# Mobile LPDDR2 SDRAM

## EDB4432BBPA, EDB8132B4PM, EDBM432B3PB, EDBM432B3PF, EDBA232B2PB, EDBA232B2PF

## Features

- Ultra-low-voltage core and I/O power supplies
- Frequency range
  - 533 MHz (data rate: 1066 Mb/s/pin)
- 4*n* prefetch DDR architecture
- 8 internal banks for concurrent operation
- Multiplexed, double data rate, command/address inputs; commands entered on each CK_t/CK_c edge
- Bidirectional/differential data strobe per byte of data (DQS_t/DQS_c)
- Programmable READ and WRITE latencies (RL/WL)
- Burst length: 4, 8 and 16
- Per-bank refresh for concurrent operation
- Auto temperature-compensated self refresh (ATCSR) by built-in temperature sensor
- Partial-array self refresh (PASR)
- Deep power-down mode (DPD)
- Selectable output drive strength (DS)
- Clock-stop capability
- Lead-free (RoHS-compliant) and halogen-free packaging

## Options

- $V_{DD1}/V_{DD2}/V_{DDQ}$: 1.8V/1.2V/1.2V
- Array configuration
  - 128 Meg x 32 (SDP)
  - 256 Meg x 32 (DDP)
  - 384 Meg x 32 (3DP)
  - 512 Meg x 32 (QDP)
- Packaging
  - 12mm x 12mm, 168-ball PoP FBGA package
- Operating temperature range
  - From –30°C to +85°C

**Table 1: Configuration Addressing**

| Architecture | | 128 Meg x 32 | 256 Meg x 32 | 384 Meg x 32 | 512 Meg x 32 |
|---|---|---|---|---|---|
| Density per package | | 4Gb | 8Gb | 12Gb | 16Gb |
| Die per package | | 1 | 2 | 3 | 4 |
| Ranks (CS_n) per channel | | 1 | 2 | 2 | 2 |
| Die per rank | CS0_n | 1 | 1 | 2 | 2 |
| | CS1_n | 0 | 1 | 1 | 2 |
| Configuration per rank (CS_n) | CS0_n | 16 Meg x 32 x 8 banks | 16 Meg x 32 x 8 banks | 32 Meg x 16 x 8 banks x 2 | 32 Meg x 16 x 8 banks x 2 |
| | CS1_n | N/A | 16 Meg x 32 x 8 banks | 16 Meg x 32 x 8 banks | 32 Meg x 16 x 8 banks x 2 |
| Row addressing | | 16K A[13:0] | 16K A[13:0] | 16K A[13:0] | 16K A[13:0] |
| Column addressing/CS_n | CS0_n | 1K A[9:0] | 1K A[9:0] | 2K A[10:0] | 2K A[10:0] |
| | CS1_n | N/A | 1K A[9:0] | 1K A[9:0] | 2K A[10:0] |


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**Table 2: Key Timing Parameters**

| Speed Grade | Clock Rate (MHz) | Data Rate (Mb/s/pin) | WRITE Latency | READ Latency |
|---|---|---|---|---|
| 1D | 533 | 1066 | 4 | 8 |

**Table 3: Part Number Description**

| Part Number | Total Density | Configuration | Ranks | Channels | Package Size | Ball Pitch |
|---|---|---|---|---|---|---|
| EDB4432BBPA-1D-F-R, EDB4432BBPA-1D-F-D | 4Gb | 128 Meg x 32 | 1 | 1 | 12mm x 12mm (0.80mm MAX height) | 0.50mm |
| EDB8132B4PM-1D-F-R, EDB8132B4PM-1D-F-D | 8Gb | 256 Meg x 32 | 2 | 1 | 12mm x 12mm (0.82mm MAX height) | 0.50mm |
| EDBM432B3PB-1D-F-R, EDBM432B3PB-1D-F-D | 12Gb | 384 Meg x 32 | 2 | 1 | 12mm x 12mm (0.90mm MAX height) | 0.50mm |
| EDBM432B3PF-1D-F-R, EDBM432B3PF-1D-F-D | 12Gb | 384 Meg x 32 | 2 | 1 | 12mm x 12mm (0.92mm MAX height) | 0.50mm |
| EDBA232B2PB-1D-F-R, EDBA232B2PB-1D-F-D | 16Gb | 512 Meg x 32 | 2 | 1 | 12mm x 12mm (1.00mm MAX height) | 0.50mm |
| EDBA232B2PF-1D-F-R, EDBA232B2PF-1D-F-D | 16Gb | 512 Meg x 32 | 2 | 1 | 12mm x 12mm (1.02mm MAX height) | 0.50mm |


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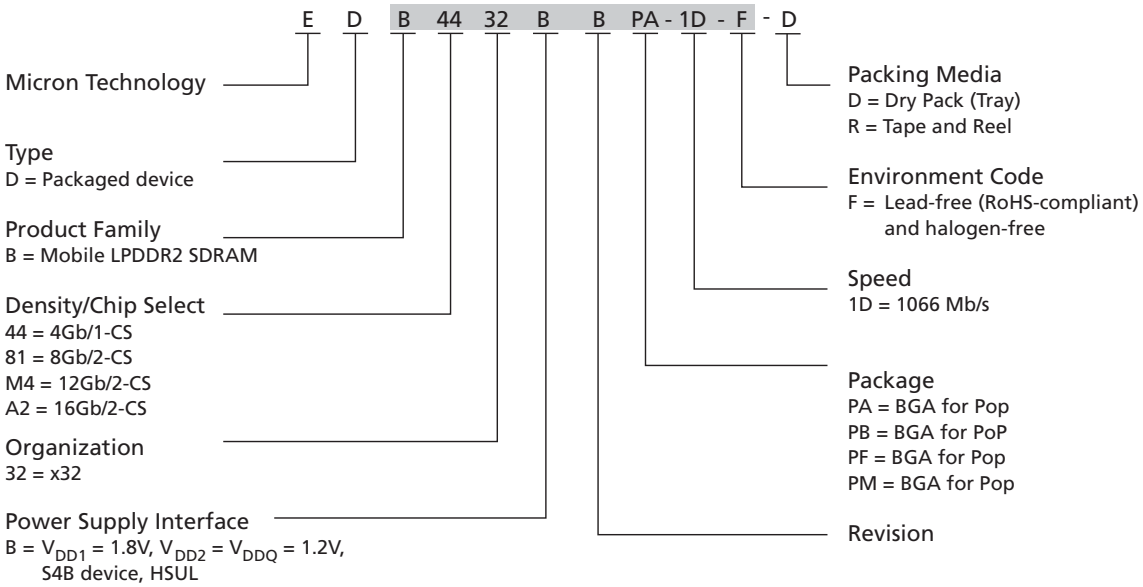
**Figure 1: Marketing Part Number Chart**




Note: 1. The characters highlighted in gray indicate the physical part marking found on the device.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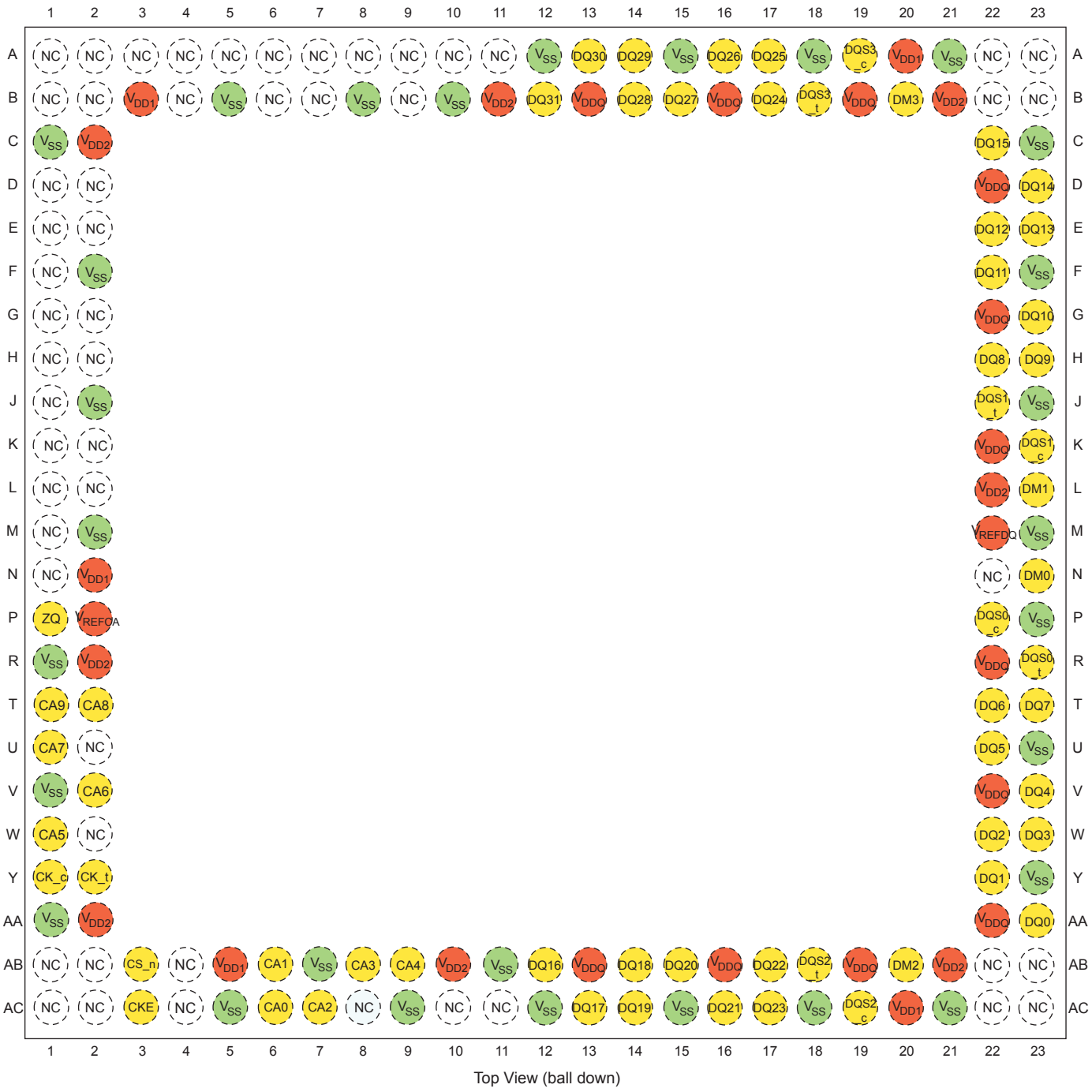
# Ball Assignments

## Figure 2: 168-Ball Single-Channel FBGA – 1 x 4Gb Die





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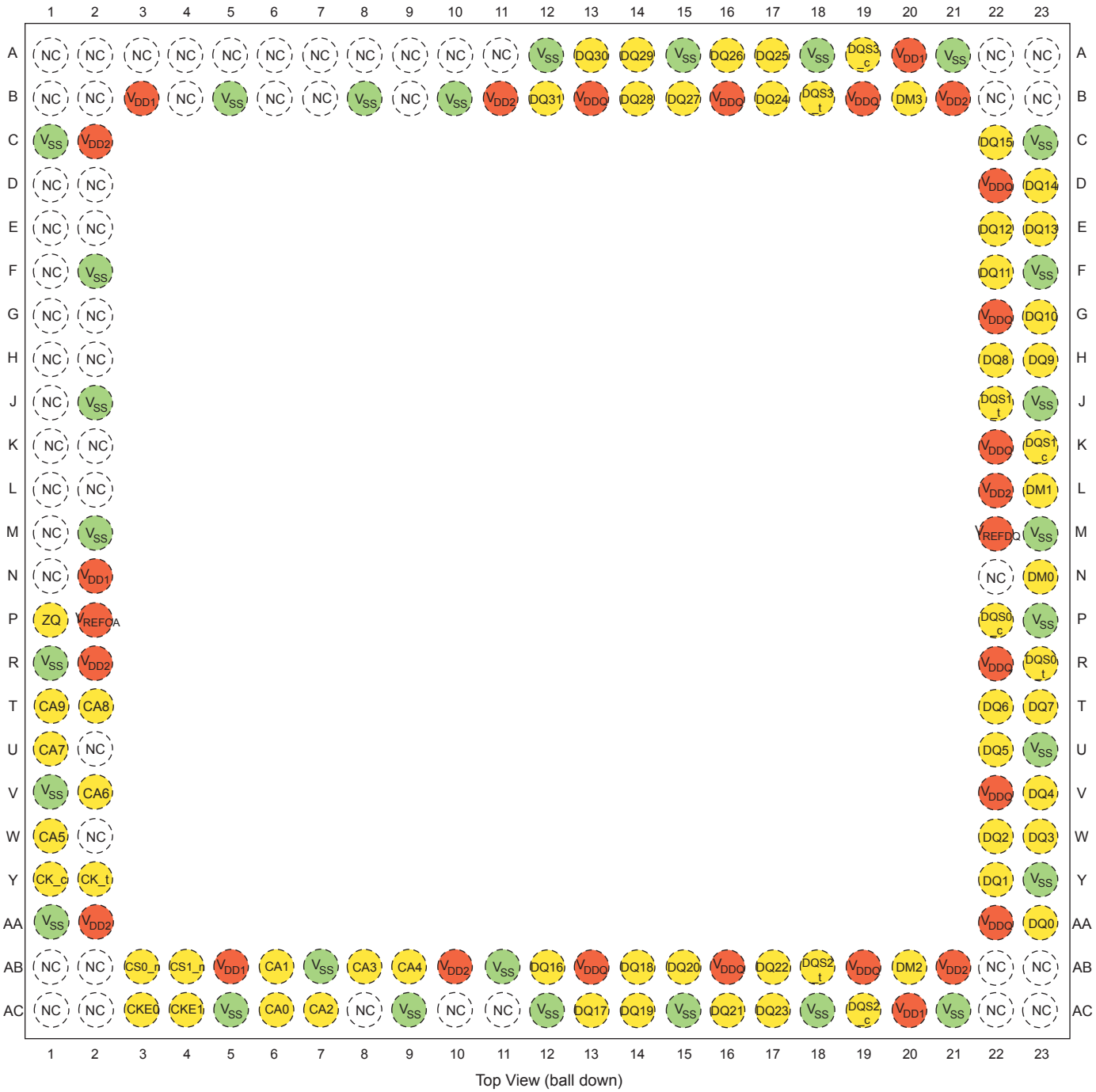
## Figure 3: 168-Ball Single-Channel FBGA – 2 x 4Gb Die




Top View (ball down)



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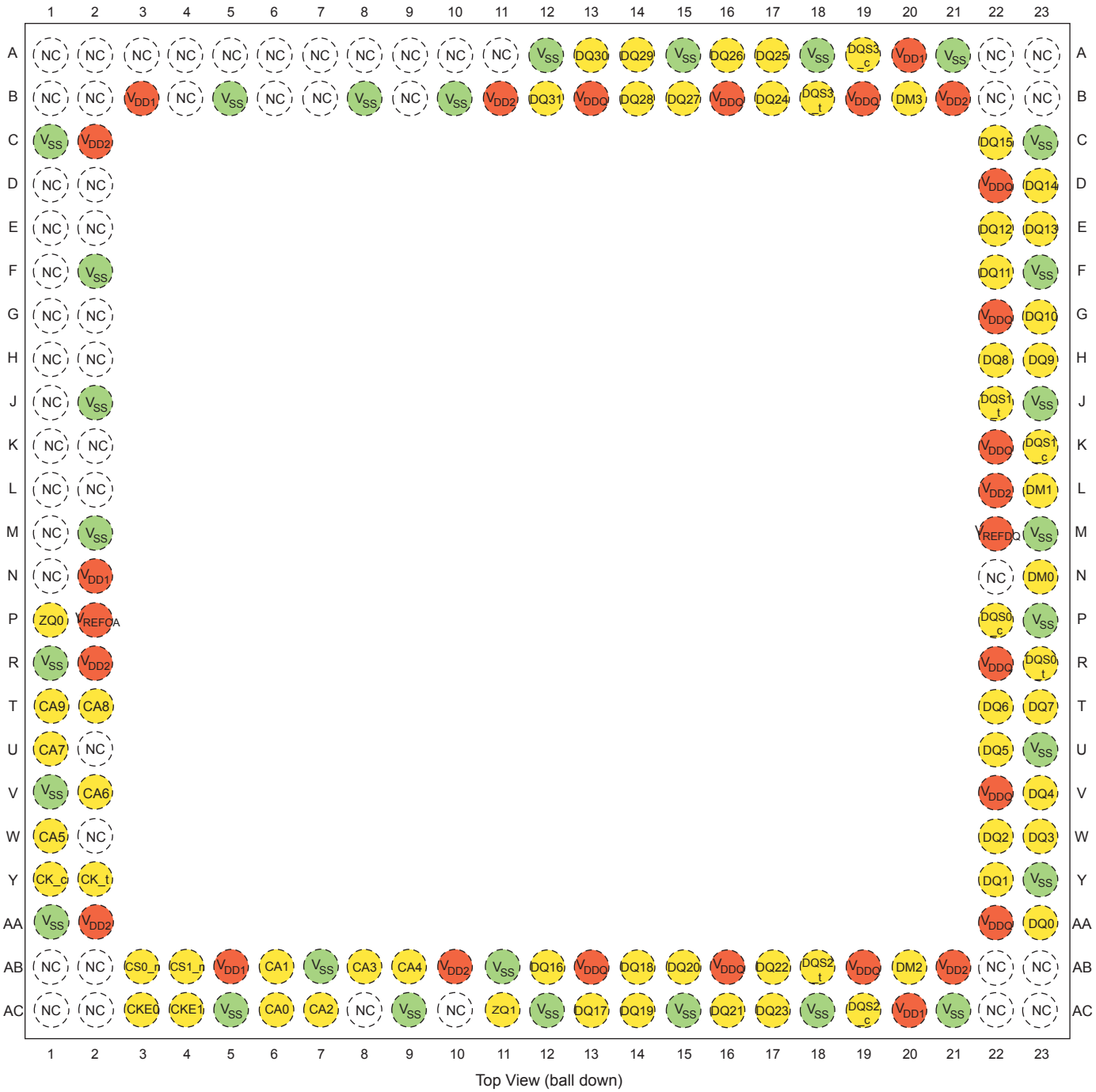
## Figure 4: 168-Ball Single-Channel FBGA – 3 or 4 x 4Gb Die



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# Ball Descriptions

The ball/pad description table below is a comprehensive list of signals for the device family. All signals listed may not be supported on this device. See Ball Assignments for information specific to this device.

**Table 4: Ball/Pad Descriptions**

| Symbol | Type | Description |
|---|---|---|
| CA[9:0] | Input | **Command/address inputs:** Provide the command and address inputs according to the command truth table. |
| CK_t, CK_c | Input | **Clock:** Differential clock inputs. All CA inputs are sampled on both rising and falling edges of CK. CS and CKE inputs are sampled at the rising edge of CK. AC timings are referenced to clock. |
| CKE[1:0] | Input | **Clock enable:** CKE HIGH activates and CKE LOW deactivates the internal clock signals, input buffers, and output drivers. Power-saving modes are entered and exited via CKE transitions. CKE is considered part of the command code. CKE is sampled on the rising edge of CK. |
| CS[1:0]_n | Input | **Chip select:** Considered part of the command code and is sampled on the rising edge of CK. |
| DM[3:0] | Input | **Input data mask:** Input mask signal for write data. Although DM balls are input-only, the DM loading is designed to match that of DQ and DQS balls. DM[3:0] is DM for each of the four data bytes, respectively. |
| DQ[31:0] | I/O | **Data input/output:** Bidirectional data bus. |
| DQS[3:0]_t, DQS[3:0]_c | I/O | **Data strobe:** Bidirectional (used for read and write data) and complementary (DQS_t and DQS_c). It is edge-aligned output with read data and centered input with write data. DQS[3:0]_t/DQS[3:0]_c is DQS for each of the four data bytes, respectively. |
| $V_{DDQ}$ | Supply | **DQ power supply:** Isolated on the die for improved noise immunity. |
| $V_{SSQ}$ | Supply | **DQ ground:** Isolated on the die for improved noise immunity. |
| $V_{DD1}$ | Supply | **Core power:** Supply 1. |
| $V_{DD2}$ | Supply | **Core power:** Supply 2. |
| $V_{SS}$ | Supply | **Common ground.** |
| $V_{REFCA}$, $V_{REFDQ}$ | Supply | **Reference voltage:** $V_{REFCA}$ is reference for command/address input buffers, $V_{REFDQ}$ is reference for DQ input buffers. |
| ZQ[1:0] | Reference | **External reference ball for output drive calibration:** This ball is tied to an external 240Ω resistor (RZQ), which is tied to $V_{SSQ}$. |
| NU | – | **Not usable:** Do not connect. |
| NC | – | **No connect:** Not internally connected. |
| (NC) | – | **No connect:** Balls indicated as (NC) are no connects; however, they could be connected together internally. |


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# Package Block Diagrams

**Figure 5: Single-Die, Single-Channel Package Block Diagram**

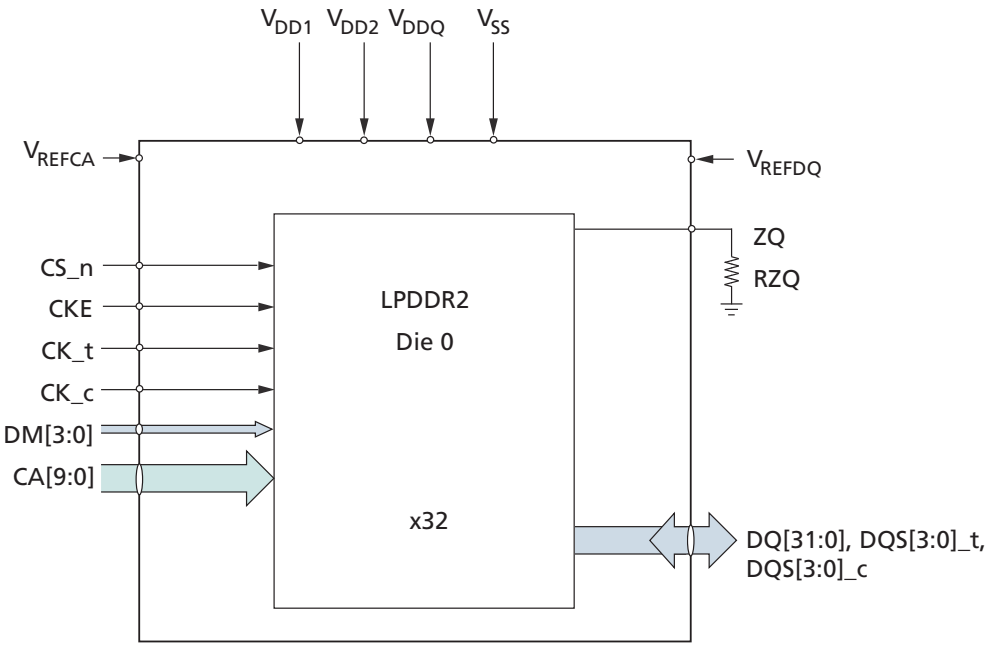



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**Figure 6: Dual-Die, Single-Channel Package Block Diagram**

