: = {HIGH, LOW, LOW, LOW}; apply BG/BA changes when directed.
- Define D_n = {CS_n, RAS_n, CAS_n, WE_n}: = {HIGH, HIGH, HIGH, HIGH}; apply invert of BG/BA changes when directed above.

**Note:** The measurement-loop patterns must be executed at least once before actual current measurements can be taken.

**Figure 235: Measurement Setup and Test Load for $I_{DDx}$, $I_{PPx}$, and $I_{DDQx}$**

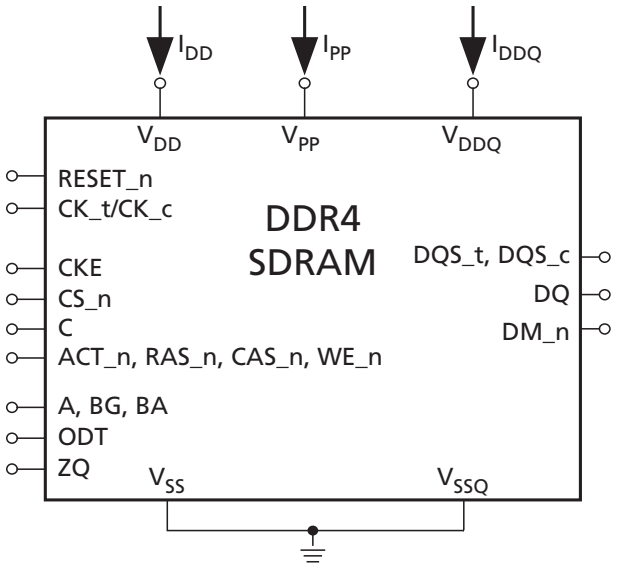
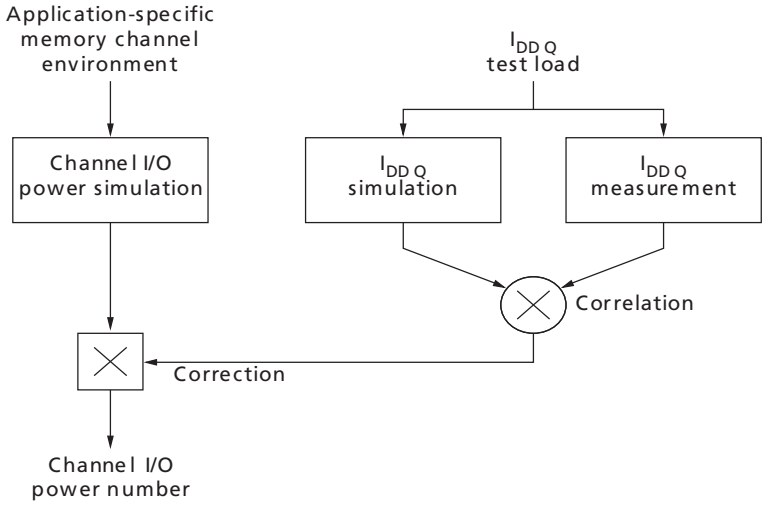



**Figure 236: Correlation: Simulated Channel I/O Power to Actual Channel I/O Power**




Note: 1. Supported by $I_{DDQ}$ measurement.

## $I_{DD}$ Definitions

**Table 124: Basic $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement Conditions**

| Symbol | Description |
|---|---|
| $I_{DD0}$ | **Operating One Bank Active-Precharge Current (AL = 0)**<br>CKE: HIGH; External clock: On; $^{t}$CK, *n*RC, *n*RAS, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: HIGH between ACT and PRE; Command, address, bank group address, bank address inputs: partially toggling according to the next table; Data I/O: $V_{DDQ}$; DM_n: stable at 0; Bank activity: cycling with one bank active at a time: 0, 0, 1, 1, 2, 2, ... (see the $I_{DD0}$ Measurement-Loop Pattern table); Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: stable at 0; Pattern details: see the $I_{DD0}$ Measurement-Loop Pattern table |
| $I_{PP0}$ | **Operating One Bank Active-Precharge $I_{PP}$ Current (AL = 0)**<br>Same conditions as $I_{DD0}$ above |
| $I_{DD1}$ | **Operating One Bank Active-Read-Precharge Current (AL = 0)**<br>CKE: HIGH; External clock: on; $^{t}$CK, *n*RC, *n*RAS, *n*RCD, CL: see the previous table; BL: 8;[1, 5] AL: 0; CS_n: HIGH between ACT, RD, and PRE; Command, address, bank group address, bank address inputs, Data I/O: partially toggling according to the $I_{DD1}$ Measurement-Loop Pattern table; DM_n: stable at 0; Bank activity: cycling with one bank active at a time: 0, 0, 1, 1, 2, 2, ... (see the following table); Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT Signal: stable at 0; Pattern details: see the $I_{DD1}$ Measurement-Loop Pattern table |
| $I_{DD2N}$ | **Precharge Standby Current (AL = 0)**<br>CKE: HIGH; External clock: On; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank group address, bank address Inputs: partially toggling according to the $I_{DD2N}$ and $I_{DD3N}$ Measurement-Loop Pattern table; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: all banks closed; Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: stable at 0; Pattern details: see the $I_{DD2N}$ and $I_{DD3N}$ Measurement-Loop Pattern table |
| $I_{DD2NT}$ | **Precharge Standby ODT Current**<br>CKE: HIGH; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank gropup address, bank address inputs: partially toggling according to the $I_{DD2NT}$ Measurement-Loop Pattern table; Data I/O: $V_{SSQ}$; DM_n: stable at 1; Bank activity: all banks closed; Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: toggling according to the $I_{DD2NT}$ Measurement-Loop Pattern table; Pattern details: see the $I_{DD2NT}$ Measurement-Loop Pattern table |
| $I_{DD2P}$ | **Precharge Power-Down Current**<br>CKE: LOW; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank group address, bank address inputs: stable at 0; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: all banks closed; Output buffer and $R_{TT}$: Enabled in mode registers;[2] ODT signal: stable at 0 |
| $I_{DD2Q}$ | **Precharge Quiet Standby Current**<br>CKE: HIGH; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank group address, bank address inputs: stable at 0; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: all banks closed; Output buffer and $R_{TT}$: Enabled in mode registers;[2] ODT signal: stable at 0 |
| $I_{DD3N}$ | **Active Standby Current (AL = 0)**<br>CKE: HIGH; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank group address, bank address inputs: partially toggling according to the $I_{DD2N}$ and $I_{DD3N}$ Measurement-Loop Pattern table; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: all banks open; Output buffer and $R_{TT}$: Enabled in mode registers;[2] ODT signal: stable at 0; Pattern details: see the $I_{DD2N}$ and $I_{DD3N}$ Measurement-Loop Pattern table |
| $I_{PP3N}$ | **Active Standby $I_{PP3N}$ Current (AL = 0)**<br>Same conditions as $I_{DD3N}$ above |

**Table 124: Basic $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement Conditions (Continued)**

| Symbol | Description |
|---|---|
| $I_{DD3P}$ | **Active Power-Down Current (AL = 0)**<br>CKE: LOW; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank group address, bank address inputs: stable at 1; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: all banks open; Output buffer and $R_{TT}$: Enabled in mode registers;[2] ODT signal: stable at 0 |
| $I_{DD4R}$ | **Operating Burst Read Current (AL = 0)**<br>CKE: HIGH; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[15] AL: 0; CS_n: HIGH between RD; Command, address, bank group address, bank address inputs: partially toggling according to the $I_{DD4R}$ Measurement-Loop Pattern table; Data I/O: seamless read data burst with different data between one burst and the next one according to the $I_{DD4R}$ Measurement-Loop Pattern table; DM_n: stable at 1; Bank activity: all banks open, RD commands cycling through banks: 0, 0, 1, 1, 2, 2, ... (see the $I_{DD4R}$ Measurement-Loop Pattern table); Output buffer and $R_{TT}$: Enabled in mode registers;[2] ODT signal: stable at 0; Pattern details: see the $I_{DD4R}$ Measurement-Loop Pattern table |
| $I_{DD4W}$ | **Operating Burst Write Current (AL = 0)**<br>CKE: HIGH; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: HIGH between WR; Command, address, bank group address, bank address inputs: partially toggling according to the $I_{DD4W}$ Measure-ment-Loop Pattern table; Data I/O: seamless write data burst with different data between one burst and the next one according to the $I_{DD4W}$ Measurement-Loop Pattern table; DM: stable at 0; Bank activity: all banks open, WR commands cycling through banks: 0, 0, 1, 1, 2, 2, ... (see $I_{DD4W}$ Measurement-Loop Pattern table); Output buffer and $R_{TT}$: enabled in mode registers (see note2); ODT signal: stable at HIGH; Pattern details: see the $I_{DD4W}$ Measurement-Loop Pattern table |
| $I_{DD5R}$ | **Distributed Refresh Current (1X REF)**<br>CKE: HIGH; External clock: on; $^{t}$CK, CL, *n*REFI: see the previous table; BL: 8;[1] AL: 0; CS_n: HIGH between REF; Command, address, bank group address, bank address inputs: partially toggling according to the $I_{DD5R}$ Measurement-Loop Pattern table; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: REF command every *n*REFI (see the $I_{DD5R}$ Measurement-Loop Pattern table); Output buffer and $R_{TT}$: enabled in mode registers[2]; ODT signal: stable at 0; Pattern details: see the $I_{DD5R}$ Measurement-Loop Pattern table |
| $I_{PP5R}$ | **Distributed Refresh Current (1X REF)**<br>Same conditions as $I_{DD5R}$ above |
| $I_{DD6N}$ | **Self Refresh Current: Normal Temperature Range**<br>$T_C$: 0–85°C; Auto self refresh (ASR): disabled;[3] Self refresh temperature range (SRT): normal;[4] CKE: LOW; External clock: off; CK_t and CK_c: LOW; CL: see the table above; BL: 8;[1] AL: 0; CS_n, command, address, bank group address, bank address, data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: SELF REFRESH operation; Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: mid level |
| $I_{DD6E}$ | **Self Refresh Current: Extended Temperature Range [4]**<br>$T_C$: 0–95°C; Auto self refresh (ASR): disabled[4]; Self refresh temperature range (SRT): extended;[4] CKE: LOW; External clock: off; CK_t and CK_c: LOW; CL: see the previous table; BL: 8;[1] AL: 0; CS_n, command, address, group bank address, bank address, data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: EXTENDED TEMPERATURE SELF REFRESH operation; Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: mid level |
| $I_{PP6x}$ | **Self Refresh $I_{PP}$ Current**<br>Same conditions as $I_{DD6E}$ above |
| $I_{DD6R}$ | **Self Refresh Current: Reduced Temperature Range**<br>$T_C$: 0–45°C; Auto self refresh (ASR): disabled; Self refresh temperature range (SRT): reduced;[4] CKE: LOW; External clock: off; CK_t and CK_c: LOW; CL: see the previous table; BL: 8;[1] AL: 0; CS_n, command, address, bank group address, bank address, data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: EXTENDED TEMPERATURE SELF REFRESH operation; Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: mid level |

**Table 124: Basic $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement Conditions (Continued)**

| Symbol | Description |
|---|---|
| $I_{DD7}$ | **Operating Bank Interleave Read Current**<br>CKE: HIGH; External clock: on; $^{t}$CK, *n*RC, *n*RAS, *n*RCD, *n*RRD, *n*FAW, CL: see the previous table; BL: 8;[15] AL: CL - 1; CS_n: HIGH between ACT and RDA; Command, address, group bank adress, bank address inputs: partially toggling according to the $I_{DD7}$ Measurement-Loop Pattern table; Data I/O: read data bursts with different data between one burst and the next one according to the $I_{DD7}$ Measurement-Loop Pattern table; DM: stable at 1; Bank activity: two times interleaved cycling through banks (0, 1, ...7) with different addressing, see the $I_{DD7}$ Measurement-Loop Pattern table; Output buffer and $R_{TT}$: enabled in mode registers;[2] ODT signal: stable at 0; Pattern details: see the $I_{DD7}$ Measurement-Loop Pattern table |
| $I_{PP7}$ | **Operating Bank Interleave Read $I_{PP}$ Current**<br>Same conditions as $I_{DD7}$ above |
| $I_{DD8}$ | **Maximum Power Down Current**<br>Place DRAM in MPSM then CKE: HIGH; External clock: on; $^{t}$CK, CL: see the previous table; BL: 8;[1] AL: 0; CS_n: stable at 1; Command, address, bank group address, bank address inputs: stable at 0; Data I/O: $V_{DDQ}$; DM_n: stable at 1; Bank activity: all banks closed; Output buffer and $R_{TT}$: Enabled in mode registers;[2] ODT signal: stable at 0 |

Notes:
1. Burst length: BL8 fixed by MRS: set MR0[1:0] 00.
2. Output buffer enable: set MR1[12] 0 (output buffer enabled); set MR1[2:1] 00 ($R_{ON}$ = $R_{ZQ}$/7); $R_{TT(NOM)}$ enable: set MR1[10:8] 011 ($R_{ZQ}$/6); $R_{TT(WR)}$ enable: set MR2[11:9] 001 ($R_{ZQ}$/2), and $R_{TT(Park)}$ enable: set MR5[8:6] 000 (disabled).
3. Auto self refresh (ASR): set MR2[6] 0 to disable or MR2[6] 1 to enable feature.
4. Self refresh temperature range (SRT): set MR2[7] 0 for normal or MR2[7] 1 for extended temperature range.
5. READ burst type: Nibble sequential, set MR0[3] 0.
6. In the dual-rank DDP case, note the following IDD measurement considerations:
   - For all IDD measurements except IDD6, the unselected rank should be in an IDD2P condition.
   - For all IPP measurements except IPP6, the unselected rank should be in an IDD3N condition.
   - For all IDD6/IPP6 measurements, both ranks should be in the same IDD6 condition.

# Current Specifications – Patterns and Test Conditions

## Current Test Definitions and Patterns

**Table 125: $I_{DD0}$ and $I_{PP0}$ Measurement-Loop Pattern[1]**

| CK_t, CK_c | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | ACT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1, 2 | D, D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 3, 4 | D_n, D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | ... | Repeat pattern 1...4 until *n*RAS - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | | *n*RAS | PRE | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | ... | Repeat pattern 1...4 until *n*RC - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | 1 | 1 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 2 | 2 × *n*RC | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 3 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 4 × *n*RC | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 5 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 6 × *n*RC | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 7 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$.
2. DQ signals are $V_{DDQ}$.

**Table 126: $I_{DD1}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | ACT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1, 2 | D, D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 3, 4 | D_n, D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | ... | Repeat pattern 1...4 until *n*RCD - AL - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | | *n*RCD - AL | RD | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | D0 = 00, D1 = FF, D2 = FF, D3 = 00, D4 = FF, D5 = 00, D5 = 00, D7 = FF |
| | | | ... | Repeat pattern 1...4 until *n*RAS - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | | *n*RAS | PRE | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | ... | Repeat pattern 1...4 until *n*RC - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | 1 | 1 × *n*RC + 0 | ACT | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1 × *n*RC + 1, 2 | D, D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1 × *n*RC + 3, 4 | D_n, D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | ... | Repeat pattern *n*RC + 1...4 until 1 × *n*RC + *n*RAS - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | | 1 × *n*RC +*n*RCD - AL | RD | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | D0 = FF, D1 = 00, D2 = 00, D3 = FF, D4 = 00, D5 = FF, D5 = FF, D7 = 00 |
| | | | ... | Repeat pattern 1...4 until *n*RAS - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | | 1 × *n*RC + *n*RAS | PRE | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | ... | Repeat pattern *n*RC + 1...4 until 2 × *n*RC - 1; truncate if necessary | | | | | | | | | | | | | | | |
| | | 2 | 2 × *n*RC | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 3 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 4 × *n*RC | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 5 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 6 × *n*RC | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 7 × *n*RC | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$ when not toggling.
2. DQ signals are VDDQ except when burst sequence drives each DQ signal by a READ command.

**Table 127: $I_{DD2N}$, $I_{DD3N}$, and $I_{PP3P}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 2 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | 3 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | 1 | 4–7 | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 2 | 8–11 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 12–15 | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 16–19 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 20–23 | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 24–27 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 28–31 | Repeat sub-loop 0, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$.
2. DQ signals are $V_{DDQ}$.

**Table 128: $I_{DD2NT}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 2 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | 3 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | 1 | 4–7 | Repeat sub-loop 0 with ODT = 1, use BG[0] = 1, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 2 | 8–11 | Repeat sub-loop 0 with ODT = 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 12–15 | Repeat sub-loop 0 with ODT = 1, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 16–19 | Repeat sub-loop 0 with ODT = 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 20–23 | Repeat sub-loop 0 with ODT = 1, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 24–27 | Repeat sub-loop 0 with ODT = 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 28–31 | Repeat sub-loop 0 with ODT = 1, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{SSQ}$.
2. DQ signals are $V_{SSQ}$.