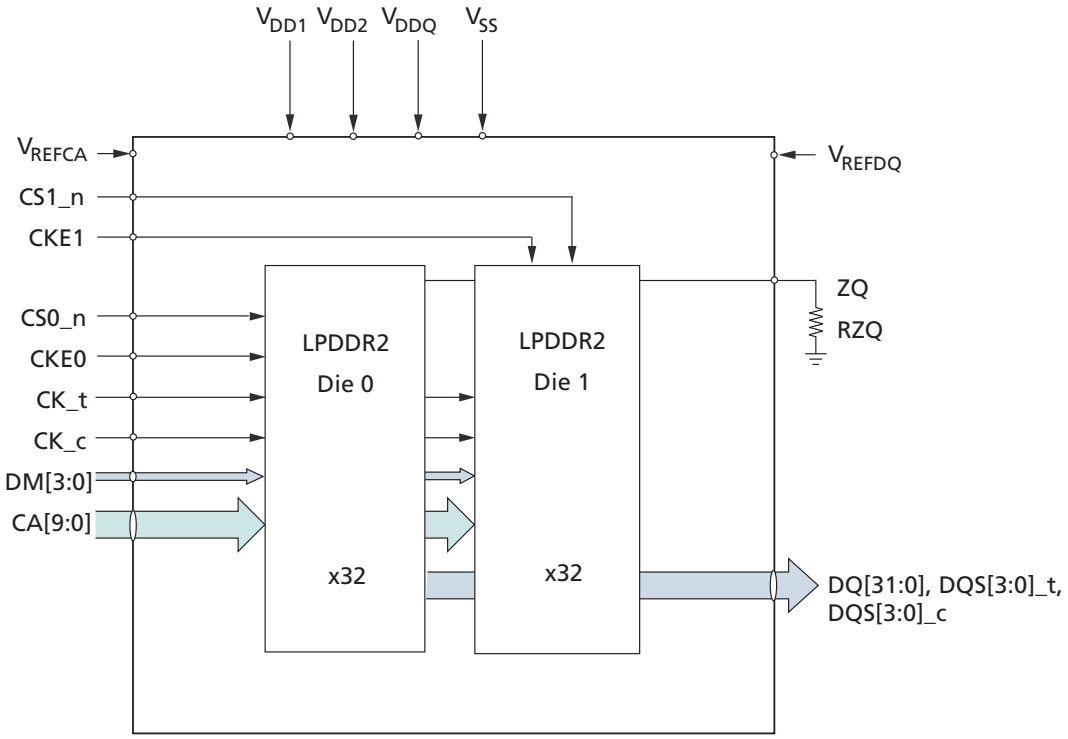



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**Figure 7: 3-Die, Single-Channel Package Block Diagram**

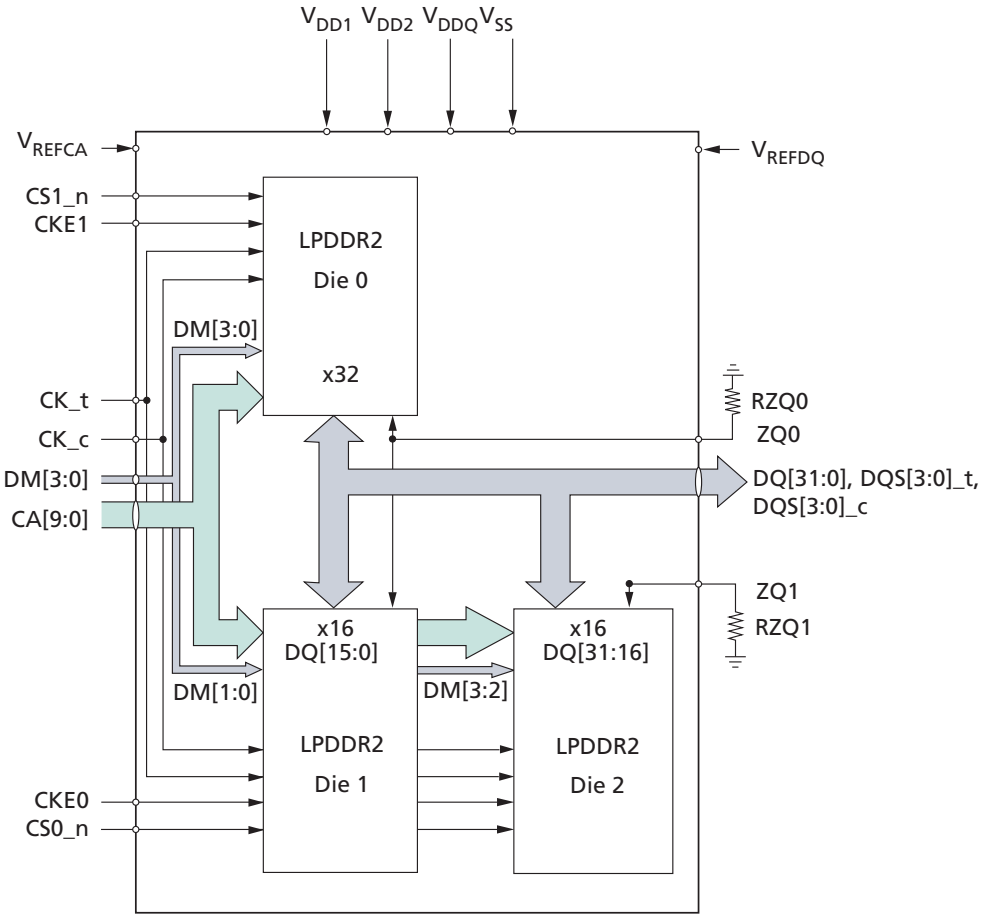



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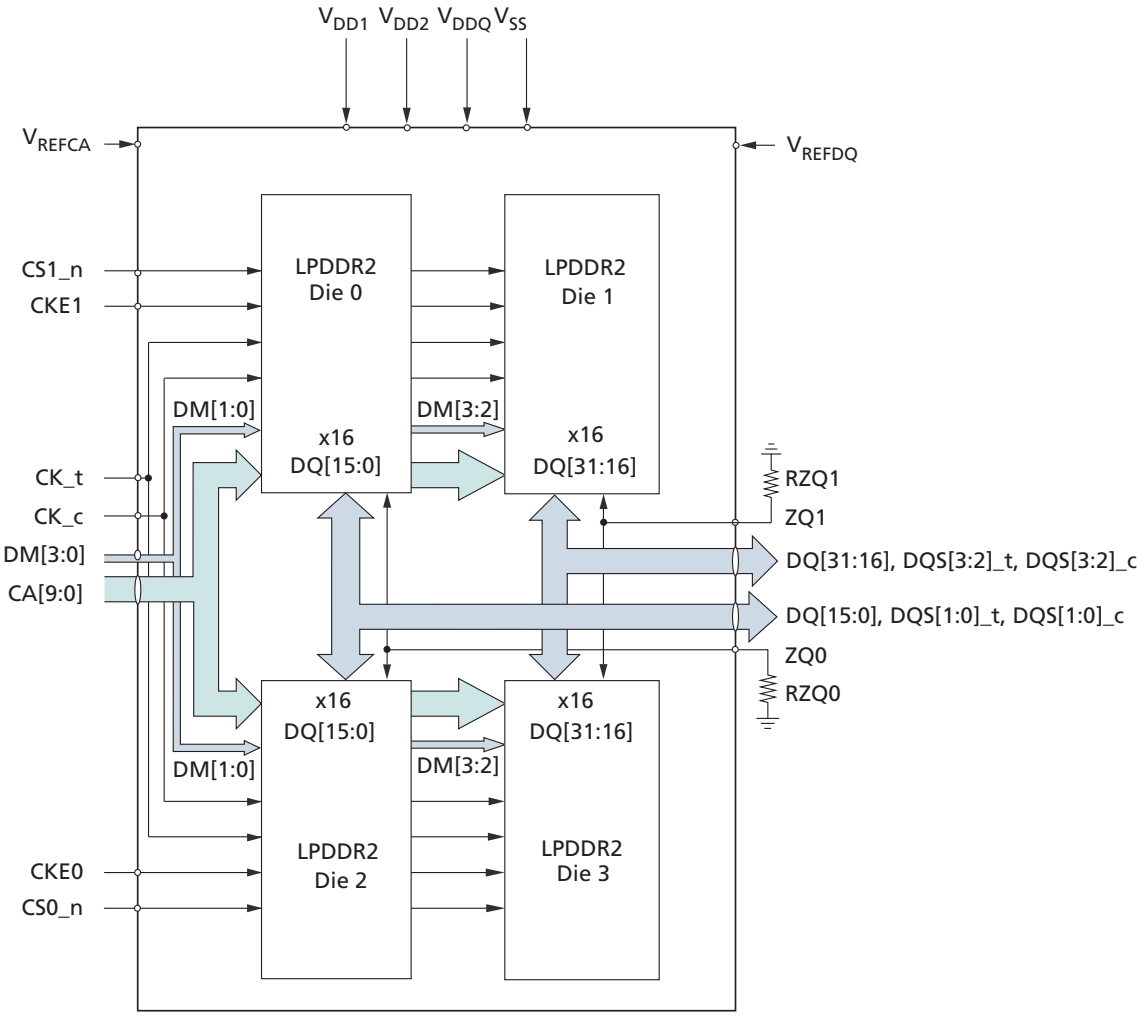
**Figure 8: Quad-Die, Single-Channel Package Block Diagram**





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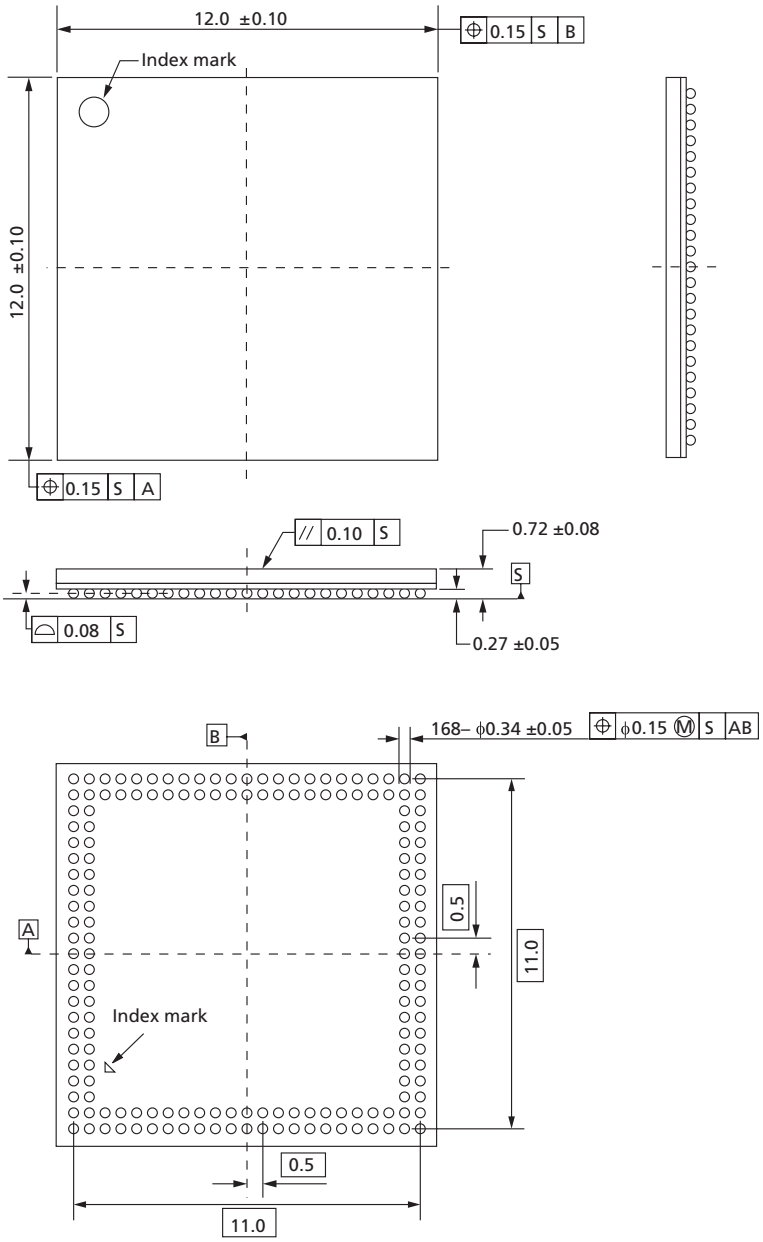
# Package Dimensions

**Figure 9: 168-Ball FBGA (12mm x 12mm) – EDB4432BBPA**




Notes:
1. Package drawing: ECA-TS2-0445-01.
2. All dimensions are in millimeters.


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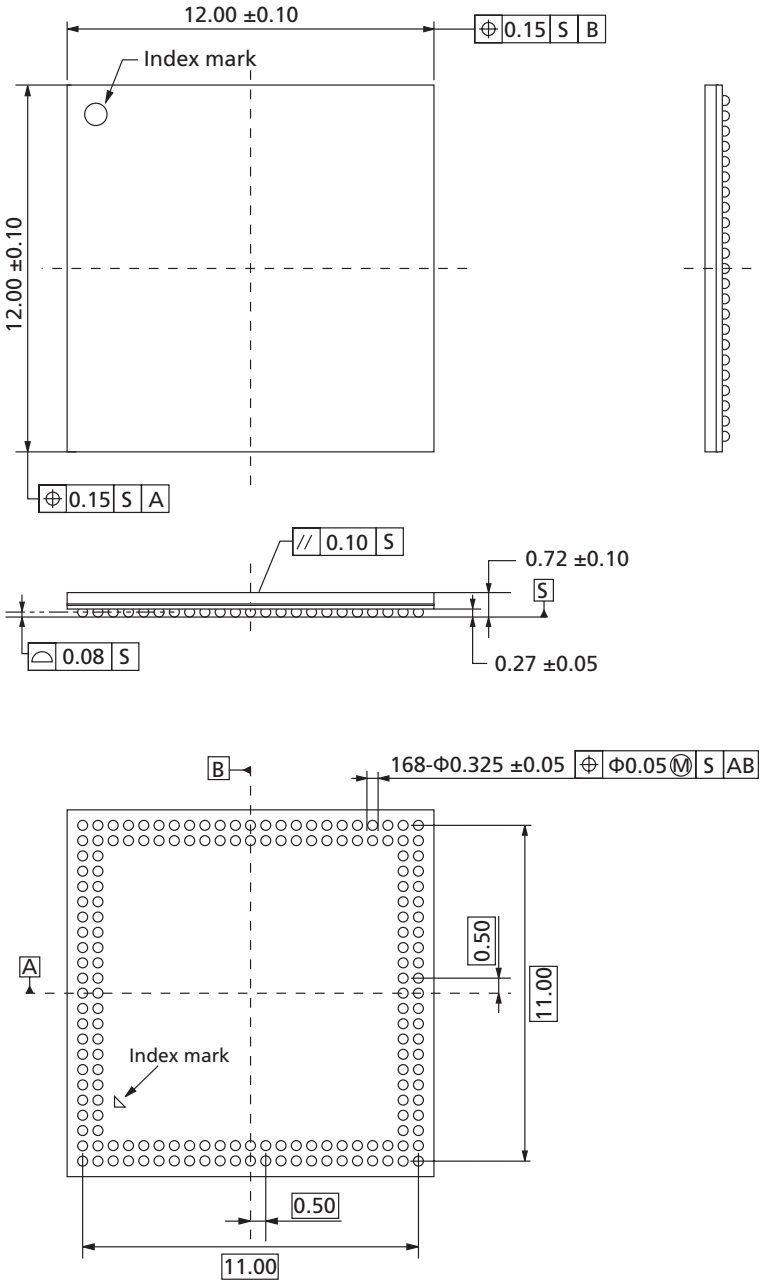
**Figure 10: 168-Ball FBGA (12mm x 12mm) – EDB8132B4PM**




Notes:
1. Package drawing: ECA-TS2-0531-01.
2. All dimensions are in millimeters.


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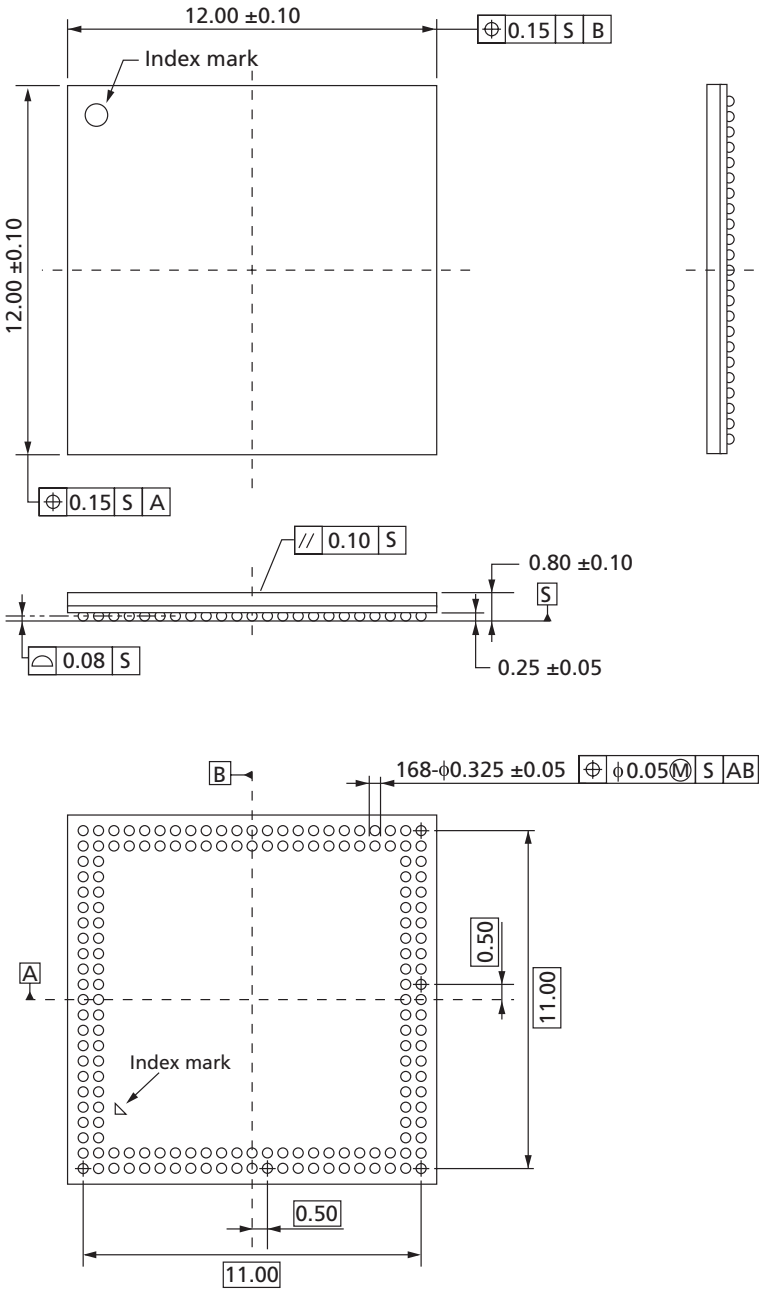
**Figure 11: 168-Ball FBGA (12mm x 12mm) – EDBM432B3PB**




Notes:
1. Package drawing: ECA-TS2-0517-02.
2. All dimensions are in millimeters.


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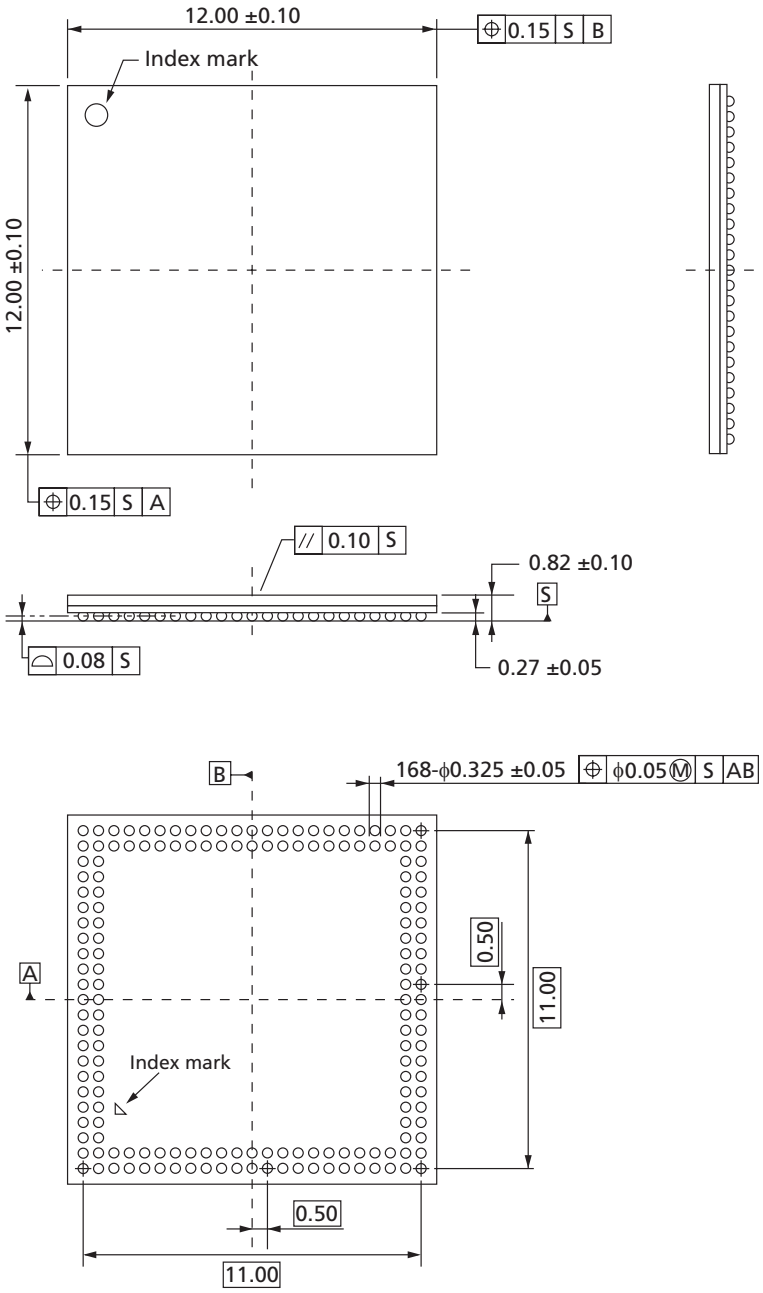
**Figure 12: 168-Ball FBGA (12mm x 12mm) – EDBM432B3PF**




Notes:
1. Package drawing: ECA-TS2-0530-01.
2. All dimensions are in millimeters.


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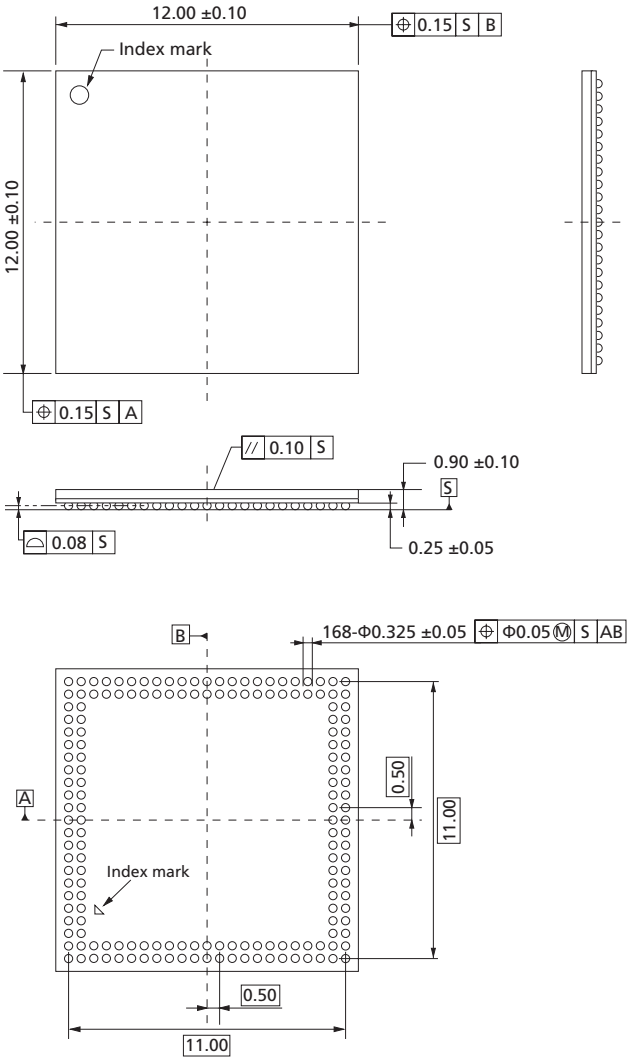
**Figure 13: 168-Ball FBGA (12mm x 12mm) – EDBA232B2PB**




Notes:
1. Package drawing: ECA-TS2-0516-02.
2. All dimensions are in millimeters.


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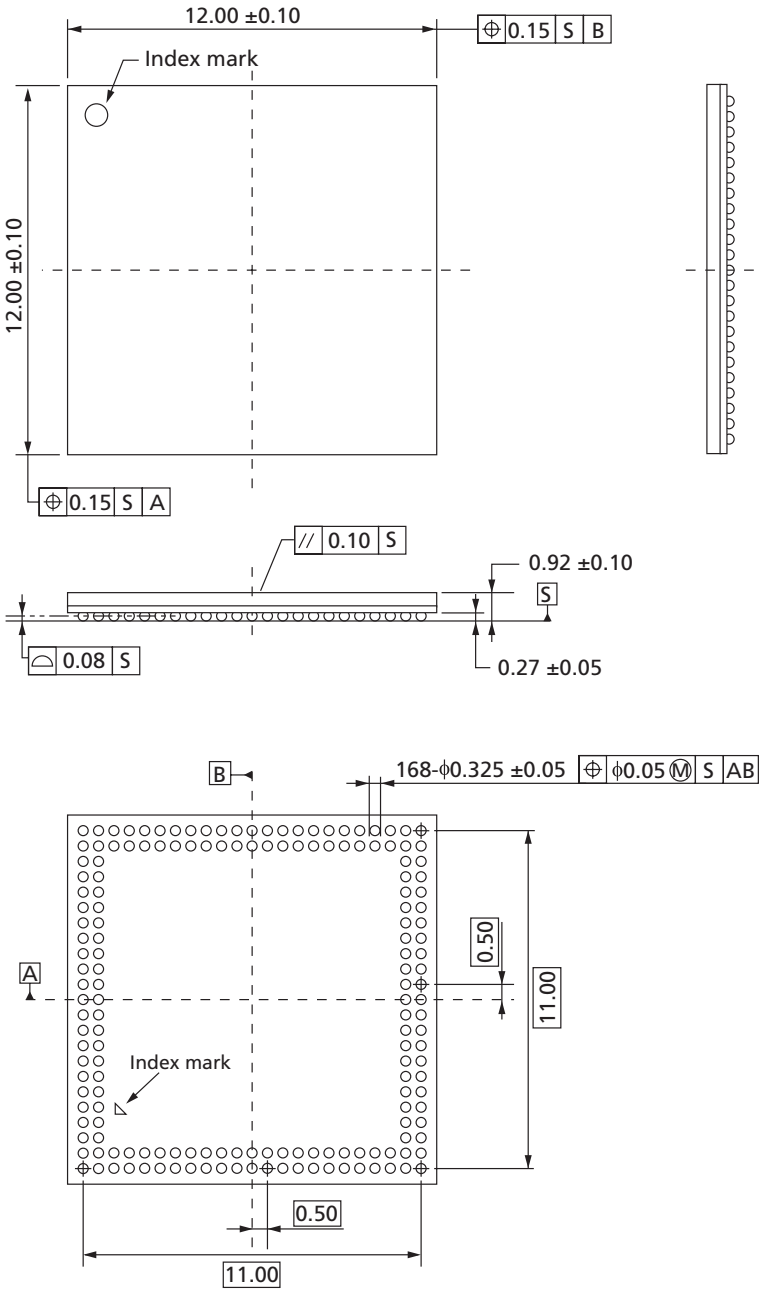
**Figure 14: 168-Ball FBGA (12mm x 12mm) – EDBA232B2PF**




Notes:
1. Package drawing: ECA-TS2-0532-01.
2. All dimensions are in millimeters.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# MR5–MR8 Readout

**Table 5: Mode Register Contents**

| Part Number | Total Density | OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|---|---|
| **MR5** | | | | | | | | | |
| EDB4432BBPA | 4Gb | Manufacturer ID = 0000 0011b: | | | | | | | |
| EDB8132B4PM | 8Gb | | | | | | | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | | | | | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | | | | | | |
| **MR6** | | | | | | | | | |
| EDB4432BBPA | 4Gb | Revision ID1 = 0000 0001b: Revision B | | | | | | | |
| EDB8132B4PM | 8Gb | | | | | | | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | | | | | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | | | | | | |
| **MR7** | | | | | | | | | |
| EDB4432BBPA | 4Gb | Revision ID2 = (RFU) | | | | | | | |
| EDB8132B4PM | 8Gb | | | | | | | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | | | | | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | | | | | | |

| MR8 | | I/O Width/CS_n | | Density | Type |
|---|---|---|---|---|---|
| | | CS0_n | CS1_n | | |
| EDB4432BBPA | 4Gb | 00b: x32 | N/A | 0110b: 4Gb | 00b: S4 |
| EDB8132B4PM | 8Gb | 00b: x32 | 00b: x32 | 0110b: 4Gb | 00b: S4 |
| EDBM432B3PB, EDBM432B3PF | 12Gb | 01b: x16 | 00b: x32 | 0110b: 4Gb | 00b: S4 |
| EDBA232B2PB, EDBA232B2PF | 16Gb | 01b: x16 | 01b: x16 | 0110b: 4Gb | 00b: S4 |

Note: 1. The contents of MR5-MR8 will reflect information specific to each in these packages.



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# $I_{DD}$ Specifications – Single Die, Single Channel

### Table 6: $I_{DD}$ Specifications

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD01}$ | $V_{DD1}$ | 8 | mA | Operating one bank active-precharge current<br>$^tCK$ = $^tCK$(avg) MIN; $^tRC$ = $^tRC$ (MIN)<br>;CKE is HIGH; CS_n is HIGH between valid commands;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD02}$ | $V_{DD2}$ | 50 | | |
| $I_{DD0,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD2P1}$ | $V_{DD1}$ | 0.4 | mA | Idle power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW; CS_n is HIGH;<br>All banks idle; CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2P2}$ | $V_{DD2}$ | 0.9 | | |
| $I_{DD2P,in}$ | $V_{DDQ}$ | 0.1 | | |
| $I_{DD2PS1}$ | $V_{DD1}$ | 0.4 | mA | Idle power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2PS2}$ | $V_{DD2}$ | 0.9 | | |
| $I_{DD2PS,in}$ | $V_{DDQ}$ | 0.1 | | |
| $I_{DD2N1}$ | $V_{DD1}$ | 0.6 | mA | Idle non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2N2}$ | $V_{DD2}$ | 13 | | |
| $I_{DD2N,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD2NS1}$ | $V_{DD1}$ | 0.6 | mA | Idle non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2NS2}$ | $V_{DD2}$ | 6 | | |
| $I_{DD2NS,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD3P1}$ | $V_{DD1}$ | 0.8 | mA | Active power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3P2}$ | $V_{DD2}$ | 5 | | |
| $I_{DD3P,in}$ | $V_{DDQ}$ | 0.1 | | |
| $I_{DD3PS1}$ | $V_{DD1}$ | 0.8 | mA | Active power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3PS2}$ | $V_{DD2}$ | 5 | | |
| $I_{DD3PS,in}$ | $V_{DDQ}$ | 0.1 | | |
| $I_{DD3N1}$ | $V_{DD1}$ | 1.2 | mA | Active non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3N2}$ | $V_{DD2}$ | 19 | | |
| $I_{DD3N,in}$ | $V_{DDQ}$ | 0.6 | | |


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**Table 6: $I_{DD}$ Specifications (Continued)**

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed 1066 | Unit | Parameter/Condition |
|---|---|---|---|---|
| $I_{DD3NS1}$ | $V_{DD1}$ | 1.2 | mA | Active non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3NS2}$ | $V_{DD2}$ | 12 | | |
| $I_{DD3NS,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD4R1}$ | $V_{DD1}$ | 2 | mA | Operating burst read current<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; RL = RL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4R2}$ | $V_{DD2}$ | 160 | | |
| $I_{DD4W1}$ | $V_{DD1}$ | 2 | mA | Operating burst write current<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; WL = WL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4W2}$ | $V_{DD2}$ | 150 | | |
| $I_{DD4W,in}$ | $V_{DDQ}$ | 1 | | |
| $I_{DD51}$ | $V_{DD1}$ | 20 | mA | All bank auto-refresh burst current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tRFCab$ (MIN); Burst refresh;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD52}$ | $V_{DD2}$ | 120 | | |
| $I_{DD5,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD5AB1}$ | $V_{DD1}$ | 2 | mA | All bank auto-refresh average current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tREFI$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5AB2}$ | $V_{DD2}$ | 16 | | |
| $I_{DD5AB,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD5PB1}$ | $V_{DD1}$ | 2 | mA | Per bank auto-refresh average current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tREFIpb$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5PB2}$ | $V_{DD2}$ | 16 | | |
| $I_{DD5PB,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD81}$ | $V_{DD1}$ | 16 | µA | Deep power-down current<br>CK_t = LOW, CK _c = HIGH; CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD82}$ | $V_{DD2}$ | 6 | | |
| $I_{DD8,in}$ | $V_{DDQ}$ | 12 | | |

Notes:
1. Published $I_{DD}$ values are the maximum of the distribution of the arithmetic mean.
2. $I_{DD}$ current specifications are tested after the device is properly initialized.


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### Table 7: $I_{DD6}$ Partial-Array Self Refresh Current at 45°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameter/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 200 | µA | Self-refresh current<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW; CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 800 | | |
| | $V_{DDQ}$ | 10 | | |
| 1/2 array | $V_{DD1}$ | 160 | | |
| | $V_{DD2}$ | 500 | | |
| | $V_{DDQ}$ | 10 | | |
| 1/4 array | $V_{DD1}$ | 130 | | |
| | $V_{DD2}$ | 300 | | |
| | $V_{DDQ}$ | 10 | | |
| 1/8 array | $V_{DD1}$ | 120 | | |
| | $V_{DD2}$ | 200 | | |
| | $V_{DDQ}$ | 10 | | |

Note: 1. $I_{DD6}$ 45°C is the typical of the distribution of the arithmetic mean.

### Table 8: $I_{DD6}$ Partial-Array Self Refresh Current at 85°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameter/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 900 | µA | Self-refresh current<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 3200 | | |
| | $V_{DDQ}$ | 12 | | |
| 1/2 array | $V_{DD1}$ | 650 | | |
| | $V_{DD2}$ | 2200 | | |
| | $V_{DDQ}$ | 12 | | |
| 1/4 array | $V_{DD1}$ | 550 | | |
| | $V_{DD2}$ | 1700 | | |
| | $V_{DDQ}$ | 12 | | |
| 1/8 array | $V_{DD1}$ | 500 | | |
| | $V_{DD2}$ | 1400 | | |
| | $V_{DDQ}$ | 12 | | |

Note: 1. $I_{DD6}$ 85°C is the maximum of the distribution of the arithmetic mean.


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# $I_{DD}$ Specifications – Dual Die, Single Channel

### Table 9: $I_{DD}$ Specifications

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD01}$ | $V_{DD1}$ | 8 | mA | One device in operating one bank active-precharge<br>Another device in deep power-down<br>Conditions for operating devices are:<br>$^tCK$ = $^tCK$(avg) MIN; $^tRC$ = $^tRC$ (MIN); CKE is HIGH; CS_n is HIGH between valid commands;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD02}$ | $V_{DD2}$ | 50 | | |
| $I_{DD0,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD2P1}$ | $V_{DD1}$ | 0.8 | mA | All devices in idle power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW; CS_n is HIGH;<br>All banks idle; CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2P2}$ | $V_{DD2}$ | 1.8 | | |
| $I_{DD2P,in}$ | $V_{DDQ}$ | 0.2 | | |
| $I_{DD2PS1}$ | $V_{DD1}$ | 0.8 | mA | All devices in idle power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2PS2}$ | $V_{DD2}$ | 1.8 | | |
| $I_{DD2PS,in}$ | $V_{DDQ}$ | 0.2 | | |
| $I_{DD2N1}$ | $V_{DD1}$ | 1.2 | mA | All devices in idle non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2N2}$ | $V_{DD2}$ | 26 | | |
| $I_{DD2N,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD2NS1}$ | $V_{DD1}$ | 1.2 | mA | All devices in idle non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2NS2}$ | $V_{DD2}$ | 12 | | |
| $I_{DD2NS,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD3P1}$ | $V_{DD1}$ | 1.6 | mA | All devices in active power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3P2}$ | $V_{DD2}$ | 10 | | |
| $I_{DD3P,in}$ | $V_{DDQ}$ | 0.2 | | |
| $I_{DD3PS1}$ | $V_{DD1}$ | 1.6 | mA | All devices in active power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3PS2}$ | $V_{DD2}$ | 10 | | |
| $I_{DD3PS,in}$ | $V_{DDQ}$ | 0.2 | | |


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**Table 9: $I_{DD}$ Specifications (Continued)**

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed 1066 | Unit | Parameter/Condition |
|---|---|---|---|---|
| $I_{DD3N1}$ | $V_{DD1}$ | 2.4 | mA | All devices in active non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3N2}$ | $V_{DD2}$ | 38 | | |
| $I_{DD3N,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD3NS1}$ | $V_{DD1}$ | 2.4 | mA | All devices in active non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3NS2}$ | $V_{DD2}$ | 24 | | |
| $I_{DD3NS,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD4R1}$ | $V_{DD1}$ | 2 | mA | One device in operating burst read<br>Another device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; RL = RL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4R2}$ | $V_{DD2}$ | 160 | | |
| $I_{DD4W1}$ | $V_{DD1}$ | 2 | mA | One device in operating burst write<br>Another device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; WL = WL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4W2}$ | $V_{DD2}$ | 150 | | |
| $I_{DD4W,in}$ | $V_{DDQ}$ | 1 | | |
| $I_{DD51}$ | $V_{DD1}$ | 20 | mA | One device in all bank auto-refresh<br>Another device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tRFCab$ (MIN); Burst refresh;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD52}$ | $V_{DD2}$ | 120 | | |
| $I_{DD5,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD5AB1}$ | $V_{DD1}$ | 2 | mA | One device in all bank auto-refresh<br>Another device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tREFI$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5AB2}$ | $V_{DD2}$ | 16 | | |
| $I_{DD5AB,in}$ | $V_{DDQ}$ | 0.6 | | |



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## Table 9: $I_{DD}$ Specifications (Continued)

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD5PB1}$ | $V_{DD1}$ | 2 | mA | One device in per bank auto-refresh<br>Another device in deep power-down<br>$^{t}CK$ = $^{t}CK$(avg) MIN; CKE is HIGH between valid commands;<br>$^{t}RC$ = $^{t}REFIpb$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5PB2}$ | $V_{DD2}$ | 16 | | |
| $I_{DD5PB,in}$ | $V_{DDQ}$ | 0.6 | | |
| $I_{DD81}$ | $V_{DD1}$ | 32 | µA | All devices in deep power-down<br>CK_t = LOW, CK _c = HIGH; CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD82}$ | $V_{DD2}$ | 12 | | |
| $I_{DD8,in}$ | $V_{DDQ}$ | 24 | | |

Notes:
1. Published $I_{DD}$ values are the maximum of the distribution of the arithmetic mean.
2. $I_{DD}$ current specifications are tested after the device is properly initialized.

## Table 10: $I_{DD6}$ Partial-Array Self Refresh Current at 45°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameter/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 400 | µA | All devices in self refresh<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW; CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 1600 | | |
| | $V_{DDQ}$ | 20 | | |
| 1/2 array | $V_{DD1}$ | 320 | | |
| | $V_{DD2}$ | 1000 | | |
| | $V_{DDQ}$ | 20 | | |
| 1/4 array | $V_{DD1}$ | 260 | | |
| | $V_{DD2}$ | 600 | | |
| | $V_{DDQ}$ | 20 | | |
| 1/8 array | $V_{DD1}$ | 240 | | |
| | $V_{DD2}$ | 400 | | |
| | $V_{DDQ}$ | 20 | | |

Note:
1. $I_{DD6}$ 45°C is the typical of the distribution of the arithmetic mean.


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### Table 11: $I_{DD6}$ Partial-Array Self Refresh Current at 85°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameter/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 1800 | µA | All devices in self refresh<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 6400 | | |
| | $V_{DDQ}$ | 24 | | |
| 1/2 array | $V_{DD1}$ | 1300 | | |
| | $V_{DD2}$ | 4400 | | |
| | $V_{DDQ}$ | 24 | | |
| 1/4 array | $V_{DD1}$ | 1100 | | |
| | $V_{DD2}$ | 3400 | | |
| | $V_{DDQ}$ | 24 | | |
| 1/8 array | $V_{DD1}$ | 1000 | | |
| | $V_{DD2}$ | 2800 | | |
| | $V_{DDQ}$ | 24 | | |

Note: 1. $I_{DD6}$ 85°C is the maximum of the distribution of the arithmetic mean.