**Table 129: $I_{DD4R}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | RD | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | D0 = 00, D1 = FF, D2 = FF, D3 = 00, D4 = FF, D5 = 00, D5 = 00, D7 = FF |
| | | | 1 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | 2, 3 | D_n, D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | 1 | 4 | RD | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 7 | F | 0 | D0 = FF, D1 = 00 D2 = 00, D3 = FF D4 = 00, D5 = FF D5 = FF, D7 = 00 |
| | | | 5 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | 6, 7 | D_n, D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | 2 | 8–11 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 12–15 | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 16–19 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 20–23 | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 24–27 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 28–31 | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$ when not toggling.
2. Burst sequence driven on each DQ signal by a READ command. Outside burst operation, DQ signals are $V_{DDQ}$.

**Table 130: $I_{DD4W}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Com-mand | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | WR | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | D0 = 00, D1 = FF, D2 = FF, D3 = 00, D4 = FF, D5 = 00, D5 = 00, D7 = FF |
| | | | 1 | D | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | 2, 3 | D_n, D_n | 1 | 1 | 1 | 1 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | 1 | 4 | WR | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 7 | F | 0 | D0 = FF, D1 = 00 D2 = 00, D3 = FF D4 = 00, D5 = FF D5 = FF, D7 = 00 |
| | | | 5 | D | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | 6, 7 | D_n, D_n | 1 | 1 | 1 | 1 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | 2 | 8–11 | Repeat sub-loop 0, use BG[1:0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 12–15 | Repeat sub-loop 1, use BG[1:0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 16–19 | Repeat sub-loop 0, use BG[1:0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 20–23 | Repeat sub-loop 1, use BG[1:0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 24–27 | Repeat sub-loop 0, use BG[1:0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 28–31 | Repeat sub-loop 1, use BG[1:0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$ when not toggling.
2. Burst sequence driven on each DQ signal by WRITE command. Outside burst operation, DQ signals are $V_{DDQ}$.

**Table 131: $I_{DD4Wc}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[3] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | WR | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | D0 = 00, D1 = FF, D2 = FF, D3 = 00, D4 = FF, D5 = 00, D8 = CRC |
| | | | 1, 2 | D, D | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | 3, 4 | D_n, D_n | 1 | 1 | 1 | 1 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | 1 | 5 | WR | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 7 | F | 0 | D0 = FF, D1 = 00, D2 = 00, D3 = FF, D4 = 00, D5 = FF, D5 = FF, D7 = 00 D8 = CRC |
| | | | 6, 7 | D, D | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | | 8, 9 | D_n, D_n | 1 | 1 | 1 | 1 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | 2 | 10–14 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 15–19 | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 20–24 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 5 | 25–29 | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 6 | 30–34 | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 7 | 35–39 | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |

Notes:
1. Pattern provided for reference only.
2. DQS_t, DQS_c are $V_{DDQ}$ when not toggling.
3. Burst sequence driven on each DQ signal by WRITE command. Outside burst operation, DQ signals are $V_{DDQ}$.

**Table 132: $I_{DD5R}$ Measurement – Loop Pattern[1]**

| CK_c, CK_t, | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | REF | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | 1 | 1 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 2 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 3 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | 4 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | 5–8 | Repeat pattern 1...4, use BG[0] = 1, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | | 9–12 | Repeat pattern 1...4, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | | 13–16 | Repeat pattern 1...4, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | | 17–20 | Repeat pattern 1...4, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | | 21–24 | Repeat pattern 1...4, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | | 25–28 | Repeat pattern 1...4, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | | 29–32 | Repeat pattern 1...4, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |
| | | 2 | 65...*n*REFI - 1 | Repeat sub-loop 1; truncate if necessary | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$.
2. DQ signals are $V_{DDQ}$.

**Table 133: $I_{DD7}$ Measurement – Loop Pattern[1]**

| CK_t, CK_c | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | BG[0] | BA[1:0] | A12/BC_n | A[17,13,11]] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | ACT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 1 | RDA | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | |
| | | | 2 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | 3 | D_n | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 3 | 0 | 0 | 0 | 7 | F | 0 | – |
| | | | ... | Repeat pattern 2...3 until *n*RRD - 1, if *n*RRD > 4. Truncate if necessary | | | | | | | | | | | | | | | |
| | | 1 | *n*RRD | ACT | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | – |
| | | | *n*RRD+1 | RDA | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | |
| | | | ... | Repeat pattern 2...3 until 2 × *n*RRD - 1, if *n*RRD > 4. Truncate if necessary | | | | | | | | | | | | | | | |
| | | 2 | 2 × *n*RRD | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 3 | 3 × *n*RRD | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 4 | 4 × *n*RRD | Repeat pattern 2...3 until *n*FAW - 1, if *n*FAW > 4 × *n*RRD. Truncate if necessary | | | | | | | | | | | | | | | |
| | | 5 | *n*FAW | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 6 | *n*FAW + *n*RRD | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 2 instead | | | | | | | | | | | | | | | |
| | | 7 | *n*FAW + 2 × *n*RRD | Repeat sub-loop 0, use BG[0] = 0, use BA[1:0] = 3 instead | | | | | | | | | | | | | | | |
| | | 8 | *n*FAW + 3 × *n*RRD | Repeat sub-loop 1, use BG[0] = 1, use BA[1:0] = 0 instead | | | | | | | | | | | | | | | |
| | | 9 | 4 × *n*FAW | Repeat pattern 2...3 until *n*RC - 1, if *n*RC > 4 × *n*FAW. Truncate if necessary | | | | | | | | | | | | | | | |

Notes: 1. DQS_t, DQS_c are $V_{DDQ}$.
2. DQ signals are $V_{DDQ}$ except when burst sequence drives each DQ signal by a READ command.

## $I_{DD}$ Specifications

**Table 134: Timings used for $I_{DD}$, $I_{PP}$, and $I_{DDQ}$ Measurement – Loop Patterns**

| Symbol | | DDR4-1600 | | | DDR4-1866 | | | DDR4-2133 | | | DDR4-2400 | | | DDR4-2666 | | | DDR4-2933 | | | DDR4-3200 | | | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10-10-10 | 11-11-11 | 12-12-12 | 12-12-12 | 13-13-13 | 14-14-14 | 14-14-14 | 15-15-15 | 16-16-16 | 16-16-16 | 17-17-17 | 18-18-18 | 18-18-18 | 19-19-19 | 20-20-20 | 20-20-20 | 21-21-21 | 22-22-22 | 20-20-20 | 22-22-22 | 24-24-24 | |
| $^{t}$CK | | 1.25 | | | 1.071 | | | 0.937 | | | 0.833 | | | 0.75 | | | 0.682 | | | 0.625 | | | ns |
| CL | | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 20 | 21 | 22 | 20 | 22 | 24 | CK |
| CWL | | 9 | 11 | 11 | 10 | 12 | 12 | 11 | 14 | 14 | 16 | 16 | 16 | 18 | 18 | 18 | 14 | 18 | 18 | 16 | 20 | 20 | CK |
| *n*RCD | | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 19 | 20 | 21 | 20 | 22 | 24 | CK |
| *n*RC | | 38 | 39 | 40 | 44 | 45 | 46 | 50 | 51 | 52 | 55 | 56 | 57 | 61 | 62 | 63 | 66 | 67 | 68 | 72 | 74 | 76 | CK |
| *n*RP | | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 18 | 18 | 19 | 20 | 19 | 20 | 21 | 20 | 22 | 24 | CK |
| *n*RAS | | 28 | | | 32 | | | 36 | | | 39 | | | 43 | | | 47 | | | 52 | | | CK |
| *n*FAW | x16 | 28 | | | 28 | | | 32 | | | 36 | | | 40 | | | 44 | | | 48 | | | CK |
| *n*RRD_S | x16 | 5 | | | 6 | | | 6 | | | 7 | | | 8 | | | 8 | | | 9 | | | CK |
| *n*RRD_L | x16 | 6 | | | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | | 11 | | | CK |
| *n*CCD_S | | 4 | | | 4 | | | 4 | | | 4 | | | 4 | | | 4 | | | 4 | | | CK |
| *n*CCD_L | | 5 | | | 5 | | | 6 | | | 6 | | | 7 | | | 8 | | | 8 | | | CK |
| *n*WTR_S | | 2 | | | 3 | | | 3 | | | 3 | | | 4 | | | 4 | | | 4 | | | CK |
| *n*WTR_L | | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | | 11 | | | 12 | | | CK |
| *n*REFI | | 6,240 | | | 7,283 | | | 8,325 | | | 9,364 | | | 10,400 | | | 11,437 | | | 12,480 | | | CK |
| *n*RFC 2Gb | | 128 | | | 150 | | | 171 | | | 193 | | | 214 | | | 235 | | | 256 | | | CK |
| *n*RFC 4Gb | | 208 | | | 243 | | | 278 | | | 313 | | | 347 | | | 382 | | | 416 | | | CK |
| *n*RFC 8Gb | | 280 | | | 327 | | | 374 | | | 421 | | | 467 | | | 514 | | | 560 | | | CK |
| *n*RFC 16Gb | | 280 | | | 327 | | | 374 | | | 421 | | | 467 | | | 514 | | | 560 | | | CK |

## Current Specifications – Limits

**Table 135: $I_{DD}$ and $I_{PP}$ Current Limits; (-40°C ≤ $T_C$ ≤ 85° C)**

| Symbol | Width | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|
| **$I_{DD0}$**: One bank ACTIVATE-to-PRECHARGE current | x16 | 66 | 67 | 68 | 69 | 70 | mA |
| **$I_{PP0}$**: One bank ACTIVATE-to-PRECHARGE $I_{PP}$ current | x16 | 4 | 4 | 4 | 4 | 4 | mA |
| **$I_{DD1}$**: One bank ACTIVATE-to-READ-to- PRECHARGE current | x16 | 86 | 87 | 88 | 89 | 90 | mA |
| **$I_{DD2N}$**: Precharge standby current | ALL | 46 | 47 | 48 | 49 | 50 | mA |
| **$I_{DD2NT}$**: Precharge standby ODT current | x16 | 54 | 55 | 56 | 57 | 58 | mA |
| **$I_{DD2P}$**: Precharge power-down current | ALL | 43 | 43 | 43 | 43 | 43 | mA |
| **$I_{DD2Q}$**: Precharge quiet standby current | ALL | 47 | 47 | 47 | 47 | 47 | mA |
| **$I_{DD3N}$**: Active standby current | x16 | 58 | 59 | 60 | 61 | 62 | mA |
| **$I_{PP3N}$**: Active standby $I_{PP}$ current | ALL | 2 | 2 | 2 | 2 | 2 | mA |
| **$I_{DD3P}$**: Active power-down current | x16 | 47 | 48 | 49 | 50 | 51 | mA |
| **$I_{DD4R}$**: Burst read current | x16 | 231 | 243 | 263 | 282 | 299 | mA |
| **$I_{DD4W}$**: Burst write current | x16 | 189 | 200 | 213 | 226 | 236 | mA |
| **$I_{DD5R}$**: Distributed refresh current (1X REF) | ALL | 68 | 68 | 68 | 68 | 68 | mA |
| **$I_{PP5R}$**: Distributed refresh $I_{PP}$ current (1X REF) | ALL | 4 | 4 | 4 | 4 | 4 | mA |
| **$I_{DD6N}$**: Self refresh current; 0–85°C[1] | ALL | 57 | 57 | 57 | 57 | 57 | mA |
| **$I_{DD6E}$**: Self refresh current; 0–95°C [2, 4] | ALL | 113 | 113 | 113 | 113 | 113 | mA |
| **$I_{DD6R}$**: Self refresh current; 0–45°C [3, 4] | ALL | 24 | 24 | 24 | 24 | 24 | mA |
| **$I_{DD6A}$**: Auto self refresh current (25°C)[4] | ALL | 18 | 18 | 18 | 18 | 18 | mA |
| **$I_{DD6A}$**: Auto self refresh current (45°C)[4] | ALL | 24 | 24 | 24 | 24 | 24 | mA |

**Table 135: $I_{DD}$ and $I_{PP}$ Current Limits; (-40°C ≤ $T_C$ ≤ 85°C) (Continued)**

| Symbol | Width | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|
| **$I_{DD6A}$**: Auto self refresh current (75°C)[4] | ALL | 51 | 51 | 51 | 51 | 51 | mA |
| **$I_{DD6A}$**: Auto self refresh current (95°C)[4] | ALL | 113 | 113 | 113 | 113 | 113 | mA |
| **$I_{PP6x}$**: Auto self refresh $I_{PP}$ current; –40–95°C[27] | ALL | 6 | 6 | 6 | 6 | 6 | mA |
| **$I_{DD7}$**: Bank interleave read current | x16 | 241 | 244 | 246 | 248 | 251 | mA |
| **$I_{PP7}$**: Bank interleave read $I_{PP}$ current | x16 | 9 | 9 | 9 | 9 | 9 | mA |
| **$I_{DD8}$**: Maximum power-down current | ALL | 38 | 38 | 38 | 38 | 38 | mA |

Notes:
1. Applicable for MR2 settings A7 = 0 and A6 = 0; manual mode with normal temperature range of operation (0–85°C).
2. Applicable for MR2 settings A7 = 1 and A6 = 0; manual mode with extended temperature range of operation (0–95°C).
3. Applicable for MR2 settings A7 = 0 and A6 = 1; manual mode with reduced temperature range of operation (0–45°C).
4. $I_{DD6R}$, $I_{DD6A}$, and $I_{DD6E}$ values are verified by design and characterization, and may not be subject to production test.
5. When additive latency is enabled for $I_{DD0}$, current changes by approximately +1%.
6. When additive latency is enabled for $I_{DD1}$, current changes by approximately +3% (x8), +2% (x16).
7. When additive latency is enabled for $I_{DD2N}$, current changes by approximately +1%.
8. When DLL is disabled for $I_{DD2N}$, current changes by approximately –4%.
9. When CAL is enabled for $I_{DD2N}$, current changes by approximately –11%.
10. When gear-down is enabled for $I_{DD2N}$, current changes by approximately 0%.
11. When CA parity is enabled for $I_{DD2N}$, current changes by approximately +8%.
12. When additive latency is enabled for $I_{DD3N}$, current changes by approximately +1%.
13. When additive latency is enabled for $I_{DD4R}$, current changes by approximately +4% (x8), +1% (x16).
14. When read DBI is enabled for $I_{DD4R}$, current changes by approximately –9%.
15. When additive latency is enabled for $I_{DD4W}$, current changes by approximately +5% (x8), +2% (x16).
16. When write DBI is enabled for $I_{DD4W}$, current changes by approximately +1%.
17. When write CRC is enabled for $I_{DD4W}$, current changes by approximately –5% (x8), –8%(x16).
18. When CA parity is enabled for $I_{DD4W}$, current changes by approximately +13% (x8), +6%(x16).
19. When 2X REF is enabled for $I_{DD5R}$, current changes by approximately 0%.
20. When 4X REF is enabled for $I_{DD5R}$, current changes by approximately 0%.
21. When 2X REF is enabled for $I_{PP5R}$, current changes by approximately 0%.
22. When 4X REF is enabled for $I_{PP5R}$, current changes by approximately 0%.
23. $I_{PP0}$ test and limit is applicable for $I_{DD0}$ and $I_{DD1}$ conditions.

24. $I_{PP3N}$ test and limit is applicable for all $I_{DD2x}$, $I_{DD3x}$, $I_{DD4x}$, and $I_{DD8}$ conditions; that is, testing $I_{PP3N}$ should satisfy the $I_{PP}$s for the noted $I_{DD}$ tests.
25. DDR4-1600 and DDR4-1866 use the same $I_{DD}$ limits as DDR4-2133.
26. The $I_{DD}$ values must be derated (increased) when operated between 85°C < $T_C$ ≤ 95°C: $I_{DD0}$ and $I_{DD1}$must be derated by 10%; $I_{DD2N}$, $I_{DD2NT}$, $I_{DD2Q}$, and $I_{DD3N}$ must be derated by 18%; $I_{DD2P}$ and $I_{DD3P}$ must be derated by 23%; $I_{DD4R}$ and $I_{DD4W}$ must be derated by 6%; $I_{DD5R}$ must be derated by 58%; $I_{DD7}$, $I_{PP7}$ and $I_{PP0}$ must be derated by 3%; $I_{DD8}$ must be derated by 28%; $I_{PP5R}$ must be derated by 97%
27. $I_{PP6x}$ is applicable to $I_{DD6N}$, $I_{DD6E}$, $I_{DD6R}$, and $I_{DD6A}$ conditions.