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# $I_{DD}$ Specifications – 3 Die, Single Channel

### Table 12: $I_{DD}$ Specifications

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD01}$ | $V_{DD1}$ | 16 | mA | Two devices in operating one-bank active-precharge<br>One device in deep power-down<br>Conditions for operating devices are:<br>$^tCK$ = $^tCK$(avg) MIN; $^tRC$ = $^tRC$ (MIN); CKE is HIGH; CS_n is HIGH between valid commands;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD02}$ | $V_{DD2}$ | 100 | | |
| $I_{DD0,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD2P1}$ | $V_{DD1}$ | 1.2 | mA | All devices in idle power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW; CS_n is HIGH;<br>All banks idle; CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2P2}$ | $V_{DD2}$ | 2.7 | | |
| $I_{DD2P,in}$ | $V_{DDQ}$ | 0.3 | | |
| $I_{DD2PS1}$ | $V_{DD1}$ | 1.2 | mA | All devices in idle power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2PS2}$ | $V_{DD2}$ | 2.7 | | |
| $I_{DD2PS,in}$ | $V_{DDQ}$ | 0.3 | | |
| $I_{DD2N1}$ | $V_{DD1}$ | 1.8 | mA | All devices in idle non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2N2}$ | $V_{DD2}$ | 39 | | |
| $I_{DD2N,in}$ | $V_{DDQ}$ | 1.8 | | |
| $I_{DD2NS1}$ | $V_{DD1}$ | 1.8 | mA | All devices in idle non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2NS2}$ | $V_{DD2}$ | 18 | | |
| $I_{DD2NS,in}$ | $V_{DDQ}$ | 1.8 | | |
| $I_{DD3P1}$ | $V_{DD1}$ | 2.4 | mA | All devices in active power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3P2}$ | $V_{DD2}$ | 15 | | |
| $I_{DD3P,in}$ | $V_{DDQ}$ | 0.3 | | |
| $I_{DD3PS1}$ | $V_{DD1}$ | 2.4 | mA | All devices in active power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3PS2}$ | $V_{DD2}$ | 15 | | |
| $I_{DD3PS,in}$ | $V_{DDQ}$ | 0.3 | | |


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## Table 12: $I_{DD}$ Specifications (Continued)

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD3N1}$ | $V_{DD1}$ | 3.6 | mA | All devices in active non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3N2}$ | $V_{DD2}$ | 57 | | |
| $I_{DD3N,in}$ | $V_{DDQ}$ | 1.8 | | |
| $I_{DD3NS1}$ | $V_{DD1}$ | 3.6 | mA | All devices in active non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3NS2}$ | $V_{DD2}$ | 36 | | |
| $I_{DD3NS,in}$ | $V_{DDQ}$ | 1.8 | | |
| $I_{DD4R1}$ | $V_{DD1}$ | 4 | mA | Two devices in operating burst read<br>One device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; RL = RL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4R2}$ | $V_{DD2}$ | 260 | | |
| $I_{DD4W1}$ | $V_{DD1}$ | 4 | mA | Two devices in operating burst write<br>One device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; WL = WL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4W2}$ | $V_{DD2}$ | 220 | | |
| $I_{DD4W,in}$ | $V_{DDQ}$ | 2 | | |
| $I_{DD51}$ | $V_{DD1}$ | 40 | mA | Two devices in all-bank auto-refresh<br>One device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tRFCab$ (MIN); Burst refresh;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD52}$ | $V_{DD2}$ | 240 | | |
| $I_{DD5,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD5AB1}$ | $V_{DD1}$ | 4 | mA | Two devices in all-bank auto-refresh<br>One device in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tREFI$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5AB2}$ | $V_{DD2}$ | 32 | | |
| $I_{DD5AB,in}$ | $V_{DDQ}$ | 1.2 | | |



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## Table 12: $I_{DD}$ Specifications (Continued)

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD5PB1}$ | $V_{DD1}$ | 4 | mA | Two devices in per-bank auto-refresh<br>One device in deep power-down<br>$^{t}CK$ = $^{t}CK$(avg) MIN; CKE is HIGH between valid commands;<br>$^{t}RC$ = $^{t}REFIpb$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5PB2}$ | $V_{DD2}$ | 32 | | |
| $I_{DD5PB,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD81}$ | $V_{DD1}$ | 48 | µA | All devices in deep power-down<br>CK_t = LOW, CK _c = HIGH; CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD82}$ | $V_{DD2}$ | 18 | | |
| $I_{DD8,in}$ | $V_{DDQ}$ | 36 | | |

Notes:
1. Published $I_{DD}$ values are the maximum of the distribution of the arithmetic mean.
2. $I_{DD}$ current specifications are tested after the device is properly initialized.

## Table 13: $I_{DD6}$ Partial-Array Self Refresh Current at 45°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameter/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 600 | µA | All devices in self refresh<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW; CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 2400 | | |
| | $V_{DDQ}$ | 30 | | |
| 1/2 array | $V_{DD1}$ | 480 | | |
| | $V_{DD2}$ | 1500 | | |
| | $V_{DDQ}$ | 30 | | |
| 1/4 array | $V_{DD1}$ | 390 | | |
| | $V_{DD2}$ | 900 | | |
| | $V_{DDQ}$ | 30 | | |
| 1/8 array | $V_{DD1}$ | 360 | | |
| | $V_{DD2}$ | 600 | | |
| | $V_{DDQ}$ | 30 | | |

Note:
1. $I_{DD6}$ 45°C is the typical of the distribution of the arithmetic mean.


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### Table 14: $I_{DD6}$ Partial-Array Self Refresh Current at 85°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameter/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 2700 | µA | All devices in self refresh<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 9600 | | |
| | $V_{DDQ}$ | 36 | | |
| 1/2 array | $V_{DD1}$ | 1950 | | |
| | $V_{DD2}$ | 6600 | | |
| | $V_{DDQ}$ | 36 | | |
| 1/4 array | $V_{DD1}$ | 1650 | | |
| | $V_{DD2}$ | 5100 | | |
| | $V_{DDQ}$ | 36 | | |
| 1/8 array | $V_{DD1}$ | 1500 | | |
| | $V_{DD2}$ | 4200 | | |
| | $V_{DDQ}$ | 36 | | |

Note: 1. $I_{DD6}$ 85°C is the maximum of the distribution of the arithmetic mean.



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# $I_{DD}$ Specifications – Quad Die, Single Channel

### Table 15: $I_{DD}$ Specifications

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD01}$ | $V_{DD1}$ | 16 | mA | Two devices in operating one bank active-precharge<br>Two devices in deep power-down<br>Conditions for operating devices are:<br>$^tCK$ = $^tCK$(avg) MIN; $^tRC$ = $^tRC$ (MIN); CKE is HIGH; CS_n is HIGH between valid commands;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD02}$ | $V_{DD2}$ | 100 | | |
| $I_{DD0,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD2P1}$ | $V_{DD1}$ | 1.6 | mA | All devices in idle power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW; CS_n is HIGH;<br>All banks idle; CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2P2}$ | $V_{DD2}$ | 3.6 | | |
| $I_{DD2P,in}$ | $V_{DDQ}$ | 0.4 | | |
| $I_{DD2PS1}$ | $V_{DD1}$ | 1.6 | mA | All devices in idle power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2PS2}$ | $V_{DD2}$ | 3.6 | | |
| $I_{DD2PS,in}$ | $V_{DDQ}$ | 0.4 | | |
| $I_{DD2N1}$ | $V_{DD1}$ | 2.4 | mA | All devices in idle non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD2N2}$ | $V_{DD2}$ | 52 | | |
| $I_{DD2N,in}$ | $V_{DDQ}$ | 2.4 | | |
| $I_{DD2NS1}$ | $V_{DD1}$ | 2.4 | mA | All devices in idle non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; All banks idle;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD2NS2}$ | $V_{DD2}$ | 24 | | |
| $I_{DD2NS,in}$ | $V_{DDQ}$ | 2.4 | | |
| $I_{DD3P1}$ | $V_{DD1}$ | 3.2 | mA | All devices in active power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3P2}$ | $V_{DD2}$ | 20 | | |
| $I_{DD3P,in}$ | $V_{DDQ}$ | 0.4 | | |
| $I_{DD3PS1}$ | $V_{DD1}$ | 3.2 | mA | All devices in active power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is LOW;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3PS2}$ | $V_{DD2}$ | 20 | | |
| $I_{DD3PS,in}$ | $V_{DDQ}$ | 0.4 | | |


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**Table 15: $I_{DD}$ Specifications (Continued)**

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed 1066 | Unit | Parameter/Condition |
|---|---|---|---|---|
| $I_{DD3N1}$ | $V_{DD1}$ | 4.8 | mA | All devices in active non power-down standby current<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD3N2}$ | $V_{DD2}$ | 76 | | |
| $I_{DD3N,in}$ | $V_{DDQ}$ | 2.4 | | |
| $I_{DD3NS1}$ | $V_{DD1}$ | 4.8 | mA | All devices in active non power-down standby current with clock stop<br>CK_t = LOW, CK_c = HIGH; CKE is HIGH;<br>CS_n is HIGH; One bank active;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD3NS2}$ | $V_{DD2}$ | 48 | | |
| $I_{DD3NS,in}$ | $V_{DDQ}$ | 2.4 | | |
| $I_{DD4R1}$ | $V_{DD1}$ | 4 | mA | Two devices in operating burst read<br>Two devices in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; RL = RL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4R2}$ | $V_{DD2}$ | 260 | | |
| $I_{DD4W1}$ | $V_{DD1}$ | 4 | mA | Two devices in operating burst write<br>Two devices in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CS_n is HIGH between valid commands;<br>One bank active; BL = 4; WL = WL (MIN);<br>CA bus inputs are SWITCHING;<br>50% data change each burst transfer |
| $I_{DD4W2}$ | $V_{DD2}$ | 220 | | |
| $I_{DD4W,in}$ | $V_{DDQ}$ | 2 | | |
| $I_{DD51}$ | $V_{DD1}$ | 40 | mA | Two devices in all bank auto-refresh<br>Two devices in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tRFCab$ (MIN); Burst refresh;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD52}$ | $V_{DD2}$ | 240 | | |
| $I_{DD5,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD5AB1}$ | $V_{DD1}$ | 4 | mA | Two devices in all bank auto-refresh<br>Two devices in deep power-down<br>$^tCK$ = $^tCK$(avg) MIN; CKE is HIGH between valid commands;<br>$^tRC$ = $^tREFI$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5AB2}$ | $V_{DD2}$ | 32 | | |
| $I_{DD5AB,in}$ | $V_{DDQ}$ | 1.2 | | |



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## Table 15: $I_{DD}$ Specifications (Continued)

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V; $T_C$ = –30°C to +85°C

| Symbol | Supply | Speed | Unit | Parameter/Condition |
|---|---|---|---|---|
| | | 1066 | | |
| $I_{DD5PB1}$ | $V_{DD1}$ | 4 | mA | Two devices in per bank auto-refresh<br>Two devices in deep power-down<br>$^{t}CK$ = $^{t}CK$(avg) MIN; CKE is HIGH between valid commands;<br>$^{t}RC$ = $^{t}REFIpb$;<br>CA bus inputs are SWITCHING;<br>Data bus inputs are STABLE |
| $I_{DD5PB2}$ | $V_{DD2}$ | 32 | | |
| $I_{DD5PB,in}$ | $V_{DDQ}$ | 1.2 | | |
| $I_{DD81}$ | $V_{DD1}$ | 64 | µA | All devices in deep power-down<br>CK_t = LOW, CK _c = HIGH; CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| $I_{DD82}$ | $V_{DD2}$ | 24 | | |
| $I_{DD8,in}$ | $V_{DDQ}$ | 48 | | |

Notes:
1. Published $I_{DD}$ values are the maximum of the distribution of the arithmetic mean.
2. $I_{DD}$ current specifications are tested after the device is properly initialized.

## Table 16: $I_{DD6}$ Partial-Array Self Refresh Current at 45°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameters/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 800 | µA | All devices in self refresh<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 3200 | | |
| | $V_{DDQ}$ | 40 | | |
| 1/2 array | $V_{DD1}$ | 640 | | |
| | $V_{DD2}$ | 2000 | | |
| | $V_{DDQ}$ | 40 | | |
| 1/4 array | $V_{DD1}$ | 520 | | |
| | $V_{DD2}$ | 1200 | | |
| | $V_{DDQ}$ | 40 | | |
| 1/8 array | $V_{DD1}$ | 480 | | |
| | $V_{DD2}$ | 800 | | |
| | $V_{DDQ}$ | 40 | | |

Note:
1. $I_{DD6}$ 45°C is the typical of the distribution of the arithmetic mean.


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### Table 17: $I_{DD6}$ Partial-Array Self Refresh Current at 85°C

$V_{DD2}$, $V_{DDQ}$ = 1.14–1.30V; $V_{DD1}$ = 1.70–1.95V

| PASR | Supply | Value | Unit | Parameters/Conditions |
|---|---|---|---|---|
| Full array | $V_{DD1}$ | 3600 | µA | All devices in self refresh<br>CK_t = LOW, CK_c = HIGH;<br>CKE is LOW;<br>CA bus inputs are STABLE;<br>Data bus inputs are STABLE |
| | $V_{DD2}$ | 12800 | | |
| | $V_{DDQ}$ | 48 | | |
| 1/2 array | $V_{DD1}$ | 2600 | | |
| | $V_{DD2}$ | 8800 | | |
| | $V_{DDQ}$ | 48 | | |
| 1/4 array | $V_{DD1}$ | 2200 | | |
| | $V_{DD2}$ | 6800 | | |
| | $V_{DDQ}$ | 48 | | |
| 1/8 array | $V_{DD1}$ | 2000 | | |
| | $V_{DD2}$ | 5600 | | |
| | $V_{DDQ}$ | 48 | | |

Note: 1. $I_{DD6}$ 85°C is the maximum of the distribution of the arithmetic mean.



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# Pin Capacitance

**Table 18: Input/Output Capacitance**

| Part Number | Density | Parameter | Symbol | Min | Max | Unit | Notes |
|---|---|---|---|---|---|---|---|
| EDB4432BBPA | 4Gb | Input capacitance, CK_t and CK_c | $C_{I1}$ | 1.5 | 3.5 | pF | 1, 2 |
| EDB8132B4PM | 8Gb | | | 2.5 | 4.5 | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | 3.5 | 6.0 | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | 4.0 | 7.5 | | |
| EDB4432BBPA | 4Gb | Input capacitance, all other input-only pins | $C_{I2}$ | 1.5 | 3.5 | pF | 1, 2 |
| EDB8132B4PM | 8Gb | | | 1.5 | 5.0 | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | 1.5 | 6.5 | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | 2.5 | 7.5 | | |
| EDB4432BBPA | 4Gb | Input/output capacitance, DQ, DM, DQS_t, DQS_c | $C_{IO}$ | 1.5 | 4.0 | pF | 1, 2, 3 |
| EDB8132B4PM | 8Gb | | | 2.5 | 6.0 | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | | | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | | | | |
| EDB4432BBPA | 4Gb | Input/output capacitance, ZQ | $C_{ZQ}$ | 1.5 | 3.5 | pF | 1, 2, 3 |
| EDB8132B4PM | 8Gb | | | | | | |
| EDBM432B3PB, EDBM432B3PF | 12Gb | | | 2.0 | 5.0 | | |
| EDBA232B2PB, EDBA232B2PF | 16Gb | | | 2.5 | 5.5 | | |

Notes:
1. This parameter is not subject to production testing. It is verified by design and characterization.
2. These parameters are measured on $f$ = 100 MHz, $V_{OUT} = V_{DDQ/2}$, $T_A$ = +25 °C.
3. $D_{OUT}$ circuits are disabled.


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# LPDDR2 Array Configuration

The 4Gb Mobile Low-Power DDR2 SDRAM (LPDDR2) is a high-speed CMOS, dynamic random-access memory containing 4,294,967,296-bits. The device is internally configured as an eight-bank DRAM. Each of the x16's 536,870,912-bit banks is organized as 16,384 rows by 2048 columns by 16 bits. Each of the x32's 536,870,912-bit banks is organized as 16,384 rows by 1024 columns by 32 bits.

## General Notes

Throughout the data sheet, figures and text refer to DQs as "DQ." DQ should be interpreted as any or all DQ collectively, unless specifically stated otherwise.

"DQS" and "CK" should be interpreted as DQS_t, DQS_c and CK_t, CK_c respectively, unless specifically stated otherwise. "BA" includes all BA pins used for a given density.

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 herein is considered undefined, illegal, is not supported, and will result in unknown operation.



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# Functional Description

Mobile LPDDR2 is a high-speed SDRAM internally configured as a 4- or 8-bank memory device. The device uses a double data rate architecture on the command/address (CA) bus to reduce the number of input pins in the system. The 10-bit CA bus is used to transmit command, address, and bank information. Each command uses one clock cycle, during which command information is transferred on both the rising and falling edges of the clock.

The LPDDR2-S4 device uses a double data rate architecture on the DQ pins to achieve high- speed operation. The double data rate architecture is essentially a 4*n* prefetch architecture with an interface designed to transfer two data bits per DQ every clock cycle at the I/O pins. A single read or write access for the LPDDR2-S4 effectively consists of a single 4*n*-bit-wide, one-clock-cycle data transfer at the internal SDRAM core and four corresponding *n*-bit-wide, one-half-clock-cycle data transfers at the I/O pins.

Read and write access is burst oriented; access starts at a selected location and continues for a programmed number of locations in a programmed sequence.

Access begins with the registration of an ACTIVATE command followed by a READ or WRITE command. Registered address and BA bits that coincide with the ACTIVATE command are used to select the row and bank to be accessed. Registered address bits that coincide with the READ or WRITE command are used to select the bank and the starting column location for the burst access.



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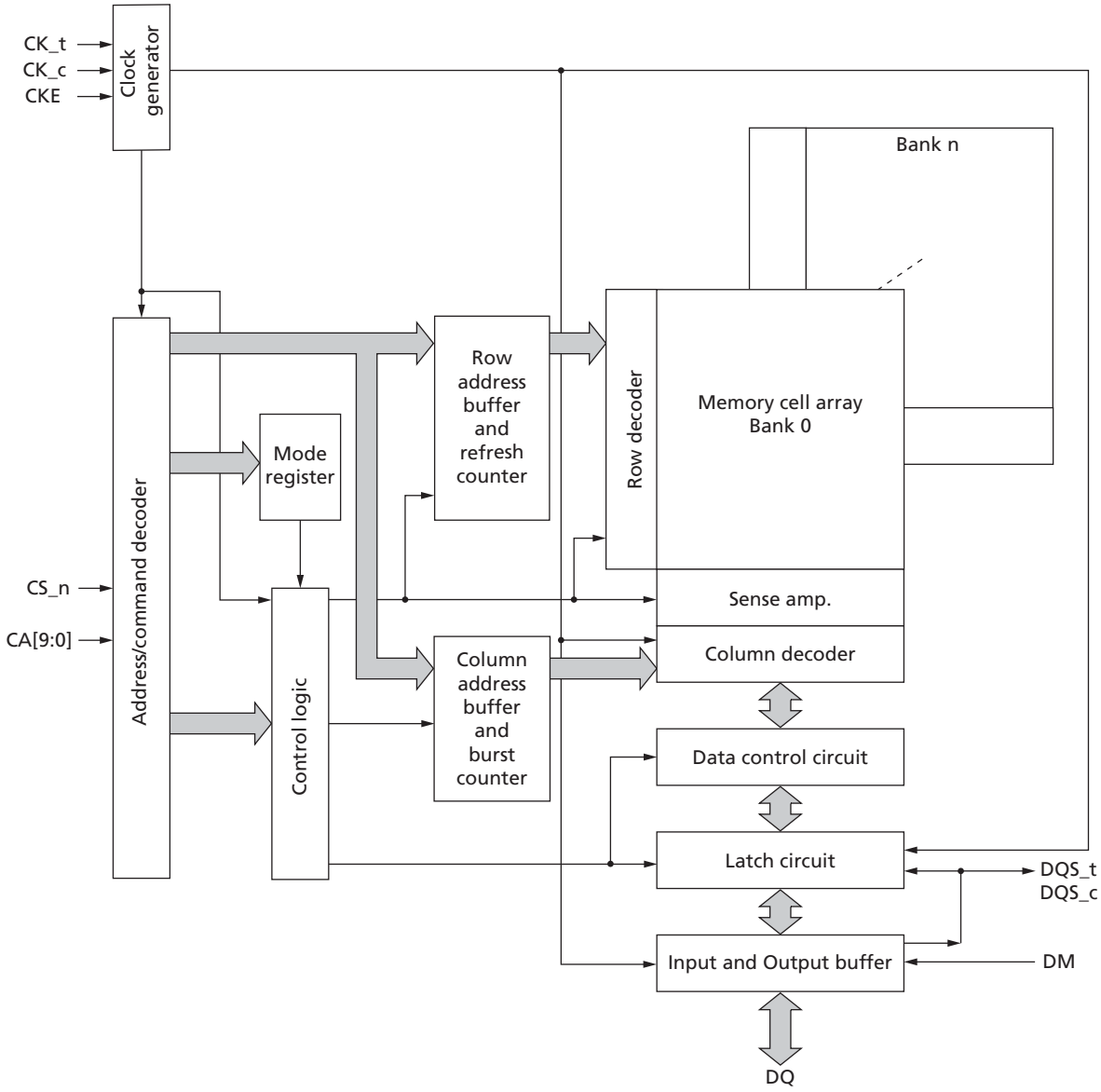
**Figure 15: Functional Block Diagram**




Note: 1. 512Mb is a 4-bank only.

## Simplified State Diagram

The state diagram provides a simplified illustration of allowed state transitions and the related commands to control them. For a complete definition of the device behavior, the information provided by the state diagram should be integrated with the truth tables and timing specification. The truth tables provide complementary information to the state diagram, they clarify the device behavior and the applied restrictions when considering the actual state of all the banks.


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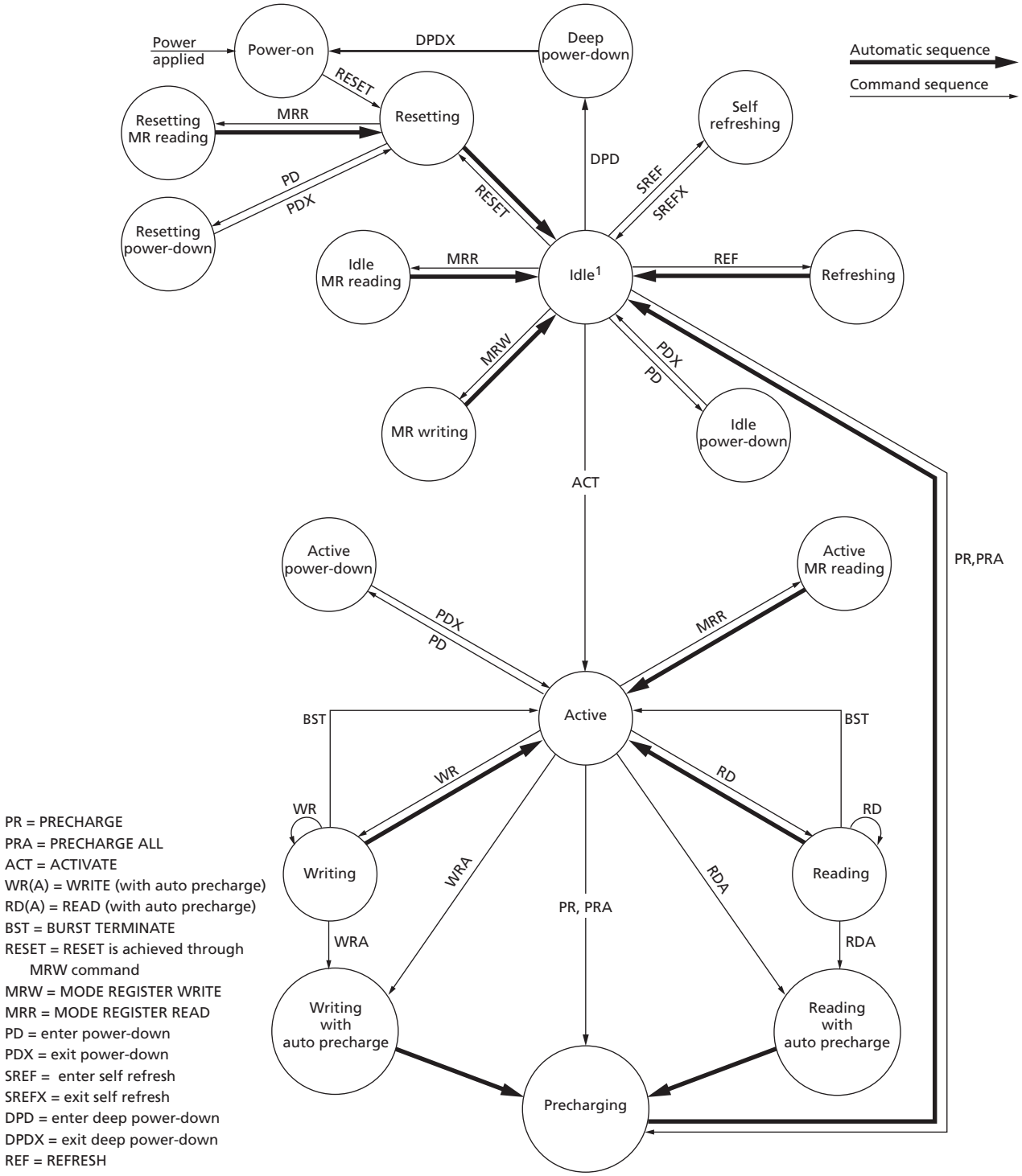
**Figure 16: Simplified State Diagram**




Note: 1. All banks are precharged in the idle state.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# Power-Up and Initialization

The device must be powered up and initialized in a predefined manner. Power-up and initialization by means other than those specified will result in undefined operation.

## Voltage Ramp and Device Initialization

The following sequence must be used to power up the device. Unless specified otherwise, this procedure is mandatory (see the Voltage Ramp and Initialization Sequence figure). Power-up and initialization by means other than those specified will result in undefined operation.

**1. Voltage Ramp Beginning**

While applying power (after Ta), CKE must be held LOW ($\leq 0.2 \times V_{DD2}$), and all other inputs must be between $V_{ILmin}$ and $V_{IHmax}$. The device outputs remain at High-Z while CKE is held LOW.

On or before the completion of the voltage ramp (Tb), CKE must be held LOW. DQ, DM, DQS_t, and DQS_c voltage levels must be between $V_{SSQ}$ and $V_{DDQ}$ during voltage ramp to avoid latchup. CK_t, CK_c, CS_n, and CA input levels must be between $V_{SS}$ and $V_{DD2}$ during voltage ramp to avoid latchup.

The following conditions apply for voltage ramp:

- Ta is the point when any power supply first reaches 300mV.
- Noted conditions apply between Ta and power-down (controlled or uncontrolled).
- Tb is the point at which all supply and reference voltages are within their defined operating ranges.
- Power ramp duration $^{t}INIT0$ (Tb - Ta) must not exceed 20ms.
- For supply and reference voltage operating conditions, see the Recommended DC Operating Conditions table.
- The voltage difference between any of $V_{SS}$, and $V_{SSQ}$ pins must not exceed 100mV.

**2. Voltage Ramp Completion**

After Ta is reached:

- $V_{DD1}$ must be greater than $V_{DD2}$ - 200mV
- $V_{DD1}$ and $V_{DD2}$ must be greater than $V_{DDQ}$ - 200mV
- $V_{REF}$ must always be less than all other supply voltages

Beginning at Tb, CKE must remain LOW for at least $^{t}INIT1$ = 100ns, after which CKE can be asserted HIGH. The clock must be stable at least $^{t}INIT2 = 5 \times {}^{t}CK$ prior to the first CKE LOW-to-HIGH transition (Tc). CKE, CS_n, and CA inputs must observe setup and hold requirements ($^{t}IS$, $^{t}IH$) with respect to the first rising clock edge (and to subsequent falling and rising edges).

If any MRRs are issued, the clock period must be within the range defined for $^{t}CKb$ (18ns to 100ns). MRWs can be issued at normal clock frequencies as long as all AC timings are met. Some AC parameters (for example, $^{t}DQSCK$) could have relaxed timings (such as $^{t}DQSCKb$) before the system is appropriately configured. While keeping CKE HIGH, NOP commands must be issued for at least $^{t}INIT3$ = 200µs (Td).



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**3. RESET Command**

After $^{t}$INIT3 is satisfied, the MRW RESET command must be issued (Td). An optional PRECHARGE ALL command can be issued prior to the MRW RESET command. Wait at least $^{t}$INIT4 while keeping CKE asserted and issuing NOP commands.

**4. MRRs and Device Auto Initialization (DAI) Polling**

After $^{t}$INIT4 is satisfied (Te), only MRR commands and power-down entry/exit commands are supported. After Te, CKE can go LOW in alignment with power-down entry and exit specifications (see Power-Down).

The MRR command can be used to poll the DAI bit, which indicates when device auto initialization is complete; otherwise, the controller must wait a minimum of $^{t}$INIT5 or until the DAI bit is set before proceeding.

Because the memory output buffers are not properly configured by Te, some AC parameters must use relaxed timing specifications before the system is appropriately configured.

After the memory device sets the DAI bit (MR0, DAI) to zero, indicating DAI complete, the device is in the idle state (Tf). DAI status can be determined by issuing the MRR command to MR0.

The device sets the DAI bit no later than $^{t}$INIT5 after the RESET command. The controller must wait at least $^{t}$INIT5 or until the DAI bit is set before proceeding.

**5. ZQ Calibration**

After $^{t}$INIT5 (Tf), the MRW initialization calibration (ZQ calibration) command can be issued to the memory (MR10).

This command is used to calibrate output impedance over process, voltage, and temperature. In systems where more than one Mobile LPDDR2 device exists on the same bus, the controller must not overlap MRW ZQ calibration commands. The device is ready for normal operation after $^{t}$ZQINIT.

**6. Normal Operation**

After (Tg), the MRW command must be used to properly configure the memory, including, for example, output buffer drive strength, latencies,and so on. Specifically, MR1, MR2, and MR3 must be set to configure the memory for the target frequency and memory configuration.

After the initialization sequence is complete, the device is ready for any valid command. After Tg, the clock frequency can be changed using the procedure described in Input Clock Frequency Changes and Stop Events.



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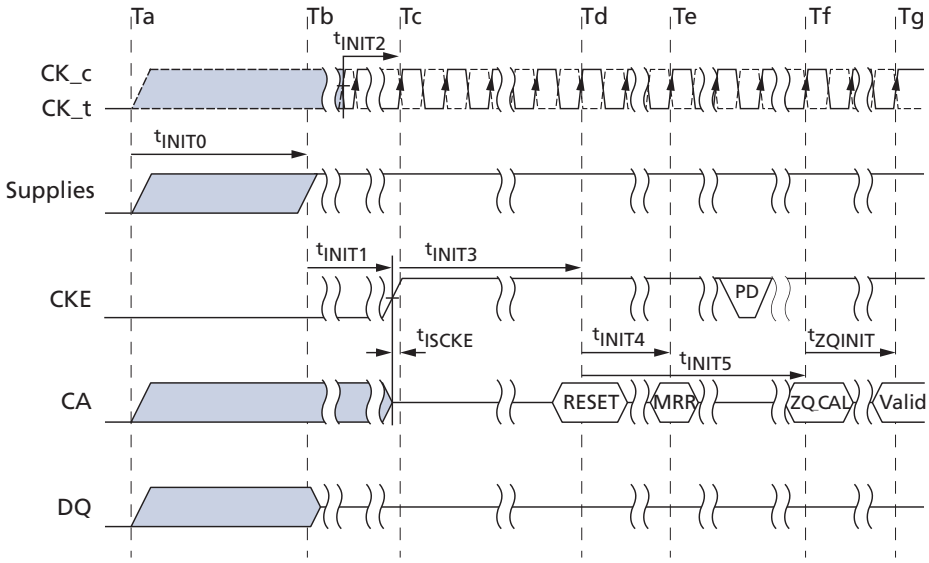
**Figure 17: Voltage Ramp and Initialization Sequence**




Note: 1. High-Z on the CA bus indicates valid NOP.

**Table 19: Initialization Timing Parameters**

| Parameter | Value | | Unit | Comment |
|---|---|---|---|---|
| | Min | Max | | |
| $^{t}$INIT0 | – | 20 | ms | Maximum voltage ramp time |
| $^{t}$INIT1 | 100 | – | ns | Minimum CKE LOW time after completion of voltage ramp |
| $^{t}$INIT2 | 5 | – | $^{t}$CK | Minimum stable clock before first CKE HIGH |
| $^{t}$INIT3 | 200 | – | µs | Minimum idle time after first CKE assertion |
| $^{t}$INIT4 | 1 | – | µs | Minimum idle time after RESET command |
| $^{t}$INIT5 | – | 10 | µs | Maximum duration of device auto initialization |
| $^{t}$ZQINIT | 1 | – | µs | ZQ initial calibration (S4 devices only) |
| $^{t}$CKb | 18 | 100 | ns | Clock cycle time during boot |

Note: 1. The $^{t}$INIT0 maximum specification is not a tested limit and should be used as a general guideline. For voltage ramp times exceeding $^{t}$INIT0 MAX, contact the factory.

## Initialization After RESET (Without Voltage Ramp)

If the RESET command is issued before or after the power-up initialization sequence, the reinitialization procedure must begin at Td.

# Power-Off Sequence

While powering off, CKE must be held LOW (≤0.2 × $V_{DD2}$); all other inputs must be between $V_{ILmin}$ and $V_{IHmax}$. The device outputs remain at High-Z while CKE is held LOW.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DQ, DM, DQS_t, and DQS_c voltage levels must be between $V_{SSQ}$ and $V_{DDQ}$ during the power-off sequence to avoid latchup. CK_t, CK_c, CS_n, and CA input levels must be between $V_{SS}$ and $V_{DD2}$ during the power-off sequence to avoid latchup.

Tx is the point where any power supply drops below the minimum value specified in the Recommended DC Operating Conditions table.

Tz is the point where all power supplies are below 300mV. After Tz, the device is powered off.

**Required Power Supply Conditions Between Tx and Tz:**

- $V_{DD1}$ must be greater than $V_{DD2}$ - 200mV
- $V_{DD1}$ must be greater than $V_{DDQ}$ - 200mV
- $V_{REF}$ must always be less than all other supply voltages

The voltage difference between $V_{SS}$ and $V_{SSQ}$ must not exceed 100mV.

For supply and reference voltage operating conditions, see Recommended DC Operating Conditions table.

### Uncontrolled Power-Off Sequence

When an uncontrolled power-off occurs, the following conditions must be met:

- At Tx, when the power supply drops below the minimum values specified in the Recommended DC Operating Conditions table, all power supplies must be turned off and all power-supply current capacity must be at zero, except for any static charge remaining in the system.
- After Tz, the point at which all power supplies first reach 300mV, the device must power off. The time between Tx and Tz must not exceed $^{t}$POFF. During this period, the relative voltage between power supplies is uncontrolled. $V_{DD1}$ and $V_{DD2}$ must decrease with a slope lower than 0.5 V/µs between Tx and Tz.

An uncontrolled power-off sequence can occur a maximum of 400 times over the life of the device.

**Table 20: Power-Off Timing**

| Parameter | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Maximum power-off ramp time | $^{t}$POFF | – | 2 | sec |

## Mode Register Definition

The LPDDR2 device contains a set of mode registers used for programming device operating parameters, reading device information and status, and for initiating special operations such as DQ calibration, ZQ calibration, and device reset.

### Mode Register Assignments and Definitions

The MRR command is used to read from a register. The MRW command is used to write to a register. An “R” in the access column of the mode register assignment table indicates read-only; a “W” indicates write-only; “R/W” indicates read or write capable or enabled.


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## Table 21: Mode Register Assignments

Notes 1–5 apply to all parameters and conditions

| MR# | MA[7:0] | Function | Access | OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 | Link |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 00h | Device info | R | RFU | | | RZQI | | RFU | DI | DAI | go to MR0 |
| 1 | 01h | Device feature 1 | W | *n*WR (for AP) | | | WC | BT | BL | | | go to MR1 |
| 2 | 02h | Device feature 2 | W | RFU | | | | RL and WL | | | | go to MR2 |
| 3 | 03h | I/O config-1 | W | RFU | | | | DS | | | | go to MR3 |
| 4 | 04h | SDRAM refresh rate | R | TUF | RFU | | | Refresh rate | | | | go to MR4 |
| 5 | 05h | Basic config-1 | R | LPDDR2 Manufacturer ID | | | | | | | | go to MR5 |
| 6 | 06h | Basic config-2 | R | Revision ID1 | | | | | | | | go to MR6 |
| 7 | 07h | Basic config-3 | R | Revision ID2 | | | | | | | | go to MR7 |
| 8 | 08h | Basic config-4 | R | I/O width | | Density | | | | Type | | go to MR8 |
| 9 | 09h | Test mode | W | Vendor-specific test mode | | | | | | | | go to MR9 |
| 10 | 0Ah | I/O calibration | W | Calibration code | | | | | | | | go to MR10 |
| 11–15 | 0Bh ≈ 0Fh | Reserved | – | RFU | | | | | | | | go to MR11 |
| 16 | 10h | PASR_Bank | W | Bank mask | | | | | | | | go to MR16 |
| 17 | 11h | PASR_Seg | W | Segment mask | | | | | | | | go to MR17 |
| 18–31 | 12h–1Fh | Reserved | – | RFU | | | | | | | | go to MR18 |
| 32 | 20h | DQ calibration pattern A | R | See Data Calibration Pattern Description table | | | | | | | | go to MR32 |
| 33–39 | 21h–27h | Do not use | | | | | | | | | | go to MR33 |
| 40 | 28h | DQ calibration pattern B | R | See Data Calibration Pattern Description table | | | | | | | | go to MR40 |
| 41–47 | 29h–2Fh | Do not use | | | | | | | | | | go to MR41 |
| 48–62 | 30h–3Eh | Reserved | – | RFU | | | | | | | | go to MR48 |
| 63 | 3Fh | RESET | W | X | | | | | | | | go to MR63 |
| 64–126 | 40h–7Eh | Reserved | – | RFU | | | | | | | | go to MR64 |
| 127 | 7Fh | Do not use | | | | | | | | | | go to MR127 |
| 128–190 | 80h–BEh | Reserved for vendor use | | RVU | | | | | | | | go to MR128 |
| 191 | BFh | Do not use | | | | | | | | | | go to MR191 |
| 192–254 | C0h–FEh | Reserved for vendor use | | RVU | | | | | | | | go to MR192 |
| 255 | FFh | Do not use | | | | | | | | | | go to MR255 |

Notes:
1. RFU bits must be set to 0 during MRW.
2. RFU bits must be read as 0 during MRR.
3. For READs to a write-only or RFU register, DQS will be toggled and undefined data is returned.
4. RFU mode registers must not be written.
5. WRITEs to read-only registers must have no impact on the functionality of the device.


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### Table 22: MR0 Device Information (MA[7:0] = 00h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| RFU | | | RZQI | | RFU | DI | DAI |

### Table 23: MR0 Op-Code Bit Definitions

Notes 1–4 apply to all parameters and conditions

| Register Information | Tag | Type | OP | Definition |
|---|---|---|---|---|
| Device auto initialization status | DAI | Read-only | OP0 | 0b: DAI complete |
| | | | | 1b: DAI in progress |
| Device information | DI | Read-only | OP1 | 0b:DDR2 Mobile RAM (S4 SDRAM) |
| Built-in self test for RZQ information | RZQI | Read-only | OP[4:3] | 01b: ZQ pin might be connected to $V_{DD2}$ or left floating |
| | | | | 10b: ZQ pin might be shorted to ground |
| | | | | 11b: ZQ pin self test complete; no error condition detected(ZQ-pin may not connect to VDD or float nor short to GND) |

Notes:
1. If RZQI is supported, it will be set upon completion of the MRW ZQ initialization calibration.
2. If ZQ is connected to $V_{DD2}$ to set default calibration, OP[4:3] must be set to 01. If ZQ is not connected to $V_{DD2}$, either OP[4:3] = 01 or OP[4:3] = 10 could indicate a ZQ-pin assembly error. It is recommended that the assembly error be corrected.
3. In the case of a possible assembly error (either OP[4:3] = 01 or OP[4:3] = 10, as defined above), the device will default to factory trim settings for $R_{ON}$(output impedance) and will ignore ZQ calibration commands. In either case, the system might not function as intended.
4. If a ZQ self test returns a value of 11b, this indicates that the device has detected a resistor connection to the ZQ pin. Note that this result cannot be used to validate the ZQ resistor value, nor does it indicate that the ZQ resistor tolerance meets the specified limits (240 ohms ±1%).

### Table 24: MR1 Device Feature 1 (MA[7:0] = 01h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| *n*WR (for AP) | | | WC | BT | BL | | |

### Table 25: MR1 Op-Code Bit Definitions

| Feature | Type | OP | Definition | Notes |
|---|---|---|---|---|
| BL = burst length | Write-only | OP[2:0] | 010b: BL4 (default) | 1 |
| | | | 011b: BL8 | |
| | | | 100b: BL16 | |
| | | | All others: Reserved | |
| BT = burst type | Write-only | OP3 | 0b: Sequential (default) | |
| | | | 1b: Interleaved | |


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**Table 25: MR1 Op-Code Bit Definitions (Continued)**

| Feature | Type | OP | Definition | Notes |
|---|---|---|---|---|
| WC = wrap control | Write-only | OP4 | 0b: Wrap (default) | |
| | | | 1b: No wrap (allowed for BL4 only) | |
| *n*WR = number of $^{t}$WR clock cycles | Write-only | OP[7:5] | 001b: *n*WR = 3 (default) | 2 |
| | | | 010b: *n*WR = 4 | |
| | | | 011b: *n*WR = 5 | |
| | | | 100b: *n*WR = 6 | |
| | | | 101b: *n*WR = 7 | |
| | | | 110b: *n*WR = 8 | |
| | | | All others: Reserved | |

Notes:
1. BL16, interleaved is not an official combination to be supported.
2. The programmed value in *n*WR register is the number of clock cycles that determines when to start internal precharge operation for a WRITE burst with AP enabled. It is determined by RU ($^{t}$WR/$^{t}$CK).

**Table 26: Burst Sequence by Burst Length (BL), Burst Type (BT), and Wrap Control (WC)**

Notes 1–5 apply to all parameters and conditions

| | | | | | | | Burst Cycle Number and Burst Address Sequence | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BL | BT | C3 | C2 | C1 | C0 | WC | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 4 | Any | X | X | 0b | 0b | Wrap | 0 | 1 | 2 | 3 | | | | | | | | | | | | |
| | | X | X | 1b | 0b | | 2 | 3 | 0 | 1 | | | | | | | | | | | | |
| | Any | X | X | X | 0b | No wrap | *y* | *y* + 1 | *y* + 2 | *y* + 3 | | | | | | | | | | | | |
| 8 | Seq | X | 0b | 0b | 0b | Wrap | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | | | | |
| | | X | 0b | 1b | 0b | | 2 | 3 | 4 | 5 | 6 | 7 | 0 | 1 | | | | | | | | |
| | | X | 1b | 0b | 0b | | 4 | 5 | 6 | 7 | 0 | 1 | 2 | 3 | | | | | | | | |
| | | X | 1b | 1b | 0b | | 6 | 7 | 0 | 1 | 2 | 3 | 4 | 5 | | | | | | | | |
| | Int | X | 0b | 0b | 0b | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | | | | |
| | | X | 0b | 1b | 0b | | 2 | 3 | 0 | 1 | 6 | 7 | 4 | 5 | | | | | | | | |
| | | X | 1b | 0b | 0b | | 4 | 5 | 6 | 7 | 0 | 1 | 2 | 3 | | | | | | | | |
| | | X | 1b | 1b | 0b | | 6 | 7 | 4 | 5 | 2 | 3 | 0 | 1 | | | | | | | | |
| | Any | X | X | X | 0b | No wrap | Illegal (not supported) | | | | | | | | | | | | | | | |



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**Table 26: Burst Sequence by Burst Length (BL), Burst Type (BT), and Wrap Control (WC) (Continued)**

Notes 1–5 apply to all parameters and conditions

| BL | BT | C3 | C2 | C1 | C0 | WC | Burst Cycle Number and Burst Address Sequence | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 16 | Seq | 0b | 0b | 0b | 0b | Wrap | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
| | | 0b | 0b | 1b | 0b | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 |
| | | 0b | 1b | 0b | 0b | | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 |
| | | 0b | 1b | 1b | 0b | | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 |
| | | 1b | 0b | 0b | 0b | | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | | 1b | 0b | 1b | 0b | | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | | 1b | 1b | 0b | 0b | | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B |
| | | 1b | 1b | 1b | 0b | | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D |
| | Int | X | X | X | 0b | | Illegal (not supported) | | | | | | | | | | | | | | | |
| | Any | X | X | X | 0b | No wrap | Illegal (not supported) | | | | | | | | | | | | | | | |

Notes:
1. C0 input is not present on CA bus. It is implied zero.
2. For BL = 4, the burst address represents C[1:0].
3. For BL = 8, the burst address represents C[2:0].
4. For BL = 16, the burst address represents C[3:0].
5. For no-wrap, BL4, the burst must not cross the page boundary or the sub-page boundary. The variable *y* can start at any address with C0 equal to 0, but must not start at any address shown in the following table.