## Speed Bin Tables

DDR4 DRAM timing is primarily covered by two types of tables: the Speed Bin tables in this section and the tables found in the Electrical Characteristics and AC Timing Param-eters section. The timing parameter tables define the applicable timing specifications based on the speed rating. The Speed Bin tables on the following pages list the $^{t}$AA, $^{t}$RCD, $^{t}$RP, $^{t}$RAS, and $^{t}$RC limits of a given speed mark and are applicable to the CL settings in the lower half of the table provided
they are applied in the correct clock range, which is noted.

### Backward Compatibility

Although the speed bin tables list the slower data rates, $^{t}$AA, CL, and CWL, it is difficult to determine whether a faster speed bin supports all of the $^{t}$AA, CL, and CWL combinations across all the data rates of a slower speed bin. To assist in this process, please refer to the Backward Compatibility table.

**Table 136: Backward Compatibility**

Note 1 applies to the entire table.

| Component Speed Bin | Speed Bin Supported | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -125 | -125E | -107 | -107E | -093 | -093E | -083D | -083 | -083E | -075D | -075 | -075E | -068D | -068 | -068E | -062 | -062E | -062Y |
| -125 | yes | | | | | | | | | | | | | | | | | |
| -125E | yes[2] | yes | | | | | | | | | | | | | | | | |
| -107 | yes | | yes | | | | | | | | | | | | | | | |
| -107E | yes[2] | yes | yes[2] | yes | | | | | | | | | | | | | | |
| -093 | yes | | yes | | yes | | | | | | | | | | | | | |
| -093E | yes[2] | yes | yes[2] | yes | yes[2] | yes | | | | | | | | | | | | |
| -083D | yes | | yes | | yes | | yes | | | | | | | | | | | |
| -083 | yes | | yes | | yes | | yes | yes | | | | | | | | | | |
| -083E | yes[2] | yes | yes[2] | yes | yes[2] | yes | yes[2] | yes[2] | yes | | | | | | | | | |
| -075D | yes | | yes | | yes | | yes | | | yes | | | | | | | | |
| -075 | yes | | yes | | yes | | yes | yes | | yes | yes | | | | | | | |
| -075E | yes | yes | yes | yes | yes | yes | yes | yes | | yes | yes | yes | | | | | | |
| -068D | yes | | yes | | yes | | yes | | | yes | | | yes | | | | | |
| -068 | yes | | yes | | yes | | yes | yes | | yes | yes | | yes | yes | | | | |
| -068E | yes | | yes | | yes | | yes | yes | | yes | yes | | yes | yes | yes | | | |
| -062 | yes | | yes | | yes | | yes | | | yes | | | yes | | | yes | | |
| -062E | yes | | yes | | yes | | yes | yes | | yes | yes | | yes | yes | | yes | yes | |
| -062Y | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | | yes | yes | yes |

Notes:
1. The backward compatibility table is not meant to guarantee that any new device will be a drop in replacement for an existing part number. Customers should review the operating conditions for any device to determine its suitability for use in their design.
2. This condition exceeds the JEDEC requirement in order to allow additional flexibility for components. However, JEDEC SPD compliance may force modules to only support the JEDEC-defined value. Refer to the SPD documentation for further clarification.

**Table 137: DDR4-1600 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-1600 Speed Bin | | | | | | | -125E | | -125 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 11-11-11 | | 12-12-12 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Unit |
| Internal READ command to first data | | | | | | $^{t}$AA | 13.75 (13.50)[4] | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 2*n*CK | $^{t}$AA (MAX) + 2*n*CK | $^{t}$AA (MIN) + 2*n*CK | $^{t}$AA (MAX) + 2*n*CK | ns |
| ACTIVATE-to-internal READ or WRITE delay time | | | | | | $^{t}$RCD | 13.75 (13.50)[4] | – | 15.00 | – | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 13.75 (13.50)[4] | – | 15.00 | – | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 35 | 9 × $^{t}$REFI | 35 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin(ns): non-DB** | **READ CL: nonDBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | - | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | 1.500 | 1.900[6] | Reserved | | ns |
| | - | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | 1.500[6] | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9, 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | 1.250 | <1.500 | ns |
| Supported CL settings | | | | | | | 9, 10[6], 11-12 | | 10, 12 | | *n*CK |
| Supported CL settings with read DBI | | | | | | | 11, 12[6], 13-14 | | 12, 14 | | *n*CK |
| Supported CWL settings | | | | | | | 9, 11 | | 9, 11 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

**Table 138: DDR4-1866 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-1866 Speed Bin | | | | | | | -107E | | -107 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 13-13-13 | | 14-14-14 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Unit |
| Internal READ command to first data | | | | | | $^{t}$AA | 13.92 (13.50)[4] | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 2*n*CK | $^{t}$AA (MAX) + 2*n*CK | $^{t}$AA (MIN) + 2*n*CK | $^{t}$AA (MAX) + 2*n*CK | ns |
| ACTIVATE to internal READ or WRITE delay time | | | | | | $^{t}$RCD | 13.92 (13.50)[4] | – | 15.00 | – | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 13.92 (13.50)[4] | – | 15.00 | – | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 34 | 9 × $^{t}$REFI | 34 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin: non-DBI** | **READ CL: nonDBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | – | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | 1.500 | 1.900[6] | Reserved | | ns |
| | – | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | 1.500[6] | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9, 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | 1.250 | <1.500 | ns |
| 1866 | -107E | 13.92 | 13 | 15 | 10, 12 | $^{t}$CK (AVG) | 1.071 | <1.250 | Reserved | | ns |
| | -107 | 15.00 | 14 | 16 | | $^{t}$CK (AVG) | | | 1.071 | <1.250 | ns |
| Supported CL settings | | | | | | | 9, 10[6] , 11–14 | | 10, 12, 14 | | *n*CK |
| Supported CL settings with read DBI | | | | | | | 11, 12[6] , 13–16 | | 12, 14, 16 | | *n*CK |
| Supported CWL settings | | | | | | | 9–12 | | 9–12 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

**Table 139: DDR4-2133 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-2133 Speed Bin | | | | | | | -093E | | -093 | | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 15-15-15 | | 16-16-16 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | |
| Internal READ command to first data | | | | | | $^{t}$AA | 14.06 (13.50)[4] | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | ns |
| ACTIVATE to internal READ or WRITE delay time | | | | | | $^{t}$RCD | 14.06 (13.50)[4] | – | 15.00 | – | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 14.06 (13.50)[4] | – | 15.00 | – | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 33 | 9 × $^{t}$REFI | 33 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin (ns): non-DBI** | **READ CL: non-DBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | – | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | 1.500 | 1.900[6] | Reserved | | ns |
| | – | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | 1.500[6] | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9 , 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | 1.250 | <1.500 | ns |
| 1866 | -107E | 13.92 | 13 | 15 | 10, 12 | $^{t}$CK (AVG) | 1.071 | <1.250 | Reserved | | ns |
| | -107 | 15.00 | 14 | 16 | | $^{t}$CK (AVG) | | | 1.071 | <1.250 | ns |
| 2133 | -093E | 14.06 | 15 | 18 | 11, 14 | $^{t}$CK (AVG) | 0.937 | <1.071 | Reserved | | ns |
| | -093 | 15.00 | 16 | 19 | | $^{t}$CK (AVG) | | | 0.937 | <1.071 | ns |
| Supported CL settings | | | | | | | 9, 10[6] , 11–16 | | 10, 12, 14, 16 | | *n*CK |
| Supported CL settings with read DBI | | | | | | | 11, 12[6] , 13–16, 18-19 | | 12, 14, 16, 19 | | *n*CK |
| Supported CWL settings | | | | | | | 9, 10, 11, 12, 14 | | 9, 10, 11, 12, 14 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

**Table 140: DDR4-2400 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-2400 Speed Bin | | | | | | | -083E | | -083 | | -083D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 16-16-16 | | 17-17-17 | | 18-18-18 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| Internal READ command to first data | | | | | | $^{t}$AA | 13.32 | 19.00[6] | 14.16 (13.75)[4] | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | ns |
| ACTIVATE to internal READ or WRITE delay time | | | | | | $^{t}$RCD | 13.32 | – | 14.16 (13.75)[4] | – | 15.00 | 19.00 | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 13.32 | – | 14.16 (13.75)[4] | – | 15.00 | 19.00 | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin (ns): non-DBI** | **READ CL: non-DBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | – | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | 1.500 | 1.900[6] | Reserved | | Reserved | | ns |
| | – | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | 1.500[6] | 1.900[6] | 1.500 | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9, 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | | | 1.250 | <1.500 | ns |
| 1866 | -107E | 13.92 | 13 | 15 | 10, 12 | $^{t}$CK (AVG) | 1.071 | <1.250 | 1.071 | <1.250 | Reserved | | ns |
| | -107 | 15.00 | 14 | 16 | | $^{t}$CK (AVG) | | | | | 1.071 | <1.250 | ns |
| 2133 | -093E | 14.06 | 15 | 18 | 11, 14 | $^{t}$CK (AVG) | 0.937 | <1.071 | 0.937 | <1.071 | Reserved | | ns |
| | -093 | 15.00 | 16 | 19 | | $^{t}$CK (AVG) | | | | | 0.937 | <1.071 | ns |
| 2400 | -083E | 13.32 | 16 | 19 | 12, 16 | $^{t}$CK (AVG) | 0.833 | <0.937 | Reserved | | Reserved | | ns |
| | -083 | 14.16 | 17 | 20 | | $^{t}$CK (AVG) | | | 0.833 | <0.937 | | | ns |
| | -083D | 15.00 | 18 | 21 | | $^{t}$CK (AVG) | | | | | 0.833 | <0.937 | ns |
| Supported CL settings | | | | | | | 9, 10[6] , 11–18 | | 10–18 | | 10, 12, 14, 16, 18 | | *n*CK |
| Supported CL settings with read DBI | | | | | | | 11, 12[6] , 13–16, 18–21 | | 12–16, 18–21 | | 12, 14, 16, 19, 21 | | *n*CK |
| Supported CWL settings | | | | | | | 9–12, 14, 16 | | 9-12, 14, 16 | | 9–12, 14, 16 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

**Table 141: DDR4-2666 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-2666 Speed Bin | | | | | | | -075E | | -075 | | -075D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 18-18-18 | | 19-19-19 | | 20-20-20 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| Internal READ command to first data | | | | | | $^{t}$AA | 13.50 | 19.00[6] | 14.25 (13.75)[4] | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | $^{t}$AA (MIN) + 3*n*CK | $^{t}$AA (MAX) + 3*n*CK | ns |
| ACTIVATE to internal READ or WRITE delay time | | | | | | $^{t}$RCD | 13.50 | – | 14.25 (13.75)[4] | – | 15.00 | – | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 13.50 | – | 14.25 (13.75)[4] | – | 15.00 | – | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin (ns): non-DBI** | **READ CL: non-DBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | - | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | 1.500 | 1.900[6] | Reserved | | Reserved | | ns |
| | - | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | | | 1.500 | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9, 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | | | 1.250 | <1.500 | ns |
| 1866 | -107E | 13.92 | 13 | 15 | 10, 12 | $^{t}$CK (AVG) | 1.071 | <1.250 | 1.071 | <1.250 | Reserved | | ns |
| | -107 | 15.00 | 14 | 16 | | $^{t}$CK (AVG) | | | | | 1.071 | <1.250 | ns |
| 2133 | -093E | 14.06 | 15 | 18 | 11, 14 | $^{t}$CK (AVG) | 0.937 | <1.071 | 0.937 | <1.071 | Reserved | | ns |
| | -093 | 15.00 | 16 | 19 | | $^{t}$CK (AVG) | | | | | 0.937 | <1.071 | ns |
| 2400 | -083E | 13.32 | 16 | 19 | 12, 16 | $^{t}$CK (AVG) | Reserved | | Reserved | | Reserved | | ns |
| | -083 | 14.16 | 17 | 20 | | $^{t}$CK (AVG) | 0.833 | <0.937 | 0.833 | <0.937 | | | ns |
| | -083D | 15.00 | 18 | 21 | | $^{t}$CK (AVG) | | | | | 0.833 | <0.937 | ns |
| 2666 | -075E | 13.50 | 18 | 21 | 14, 18 | $^{t}$CK (AVG) | 0.750 | <0.833 | Reserved | | Reserved | | ns |
| | -075 | 14.25 | 19 | 22 | | $^{t}$CK (AVG) | | | 0.750 | <0.833 | | | ns |
| | -075D | 15.00 | 20 | 23 | | $^{t}$CK (AVG) | | | | | 0.750 | <0.833 | ns |
| Supported CL settings | | | | | | | 9–20 | | 10-20 | | 10, 12, 14, 16, 18, 20 | | *n*CK |

**Table 141: DDR4-2666 Speed Bins and Operating Conditions (Continued)**

Notes 1–3 apply to the entire table

| DDR4-2666 Speed Bin | | -075E | | -075 | | -075D | | |
|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | 18-18-18 | | 19-19-19 | | 20-20-20 | | |
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| Supported CL settings with read DBI | | 11–16, 18–23 | | 12–16, 18–23 | | 12, 14, 16, 19, 21, 23 | | *n*CK |
| Supported CWL settings | | 9–12, 14, 16, 18 | | 9–12, 14, 16, 18 | | 9–12, 14, 16, 18 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

**Table 142: DDR4-2933 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-2933 Speed Bin | | | | | | | -068E | | -068 | | -068D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 20-20-20 | | 21-21-21 | | 22-22-22 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| Internal READ command to first data | | | | | | $^{t}$AA | 13.64 | 19.00[6] | 14.32 (13.75)[4] | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 4*n*CK | $^{t}$AA (MAX) + 4*n*CK | $^{t}$AA (MIN) + 4*n*CK | $^{t}$AA (MAX) + 4*n*CK | $^{t}$AA (MIN) + 4*n*CK | $^{t}$AA (MAX) + 4*n*CK | ns |
| ACTIVATE-to-internal READ or WRITE delay time | | | | | | $^{t}$RCD | 13.64 | – | 14.32 (13.75)[4] | – | 15.00 | – | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 13.64 | – | 14.32 (13.75)[4] | – | 15.00 | – | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin(ns): non-DBI** | **READ CL: non-DBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | – | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | Reserved | | Reserved | | Reserved | | ns |
| | – | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | 1.500 | 1.900[6] | 1.500 | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9, 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | | | 1.250 | <1.500 | ns |
| 1866 | -107E | 13.92 | 13 | 15 | 10, 12 | $^{t}$CK (AVG) | 1.071 | <1.250 | 1.071 | <1.250 | Reserved | | ns |
| | -107 | 15.00 | 14 | 16 | | $^{t}$CK (AVG) | | | | | 1.071 | <1.250 | ns |
| 2133 | -093E | 14.06 | 15 | 18 | 11, 14 | $^{t}$CK (AVG) | 0.937 | <1.071 | 0.937 | <1.071 | Reserved | | ns |
| | -093 | 15.00 | 16 | 19 | | $^{t}$CK (AVG) | | | | | 0.937 | <1.071 | ns |
| 2400 | -083E | 13.32 | 16 | 19 | 12, 16 | $^{t}$CK (AVG) | Reserved | | Reserved | | Reserved | | ns |
| | -083 | 14.16 | 17 | 20 | | $^{t}$CK (AVG) | 0.833 | <0.937 | 0.833 | <0.937 | | | ns |
| | 083D | 15.00 | 18 | 21 | | $^{t}$CK (AVG) | | | | | 0.833 | <0.937 | ns |
| 2666 | -075E | 13.50 | 18 | 21 | 14, 18 | $^{t}$CK (AVG) | Reserved | | Reserved | | Reserved | | ns |
| | -075 | 14.25 | 19 | 22 | | $^{t}$CK (AVG) | 0.750 | <0.833 | 0.750 | <0.833 | | | ns |
| | -075D | 15.00 | 20 | 23 | | $^{t}$CK (AVG) | | | | | 0.750 | <0.833 | ns |

**Table 142: DDR4-2933 Speed Bins and Operating Conditions (Continued)**

Notes 1–3 apply to the entire table

| DDR4-2933 Speed Bin | | | | | | | -068E | | -068 | | -068D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 20-20-20 | | 21-21-21 | | 22-22-22 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| 2933 | -068E | 13.64 | 20 | 24 | 16, 20 | $^{t}$CK (AVG) | 0.682 | <0.750 | Reserved | | Reserved | | ns |
| | -068 | 14.32 | 21 | 25 | | $^{t}$CK (AVG) | | | 0.682 | <0.750 | | | ns |
| | -068D | 15.00 | 22 | 26 | | $^{t}$CK (AVG) | | | | | 0.682 | <0.750 | ns |
| | – | 16.37 | 24 | 28 | | $^{t}$CK (AVG) | Reserved | | Reserved | | Reserved | | ns |
| Supported CL settings | | | | | | | 10–22 | | 10–22 | | 10, 12, 14, 16, 18, 20, 22 | | *n*CK |
| Supported CL settings with read DBI | | | | | | | 12–16, 18–26 | | 12–16,18–23, 25-26 | | 12, 14, 16, 19, 21, 23, 26 | | *n*CK |
| Supported CWL settings | | | | | | | 9–12, 14, 16, 18, 20 | | 9–12, 14, 16, 18, 20 | | 9–12, 14, 16, 18, 20 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

**Table 143: DDR4-3200 Speed Bins and Operating Conditions**

Notes 1–3 apply to the entire table

| DDR4-3200 Speed Bin | | | | | | | -062Y[6] | | -062E | | -062 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 22-22-22 | | 22-22-22 | | 24-24-24 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| Internal READ command to first data | | | | | | $^{t}$AA | 13.75 (13.32)[4] | 19.00[6] | 13.75 | 19.00[6] | 15.00 | 19.00[6] | ns |
| Internal READ command to first data with read DBI enabled | | | | | | $^{t}$AA_DBI | $^{t}$AA (MIN) + 4*n*CK | $^{t}$AA (MAX) + 4*n*CK | $^{t}$AA (MIN) + 4*n*CK | $^{t}$AA (MAX) + 4*n*CK | $^{t}$AA (MIN) + 4*n*CK | $^{t}$AA (MAX) + 4*n*CK | ns |
| ACTIVATE-to-internal READ or WRITE delay time | | | | | | $^{t}$RCD | 13.75 (13.32)[4] | – | 13.75 | – | 15.00 | – | ns |
| PRECHARGE command period | | | | | | $^{t}$RP | 13.75 (13.32)[4] | – | 13.75 | – | 15.00 | – | ns |
| ACTIVATE-to-PRECHARGE command period | | | | | | $^{t}$RAS | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | 32 | 9 × $^{t}$REFI | ns |
| ACTIVATE-to-ACTIVATE or REFRESH command period | | | | | | $^{t}$RC[5] | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | $^{t}$RAS + $^{t}$RP | – | ns |
| **Data Rate Max (MT/s)** | **Equivalent Speed Bin** | **$^{t}$AAmin (ns): non-DBI** | **READ CL: non-DBI** | **READ CL: DBI** | **WRITE CWL** | **Symbol** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Unit** |
| 1333 | - | 13.50 | 9 | 11 | 9 | $^{t}$CK (AVG) | 1.500 | 1.900[6] | Reserved | | Reserved | | ns |
| | - | 15.00 | 10 | 12 | | $^{t}$CK (AVG) | | | 1.500 | 1.900[6] | 1.500 | 1.900[6] | ns |
| 1600 | -125E | 13.75 | 11 | 13 | 9, 11 | $^{t}$CK (AVG) | 1.250 | <1.500 | 1.250 | <1.500 | Reserved | | ns |
| | -125 | 15.00 | 12 | 14 | | $^{t}$CK (AVG) | | | | | 1.250 | <1.500 | ns |
| 1866 | -107E | 13.92 | 13 | 15 | 10, 12 | $^{t}$CK (AVG) | 1.071 | <1.250 | 1.071 | <1.250 | Reserved | | ns |
| | -107 | 15.00 | 14 | 16 | | $^{t}$CK (AVG) | | | | | 1.071 | <1.250 | ns |
| 2133 | -093E | 14.06 | 15 | 18 | 11, 14 | $^{t}$CK (AVG) | 0.937 | <1.071 | 0.937 | <1.071 | Reserved | | ns |
| | -093 | 15.00 | 16 | 19 | | $^{t}$CK (AVG) | | | | | 0.937 | <1.071 | ns |
| 2400 | -083E | 13.32 | 16 | 19 | 12, 16 | $^{t}$CK (AVG) | 0.833 | <0.937 | Reserved | | Reserved | | ns |
| | -083 | 14.16 | 17 | 20 | | $^{t}$CK (AVG) | | | 0.833 | <0.937 | | | ns |
| | -083D | 15.00 | 18 | 21 | | $^{t}$CK (AVG) | | | | | 0.833 | <0.937 | ns |
| 2666 | -075E | 13.50 | 18 | 21 | 14, 18 | $^{t}$CK (AVG) | 0.750 | <0.833 | Reserved | | Reserved | | ns |
| | -075 | 14.25 | 19 | 22 | | $^{t}$CK (AVG) | | | 0.750 | <0.833 | | | ns |
| | -075D | 15.00 | 20 | 23 | | $^{t}$CK (AVG) | | | | | 0.750 | <0.833 | ns |

**Table 143: DDR4-3200 Speed Bins and Operating Conditions (Continued)**

Notes 1–3 apply to the entire table

| DDR4-3200 Speed Bin | | | | | | | -062Y[6] | | -062E | | -062 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CL-*n*RCD-*n*RP | | | | | | | 22-22-22 | | 22-22-22 | | 24-24-24 | | |
| Parameter | | | | | | Symbol | Min | Max | Min | Max | Min | Max | Unit |
| 2933 | -068E | 13.64 | 20 | 24 | 16, 20 | $^{t}$CK (AVG) | Reserved | | Reserved | | Reserved | | ns |
| | -068 | 14.32 | 21 | 25 | | $^{t}$CK (AVG) | 0.682 | <0.750 | 0.682 | <0.750 | | | ns |
| | -068D | 15.00 | 22 | 26 | | $^{t}$CK (AVG) | | | 0.682 | <0.750 | 0.682 | <0.750 | ns |
| | – | 16.37 | 24 | 28 | | $^{t}$CK (AVG) | | | | | 0.682 | <0.750 | ns |
| 3200 | -062E | 13.75 | 22 | 26 | 16, 20 | $^{t}$CK (AVG) | 0.625 | <0.682 | 0.625 | <0.682 | Reserved | | ns |
| | -062 | 15.00 | 24 | 28 | | $^{t}$CK (AVG) | | | | | 0.625 | <0.682 | ns |
| Supported CL settings | | | | | | | 9–22, 24 | | 10–22, 24 | | 10, 12, 14, 16, 18, 20, 22, 24 | | *n*CK |
| Supported CL settings with read DBI | | | | | | | 11–16, 18–23, 25-26, 28 | | 12–16, 18–23, 25-26, 28 | | 12, 14, 16, 19, 21, 23, 26, 28 | | *n*CK |
| Supported CWL settings | | | | | | | 9–12, 14, 16, 18, 20 | | 9–12, 14, 16, 18, 20 | | 9–12, 14, 16, 18, 20 | | *n*CK |

Notes:
1. Speed Bin table is only valid with DLL enabled.
2. When operating in 2$^{t}$CK WRITE preamble mode, CWL must be programmed to a value at least 1 clock greater than the lowest CWL setting supported in the applicable $^{t}$CK range.
3. The programmed value of CWL must be less than or equal to the programmed value of CL.
4. This value applies to non-native $^{t}$CK-CL-*n*RCD-*n*RP combinations.
5. When calculating $^{t}$RC in clocks, values may not be used in a combination that violate $^{t}$RAS or $^{t}$RP.
6. This value exceeds the JEDEC requirement in order to allow additional flexibility, especially for components. However, JEDEC SPD compliance may force modules to only support the JEDEC defined value, please refer to the SPD documentation.

## Refresh Parameters By Device Density

**Table 144: Refresh Parameters by Device Density**

| Parameter | Symbol | | 2Gb | 4Gb | 8Gb | 16Gb | Unit | Notes |
|---|---|---|---|---|---|---|---|---|
| REF command to ACT or REF command time | $^{t}$RFC (All bank groups) | | 160 | 260 | 350 | 350 | ns | |
| Average periodic refresh interval | $^{t}$REFI | -40°C ≤ $T_C$ ≤ 85°C | 7.8 | 7.8 | 7.8 | 7.8 | µs | |
| | | 85°C < $T_C$ ≤ 95°C | 3.9 | 3.9 | 3.9 | 3.9 | µs | 1 |

Note:
1. Users should refer to the DRAM supplier data sheet and/or the DIMM SPD to determine if the devices support these options or requirements.

## Electrical Characteristics and AC Timing Parameters

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400**

| Parameter | | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| **Clock Timing** | | | | | | | | | | | | |
| Clock period average (DLL off mode) | | $^{t}$CK (DLL_OFF) | 8 | 20 | 8 | 20 | 8 | 20 | 8 | 20 | ns | |
| Clock period average | | $^{t}$CK (AVG, DLL_ON) | 1.25 | 1.9 | 1.071 | 1.9 | 0.937 | 1.9 | 0.833 | 1.9 | ns | (page 0 ), 13 |
| High pulse width average | | $^{t}$CH (AVG) | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | $^{t}$CK (AVG) | |
| Low pulse width average | | $^{t}$CL (AVG) | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | $^{t}$CK (AVG) | |
| Clock period jitter | Total | $^{t}$JITper_tot | –63 | 63 | –54 | 54 | –47 | 47 | –42 | 42 | ps | 17 , 18 |
| | Deterministic | $^{t}$JITper_dj | –31 | 31 | –27 | 27 | –23 | 23 | –21 | 21 | ps | 17 |
| | DLL locking | $^{t}$JITper,lck | –50 | 50 | –43 | 43 | –38 | 38 | -33 | 33 | ps | |
| Clock absolute period | | $^{t}$CK (ABS) | MIN = $^{t}$CK (AVG) MIN + $^{t}$JITper_tot MIN; MAX = $^{t}$CK (AVG) MAX + $^{t}$JITper_tot MAX | | | | | | | | ps | |
| Clock absolute high pulse width (includes duty cycle jitter) | | $^{t}$CH (ABS) | 0.45 | – | 0.45 | – | 0.45 | – | 0.45 | – | $^{t}$CK (AVG) | |
| Clock absolute low pulse width (includes duty cycle jitter) | | $^{t}$CL (ABS) | 0.45 | – | 0.45 | – | 0.45 | – | 0.45 | – | $^{t}$CK (AVG) | |
| Cycle-to-cycle jitter | Total | $^{t}$JITcc _tot | – | 125 | – | 107 | – | 94 | – | 83 | ps | |
| | DLL locking | $^{t}$JITcc,lck | – | 100 | – | 86 | – | 75 | – | 67 | ps | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Cumulative error across | 2 cycles | $^{t}$ERR2per | –92 | 92 | –79 | 79 | –69 | 69 | –61 | 61 | ps | |
| | 3 cycles | $^{t}$ERR3per | –109 | 109 | –94 | 94 | –82 | 82 | –73 | 73 | ps | |
| | 4 cycles | $^{t}$ERR4per | –121 | 121 | –104 | 104 | –91 | 91 | –81 | 81 | ps | |
| | 5 cycles | $^{t}$ERR5per | –131 | 131 | –112 | 112 | –98 | 98 | –87 | 87 | ps | |
| | 6 cycles | $^{t}$ERR6per | –139 | 139 | –119 | 119 | –104 | 104 | –92 | 92 | ps | |
| | 7 cycles | $^{t}$ERR7per | –145 | 145 | –124 | 124 | –109 | 109 | –97 | 97 | ps | |
| | 8 cycles | $^{t}$ERR8per | –151 | 151 | –129 | 129 | –113 | 113 | –101 | 101 | ps | |
| | 9 cycles | $^{t}$ERR9per | –156 | 156 | –134 | 134 | –117 | 117 | –104 | 104 | ps | |
| | 10 cycles | $^{t}$ERR10per | –160 | 160 | –137 | 137 | –120 | 120 | –107 | 107 | ps | |
| | 11 cycles | $^{t}$ERR11per | –164 | 164 | –141 | 141 | –123 | 123 | –110 | 110 | ps | |
| | 12 cycles | $^{t}$ERR12per | –168 | 168 | –144 | 144 | –126 | 126 | –112 | 112 | ps | |
| | *n* = 13, 14 . . . 49, 50 cycles | $^{t}$ERR*n*per | $^{t}$ERR*n*per MIN = (1 + 0.68ln[*n*]) × $^{t}$JITper_tot MIN<br>$^{t}$ERR*n*per MAX = (1 + 0.68ln[*n*]) × $^{t}$JITper_tot MAX | | | | | | | | ps | |
| **DQ Input Timing** | | | | | | | | | | | | |
| Data setup time to DQS_t, DQS_c | Base (calibrated $V_{REF}$) | $^{t}$DS | Refer to DQ Input Receiver Specification section (approximately 0.15$^{t}$CK to 0.28$^{t}$CK ) | | | | | | | | – | |
| | Noncalibrated $V_{REF}$ | $^{t}$PDA_S | minimum of 0.5UI | | | | | | | | UI | 22 |
| Data hold time from DQS_t, DQS_c | Base (calibrated $V_{REF}$) | $^{t}$DH | Refer to DQ Input Receiver Specification section (approximately 0.15$^{t}$CK to 0.28$^{t}$CK ) | | | | | | | | – | |
| | Noncalibrated $V_{REF}$ | $^{t}$PDA_H | minimum of 0.5UI | | | | | | | | UI | 22 |
| DQ and DM minimum data pulse width for each input | | $^{t}$DIPW | 0.58 | – | 0.58 | – | 0.58 | – | 0.58 | – | UI | |
| **DQ Output Timing (DLL enabled)** | | | | | | | | | | | | |
| DQS_t, DQS_c to DQ skew, per group, per access | | $^{t}$DQSQ | – | 0.16 | – | 0.16 | – | 0.16 | – | 0.17 | UI | |
| DQ output hold time from DQS_t, DQS_c | | $^{t}$QH | 0.76 | – | 0.76 | – | 0.76 | – | 0.74 | – | UI | |
| Data Valid Window per device: $^{t}$QH - $^{t}$DQSQ each device's output per UI | | $^{t}$DVW$_d$ | 0.63 | | 0.63 | | 0.64 | | 0.64 | | UI | |
| Data Valid Window per device, per pin: $^{t}$QH - $^{t}$DQSQ each device's output per UI | | $^{t}$DVW$_p$ | 0.66 | – | 0.66 | – | 0.69 | – | 0.72 | – | UI | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| DQ Low-Z time from CK_t, CK_c | $^{t}$LZDQ | –450 | 225 | –390 | 195 | –360 | 180 | –330 | 175 | ps | |
| DQ High-Z time from CK_t, CK_c | $^{t}$HZDQ | – | 225 | – | 195 | – | 180 | – | 175 | ps | |
| **DQ Strobe Input Timing** | | | | | | | | | | | |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge for 1$^{t}$CKpreamble | $^{t}DQSS_{1ck}$ | –0.27 | 0.27 | –0.27 | 0.27 | –0.27 | 0.27 | –0.27 | 0.27 | CK | |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge for 2$^{t}$CKpreamble | $^{t}DQSS_{2ck}$ | –0.50 | 0.50 | –0.50 | 0.50 | –0.50 | 0.50 | –0.50 | 0.50 | CK | |
| DQS_t, DQS_c differential input low pulse width | $^{t}$DQSL | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | CK | |
| DQS_t, DQS_c differential input high pulse width | $^{t}$DQSH | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | CK | |
| DQS_t, DQS_c falling edge setup to CK_t, CK_c rising edge | $^{t}$DSS | 0.18 | – | 0.18 | – | 0.18 | – | 0.18 | – | CK | |
| DQS_t, DQS_c falling edge hold from CK_t, CK_c rising edge | $^{t}$DSH | 0.18 | – | 0.18 | – | 0.18 | – | 0.18 | – | CK | |
| DQS_t, DQS_c differential WRITE preamble for 1$^{t}$CKpreamble | $^{t}WPRE_{1ck}$ | 0.9 | – | 0.9 | – | 0.9 | – | 0.9 | – | CK | |
| DQS_t, DQS_c differential WRITE preamble for 2$^{t}$CKpreamble | $^{t}WPRE_{2ck}$ | 1.8 | – | 1.8 | – | 1.8 | – | 1.8 | – | CK | |
| DQS_t, DQS_c differential WRITE postamble | $^{t}$WPST | 0.33 | – | 0.33 | – | 0.33 | – | 0.33 | – | CK | |
| **DQS Strobe Output Timing (DLL enabled)** | | | | | | | | | | | |
| DQS_t, DQS_c rising edge output access time from rising CK_t, CK_c | $^{t}$DQSCK | –225 | 225 | –195 | 195 | –180 | 180 | –175 | 175 | ps | |
| DQS_t, DQS_c rising edge output variance window per DRAM | $^{t}$DQSCKi | – | 370 | – | 330 | – | 310 | – | 290 | ps | |
| DQS_t, DQS_c differential output high time | $^{t}$QSH | 0.4 | – | 0.4 | – | 0.4 | – | 0.4 | – | CK | |
| DQS_t, DQS_c differential output low time | $^{t}$QSL | 0.4 | – | 0.4 | – | 0.4 | – | 0.4 | – | CK | |
| DQS_t, DQS_c Low-Z time (RL - 1) | $^{t}$LZDQS | –450 | 225 | –390 | 195 | –360 | 180 | –330 | 175 | ps | |
| DQS_t, DQS_c High-Z time (RL + BL/2) | $^{t}$HZDQS | – | 225 | – | 195 | – | 180 | – | 175 | ps | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| DQS_t, DQS_c differential READ preamble for 1tCKpreamble | | $^{t}RPRE_{1ck}$ | 0.9 | – | 0.9 | – | 0.9 | – | 0.9 | – | CK | 20 |
| DQS_t, DQS_c differential READ preamble for 2tCK preamble | | $^{t}RPRE_{2ck}$ | 1.8 | – | 1.8 | – | 1.8 | – | 1.8 | – | CK | 20 |
| DQS_t, DQS_c differential READ postamble | | $^{t}RPST$ | 0.33 | – | 0.33 | – | 0.33 | – | 0.33 | – | CK | 21 |
| **Command and Address Timing** | | | | | | | | | | | | |
| DLL locking time | | $^{t}DLLK$ | 597 | – | 597 | – | 768 | – | 768 | – | CK | 2, 4 |
| CMD, ADDR setup time to CK_t, CK_c Base referenced to $V_{IH(AC)}$ and $V_{IL(AC)}$ levels | Base | $^{t}IS$ | 115 | – | 100 | – | 80 | – | 62 | – | ps | |
| | $V_{REFCA}$ | $^{t}IS_{VREF}$ | 215 | – | 200 | – | 180 | – | 162 | – | ps | |
| CMD, ADDR hold time to CK_t, CK_c Base referenced to $V_{IH(DC)}$ and $V_{IL(DC)}$ levels | Base | $^{t}IH$ | 140 | – | 125 | – | 105 | – | 87 | – | ps | |
| | $V_{REFCA}$ | $^{t}IH_{VREF}$ | 215 | – | 200 | – | 180 | – | 162 | – | ps | |
| CTRL, ADDR pulse width for each input | | $^{t}IPW$ | 600 | – | 525 | – | 460 | – | 410 | – | ps | |
| ACTIVATE to internal READ or WRITE delay | | $^{t}RCD$ | See Speed Bin Tables for $^{t}RCD$ | | | | | | | | ns | |
| PRECHARGE command period | | $^{t}RP$ | See Speed Bin Tables for $^{t}RP$ | | | | | | | | ns | |
| ACTIVATE-to-PRECHARGE command period | | $^{t}RAS$ | See Speed Bin Tables for $^{t}RAS$ | | | | | | | | ns | 12 |
| ACTIVATE-to-ACTIVATE or REF command period | | $^{t}RC$ | See Speed Bin Tables for $^{t}RC$ | | | | | | | | ns | 12 |
| ACTIVATE-to-ACTIVATE command period to different bank groups for 1/2KB page size | | $^{t}RRD\_S$ (1/2KB) | MIN = greater of 4CK or 5ns | | MIN = greater of 4CK or 4.2ns | | MIN = greater of 4CK or 3.7ns | | MIN = greater of 4CK or 3.3ns | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to different bank groups for 1KB page size | | $^{t}RRD\_S$ (1KB) | MIN = greater of 4CK or 5ns | | MIN = greater of 4CK or 4.2ns | | MIN = greater of 4CK or 3.7ns | | MIN = greater of 4CK or 3.3ns | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to different bank groups for 2KB page size | | $^{t}RRD\_S$ (2KB) | MIN = greater of 4CK or 6ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 5.3ns | | CK | 1 |