**Table 27: No-Wrap Restrictions**

| Width | 64Mb | 128Mb/256Mb | 512Mb/1Gb/2Gb | 4Gb/8Gb |
|---|---|---|---|---|
| Cannot cross full-page boundary | | | | |
| x16 | FE, FF, 00, 01 | 1FE, 1FF, 000, 001 | 3FE, 3FF, 000, 001 | 7FE, 7FF, 000, 001 |
| x32 | 7E, 7F, 00, 01 | FE, FF, 00, 01 | 1FE, 1FF, 000, 001 | 3FE, 3FF, 000, 001 |
| Cannot cross sub-page boundary | | | | |
| x16 | 7E, 7F, 80, 81 | 0FE, 0FF, 100, 101 | 1FE, 1FF, 200, 201 | 3FE, 3FF, 400, 401 |
| x32 | None | None | None | None |

Note:
1. No-wrap BL = 4 data orders shown are prohibited.

**Table 28: MR2 Device Feature 2 (MA[7:0] = 02h)**

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| RFU | | | | RL and WL | | | |



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### Table 29: MR2 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| RL and WL | Write-only | OP[3:0] | 0001b: RL3/WL1 (default) |
| | | | 0010b: RL4/WL2 |
| | | | 0011b: RL5/WL2 |
| | | | 0100b: RL6/WL3 |
| | | | 0101b: RL7/WL4 |
| | | | 0110b: RL8/WL4 |
| | | | All others: Reserved |

### Table 30: MR3 I/O Configuration 1 (MA[7:0] = 03h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| RFU | | | | DS | | | |

### Table 31: MR3 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| DS | Write-only | OP[3:0] | 0000b: Reserved |
| | | | 0001b: 34.3 ohm typical |
| | | | 0010b: 40 ohm typical (default) |
| | | | 0011b: 48 ohm typical |
| | | | 0100b: 60 ohm typical |
| | | | 0101b: Reserved |
| | | | 0110b: 80 ohm typical |
| | | | 0111b: 120 ohm typical |
| | | | All others: Reserved |

### Table 32: MR4 Device Temperature (MA[7:0] = 04h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| TUF | RFU | | | | SDRAM refresh rate | | |



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### Table 33: MR4 Op-Code Bit Definitions

Notes 1–8 apply to all parameters and conditions

| Feature | Type | OP | Definition |
|---|---|---|---|
| SDRAM refresh rate | Read-only | OP[2:0] | 000b: SDRAM low temperature operating limit exceeded |
| | | | 001b: 4 × $^{t}$REFI, 4 × $^{t}$REFIpb, 4 × $^{t}$REFW |
| | | | 010b: 2 × $^{t}$REFI, 2 × $^{t}$REFIpb, 2 × $^{t}$REFW |
| | | | 011b: 1 × $^{t}$REFI, 1 × $^{t}$REFIpb, 1 × $^{t}$REFW (≤85°C) |
| | | | 100b: Reserved |
| | | | 101b: 0.25 × $^{t}$REFI, 0.25 × $^{t}$REFIpb, 0.25 × $^{t}$REFW, do not derate SDRAM AC timing |
| | | | 110b: 0.25 × $^{t}$REFI, 0.25 × $^{t}$REFIpb, 0.25 × $^{t}$REFW, derate SDRAM AC timing |
| | | | 111b: SDRAM high temperature operating limit exceeded |
| Temperature update flag (TUF) | Read-only | OP7 | 0b: OP[2:0] value has not changed since last read of MR4 |
| | | | 1b: OP[2:0] value has changed since last read of MR4 |

Notes:
1. A MODE REGISTER READ from MR4 will reset OP7 to 0.
2. OP7 is reset to 0 at power-up.
3. If OP2 = 1, the device temperature is greater than 85°C.
4. OP7 is set to 1 if OP[2:0] has changed at any time since the last MR4 read.
5. The device might not operate properly when OP[2:0] = 000b or 111b.
6. For specified operating temperature range and maximum operating temperature, refer to the Operating Temperature Range table.
7. LPDDR2 devices must be derated by adding 1.875ns to the following core timing parameters: $^{t}$RCD, $^{t}$RC, $^{t}$RAS, $^{t}$RP, and $^{t}$RRD. The $^{t}$DQSCK parameter must be derated as specified in AC Timing. Prevailing clock frequency specifications and related setup and hold timings remain unchanged.
8. The recommended frequency for reading MR4 is provided in Temperature Sensor.

### Table 34: MR5 Basic Configuration 1 (MA[7:0] = 05h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| LPDDR2 Manufacturer ID | | | | | | | |

### Table 35: MR5 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| Manufacturer ID | Read-only | OP[7:0] | 00000011b |
| | | | All others: Reserved |

### Table 36: MR6 Basic Configuration 2 (MA[7:0] = 06h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| Revision ID1 (Die Revision) | | | | | | | |

Note:
1. MR6 is vendor-specific.



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### Table 37: MR6 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| Revision ID1 (Die Revision) | Read-only | OP[7:0] | 0000 0000b: Version A<br>0000 0001b: Version B<br>0000 0010b: Version C<br>0000 0010b: Version D(512Mb only)<br>0000 0011b: Version D |

### Table 38: MR7 Basic Configuration 3 (MA[7:0] = 07h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| Revision ID2 (RFU) | | | | | | | |

### Table 39: MR7 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| Revision ID2 (RFU) | Read-only | OP[7:0] | 0000 0000b: Default Value |

Note: 1. MR7 is vendor-specific.

### Table 40: MR8 Basic Configuration 4 (MA[7:0] = 08h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| I/O width | | Density | | | | Type | |

### Table 41: MR8 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| Type | Read-only | OP[1:0] | 00b: S4 SDRAM |
| | | | 01b: S2 SDRAM |
| | | | 10b: Reserved |
| | | | 11b: Reserved |
| Density | Read-only | OP[5:2] | 0000b: 64Mb |
| | | | 0001b: 128Mb |
| | | | 0010b: 256Mb |
| | | | 0011b: 512Mb |
| | | | 0100b: 1Gb |
| | | | 0101b: 2Gb |
| | | | 0110b: 4Gb |
| | | | 0111b: 8Gb |
| | | | 1000b: 16Gb |
| | | | 1001b: 32Gb |
| | | | All others: Reserved |


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**Table 41: MR8 Op-Code Bit Definitions (Continued)**

| Feature | Type | OP | Definition |
|---|---|---|---|
| I/O width | Read-only | OP[7:6] | 00b: x32 |
| | | | 01b: x16 |
| | | | 10b: x8 |
| | | | 11b: not used |

**Table 42: MR9 Test Mode (MA[7:0] = 09h)**

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| Vendor-specific test mode | | | | | | | |

**Table 43: MR10 Calibration (MA[7:0] = 0Ah)**

| | OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|---|
| S4 | Calibration code | | | | | | | |

**Table 44: MR10 Op-Code Bit Definitions**

Notes 1–6 apply to all parameters and conditions

| Feature | Type | OP | Definition |
|---|---|---|---|
| Calibration code | Write-only | OP[7:0] | 0xFF: Calibration command after initialization |
| | | | 0xAB: Long calibration |
| | | | 0x56: Short calibration |
| | | | 0xC3: ZQRESET |
| | | | All others: Reserved |

Notes:
1. Host processor must not write MR10 with reserved values.
2. The device ignores calibration commands when a reserved value is written into MR10.
3. See AC timing table for the calibration latency.
4. If ZQ is connected to $V_{SS}$ through $R_{ZQ}$, either the ZQ calibration function (see MODE REGISTER WRITE command) or default calibration (through the ZQRESET command) is supported. If ZQ is connected to $V_{DD2}$, the device operates with default calibration, and ZQ calibration commands are ignored. In both cases, the ZQ connection must not change after power is supplied to the device.
5. LPDDR2 devices that do not support calibration shall ignore the ZQ Calibration command.
6. Optionally, the MRW ZQ Initialization Calibration command will update MR0 to indicate RZQ pin connection.

**Table 45: MR[11:15] Reserved (MA[7:0] = 0Bh–0Fh)**

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| Reserved | | | | | | | |



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### Table 46: MR16 PASR Bank Mask (MA[7:0] = 010h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| Bank mask (4-bank or 8-bank) | | | | | | | |

### Table 47: MR16 Op-Code Bit Definitions

| Feature | Type | OP | Definition |
|---|---|---|---|
| Bank[7:0] mask | Write-only | OP[7:0] | 0b: refresh enable to the bank = unmasked (default) |
| | | | 1b: refresh blocked = masked |

Note: 1. For 4-bank devices, only OP[3:0] are used.

### Table 48: MR16 Bank and OP corresponding table

| Feature | Type | OP | 4-Bank Mask | | 8-Bank Mask | |
|---|---|---|---|---|---|---|
| | | | Bank # | Bank Address | Bank # | Bank Address |
| Bank[7:0] mask | Write-only | 0 | Bank 0 | 000b | Bank 0 | 000b |
| | | 1 | Bank 1 | 001b | Bank 1 | 001b |
| | | 2 | Bank 2 | 010b | Bank 2 | 010b |
| | | 3 | Bank 3 | 011b | Bank 3 | 011b |
| | | 4 | - | - | Bank 4 | 100b |
| | | 5 | - | - | Bank 5 | 101b |
| | | 6 | - | - | Bank 6 | 110b |
| | | 7 | - | - | Bank 7 | 111b |

Note: 1. Each bank can be masked independently by setting each OP value.

### Table 49: MR17 PASR Segment Mask (MA[7:0] = 011h)

| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| Segment mask | | | | | | | |

Note: 1. This table applies for 1Gb to 8Gb devices only.

### Table 50: MR17 PASR Segment Mask Definitions (1Gb - 8Gb only)

| Feature | Type | OP | Definition |
|---|---|---|---|
| Segment[7:0] mask | Write-only | OP[7:0] | 0b: refresh enable to the segment: = unmasked (default) |
| | | | 1b: refresh blocked: = masked |


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**Table 51: MR17 PASR Row Address Ranges in Masked Segments**

| Segment | OP | Segment Mask | 1Gb | 2Gb, 4Gb | 8Gb |
|---|---|---|---|---|---|
| | | | R[12:10] | R[13:11] | R[14:12] |
| 0 | 0 | XXXXXXX1 | 000b | | |
| 1 | 1 | XXXXXX1X | 001b | | |
| 2 | 2 | XXXXX1XX | 010b | | |
| 3 | 3 | XXXX1XXX | 011b | | |
| 4 | 4 | XXX1XXXX | 100b | | |
| 5 | 5 | XX1XXXXX | 101b | | |
| 6 | 6 | X1XXXXXX | 110b | | |
| 7 | 7 | 1XXXXXXX | 111b | | |

Note: 1. X is "Don't Care" for the designated segment.

**Table 52: Reserved Mode Registers**

| Mode Register | MA | Address | Restriction | OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MR[18:19] | MA[7:0] | 12h–13h | RFU | Reserved | | | | | | | |
| MR[20:31] | | 14h–1Fh | NVM[1] | | | | | | | | |
| MR[33:39] | | 21h–27h | DNU[1] | | | | | | | | |
| MR[41:47] | | 29h–2Fh | | | | | | | | | |
| MR[48:62] | | 30h–3Eh | RFU | | | | | | | | |
| MR[64:126] | | 40h–7Eh | RFU | | | | | | | | |
| MR127 | | 7Fh | DNU | | | | | | | | |
| MR[128:190] | | 80h–BEh | RVU[1] | | | | | | | | |
| MR191 | | BFh | DNU | | | | | | | | |
| MR[192:254] | | C0h–FEh | RVU | | | | | | | | |
| MR255 | | FFh | DNU | | | | | | | | |

Note: 1. NVM = nonvolatile memory use only; DNU = Do not use; RVU = Reserved for vendor use.

**Table 53: MR32 DQ Calibration Pattern A (MA[7:0] = 20H)**

| MR32 Reads |
|---|
| Reads to MR32 return DQ Calibration Pattern A |

**Table 54: MR40 DQ Calibration Pattern B (MA[7:0] = 28H)**

| MR40 Reads |
|---|
| Reads to MR40 return DQ Calibration Pattern B |


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**Table 55: MR63 RESET (MA[7:0] = 3Fh) – MRW Only**

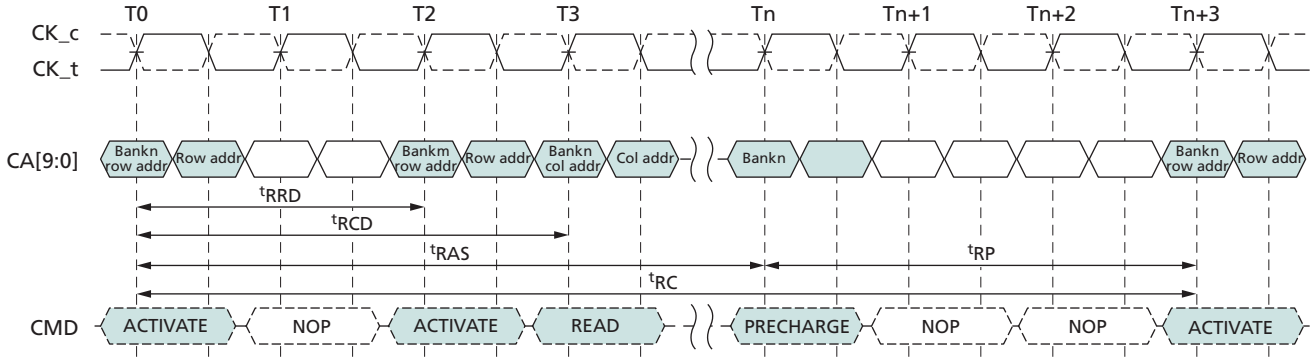
| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|---|---|---|---|---|---|---|---|
| X | | | | | | | |

Note: 1. For additional information on MRW RESET see MODE REGISTER WRITE Command.

# ACTIVATE Command

The ACTIVATE command is issued by holding CS_n LOW, CA0 LOW, and CA1 HIGH at the rising edge of the clock. The bank addresses BA[2:0] are used to select the desired bank. Row addresses are used to determine which row to activate in the selected bank. The ACTIVATE command must be applied before any READ or WRITE operation can be executed. The device can accept a READ or WRITE command at $^{t}$RCD after the ACTIVATE command is issued. After a bank has been activated, it must be precharged before another ACTIVATE command can be applied to the same bank. The bank active and precharge times are defined as $^{t}$RAS and $^{t}$RP, respectively. The minimum time interval between successive ACTIVATE commands to the same bank is determined by the RAS cycle time of the device ($^{t}$RC). The minimum time interval between ACTIVATE commands to different banks is $^{t}$RRD.

**Figure 18: ACTIVATE Command**




Notes: 1. $^{t}$RCD = 3, $^{t}$RP = 3, $^{t}$RRD = 2.
2. A PRECHARGE ALL command uses $^{t}$RPab timing, and a single-bank PRECHARGE command uses $^{t}$RPpb timing. In this figure, $^{t}$RP is used to denote either an all-bank PRECHARGE or a single-bank PRECHARGE.

## 8-Bank Device Operation

Two rules regarding 8-bank device operation must be observed: One rule restricts the number of sequential ACTIVATE commands that can be issued; the second rule provides additional RAS precharge time for a PRECHARGE ALL command.

**The 8-Bank Device Sequential Bank Activation Restriction:** No more than four banks can be activated (or refreshed, in the case of REFpb) in a rolling $^{t}$FAW window. To convert to clocks, divide $^{t}$FAW[ns] by $^{t}$CK[ns], and round up to the next integer value. For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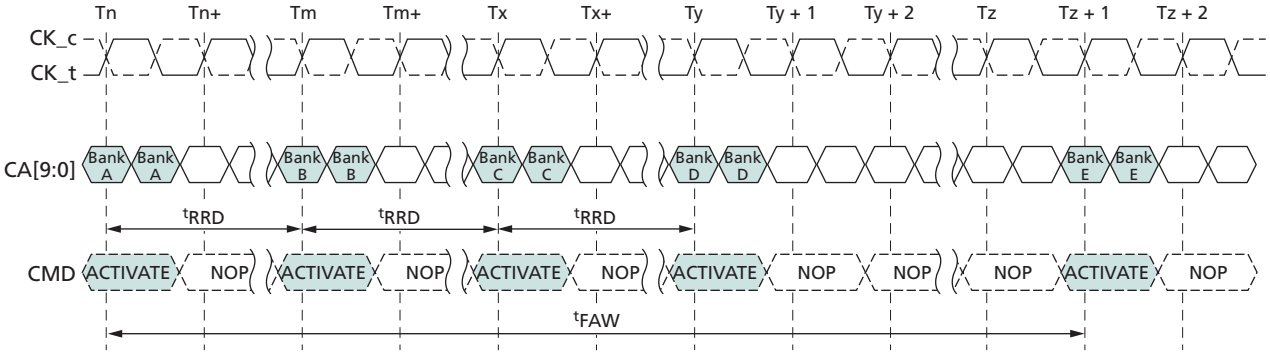
example, if RU(tFAW/tCK) is 10 clocks, and an ACTIVATE command is issued in clock *n*, no more than three further ACTIVATE commands can be issued at or between clock *n* + 1 and *n* + 9. REFpb also counts as bank activation for purposes of tFAW.

**The 8-Bank Device PRECHARGE ALL Provision:** tRP for a PRECHARGE ALL command must equal tRPab, which is greater than tRPpb.

**Figure 19: tFAW Timing (8-Bank Devices)**

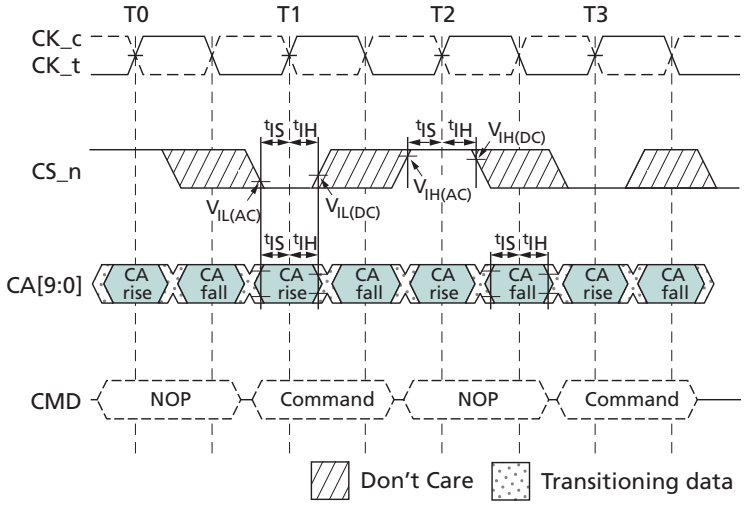



Note: 1. Exclusively for 8-bank devices.

## Commands and Timing

The setup and hold timings shown in the figures below apply for all commands.

**Figure 20: Command and Input Setup and Hold**




Note: 1. Setup and hold conditions also apply to the CKE pin. For timing diagrams related to the CKE pin, see the Power-Down section.


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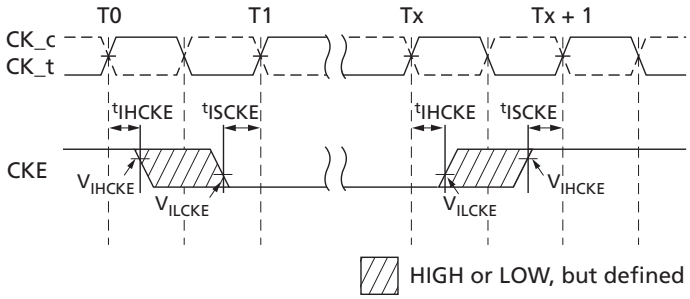
**Figure 21: CKE Input Setup and Hold**




Notes:
1. After CKE is registered LOW, the CKE signal level is maintained below $V_{ILCKE}$ for $^{t}$CKE specification (LOW pulse width).
2. After CKE is registered HIGH, the CKE signal level is maintained below $V_{IHCKE}$ for $^{t}$CKE specification (HIGH pulse width).

## Read and Write Access Modes

After a bank is activated, a READ or WRITE command can be issued with CS_n LOW, CA0 HIGH, and CA1 LOW at the rising edge of the clock. CA2 must also be defined at this time to determine whether the access cycle is a READ operation (CA2 HIGH) or a WRITE operation (CA2 LOW). A single READ or WRITE command initiates a burst READ or burst WRITE operation on successive clock cycles.

A new burst access must not interrupt the previous 4-bit burst operation when BL = 4. When BL = 8 or BL = 16, a READ can be interrupted by a READ and a WRITE can be interrupted by a WRITE, provided that the interrupt occurs on a 4-bit boundary and that $^{t}$CCD is met.

## Burst READ Command

The burst READ command is initiated with CS_n LOW, CA0 HIGH, CA1 LOW, and CA2 HIGH at the rising edge of the clock. The command address bus inputs, CA5r–CA6r and CA1f–CA9f, determine the starting column address for the burst. The read latency (RL) is defined from the rising edge of the clock on which the READ command is issued to the rising edge of the clock from which the $^{t}$DQSCK delay is measured. The first valid data is available RL × $^{t}$CK + $^{t}$DQSCK + $^{t}$DQSQ after the rising edge of the clock when the READ command is issued. The data strobe output is driven LOW $^{t}$RPRE before the first valid rising strobe edge. The first bit of the burst is synchronized with the first rising edge of the data strobe. Each subsequent data-out appears on each DQ pin, edge-aligned with the data strobe. The RL is programmed in the mode registers.

Pin input timings for the data strobe are measured relative to the crosspoint of DQS_t and its complement, DQS_c.