**Table 145 Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| ACTIVATE-to-ACTIVATE command period to same bank groups for 1/2KB page size | $^{t}$RRD_L (1/2KB) | MIN = greater of 4CK or 6ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 4.9ns | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to same bank groups for 1KB page size | $^{t}$RRD_L (1KB) | MIN = greater of 4CK or 6ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 4.9ns | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to same bank groups for 2KB page size | $^{t}$RRD_L (2KB) | MIN = greater of 4CK or 7.5ns | | MIN = greater of 4CK or 6.4ns | | MIN = greater of 4CK or 6.4ns | | MIN = greater of 4CK or 6.4ns | | CK | 1 |
| Four ACTIVATE windows for 1/2KB page size | $^{t}$FAW (1/2KB) | MIN = greater of 16CK or 20ns | | MIN = greater of 16CK or 17ns | | MIN = greater of 16CK or 15ns | | MIN = greater of 16CK or 13ns | | ns | |
| Four ACTIVATE windows for 1KB page size | $^{t}$FAW (1KB) | MIN = greater of 20CK or 25ns | | MIN = greater of 20CK or 23ns | | MIN = greater of 20CK or 21ns | | MIN = greater of 20CK or 21ns | | ns | |
| Four ACTIVATE windows for 2KB page size | $^{t}$FAW (2KB) | MIN = greater of 28CK or 35ns | | MIN = greater of 28CK or 30ns | | MIN = greater of 28CK or 30ns | | MIN = greater of 28CK or 30ns | | ns | |
| WRITE recovery time | $^{t}$WR | MIN = 15ns | | | | | | | | ns | 5, 9, 1 |
| | $^{t}$WR$_2$ | MIN = 1CK + $^{t}$WR | | | | | | | | CK | 5, 10, 1 |
| WRITE recovery time when CRC and DM are both enabled | $^{t}$WR_CRC_DM | MIN = $^{t}$WR + greater of (4CK or 3.75ns) | | MIN = $^{t}$WR + greater of (5CK or 3.75ns) | | | | | | CK | 6, 9, 1 |
| | $^{t}$WR_CRC_DM$_2$ | MIN = 1CK + $^{t}$WR_CRC_DM | | | | | | | | CK | 6, 10, 1 |
| Delay from start of internal WRITE t ransaction to internal READ command – Same bank group | $^{t}$WTR_L | MIN = greater of 4CK or 7.5ns | | | | | | | | CK | 5, 9, 1 |
| | $^{t}$WTR_L$_2$ | MIN = 1CK + $^{t}$WTR_L | | | | | | | | CK | 5, 10, 1 |
| Delay from start of internal WRITE transaction to internal READ command – Same bank group when CRC and DM are both enabled | $^{t}$WTR_L_CRC_DM | MIN = $^{t}$WTR_L + greater of (4CK or 3.75ns) | | MIN = $^{t}$WTR_L + greater of (5CK or 3.75ns) | | | | | | CK | 6, 9, 1 |
| | $^{t}$WTR_L_CRC_DM$_2$ | MIN = 1CK + $^{t}$WTR_L_CRC_DM | | | | | | | | CK | 6, 10, 1 |
| Delay from start of internal WRITE transaction to internal READ command – Different bank group | $^{t}$WTR_S | MIN = greater of (2CK or 2.5ns) | | | | | | | | CK | 5, 7, 8, 9, 1 |
| | $^{t}$WTR_S$_2$ | MIN = 1CK + $^{t}$WTR_S | | | | | | | | CK | 5, 7, 8, 10, 1 |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Delay from start of internal WRITE transaction to internal READ command – Different bank group when CRC and DM are both enabled | $^{t}$WTR_S_CRC_DM | MIN = $^{t}$WTR_S + greater of (4CK or 3.75ns) | | MIN = $^{t}$WTR_S + greater of (5CK or 3.75ns) | | | | | | CK | 6, 7, 8, 9, 1 |
| | $^{t}$WTR_S_CRC_DM$_2$ | MIN = 1CK + $^{t}$WTR_S_CRC_DM | | | | | | | | CK | 6, 7, 8, 10, 1 |
| READ-to-PRECHARGE time | $^{t}$RTP | MIN = greater of 4CK or 7.5ns | | | | | | | | CK | 1 |
| CAS_n-to-CAS_n command delay to different bank group | $^{t}$CCD_S | 4 | – | 4 | – | 4 | – | 4 | – | CK | |
| CAS_n-to-CAS_n command delay to same bank group | $^{t}$CCD_L | MIN = greater of 4CK or 6.25ns | – | MIN = greater of 4CK or 5.355ns | – | MIN = greater of 4CK or 5.355ns | – | MIN = greater of 4CK or 5ns | – | CK | 14 |
| Auto precharge write recovery + pre-charge time | $^{t}$DAL (MIN) | MIN = WR + ROUND$^{t}$RP/$^{t}$CK (AVG); MAX = N/A | | | | | | | | CK | 8 |
| **MRS Command Timing** | | | | | | | | | | | |
| MRS command cycle time | $^{t}$MRD | 8 | – | 8 | – | 8 | – | 8 | – | CK | |
| MRS command cycle time in PDA mode | $^{t}$MRD_PDA | MIN = greater of (16nCK, 10ns) | | | | | | | | CK | 1 |
| MRS command cycle time in CAL mode | $^{t}$MRD_CAL | MIN = $^{t}$MOD + $^{t}$CAL | | | | | | | | CK | |
| MRS command update delay | $^{t}$MOD | MIN = greater of (24nCK, 15ns) | | | | | | | | CK | 1 |
| MRS command update delay in PDA mode | $^{t}$MOD_PDA | MIN = $^{t}$MOD | | | | | | | | CK | |
| MRS command update delay in CAL mode | $^{t}$MOD_CAL | MIN = $^{t}$MOD + $^{t}$CAL | | | | | | | | CK | |
| MRS command to DQS drive in preamble training | $^{t}$SDO | MIN = $^{t}$MOD + 9ns | | | | | | | | | |
| **MPR Command Timing** | | | | | | | | | | | |
| Multipurpose register recovery time | $^{t}$MPRR | MIN = 1CK | | | | | | | | CK | |
| Multipurpose register write recovery time | $^{t}$WR_MPR | MIN = $^{t}$MOD + AL + PL | | | | | | | | | |
| **CRC Error Reporting Timing** | | | | | | | | | | | |
| CRC error to ALERT_n latency | $^{t}$CRC_ALERT | 3 | 13 | 3 | 13 | 3 | 13 | 3 | 13 | ns | |
| CRC ALERT_n pulse width | $^{t}$CRC_ALERT_PW | 6 | 10 | 6 | 10 | 6 | 10 | 6 | 10 | CK | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| **CA Parity Timing** | | | | | | | | | | | |
| Parity latency | PL | 4 | – | 4 | – | 4 | – | 5 | – | CK | |
| Commands uncertain to be executed during this time | tPAR_UNKNOWN | – | PL | – | PL | – | PL | – | PL | CK | |
| Delay from errant command to ALERT_n assertion | tPAR_ALERT_ON | – | PL + 6ns | – | P L + 6ns | – | PL + 6ns | – | PL + 6ns | CK | |
| Pulse width of ALERT_n signal when asserted | tPAR_ALERT_PW | 48 | 96 | 56 | 112 | 64 | 128 | 72 | 144 | CK | |
| Time from alert asserted until DES commands required in persistent CA parity mode | tPAR_ALERT_RSP | – | 43 | – | 50 | – | 57 | – | 64 | CK | |
| **CAL Timing** | | | | | | | | | | | |
| CS_n to command address latency | tCAL | 3 | – | 4 | – | 4 | – | 5 | – | CK | 19 |
| CS_n to command address latency in gear-down mode | tCALg | N/A | – | N/A | – | N/A | – | N/A | – | CK | |
| **MPSM Timing** | | | | | | | | | | | |
| Command path disable delay upon MPSM entry | tMPED | MIN = tMOD (MIN) + tCPDED (MIN) | | | | | | | | CK | 1 |
| Valid clock requirement after MPSM entry | tCKMPE | MIN = tMOD (MIN) + tCPDED (MIN) | | | | | | | | CK | 1 |
| Valid clock requirement before MPSM exit | tCKMPX | MIN = tCKSRX (MIN) | | | | | | | | CK | 1 |
| Exit MPSM to commands not requiring a locked DLL | tXMP | tXS (MIN) | | | | | | | | CK | |
| Exit MPSM to commands requiring a locked DLL | tXMPDLL | MIN = tXMP (MIN) + tXSDLL (MIN) | | | | | | | | CK | 1 |
| CS setup time to CKE | tMPX_S | MIN = tIS (MIN) + tIH (MIN) | | | | | | | | ns | |
| CS_n HIGH hold time to CKE rising edge | tMPX_HH | MIN = tXP | | | | | | | | ns | |
| CS_n LOW hold time to CKE rising edge | tMPX_LH | 12 | tXMP-10ns | 12 | tXMP-10ns | 12 | tXMP-10ns | 12 | tXMP-10ns | ns | |
| **Connectivity Test Timing** | | | | | | | | | | | |
| TEN pin HIGH to CS_n LOW – Enter CT mode | tCT_Enable | 200 | – | 200 | – | 200 | – | 200 | – | ns | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| CS_n LOW and valid input to valid output | | tCT_Valid | – | 200 | – | 200 | – | 200 | – | 200 | ns | |
| CK_t, CK_c valid and CKE HIGH after TEN goes HIGH | | tCTCKE_Valid | 10 | – | 10 | – | 10 | – | 10 | – | ns | |
| **Calibration and $V_{REFDQ}$ Train Timing** | | | | | | | | | | | | |
| ZQCL command: Long calibration time | POWER-UP and RESET operation | tZQinit | 1024 | – | 1024 | – | 1024 | – | 1024 | – | CK | |
| | Normal operation | tZQoper | 512 | – | 512 | – | 512 | – | 512 | – | CK | |
| ZQCS command: Short calibration time | | tZQCS | 128 | – | 128 | – | 128 | – | 128 | – | CK | |
| The $V_{REF}$ increment/decrement step time | | $V_{REF\_time}$ | MIN = 150ns | | | | | | | | | |
| Enter $V_{REFDQ}$ training mode to the first write or $V_{REFDQ}$ MRS command delay | | tVREFDQE | MIN = 150ns | | | | | | | | ns | 1 |
| Exit $V_{REFDQ}$ training mode to the first WRITE command delay | | tVREFDQX | MIN = 150ns | | | | | | | | ns | 1 |
| **Initialization and Reset Timing** | | | | | | | | | | | | |
| Exit reset from CKE HIGH to a valid command | | tXPR | MIN = greater of 5CK or tRFC (MIN) + 10ns | | | | | | | | CK | 1 |
| RESET_L pulse low after power stable | | tPW_RESET_S | 1.0 | – | 1.0 | – | 1.0 | – | 1.0 | – | µs | |
| RESET_L pulse low at power-up | | tPW_RESET_L | 200 | – | 200 | – | 200 | – | 200 | – | µs | |
| Begin power supply ramp to power supplies stable | | tVDDPR | MIN = N/A; MAX = 200 | | | | | | | | ms | |
| RESET_n LOW to power supplies stable | | tRPS | MIN = 0; MAX = 0 | | | | | | | | ns | |
| **Refresh Timing** | | | | | | | | | | | | |
| REFRESH-to-ACTIVATE or REFRESH command period (all bank groups) | 4Gb | tRFC1 | MIN = 260 | | | | | | | | ns | 1, 11 |
| | | tRFC2 | MIN = 160 | | | | | | | | ns | 1, 11 |
| | | tRFC4 | MIN = 110 | | | | | | | | ns | 1, 11 |
| | 8Gb | tRFC1 | MIN = 350 | | | | | | | | ns | 1, 11 |
| | | tRFC2 | MIN = 260 | | | | | | | | ns | 1, 11 |
| | | tRFC4 | MIN = 160 | | | | | | | | ns | 1, 11 |
| | 16Gb | tRFC1 | MIN = 350 | | | | | | | | ns | 1, 11 |
| | | tRFC2 | MIN = 260 | | | | | | | | ns | 1, 11 |
| | | tRFC4 | MIN = 160 | | | | | | | | ns | 1, 11 |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Average periodic re-fresh interval | -40°C ≤ $T_C$ ≤ 85°C | $^t$REFI | MIN = N/A; MAX = 7.8 | | | | | | | | µs | 11 |
| | 85°C < $T_C$ ≤ 95°C | $^t$REFI | MIN = N/A; MAX = 3.9 | | | | | | | | µs | 11 |
| **Self Refresh Timing** | | | | | | | | | | | | |
| Exit self refresh to commands not requiring a locked DLL | | $^t$XS | MIN = $^t$RFC + 10ns | | | | | | | | ns | 1 |
| Exit self refresh to commands not requiring a locked DLL in self refresh abort | | $^t$XS_ABORT | MIN = $^t$RFC4 + 10ns | | | | | | | | ns | 1 |
| Exit self refresh to ZQCL, ZQCS and MRS (CL, CWL, WR, RTP and gear-down) | | $^t$XS_FAST | MIN = $^t$RFC4 + 10ns | | | | | | | | ns | 1 |
| Exit self refresh to commands requiring a locked DLL | | $^t$XSDLL | MIN = $^t$DLLK (MIN) | | | | | | | | CK | 1 |
| Minimum CKE low pulse width for self refresh entry to self refresh exit timing | | $^t$CKESR | MIN = $^t$CKE (MIN) + 1*n*CK | | | | | | | | CK | 1 |
| Minimum CKE low pulse width for self refresh entry to self refresh exit timing when CA parity is enabled | | $^t$CKESR_PAR | MIN = $^t$CKE (MIN) + 1*n*CK + PL | | | | | | | | CK | 1 |
| Valid clocks after self refresh entry (SRE) or power-down entry (PDE) | | $^t$CKSRE | MIN = greater of (5CK, 10ns) | | | | | | | | CK | 1 |
| Valid clock requirement after self refresh entry or power-down when CA parity is enabled | | $^t$CKSRE_PAR | MIN = greater of (5CK, 10ns) + PL | | | | | | | | CK | 1 |
| Valid clocks before self refresh exit (SRX) or power-down exit (PDX), or reset exit | | $^t$CKSRX | MIN = greater of (5CK, 10ns) | | | | | | | | CK | 1 |
| **Power-Down Timing** | | | | | | | | | | | | |
| Exit power-down with DLL on to any valid command | | $^t$XP | MIN = greater of 4CK or 6ns | | | | | | | | CK | 1 |
| Exit power-down with DLL on to any valid command when CA Parity is enabled. | | $^t$XP _PAR | MIN = (greater of 4CK or 6ns) + PL | | | | | | | | CK | 1 |
| CKE MIN pulse width | | $^t$CKE (MIN) | MIN = greater of 3CK or 5ns | | | | | | | | CK | 1 |
| Command pass disable delay | | $^t$CPDED | 4 | – | 4 | – | 4 | – | 4 | – | CK | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Power-down entry to power-down exit timing | tPD | MIN = tCKE (MIN); MAX = 9 × tREFI | | | | | | | | CK | |
| Begin power-down period prior to CKE registered HIGH | tANPD | WL - 1CK | | | | | | | | CK | |
| Power-down entry period: ODT either synchronous or asynchronous | PDE | Greater of tANPD or tRFC - REFRESH command to CKE LOW time | | | | | | | | CK | |
| Power-down exit period: ODT either synchronous or asynchronous | PDX | tANPD + tXSDLL | | | | | | | | CK | |
| **Power-Down Entry Minimum Timing** | | | | | | | | | | | |
| ACTIVATE command to power-down entry | tACTPDEN | 1 | – | 1 | – | 2 | – | 2 | – | CK | |
| PRECHARGE/PRECHARGE ALL command to power-down entry | tPRPDEN | 1 | – | 1 | – | 2 | – | 2 | – | CK | |
| REFRESH command to power-down entry | tREFPDEN | 1 | – | 1 | – | 2 | – | 2 | – | CK | |
| MRS command to power-down entry | tMRSPDEN | MIN = tMOD (MIN) | | | | | | | | CK | 1 |
| READ/READ with auto precharge command to power-down entry | tRDPDEN | MIN = RL + 4 + 1 | | | | | | | | CK | 1 |
| WRITE command to power-down entry (BL8OTF, BL8MRS, BC4OTF) | tWRPDEN | MIN = WL + 4 + tWR/tCK (AVG) | | | | | | | | CK | 1 |
| WRITE command to power-down entry (BC4MRS) | tWRPBC4DEN | MIN = WL + 2 + tWR/tCK (AVG) | | | | | | | | CK | 1 |
| WRITE with auto precharge command to power-down entry (BL8OTF, BL8MRS,BC4OTF) | tWRAPDEN | MIN = WL + 4 + WR + 1 | | | | | | | | CK | 1 |
| WRITE with auto precharge command to power-down entry (BC4MRS) | tWRAPBC4DEN | MIN = WL + 2 + WR + 1 | | | | | | | | CK | 1 |
| **ODT Timing** | | | | | | | | | | | |
| Direct ODT turn-on latency | DODTLon | WL - 2 = CWL + AL + PL - 2 | | | | | | | | CK | |
| Direct ODT turn-off latency | DODTLoff | WL - 2 = CWL + AL + PL - 2 | | | | | | | | CK | |
| $R_{TT}$ dynamic change skew | tADC | 0.3 | 0.7 | 0.3 | 0.7 | 0.3 | 0.7 | 0.3 | 0.7 | CK | |
| Asynchronous $R_{TT(NOM)}$ turn-on delay (DLL off) | tAONAS | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | ns | |

**Table 145: Electrical Characteristics and AC Timing Parameters: DDR4-1600 through DDR4-2400 (Continued)**

| Parameter | Symbol | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Asynchronous $R_{TT(NOM)}$ turn-off delay (DLL off) | $^{t}$AOFAS | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | ns | |
| ODT HIGH time with WRITE command and BL8 | ODTH8 1$^{t}$CK | 6 | – | 6 | – | 6 | – | 6 | – | CK | |
| | ODTH8 2$^{t}$CK | 7 | – | 7 | – | 7 | – | 7 | – | | |
| ODT HIGH time without WRITE command or with WRITE command and BC4 | ODTH4 1$^{t}$CK | 4 | – | 4 | – | 4 | – | 4 | – | CK | |
| | ODTH4 2$^{t}$CK | 5 | – | 5 | – | 5 | – | 5 | – | | |
| **Write Leveling Timing** | | | | | | | | | | | |
| First DQS_t, DQS_c rising edge after write leveling mode is programmed | $^{t}$WLMRD | 40 | – | 40 | – | 40 | – | 40 | – | CK | |
| DQS_t, DQS_c delay after write leveling mode is programmed | $^{t}$WLDQSEN | 25 | – | 25 | – | 25 | – | 25 | – | CK | |
| Write leveling setup from rising CK_t, CK_c crossing to rising DQS_t, DQS_c crossing | $^{t}$WLS | 0.13 | – | 0.13 | – | 0.13 | – | 0.13 | – | $^{t}$CK (AVG) | |
| Write leveling hold from rising DQS_t, DQS_c crossing to rising CK_t, CK_c crossing | $^{t}$WLH | 0.13 | – | 0.13 | – | 0.13 | – | 0.13 | – | $^{t}$CK (AVG) | |
| Write leveling output delay | $^{t}$WLO | 0 | 9.5 | 0 | 9.5 | 0 | 9.5 | 0 | 9.5 | ns | |
| Write leveling output error | $^{t}$WLOE | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | ns | |
| **Gear-Down Timing (Not Supported Below DDR4-2666)** | | | | | | | | | | | |
| Exit reset from CKE HIGH to a valid MRS gear-down | $^{t}$XPR_GEAR | N/A | | N/A | | N/A | | N/A | | CK | |
| CKE HIGH assert to gear-down enable time) | $^{t}$XS_GEAR | N/A | | N/A | | N/A | | N/A | | CK | |
| MRS command to sync pulse time | $^{t}$SYNC_GEAR | N/A | | N/A | | N/A | | N/A | | CK | |
| Sync pulse to first valid command | $^{t}$CMD_GEAR | N/A | | N/A | | N/A | | N/A | | CK | |
| Gear-down setup time | $^{t}$GEAR_setup | N/A | – | N/A | – | N/A | – | N/A | – | CK | |
| Gear-down hold time | $^{t}$GEAR_hold | N/A | – | N/A | – | N/A | – | N/A | – | CK | |

Notes:
1. Maximum limit not applicable.
2. Alliance tDLLK values support the legacy JEDEC tDLLK specifications.
3. DDR4-1600 AC timing parameters apply if DRAM operates at lower than 1600 MT/s data rate.
4. Data rate is greater than or equal to 1066 Mb/s.
5. WRITE-to-READ when CRC and DM are both not enabled.
6. WRITE-to-READ delay when CRC and DM are both enabled.
7. The start of internal write transactions is defined as follows:
   - For BL8 (fixed by MRS and on-the-fly): rising clock edge four clock cycles after WL
   - For BC4 (on-the-fly): rising clock edge four clock cycles after WL
   - For BC4 (fixed by MRS): rising clock edge two clock cycles after WL
8. For these parameters, the device supports $^{t}n$PARAM [$n$CK] = ROUND{$^{t}$PARAM [ns]/$^{t}$CK (AVG) [ns]} according to the rounding algorithms found in the Converting Time-Based Specifications to Clock-Based Requirements section, in clock cycles, assuming all input clock jitter specifications are satisfied.
9. When operating in 1$^{t}$CK WRITE preamble mode.
10. When operating in 2$^{t}$CK WRITE preamble mode.
11. When CA parity mode is selected and the DLLoff mode is used, each REF command requires an additional "PL" added to $^{t}$RFC refresh time.
12. DRAM devices should be evenly addressed when being accessed. Disproportionate accesses to a particular row address may result in reduction of the product lifetime and/or reduction in data retention ability.
13. Applicable from $^{t}$CK (AVG) MIN to $^{t}$CK (AVG) MAX as stated in the Speed Bin tables.
14. JEDEC specifies a minimum of five clocks.
15. The maximum read postamble is bound by $^{t}$DQSCK (MIN) plus $^{t}$QSH (MIN) on the left side and $^{t}$HZ(DQS) MAX on the right side.
16. The reference level of DQ output signal is specified with a midpoint as a widest part of output signal eye, which should be approximately 0.7 × $V_{DDQ}$ as a center level of the static single-ended output peak-to-peak swing with a driver impedance of 34 ohms and an effective test load of 50 ohms to $V_{TT}$ = $V_{DDQ}$.
17. JEDEC hasn't agreed upon the definition of the deterministic jitter; the user should focus on meeting the total limit.
18. Spread spectrum is not included in the jitter specification values. However, the input clock can accommodate spread-spectrum at a sweep rate in the range of 20–60 kHz with an additional 1% of $^{t}$CK (AVG) as a long-term jitter component; however, the spread spectrum may not use a clock rate below $^{t}$CK (AVG) MIN.
19. The actual $^{t}$CAL minimum is the larger of 3 clocks or 3.748ns/$^{t}$CK; the table lists the applicable clocks required at targeted speed bin.
20. The maximum READ preamble is bounded by $^{t}$LZ(DQS) MIN on the left side and $^{t}$DQSCK (MAX) on the right side. See figure in the Clock to Data Strobe Relationship section. Boundary of DQS Low-Z occurs one cycle earlier in 2$^{t}$CK toggle mode, as illustrated in the READ Preamble section.
21. DQ falling signal middle-point of transferring from HIGH to LOW to first rising edge of DQS differential signal cross-point.
22. The $^{t}$PDA_S/$^{t}$PDA_H parameters may use the $^{t}$DS/$^{t}$DH limits, respectively, if the signal is LOW the entire BL8.