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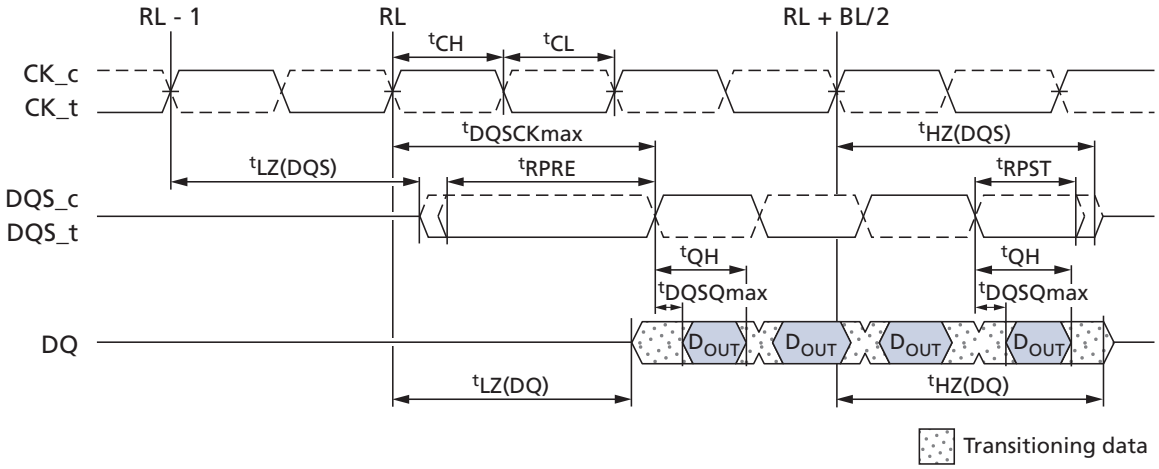
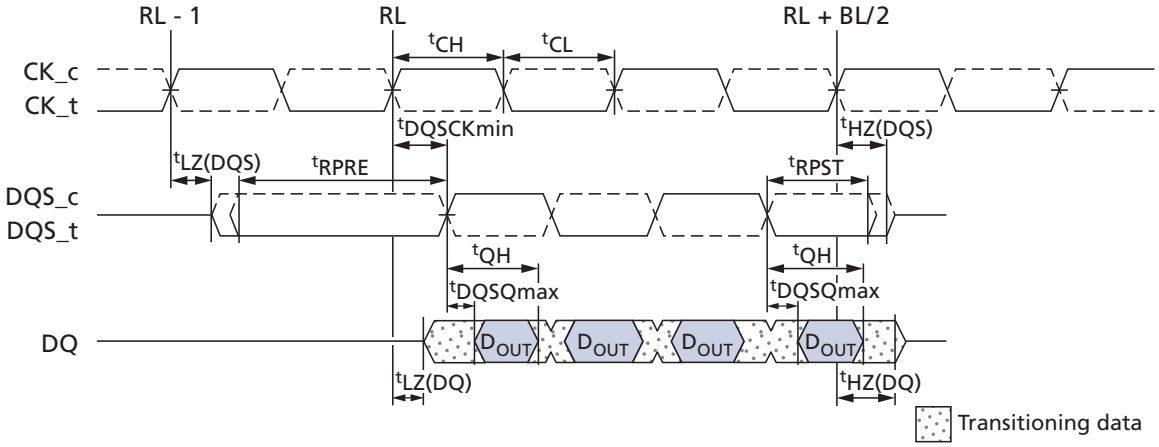
**Figure 22: READ Output Timing – $^{t}$DQSCK (MAX)**




Notes: 1. $^{t}$DQSCK can span multiple clock periods.
2. An effective burst length of 4 is shown.

**Figure 23: READ Output Timing – $^{t}$DQSCK (MIN)**




Note: 1. An effective burst length of 4 is shown.


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**Figure 24: Burst READ – RL = 5, BL = 4, $^{t}$DQSCK > $^{t}$CK**

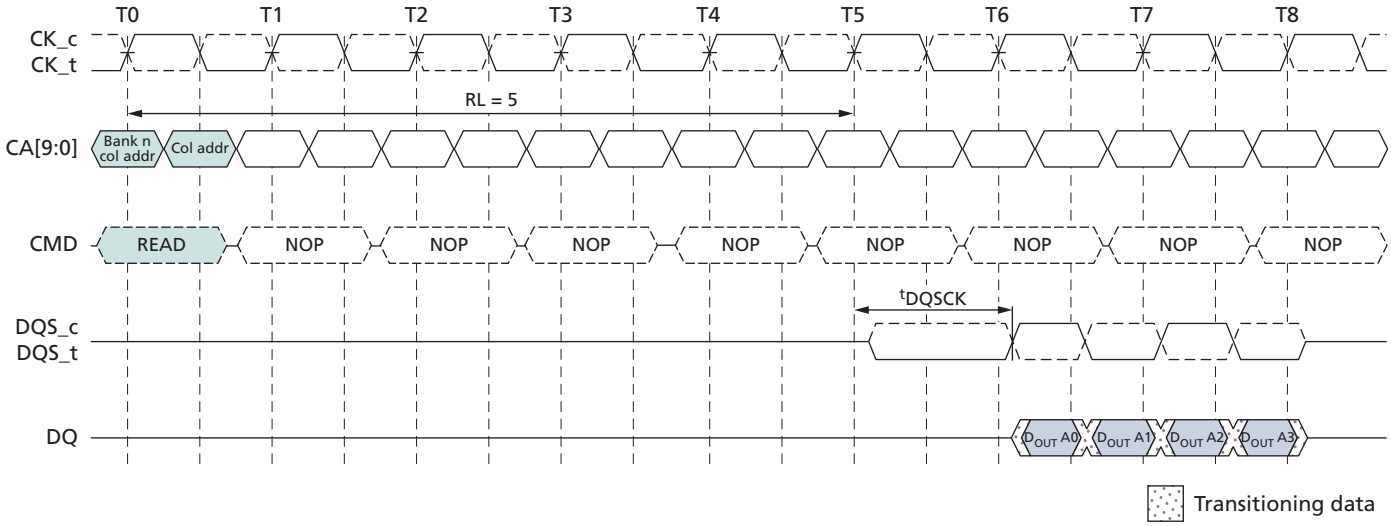


**Figure 25: Burst READ – RL = 3, BL = 8, $^{t}$DQSCK < $^{t}$CK**

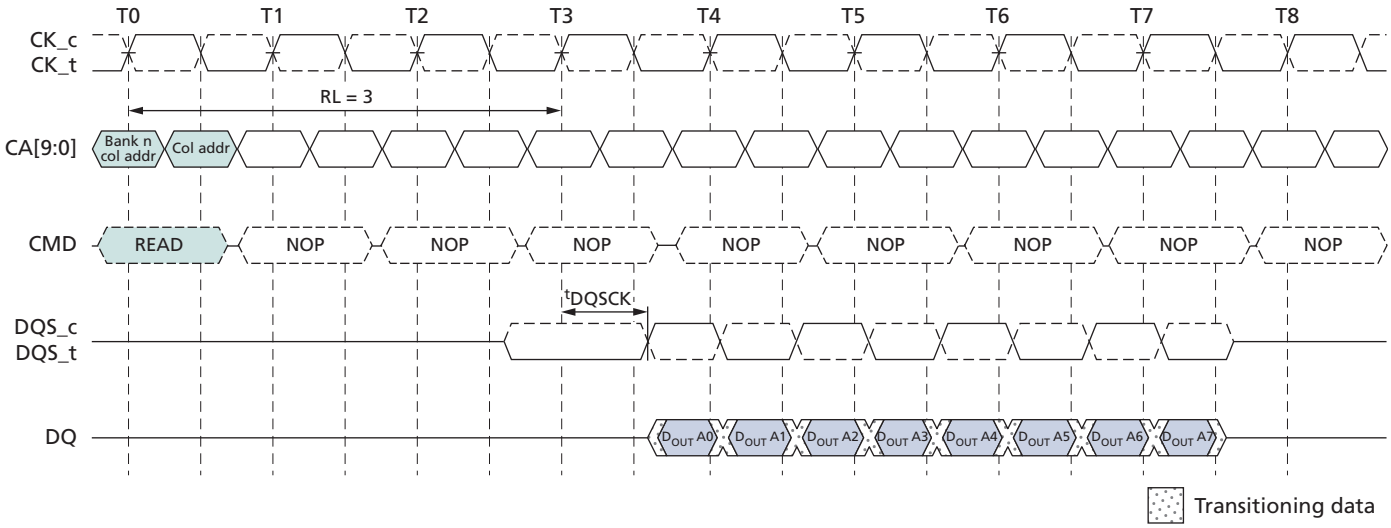



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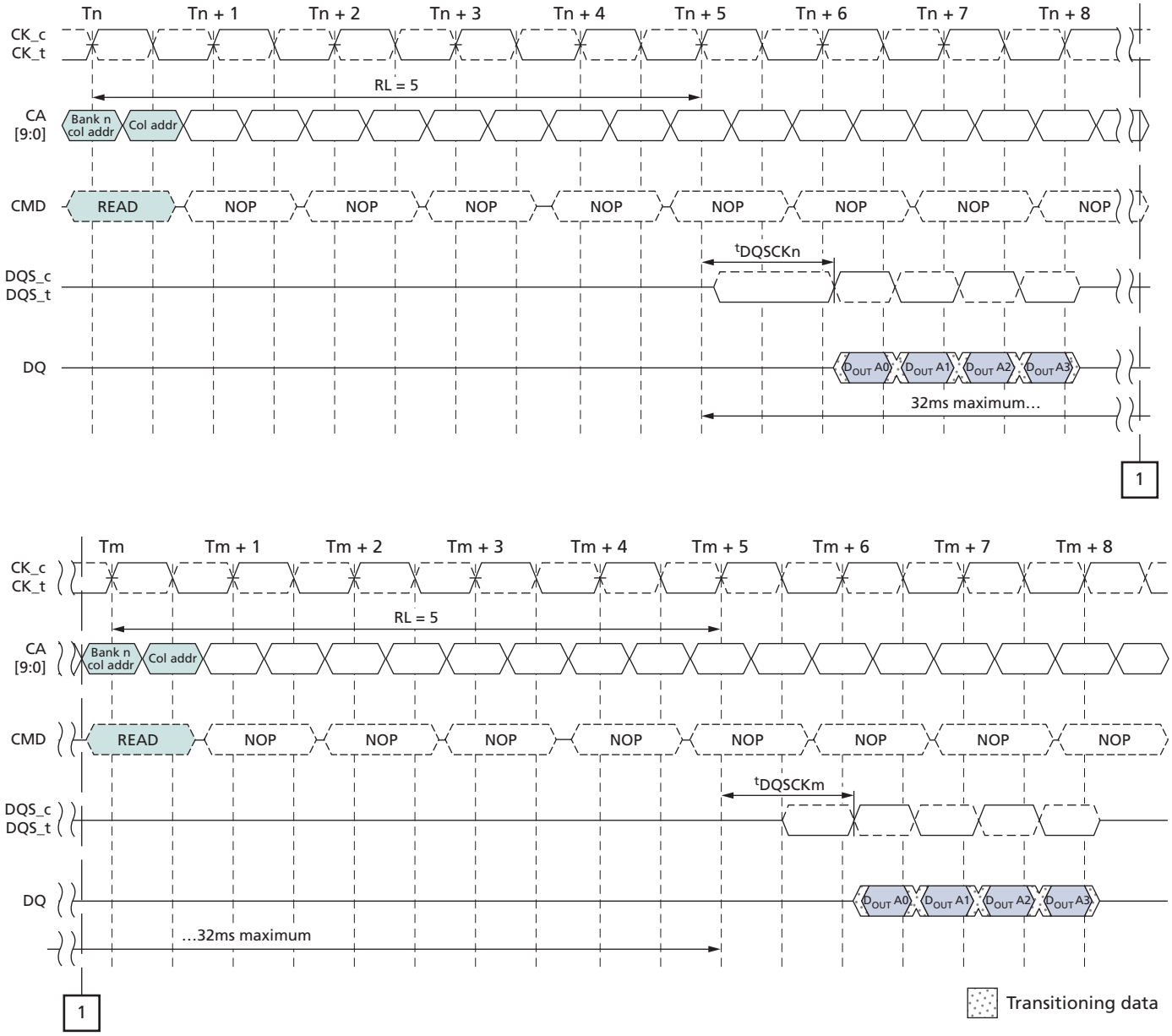
**Figure 26: tDQSCKDL Timing**




Notes:
1. tDQSCKDL = (tDQSCK*n* - tDQSCK*m*).
2. tDQSCKDL (MAX) is defined as the maximum of ABS (tDQSCK*n* - tDQSCK*m*) for any (tDQSCK*n*, tDQSCK*m*) pair within any 32ms rolling window.


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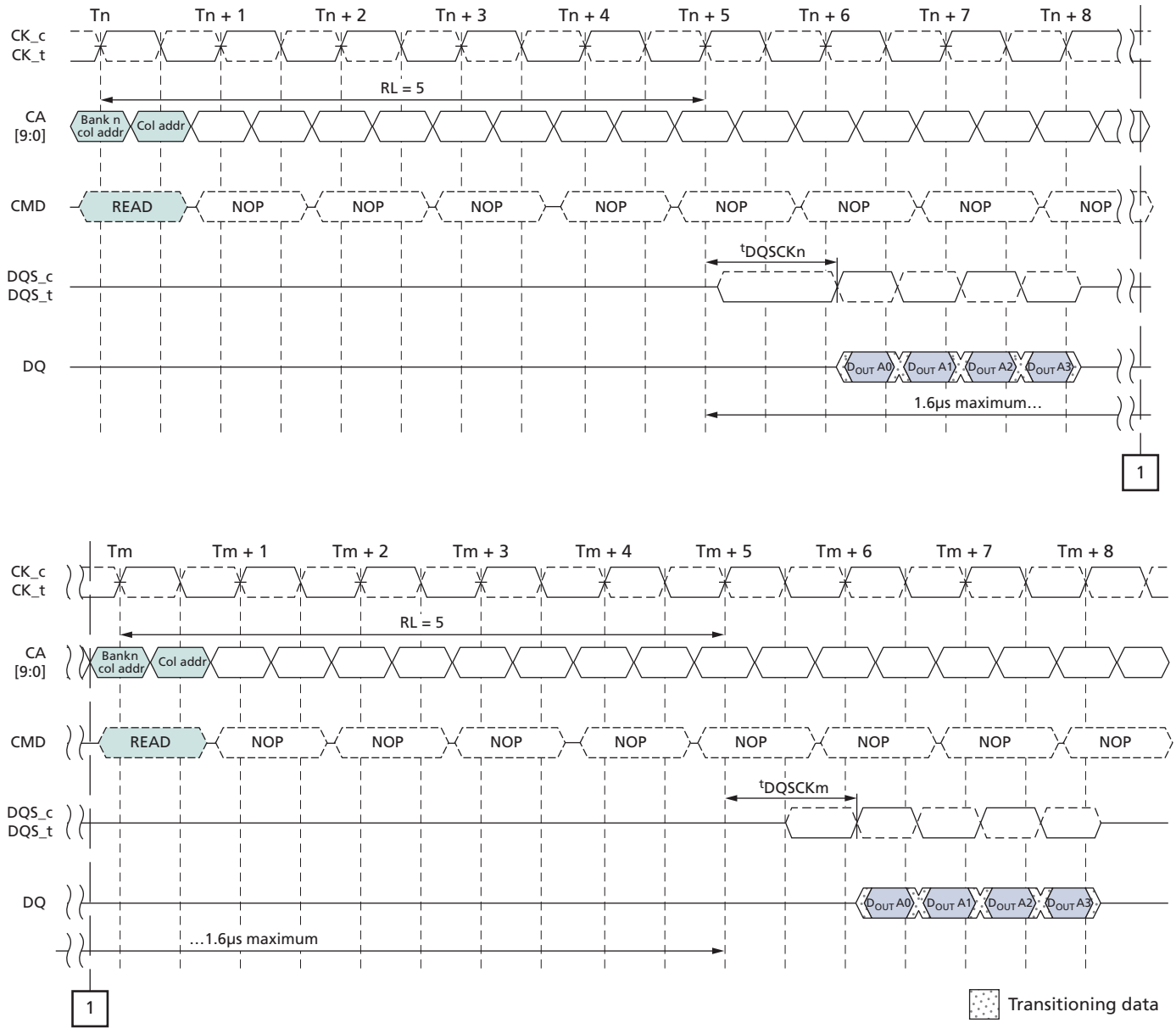
**Figure 27: tDQSCKDM Timing**




Notes:
1. tDQSCKDM = (tDQSCK*n* - tDQSCK*m*).
2. tDQSCKDM (MAX) is defined as the maximum of ABS (tDQSCK*n* - tDQSCK*m*) for any (tDQSCK*n*, tDQSCK*m*) pair within any 1.6µs rolling window.


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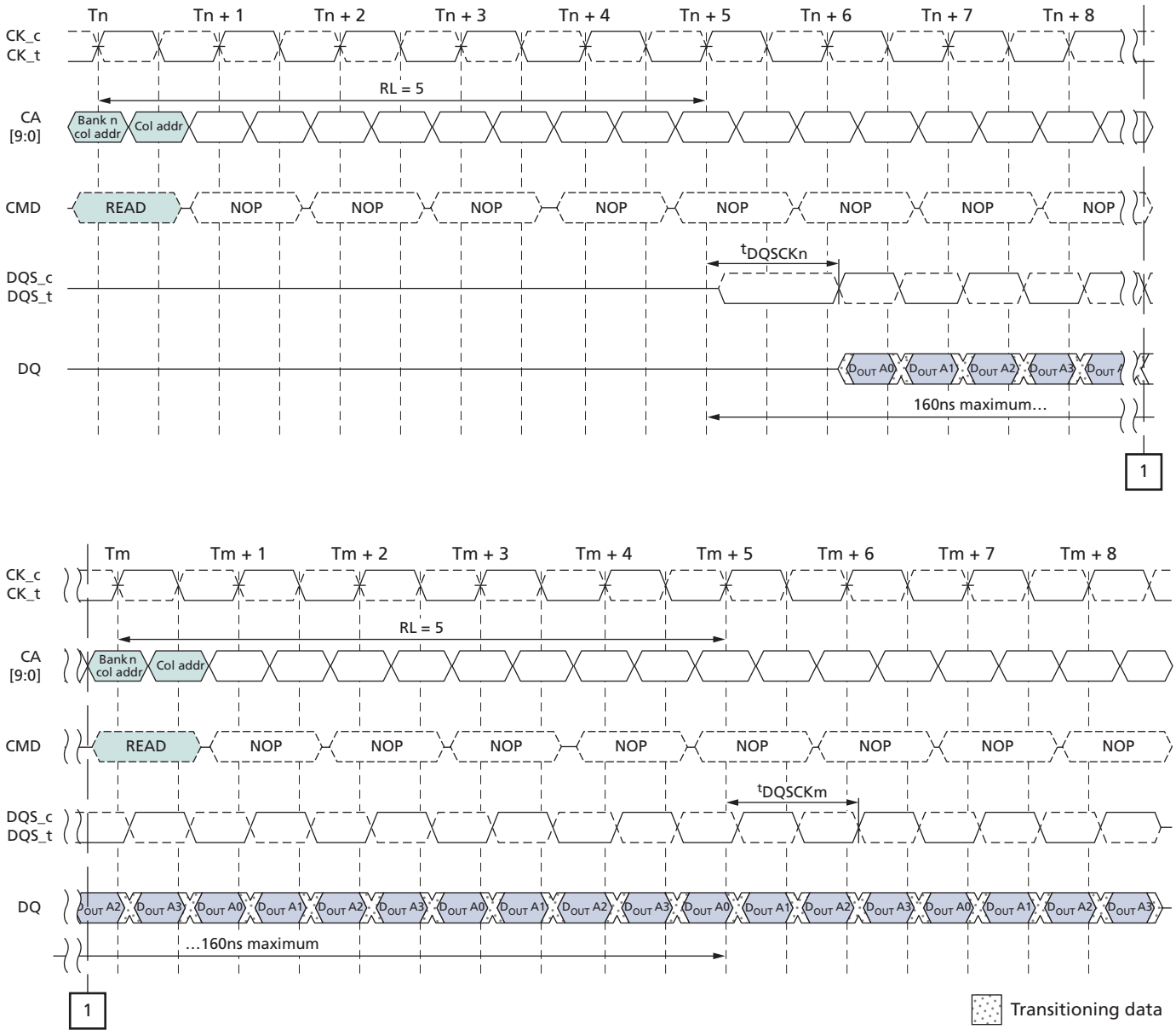
**Figure 28: $^{t}$DQSCKDS Timing**




Notes:
1. $^{t}$DQSCKDS = ($^{t}$DQSCK*n* - $^{t}$DQSCK*m*).
2. $^{t}$DQSCKDS (MAX) is defined as the maximum of ABS ($^{t}$DQSCK*n* - $^{t}$DQSCK*m*) for any ($^{t}$DQSCK*n*, $^{t}$DQSCK*m*) pair for READs within a consecutive burst, within any 160ns rolling window.