## Electrical Characteristics and AC Timing Parameters: 2666 Through 3200

**Table 146: Electrical Characteristics and AC Timing Parameters**

| Parameter | | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| **Clock Timing** | | | | | | | | | | | | |
| Clock period average (DLL off mode) | | $^{t}$CK (DLL_OFF) | 8 | 20 | 8 | 20 | 8 | 20 | | | ns | |
| Clock period average | | $^{t}$CK (AVG, DLL_ON) | 0.75 | 1.9 | 0.682 | 1.9 | 0.625 | 1.9 | | | ns | (page 0 ), 13 |
| High pulse width average | | $^{t}$CH (AVG) | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | | | $^{t}$CK (AVG) | |
| Low pulse width average | | $^{t}$CL (AVG) | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | | | $^{t}$CK (AVG) | |
| Clock period jitter | Total | $^{t}$JITper_tot | –38 | 38 | -34 | 34 | –32 | 32 | | | ps | 17 , 18 |
| | Deterministic | $^{t}$JITper_dj | –19 | 19 | -17 | 17 | –16 | 16 | | | ps | 17 |
| | DLL locking | $^{t}$JITper,lck | –30 | 30 | -27 | 27 | –25 | 25 | | | ps | |
| Clock absolute period | | $^{t}$CK (ABS) | MIN = $^{t}$CK (AVG) MIN + $^{t}$JITper_tot MIN; MAX = $^{t}$CK (AVG) MAX + $^{t}$JITper_tot MAX | | | | | | | | ps | |
| Clock absolute high pulse width (includes duty cycle jitter) | | $^{t}$CH (ABS) | 0.45 | – | 0.45 | – | 0.45 | – | | | $^{t}$CK (AVG) | |
| Clock absolute low pulse width (includes duty cycle jitter) | | $^{t}$CL (ABS) | 0.45 | – | 0.45 | – | 0.45 | – | | | $^{t}$CK (AVG) | |
| Cycle-to-cycle jitter | Total | $^{t}$JITcc _tot | – | 75 | – | 68 | – | 62 | | | ps | |
| | DLL locking | $^{t}$JITcc,lck | – | 60 | – | 55 | – | 62 | | | ps | |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Cumulative error across | 2 cycles | $^{t}$ERR2per | –55 | 55 | -50 | 50 | –46 | 46 | | | ps | |
| | 3 cycles | $^{t}$ERR3per | –66 | 66 | -60 | 60 | –55 | 55 | | | ps | |
| | 4 cycles | $^{t}$ERR4per | –73 | 73 | -66 | 66 | –61 | 61 | | | ps | |
| | 5 cycles | $^{t}$ERR5per | –78 | 78 | -71 | 71 | –65 | 65 | | | ps | |
| | 6 cycles | $^{t}$ERR6per | –83 | 83 | -75 | 75 | –69 | 69 | | | ps | |
| | 7 cycles | $^{t}$ERR7per | –87 | 87 | -79 | 79 | –73 | 73 | | | ps | |
| | 8 cycles | $^{t}$ERR8per | –91 | 91 | -83 | 83 | –76 | 76 | | | ps | |
| | 9 cycles | $^{t}$ERR9per | –94 | 94 | -85 | 85 | –78 | 78 | | | ps | |
| | 10 cycles | $^{t}$ERR10per | –96 | 96 | -88 | 88 | –80 | 80 | | | ps | |
| | 11 cycles | $^{t}$ERR11per | –99 | 99 | -90 | 90 | –83 | 83 | | | ps | |
| | 12 cycles | $^{t}$ERR12per | –101 | 101 | -92 | 92 | –84 | 84 | | | ps | |
| | *n* = 13, 14 . . . 49, 50 cycles | $^{t}$ERR*n*per | $^{t}$ERR*n*per MIN = (1 + 0.68ln[*n*]) × $^{t}$JITper_tot MIN<br>$^{t}$ERR*n*per MAX = (1 + 0.68ln[*n*]) × $^{t}$JITper_tot MAX | | | | | | | | ps | |
| **DQ Input Timing** | | | | | | | | | | | | |
| Data setup time to DQS_t, DQS_c | Base (calibrated $V_{REF}$) | $^{t}$DS | Refer to DQ Input Receiver Specification section (approximately 0.15$^{t}$CK to 0.28$^{t}$CK ) | | | | | | | | – | |
| | Non-calibrated $V_{REF}$ | $^{t}$PDA_S | minimum of 0.5ui | | | | | | | | UI | 22 |
| Data hold time from DQS_t, DQS_c | Base (calibrated $V_{REF}$) | $^{t}$DH | Refer to DQ Input Receiver Specification section (approximately 0.15$^{t}$CK to 0.28$^{t}$CK ) | | | | | | | | – | |
| | Non-calibrated $V_{REF}$ | $^{t}$PDA_H | minimum of 0.5UI | | | | | | | | UI | 22 |
| DQ and DM minimum data pulse width for each input | | $^{t}$DIPW | 0.58 | – | 0.58 | – | 0.58 | – | | | UI | |
| **DQ Output Timing (DLL enabled)** | | | | | | | | | | | | |
| DQS_t, DQS_c to DQ skew, per group, per access | | $^{t}$DQSQ | – | 0.18 | – | 0.19 | – | 0.20 | | | UI | |
| DQ output hold time from DQS_t, DQS_c | | $^{t}$QH | 0.74 | – | 0.72 | – | 0.70 | – | | | UI | |
| Data Valid Window per device: $^{t}$QH - $^{t}$DQSQ each device's output per UI | | $^{t}$DVW$_d$ | 0.64 | – | 0.64 | – | 0.64 | – | | | UI | |
| Data Valid Window per device, per pin: $^{t}$QH - $^{t}$DQSQ each device's output per UI | | $^{t}$DVW$_p$ | 0.72 | – | 0.72 | – | 0.72 | – | | | UI | |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| DQ Low-Z time from CK_t, CK_c | $^{t}$LZDQ | –310 | 170 | –280 | 165 | –250 | 160 | | | ps | |
| DQ High-Z time from CK_t, CK_c | $^{t}$HZDQ | – | 170 | – | 165 | – | 160 | | | ps | |
| **DQ Strobe Input Timing** | | | | | | | | | | | |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge for 1$^{t}$CKpreamble | $^{t}DQSS_{1ck}$ | –0.27 | 0.27 | –0.27 | 0.27 | –0.27 | 0.27 | | | CK | |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge for 2$^{t}$CKpreamble | $^{t}DQSS_{2ck}$ | –0.50 | 0.50 | –0.50 | 0.50 | –0.50 | 0.50 | | | CK | |
| DQS_t, DQS_c differential input low pulse width | $^{t}$DQSL | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | | | CK | |
| DQS_t, DQS_c differential input high pulse width | $^{t}$DQSH | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | | | CK | |
| DQS_t, DQS_c falling edge setup to CK_t, CK_c rising edge | $^{t}$DSS | 0.18 | – | 0.18 | – | 0.18 | – | | | CK | |
| DQS_t, DQS_c falling edge hold from CK_t, CK_c rising edge | $^{t}$DSH | 0.18 | – | 0.18 | – | 0.18 | – | | | CK | |
| DQS_t, DQS_c differential WRITE preamble for 1$^{t}$CKpreamble | $^{t}WPRE_{1ck}$ | 0.9 | – | 0.9 | – | 0.9 | – | | | CK | |
| DQS_t, DQS_c differential WRITE preamble for 2$^{t}$CKpreamble | $^{t}WPRE_{2ck}$ | 1.8 | – | 1.8 | – | 1.8 | – | | | CK | |
| DQS_t, DQS_c differential WRITE postamble | $^{t}$WPST | 0.33 | – | 0.33 | – | 0.33 | – | | | CK | |
| **DQS Strobe Output Timing (DLL enabled)** | | | | | | | | | | | |
| DQS_t, DQS_c rising edge output access time from rising CK_t, CK_c | $^{t}$DQSCK | –170 | 170 | –165 | 165 | –160 | 160 | | | ps | |
| DQS_t, DQS_c rising edge output variance window per DRAM | $^{t}$DQSCKi | – | 270 | – | 265 | – | 260 | | | ps | |
| DQS_t, DQS_c differential output high time | $^{t}$QSH | 0.40 | – | 0.40 | – | 0.40 | – | | | CK | |
| DQS_t, DQS_c differential output low time | $^{t}$QSL | 0.40 | – | 0.40 | – | 0.40 | – | | | CK | |
| DQS_t, DQS_c Low-Z time (RL - 1) | $^{t}$LZDQS | –310 | 170 | –280 | 165 | –250 | 160 | | | ps | |
| DQS_t, DQS_c High-Z time (RL + BL/2) | $^{t}$HZDQS | – | 170 | – | 165 | – | 160 | | | ps | |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| DQS_t, DQS_c differential READ preamble for 1tCKpreamble | | $^{t}RPRE_{1ck}$ | 0.9 | – | 0.9 | – | 0.9 | – | | | CK | 20 |
| DQS_t, DQS_c differential READ preamble for 2tCKpreamble | | $^{t}RPRE_{2ck}$ | 1.8 | – | 1.8 | – | 1.8 | – | | | CK | 20 |
| DQS_t, DQS_c differential READ postamble | | $^{t}RPST$ | 0.33 | – | 0.33 | – | 0.33 | – | | | CK | 21 |
| **Command and Address Timing** | | | | | | | | | | | | |
| DLL locking time | | $^{t}DLLK$ | 854 | – | 940 | – | 1024 | – | | | CK | 2, 4 |
| CMD, ADDR setup time to CK_t, CK_c referenced to $V_{IH(AC)}$ and $V_{IL(AC)}$ levels | Base | $^{t}IS$ | 55 | – | 48 | – | 40 | – | | | ps | |
| | $V_{REFCA}$ | $^{t}IS_{VREF}$ | 145 | – | 138 | – | 130 | – | | | ps | |
| CMD, ADDR hold time to CK_t, CK_c referenced to $V_{IH(DC)}$ and $V_{IL(DC)}$ levels | Base | $^{t}IH$ | 80 | – | 73 | – | 65 | – | | | ps | |
| | $V_{REFCA}$ | $^{t}IH_{VREF}$ | 145 | – | 138 | – | 130 | – | | | ps | |
| CTRL, ADDR pulse width for each input | | $^{t}IPW$ | 385 | – | 365 | – | 340 | – | | | ps | |
| ACTIVATE to internal READ or WRITE delay | | $^{t}RCD$ | See Speed Bin Tables for $^{t}RCD$ | | | | | | | | ns | |
| PRECHARGE command period | | $^{t}RP$ | See Speed Bin Tables for $^{t}RP$ | | | | | | | | ns | |
| ACTIVATE-to-PRECHARGE command period | | $^{t}RAS$ | See Speed Bin Tables for $^{t}RAS$ | | | | | | | | ns | 12 |
| ACTIVATE-to-ACTIVATE or REF command period | | $^{t}RC$ | See Speed Bin Tables for $^{t}RC$ | | | | | | | | ns | 12 |
| ACTIVATE-to-ACTIVATE command period to different bank groups for 1/2KB page size | | $^{t}RRD\_S$ (1/2KB) | MIN = greater of 4CK or 3.0ns | | MIN = greater of 4CK or 2.7ns | | MIN = greater of 4CK or 2.5ns | | | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to different bank groups for 1KB page size | | $^{t}RRD\_S$ (1KB) | MIN = greater of 4CK or 3.0ns | | MIN = greater of 4CK or 2.7ns | | MIN = greater of 4CK or 2.5ns | | | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to different bank groups for 2KB page size | | $^{t}RRD\_S$ (2KB) | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 5.3ns | | MIN = greater of 4CK or 5.3ns | | | | CK | 1 |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| ACTIVATE-to-ACTIVATE command period to same bank groups for 1/2KB page size | $^{t}$RRD_L (1/2KB) | MIN = greater of 4CK or 4.9ns | | MIN = greater of 4CK or 4.9ns | | MIN = greater of 4CK or 4.9ns | | | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to same bank groups for 1KB page size | $^{t}$RRD_L (1KB) | MIN = greater of 4CK or 4.9ns | | MIN = greater of 4CK or 4.9ns | | MIN = greater of 4CK or 4.9ns | | | | CK | 1 |
| ACTIVATE-to-ACTIVATE command period to same bank groups for 2KB page size | $^{t}$RRD_L (2KB) | MIN = greater of 4CK or 6.4ns | | MIN = greater of 4CK or 6.4ns | | MIN = greater of 4CK or 6.4ns | | | | CK | 1 |
| Four ACTIVATE windows for 1/2KB page size | $^{t}$FAW (1/2KB) | MIN = greater of 16CK or 12ns | | MIN = greater of 16CK or 10.875ns | | MIN = greater of 16CK or 10ns | | | | ns | |
| Four ACTIVATE windows for 1KB page size | $^{t}$FAW (1KB) | MIN = greater of 20CK or 21ns | | MIN = greater of 20CK or 21ns | | MIN = greater of 20CK or 21ns | | | | ns | |
| Four ACTIVATE windows for 2KB page size | $^{t}$FAW (2KB) | MIN = greater of 28CK or 30ns | | MIN = greater of 28CK or 30ns | | MIN = greater of 28CK or 30ns | | | | ns | |
| WRITE recovery time | $^{t}$WR | MIN = 15ns | | | | | | | | ns | 5, 9, 1 |
| | $^{t}$WR$_2$ | MIN = 1CK + $^{t}$WR | | | | | | | | CK | 5, 10, 1 |
| WRITE recovery time when CRC and DM are both enabled | $^{t}$WR_CRC_DM | MIN = $^{t}$WR + greater of (5CK or 3.75ns) | | | | | | | | CK | 6, 9, 1 |
| WRITE recovery time when CRC and DM are both enabled | $^{t}$WR_CRC_DM$_2$ | MIN = 1CK + $^{t}$WR_CRC_DM | | | | | | | | CK | 6, 10, 1 |
| Delay from start of internal WRITE transaction to internal READ command – Same bank group | $^{t}$WTR_L | MIN = greater of 4CK or 7.5ns | | | | | | | | CK | 5, 9, 1 |
| | $^{t}$WTR_L$_2$ | MIN = 1CK + $^{t}$WTR_L | | | | | | | | CK | 5, 10, 1 |
| Delay from start of internal WRITE transaction to internal READ command – Same bank group when CRC and DM are both enabled | $^{t}$WTR_L_CRC_DM | MIN = $^{t}$WTR_L + greater of (5CK or 3.75ns) | | | | | | | | CK | 6, 9, 1 |
| | $^{t}$WTR_L_CRC_DM$_2$ | MIN = 1CK + $^{t}$WTR_L_CRC_DM | | | | | | | | CK | 6, 10, 1 |
| Delay from start of internal WRITE transaction to internal READ command – Different bank group | $^{t}$WTR_S | MIN = greater of (2CK or 2.5ns) | | | | | | | | CK | 5, 7, 8, 9, 1 |
| | $^{t}$WTR_S$_2$ | MIN = 1CK + $^{t}$WTR_S | | | | | | | | CK | 5, 7, 8, 10, 1 |
| Delay from start of internal WRITE transaction to internal READ command – Different bank group when CRC and DM are both enabled | $^{t}$WTR_S_CRC_DM | MIN = $^{t}$WTR_S + greater of (5CK or 3.75ns) | | | | | | | | CK | 6, 7, 8, 9, 1 |
| | $^{t}$WTR_S_CRC_DM$_2$ | MIN = 1CK + $^{t}$WTR_S_CRC_DM | | | | | | | | CK | 6, 7, 8, 10, 1 |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| READ-to-PRECHARGE time | $^{t}$RTP | MIN = greater of 4CK or 7.5ns | | | | | | | | CK | 1 |
| CAS_n-to-CAS_n command delay to different bank group | $^{t}$CCD_S | 4 | – | 4 | – | 4 | – | | | CK | |
| CAS_n-to-CAS_n command delay to same bank group | $^{t}$CCD_L | MIN = greater of 4CK or 5ns | – | MIN = greater of 4CK or 5ns | – | MIN = greater of 4CK or 5ns | – | | | CK | 14 |
| Auto precharge write recovery + pre-charge time | $^{t}$DAL (MIN) | MIN = WR + ROUND$^{t}$RP/$^{t}$CK (AVG); MAX = N/A | | | | | | | | CK | 8 |
| **MRS Command Timing** | | | | | | | | | | | |
| MRS command cycle time | $^{t}$MRD | 8 | – | 8 | – | 8 | – | | | CK | |
| MRS command cycle time in PDA mode | $^{t}$MRD_PDA | MIN = greater of (16nCK, 10ns) | | | | | | | | | 1 |
| MRS command cycle time in CAL mode | $^{t}$MRD_CAL | MIN = $^{t}$MOD + $^{t}$CAL | | | | | | | | CK | |
| MRS command update delay | $^{t}$MOD | MIN = greater of (24nCK, 15ns) | | | | | | | | CK | 1 |
| MRS command update delay in PDA mode | $^{t}$MOD_PDA | MIN = $^{t}$MOD | | | | | | | | CK | |
| MRS command update delay in CAL mode | $^{t}$MOD_CAL | MIN = $^{t}$MOD + $^{t}$CAL | | | | | | | | CK | |
| MRS command to DQS drive in preamble training | $^{t}$SDO | MIN = $^{t}$MOD + 9ns | | | | | | | | | |
| **MPR Command Timing** | | | | | | | | | | | |
| Multipurpose register recovery time | $^{t}$MPRR | MIN = 1nCK | | | | | | | | CK | |
| Multipurpose register write recovery time | $^{t}$WR_MPR | MIN = $^{t}$MOD + AL + PL | | | | | | | | | |
| **CRC Error Reporting Timing** | | | | | | | | | | | |
| CRC error to ALERT_n latency | $^{t}$CRC_ALERT | 3 | 13 | 3 | 13 | 3 | 13 | | | ns | |
| CRC ALERT_n pulse width | $^{t}$CRC_ALERT_PW | 6 | 10 | 6 | 10 | 6 | 10 | | | CK | |
| **CA Parity Timing** | | | | | | | | | | | |
| Parity latency | PL | 5 | – | 6 | – | 6 | – | | | CK | |
| Commands uncertain to be executed during this time | $^{t}$PAR_UNKNOWN | – | PL | – | PL | – | PL | | | CK | |
| Delay from errant command to ALERT_n assertion | $^{t}$PAR_ALERT_ON | – | PL + 6ns | – | PL + 6ns | – | PL + 6ns | | | CK | |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Pulse width of ALERT_n signal when asserted | $^{t}$PAR_ALERT_PW | 80 | 160 | 88 | 176 | 96 | 192 | | | CK | |
| Time from alert asserted until DES commands required in persistent CA parity mode | $^{t}$PAR_ALERT_RSP | – | 71 | – | 78 | – | 85 | | | CK | |
| **CAL Timing** | | | | | | | | | | | |
| CS_n to command address latency | $^{t}$CAL | 5 | – | 6 | – | 6 | – | | | CK | 19 |
| CS_n to command address latency in gear-down mode | $^{t}$CALg | 6 | – | 8 | – | 8 | – | | | CK | |
| **MPSM Timing** | | | | | | | | | | | |
| Command path disable delay upon MPSM entry | $^{t}$MPED | MIN = $^{t}$MOD (MIN) + $^{t}$CPDED (MIN) | | | | | | | | CK | 1 |
| Valid clock requirement after MPSM entry | $^{t}$CKMPE | MIN = $^{t}$MOD (MIN) + $^{t}$CPDED (MIN) | | | | | | | | CK | 1 |
| Valid clock requirement before MPSM exit | $^{t}$CKMPX | MIN = $^{t}$CKSRX (MIN) | | | | | | | | CK | 1 |
| Exit MPSM to commands not requiring a locked DLL | $^{t}$XMP | $^{t}$XS (MIN) | | | | | | | | CK | |
| Exit MPSM to commands requiring a locked DLL | $^{t}$XMPDLL | MIN = $^{t}$XMP (MIN) + $^{t}$XSDLL (MIN) | | | | | | | | CK | 1 |
| CS setup time to CKE | $^{t}$MPX_S | MIN = $^{t}$IS (MIN) + $^{t}$IH (MIN) | | | | | | | | ns | |
| CS_n HIGH hold time to CKE rising edge | $^{t}$MPX_HH | MIN = $^{t}$XP | | | | | | | | ns | |
| CS_n LOW hold time to CKE rising edge | $^{t}$MPX_LH | 12 | $^{t}$XMP-10ns | 12 | $^{t}$XMP-10ns | 12 | $^{t}$XMP-10ns | | | ns | |
| **Connectivity Test Timing** | | | | | | | | | | | |
| TEN pin HIGH to CS_n LOW – Enter CT mode | $^{t}$CT_Enable | 200 | – | 200 | – | 200 | – | | | ns | |
| CS_n LOW and valid input to valid output | $^{t}$CT_Valid | – | 200 | – | 200 | – | 200 | | | ns | |
| CK_t, CK_c valid and CKE HIGH after TEN goes HIGH | $^{t}$CTCKE_Valid | 10 | – | 10 | – | 10 | – | | | ns | |
| **Calibration and $V_{REFDQ}$ Train Timing** | | | | | | | | | | | |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| ZQCL command: Long calibration time | POWER-UP and RESET operation | $^{t}$ZQinit | 1024 | – | 1024 | – | 1024 | – | | | CK | |
| | Normal operation | $^{t}$ZQoper | 512 | – | 512 | – | 512 | – | | | CK | |
| ZQCS command: Short calibration time | | $^{t}$ZQCS | 128 | – | 128 | – | 128 | – | | | CK | |
| The $V_{REF}$ increment/decrement step time | | $V_{REF\_time}$ | MIN = 150ns | | | | | | | | | |
| Enter $V_{REFDQ}$ training mode to the first write or $V_{REFDQ}$ MRS command delay | | $^{t}$VREFDQE | MIN = 150ns | | | | | | | | ns | 1 |
| Exit $V_{REFDQ}$ training mode to the first WRITE command delay | | $^{t}$VREFDQX | MIN = 150ns | | | | | | | | ns | 1 |
| **Initialization and Reset Timing** | | | | | | | | | | | | |
| Exit reset from CKE HIGH to a valid command | | $^{t}$XPR | MIN = $^{t}$RFC1 + 10ns | | | | | | | | ns | 1 |
| RESET_L pulse low after power stable | | $^{t}$PW_RESET_S | 1.0 | – | 1.0 | – | 1.0 | – | | | µs | |
| RESET_L pulse low at power-up | | $^{t}$PW_RESET_L | 200 | – | 200 | – | 200 | – | | | µs | |
| Begin power supply ramp to power supplies stable | | $^{t}$VDDPR | MIN = N/A; MAX = 200 | | | | | | | | ms | |
| RESET_n LOW to power supplies stable | | $^{t}$RPS | MIN = 0; MAX = 0 | | | | | | | | ns | |
| **Refresh Timing** | | | | | | | | | | | | |
| REFRESH-to-ACTIVATE or REFRESH command period (all bank groups) | 4Gb | $^{t}$RFC1 | MIN = 260 | | | | | | | | ns | 1, 11 |
| | | $^{t}$RFC2 | MIN = 160 | | | | | | | | ns | 1, 11 |
| | | $^{t}$RFC4 | MIN = 110 | | | | | | | | ns | 1, 11 |
| | 8Gb | $^{t}$RFC1 | MIN = 350 | | | | | | | | ns | 1, 11 |
| | | $^{t}$RFC2 | MIN = 260 | | | | | | | | ns | 1, 11 |
| | | $^{t}$RFC4 | MIN = 160 | | | | | | | | ns | 1, 11 |
| | 16Gb | $^{t}$RFC1 | MIN = 350 | | | | | | | | ns | 1, 11 |
| | | $^{t}$RFC2 | MIN = 260 | | | | | | | | ns | 1, 11 |
| | | $^{t}$RFC4 | MIN = 160 | | | | | | | | ns | 1, 11 |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Average periodic refresh interval | -40°C ≤ $T_C$ ≤ 85°C | $^tREFI$ | MIN = N/A; MAX = 7.8 | | | | | | | | µs | 11 |
| | 85°C < $T_C$ ≤ 95°C | $^tREFI$ | MIN = N/A; MAX = 3.9 | | | | | | | | µs | 11 |
| | 95°C < $T_C$ ≤ 105°C | $^tREFI$ | MIN = N/A; MAX = 1.95 | | | | | | | | µs | 11 |
| | 105°C < $T_C$ ≤ 125°C | $^tREFI$ | MIN = N/A; MAX = 0.975 | | | | | | | | µs | 11 |
| **Self Refresh Timing** | | | | | | | | | | | | |
| Exit self refresh to commands not requiring a locked DLL | | $^tXS$ | MIN = $^tRFC1$ + 10ns | | | | | | | | ns | 1 |
| Exit self refresh to commands not requiring a locked DLL in self refresh abort | | $^tXS\_ABORT$ | MIN = $^tRFC4$ + 10ns | | | | | | | | ns | 1 |
| Exit self refresh to ZQCL, ZQCS and MRS (CL, CWL, WR, RTP and gear-down) | | $^tXS\_FAST$ | MIN = $^tRFC4$ + 10ns | | | | | | | | ns | 1 |
| Exit self refresh to commands requiring a locked DLL | | $^tXSDLL$ | MIN = $^tDLLK$ (MIN) | | | | | | | | CK | 1 |
| Minimum CKE low pulse width for self refresh entry to self refresh exit timing | | $^tCKESR$ | MIN = $^tCKE$ (MIN) + 1*n*CK | | | | | | | | CK | 1 |
| Minimum CKE low pulse width for self refresh entry to self refresh exit timing when CA parity is enabled | | $^tCKESR\_par$ | MIN = $^tCKE$ (MIN) + 1*n*CK + PL | | | | | | | | CK | 1 |
| Valid clocks after self refresh entry (SRE) or power-down entry (PDE) | | $^tCKSRE$ | MIN = greater of (5CK, 10ns) | | | | | | | | CK | 1 |
| Valid clock requirement after self refresh entry or power-down when CA parity is enabled | | $^tCKSRE\_par$ | MIN = greater of (5CK, 10ns) + PL | | | | | | | | CK | 1 |
| Valid clocks before self refresh exit (SRX) or power-down exit (PDX), or reset exit | | $^tCKSRX$ | MIN = greater of (5CK, 10ns) | | | | | | | | CK | 1 |
| **Power-Down Timing** | | | | | | | | | | | | |
| Exit power-down with DLL on to any valid command | | $^tXP$ | MIN = greater of 4CK or 6ns | | | | | | | | CK | 1 |
| Exit precharge power-down with DLL frozen to commands not requiring a locked DLL when CA Parity is enabled. | | $^tXP\ \_PAR$ | MIN = (greater of 4CK or 6ns) + PL | | | | | | | | CK | 1 |
| CKE MIN pulse width | | $^tCKE$ (MIN) | MIN = greater of 3CK or 5ns | | | | | | | | CK | 1 |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Command pass disable delay | tCPDED | 4 | – | 4 | – | 4 | – | | | CK | |
| Power-down entry to power-down exit timing | tPD | MIN = tCKE (MIN); MAX = 9 × tREFI | | | | | | | | CK | |
| Begin power-down period prior to CKE registered HIGH | tANPD | WL - 1CK | | | | | | | | CK | |
| Power-down entry period: ODT either synchronous or asynchronous | PDE | Greater of tANPD or tRFC - REFRESH command to CKE LOW time | | | | | | | | CK | |
| Power-down exit period: ODT either synchronous or asynchronous | PDX | tANPD + tXSDLL | | | | | | | | CK | |
| **Power-Down Entry Minimum Timing** | | | | | | | | | | | |
| ACTIVATE command to power-down entry | tACTPDEN | 2 | – | 2 | – | 2 | – | | | CK | |
| PRECHARGE/PRECHARGE ALL command to power-down entry | tPRPDEN | 2 | – | 2 | – | 2 | – | | | CK | |
| REFRESH command to power-down entry | tREFPDEN | 2 | – | 2 | – | 2 | – | | | CK | |
| MRS command to power-down entry | tMRSPDEN | MIN = tMOD (MIN) | | | | | | | | CK | 1 |
| READ/READ with auto precharge command to power-down entry | tRDPDEN | MIN = RL + 4 + 1 | | | | | | | | CK | 1 |
| WRITE command to power-down entry (BL8OTF, BL8MRS, BC4OTF) | tWRPDEN | MIN = WL + 4 + tWR/tCK (AVG) | | | | | | | | CK | 1 |
| WRITE command to power-down entry (BC4MRS) | tWRPBC4DEN | MIN = WL + 2 + tWR/tCK (AVG) | | | | | | | | CK | 1 |
| WRITE with auto precharge command to power-down entry (BL8OTF, BL8MRS,BC4OTF) | tWRAPDEN | MIN = WL + 4 + WR + 1 | | | | | | | | CK | 1 |
| WRITE with auto precharge command to power-down entry (BC4MRS) | tWRAPBC4DEN | MIN = WL + 2 + WR + 1 | | | | | | | | CK | 1 |
| **ODT Timing** | | | | | | | | | | | |
| Direct ODT turn-on latency | DODTLon | WL - 2 = CWL + AL + PL - 2 | | | | | | | | CK | |
| Direct ODT turn-off latency | DODTLoff | WL - 2 = CWL + AL + PL - 2 | | | | | | | | CK | |
| $R_{TT}$ dynamic change skew | tADC | 0.28 | 0.72 | 0.26 | 0.74 | 0.26 | 0.74 | | | CK | |
| Asynchronous $R_{TT(NOM)}$ turn-on delay (DLL off) | tAONAS | 1 | 9 | 1 | 9 | 1 | 9 | | | ns | |

**Table 146: Electrical Characteristics and AC Timing Parameters (Continued)**

| Parameter | Symbol | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Reserved | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Asynchronous $R_{TT(NOM)}$ turn-off delay (DLL off) | $^{t}$AOFAS | 1 | 9 | 1 | 9 | 1 | 9 | | | ns | |
| ODT HIGH time with WRITE command and BL8 | ODTH8 1$^{t}$CK | 6 | – | 6 | – | 6 | – | | | CK | |
| | ODTH8 2$^{t}$CK | 7 | – | 7 | – | 7 | – | | | | |
| ODT HIGH time without WRITE command or with WRITE command and BC4 | ODTH4 1$^{t}$CK | 4 | – | 4 | – | 4 | – | | | CK | |
| | ODTH4 2$^{t}$CK | 5 | – | 5 | – | 5 | – | | | | |
| **Write Leveling Timing** | | | | | | | | | | | |
| First DQS_t, DQS_c rising edge after write leveling mode is programmed | $^{t}$WLMRD | 40 | – | 40 | – | 40 | – | | | CK | |
| DQS_t, DQS_c delay after write leveling mode is programmed | $^{t}$WLDQSEN | 25 | – | 25 | – | 25 | – | | | CK | |
| Write leveling setup from rising CK_t, CK_c crossing to rising DQS_t, DQS_c crossing | $^{t}$WLS | 0.13 | – | 0.13 | – | 0.13 | – | | | CK | |
| Write leveling hold from rising DQS_t, DQS_c crossing to rising CK_t, CK_c crossing | $^{t}$WLH | 0.13 | – | 0.13 | – | 0.13 | – | | | CK | |
| Write leveling output delay | $^{t}$WLO | 0 | 9.5 | 0 | 9.5 | 0 | 9.5 | | | ns | |
| Write leveling output error | $^{t}$WLOE | 0 | 2 | 0 | 2 | 0 | 2 | | | ns | |
| **Gear-Down Timing** | | | | | | | | | | | |
| Exit reset from CKE HIGH to a valid MRS gear-down | $^{t}$XPR_GEAR | $^{t}$XPR | | $^{t}$XPR | | $^{t}$XPR | | | | CK | |
| CKE HIGH assert to gear-down enable time) | $^{t}$XS_GEAR | $^{t}$XS | | $^{t}$XS | | $^{t}$XS | | | | CK | |
| MRS command to sync pulse time | $^{t}$SYNC_GEAR | $^{t}$MOD + 4CK | | $^{t}$MOD + 4CK | | $^{t}$MOD + 4CK | | | | CK | |
| Sync pulse to first valid command | $^{t}$CMD_GEAR | $^{t}$MOD | | $^{t}$MOD | | $^{t}$MOD | | | | CK | |
| Gear-down setup time | $^{t}$GEAR_setup | 2CK | – | 2CK | – | 2CK | – | | | CK | |
| Gear-down hold time | $^{t}$GEAR_hold | 2CK | – | 2CK | – | 2CK | – | | | CK | |

Notes:
1. Maximum limit not applicable.
2. Alliance tDLLK values support the legacy JEDEC tDLLK specifications.
3. DDR4-1600 AC timing parameters apply if DRAM operates at lower than 1600 MT/s data rate.
4. Data rate is greater than or equal to 1066 Mb/s.
5. WRITE-to-READ when CRC and DM are both not enabled.
6. WRITE-to-READ delay when CRC and DM are both enabled.
7. The start of internal write transactions is defined as follows:
   - For BL8 (fixed by MRS and on-the-fly): rising clock edge four clock cycles after WL
   - For BC4 (on-the-fly): rising clock edge four clock cycles after WL
   - For BC4 (fixed by MRS): rising clock edge two clock cycles after WL
8. For these parameters, the device supports $^{t}n$PARAM [$n$CK] = ROUND{$^{t}$PARAM [ns]/$^{t}$CK (AVG) [ns]} according to the rounding algorithms found in the Converting Time-Based Specifications to Clock-Based Requirements section, in clock cycles, assuming all input clock jitter specifications are satisfied.
9. When operating in 1$^{t}$CK WRITE preamble mode.
10. When operating in 2$^{t}$CK WRITE preamble mode.
11. When CA parity mode is selected and the DLLoff mode is used, each REF command requires an additional "PL" added to $^{t}$RFC refresh time.
12. DRAM devices should be evenly addressed when being accessed. Disproportionate accesses to a particular row address may result in reduction of the product lifetime and/or reduction in data retention ability.
13. Applicable from $^{t}$CK (AVG) MIN to $^{t}$CK (AVG) MAX as stated in the Speed Bin tables.
14. JEDEC specifies a minimum of five clocks.
15. The maximum read postamble is bound by $^{t}$DQSCK (MIN) plus $^{t}$QSH (MIN) on the left side and $^{t}$HZ(DQS) MAX on the right side.
16. The reference level of DQ output signal is specified with a midpoint as a widest part of output signal eye, which should be approximately 0.7 × $V_{DDQ}$ as a center level of the static single-ended output peak-to-peak swing with a driver impedance of 34 ohms and an effective test load of 50 ohms to $V_{TT}$ = $V_{DDQ}$.
17. JEDEC hasn't agreed upon the definition of the deterministic jitter; the user should focus on meeting the total limit.
18. Spread spectrum is not included in the jitter specification values. However, the input clock can accommodate spread-spectrum at a sweep rate in the range of 20–60 kHz with an additional 1% of $^{t}$CK (AVG) as a long-term jitter component; however, the spread spectrum may not use a clock rate below $^{t}$CK (AVG) MIN.
19. The actual $^{t}$CAL minimum is the larger of 3 clocks or 3.748ns/$^{t}$CK; the table lists the applicable clocks required at targeted speed bin.
20. The maximum READ preamble is bounded by $^{t}$LZ(DQS) MIN on the left side and $^{t}$DQSCK (MAX) on the right side. See figure in the Clock to Data Strobe Relationship section. Boundary of DQS Low-Z occurs one cycle earlier in 2$^{t}$CK toggle mode, as illustrated in the READ Preamble section.
21. DQ falling signal middle-point of transferring from HIGH to LOW to first rising edge of DQS differential signal cross-point.
22. The $^{t}$PDA_S/$^{t}$PDA_H parameters may use the $^{t}$DS/$^{t}$DH limits, respectively, if the signal is LOW the entire BL8.

## Converting Time-Based Specifications to Clock-Based Requirements

Software algorithms for calculation of timing parameters are subject to potential rounding errors when converting DRAM timing requirements to system clocks; for example, a

memory clock with a nominal frequency of 933.33...3MHz which yields a clock period of 1.071428571429...ns. It is unrealistic to represent all digits after the decimal point exactly and some sort of rounding needs to be done.

DDR4 SDRAM SPD-based specifications use a minimum granularity for SPD-associated timing parameters of 1ps. Clock periods such as $^{t}$CK (AVG) MIN are defined to the nearest picosecond. For example, 1.071428571429...ns is stated as 1071ps. Parameters such as $^{t}$AA MIN are specified in units of time (nanoseconds) and require mathematical com-putation to convert to system clocks (*n*CK). Rules for rounding allow optimization of device performance without violating device parameters. These SPD algorithms rely on results that are within *n*CK adjustment factors on device testing and specification to avoid losing performance due to rounding errors when using SPD-based parameters. Note that JEDEC also defines an *n*CK adjustment factor, but mandates the inverse *n*CK adjustment factor be used in case of conflicting results, so only the inverse *n*CK adjust-ment factor is discussed here.

Guidance converting SPD associated timing parameters to system clock requirements:

- Round the application clock period up to the nearest picosecond.
- Express the timing specification and application clock period in picoseconds; scaling a nanosecond-based parameter value by 1000 allows programmers to use integer math instead of real math by expressing timing in ps.
- Divide the picosecond-based parameter by the picoseconds based application clock period.
- Add an inverse *n*CK adjustment factor of 97.4%.
- Truncate down to the next lower integer value.
- *n*CK = Truncate[(parameter in ps)/(application $^{t}$CK in ps) + (974/1000)].

Guidance converting nonSPD associated timing parameters to system clock requirements:

- Divide the time base specification (in ns) and divided by the clock period (in ns).
- The resultant is set to the next higher integer number of clocks.
- *n*CK = Ceiling[(parameter in ns/application $^{t}$CK in ns)].

## Options Tables

**Table 147: Options – Speed Based**

| Function | Acronym | Data Rate | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 |
| Write leveling | WL | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Temperature controlled refresh | TCR | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Low-power auto self refresh | LPASR | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Fine granularity refresh | FGR | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Multipurpose register | MR | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Data mask | DM | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Data bus inversion | DBI | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| TDQS | – | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| ZQ calibration | ZQ CAL | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $V_{REFDQ}$ calibration | – | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Per-DRAM addressability | Per DRAM | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mode register readout | – | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Command/Address latency | CAL | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Write CRC | CRC | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| CA parity | – | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Gear-down mode | – | **No** | **No** | **No** | **No** | Yes | Yes | Yes |
| Programmable preamble | – | **No** | **No** | **No** | Yes | Yes | Yes | Yes |
| Maximum power saving mode | MPSM | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Additive latency | AL | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Connectivity test mode | CT | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Hard post package repair mode | hPPR | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Soft post package repair mode | sPPR | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

**Table 148: Options – Width Based**

| Function | Acronym | Width |
|---|---|---|
| | | x16 |
| Write leveling | WL | Yes |
| Temperature controlled refresh | TCR | Yes |
| Low-power auto self refresh | LPASR | Yes |
| Fine granularity refresh | FGR | Yes |
| Multipurpose register | MR | Yes |
| Data mask | DM | Yes |
| Data bus inversion | DBI | Yes |
| TDQS | – | **No** |
| ZQ calibration | ZQ CAL | Yes |
| $V_{REFDQ}$ calibration | – | Yes |
| Per-DRAM addressability | Per DRAM | Yes |
| Mode regsiter readout | – | Yes |
| Command/Address latency | CAL | Yes |
| Write CRC | CRC | Yes |
| CA parity | – | Yes |
| Gear-down mode | – | Yes |
| Programmable preamble | – | Yes |
| Maximum power-down mode | MPSM | Yes |
| Additive latency | AL | Yes |
| Connectivity test mode | CT | JEDEC optional on 8Gb and larger densities<br>**Alliance supports on all densities** |
| Hard post package repair mode | hPPR | JEDEC optional on 4Gb<br>**Alliance supports on all densities** |
| Soft post package repair mode | sPPR | JEDEC optional on 4Gb and 8Gb<br>**Alliance supports on all densities** |

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