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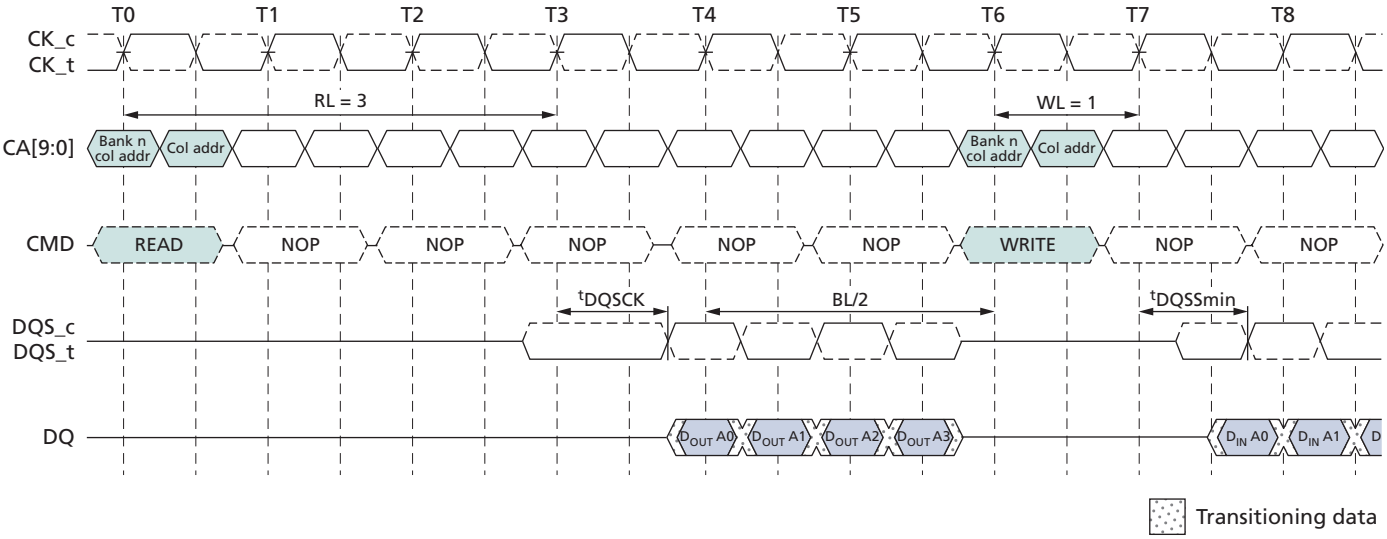
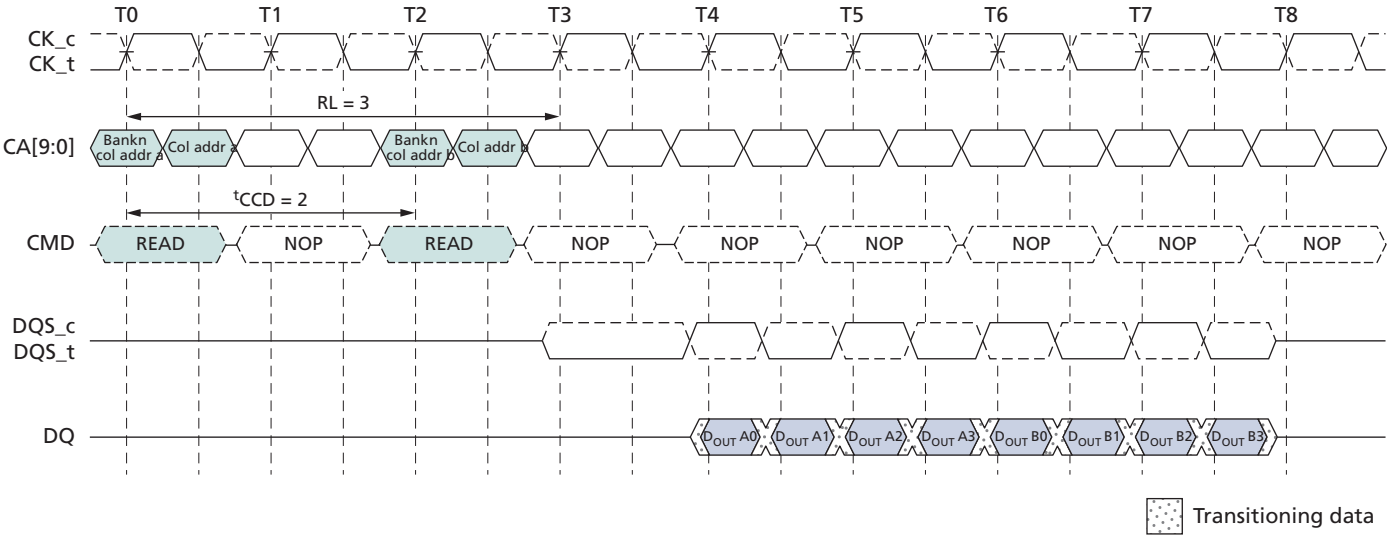
**Figure 29: Burst READ Followed by Burst WRITE – RL = 3, WL = 1, BL = 4**




The minimum time from the burst READ command to the burst WRITE command is defined by the read latency (RL) and the burst length (BL). Minimum READ-to-WRITE latency is RL + RU($^{t}$DQSCK(MAX)/$^{t}$CK) + BL/2 + 1 - WL clock cycles. Note that if a READ burst is truncated with a burst TERMINATE (BST) command, the effective burst length of the truncated READ burst should be used for BL when calculating the minimum READ-to-WRITE delay.

**Figure 30: Seamless Burst READ – RL = 3, BL = 4, $^{t}$CCD = 2**





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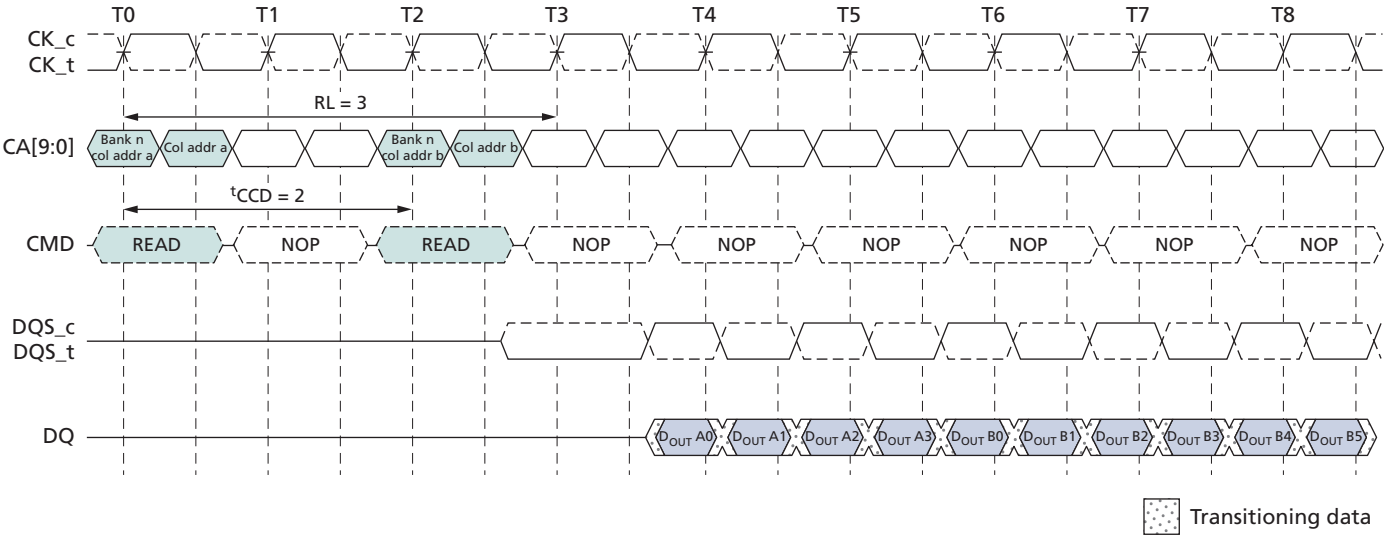
A seamless burst READ operation is supported by enabling a READ command at every other clock cycle for BL = 4 operation, every fourth clock cycle for BL = 8 operation, and every eighth clock cycle for BL = 16 operation. This operation is supported as long as the banks are activated, whether the accesses read the same or different banks.

### READs Interrupted by a READ

A burst READ can be interrupted by another READ with a 4-bit burst boundary, provided that $^{t}$CCD is met.

**Figure 31: READ Burst Interrupt Example – RL = 3, BL = 8, $^{t}$CCD = 2**




Notes:
1. For DDR2 Mobile RAM-S4 devices, a READ burst interrupt function is allowed only on a burst of 8 and 16.
2. For DDR2 Mobile RAM-S4 devices, a READ burst interrupt can occur only on even clock cycles after a previous READ command, provided that $^{t}$CCD is met.
3. A READ can be interrupted only by other READ commands or by a BST command.
4. A READ burst to any bank inside DRAM can be interrupted.
5. A READ burst with auto-precharge cannot be interrupted.
6. The effective burst length of the first READ equals two times the number of clock cycles between the first READ and the interrupting READ.

## Burst WRITE Command

The burst WRITE command is initiated with CS_n LOW, CA0 HIGH, CA1 LOW, and CA2 LOW at the rising edge of the clock. The command address bus inputs, CA5r–CA6r and CA1f–CA9f, determine the starting column address for the burst. Write latency (WL) is defined from the rising edge of the clock on which the WRITE command is issued to the rising edge of the clock from which the $^{t}$DQSS delay is measured. The first valid data must be driven WL × $^{t}$CK + $^{t}$DQSS from the rising edge of the clock from which the WRITE command is issued. The data strobe signal (DQS_t,DQS_c) must be driven LOW $^{t}$WPRE prior to data input. The burst cycle data bits must be applied to the DQ pins $^{t}$DS prior to the associated edge of the DQS_t,DQS_c and held valid until $^{t}$DH after that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edge. Burst data is sampled on successive edges of the DQS_t,DQS_c until the 4-, 8-, or 16-bit burst length is completed. After a burst WRITE operation, tWR must be satisfied before a PRECHARGE command to the same bank can be issued.

Pin input timings are measured relative to the crosspoint of DQS_t and its complement, DQS_c.

**Figure 32: Data Input (WRITE) Timing**

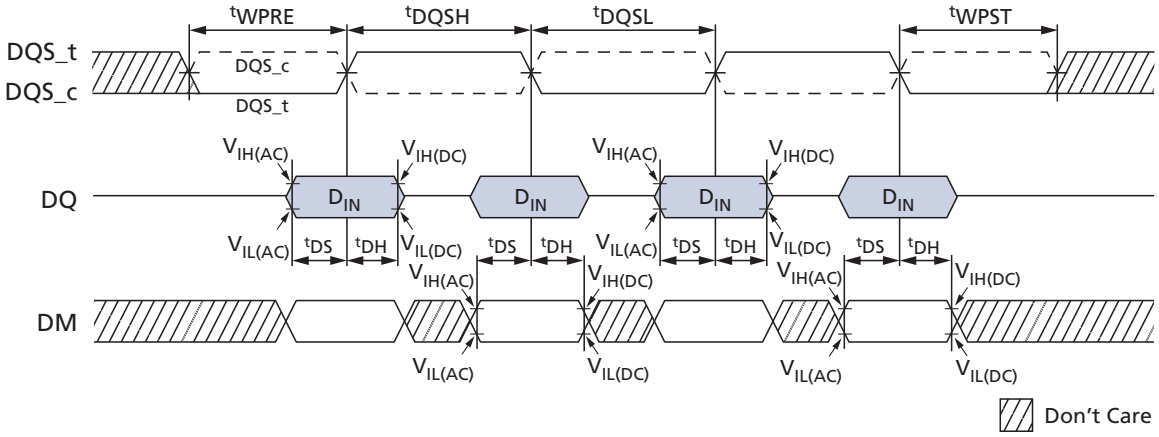


**Figure 33: Burst WRITE – WL = 1, BL = 4**

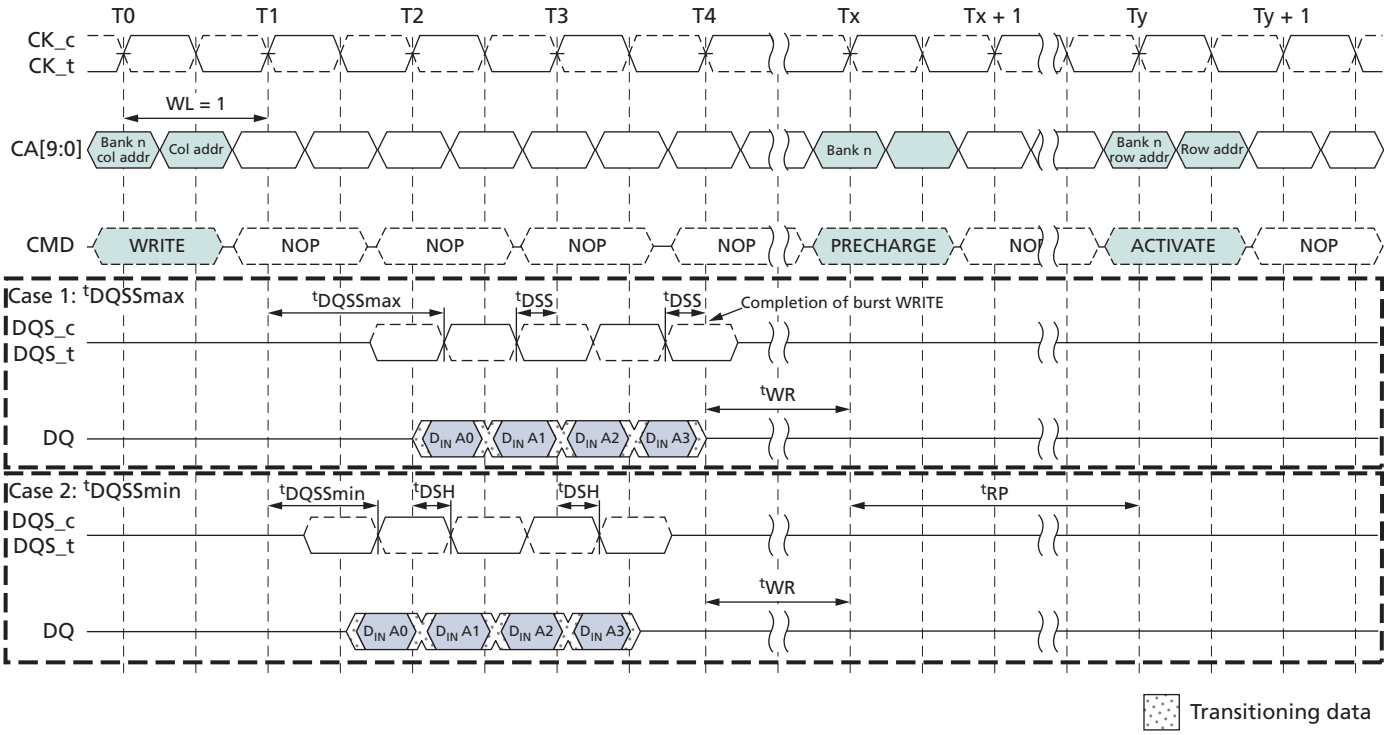



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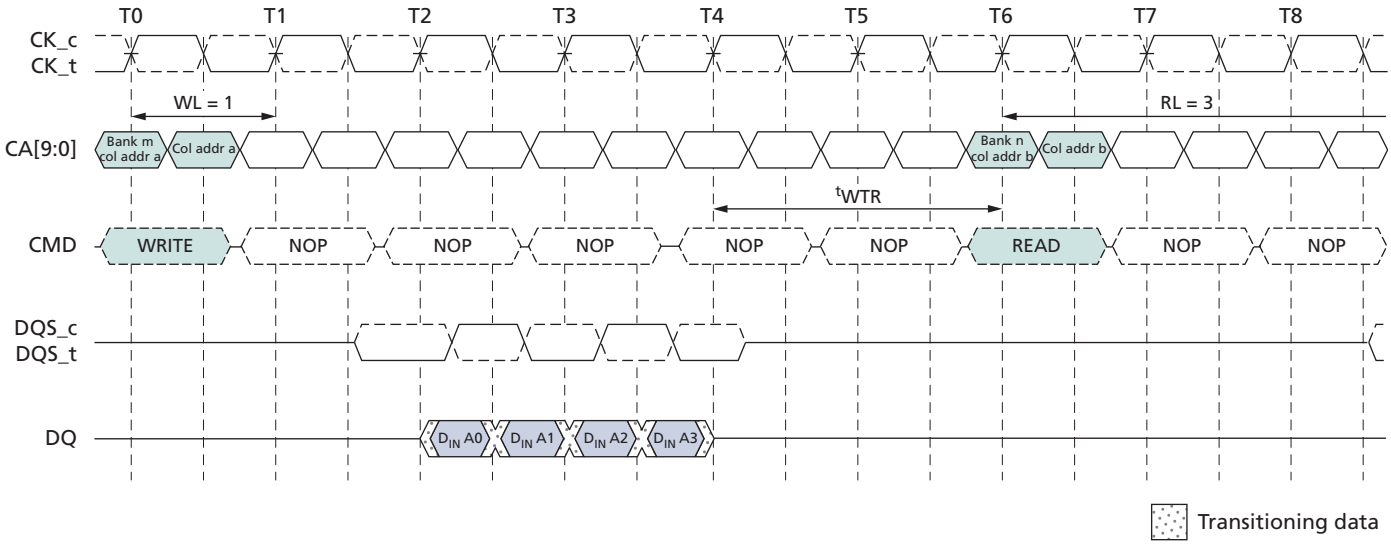
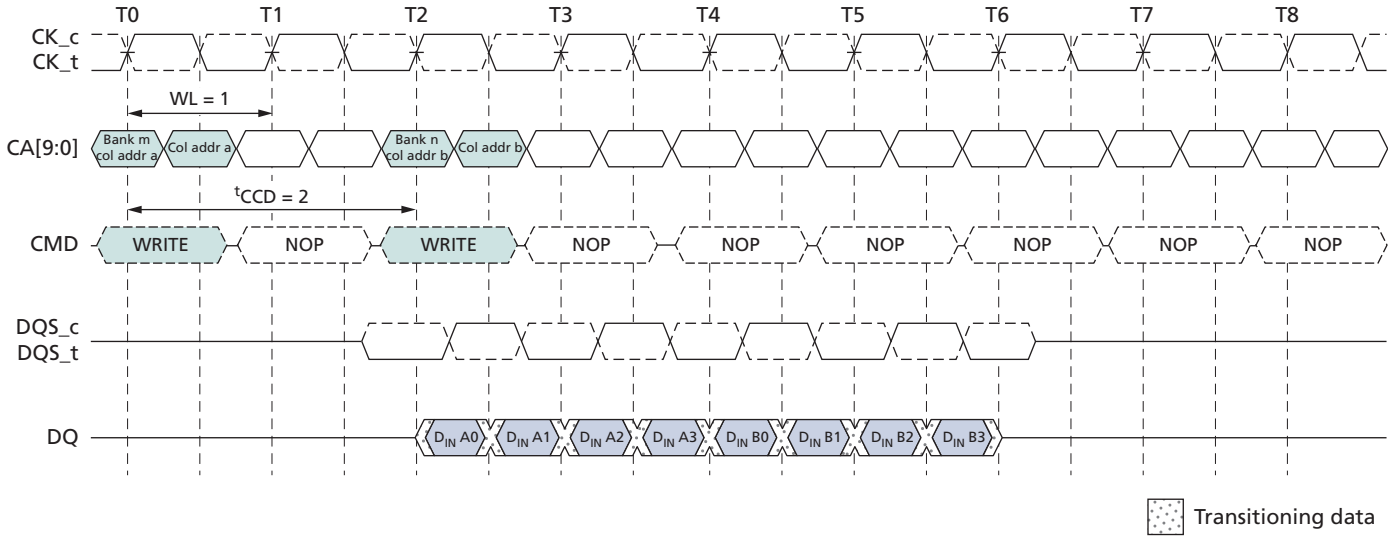
**Figure 34: Burst WRITE Followed by Burst READ – RL = 3, WL = 1, BL = 4**




Notes:
1. The minimum number of clock cycles from the burst WRITE command to the burst READ command for any bank is [WL + 1 + BL/2 + RU($^{t}$WTR/$^{t}$CK)].
2. $^{t}$WTR starts at the rising edge of the clock after the last valid input data.
3. If a WRITE burst is truncated with a BST command, the effective burst length of the truncated WRITE burst should be used as BL to calculate the minimum WRITE-to-READ delay.

**Figure 35: Seamless Burst WRITE – WL = 1, BL = 4, $^{t}$CCD = 2**





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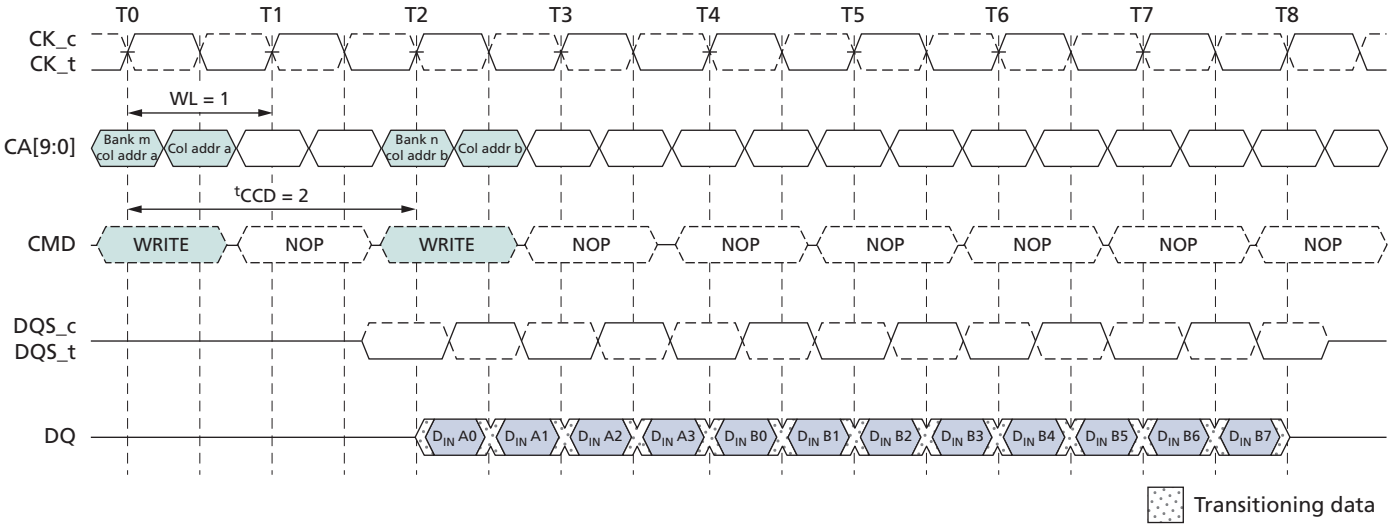
Note: 1. The seamless burst WRITE operation is supported by enabling a WRITE command every other clock for BL = 4 operation, every four clocks for BL = 8 operation, or every eight clocks for BL = 16 operation. This operation is supported for any activated bank.

### WRITEs Interrupted by a WRITE

A burst WRITE can be interrupted only by another WRITE with a 4-bit burst boundary, provided that $^{t}$CCD (MIN) is met.

A WRITE burst interrupt can occur on even clock cycles after the initial WRITE command, provided that $^{t}$CCD (MIN) is met.

**Figure 36: WRITE Burst Interrupt Timing – WL = 1, BL = 8, $^{t}$CCD = 2**




Notes:
1. A WRITE operation can be interrupted only by another WRITE command or a BST command.
2. The effective burst length of the first WRITE equals two times the number of clock cycles between the first WRITE and the interrupting WRITE.
3. For DDR2 Mobile RAM-S4 devices, a WRITE burst interrupt function is allowed only on a burst of 8 and 16.
4. For DDR2 Mobile RAM-S4 devices, a WRITE burst interrupt can occur only on even clock cycles after the previous WRITE command, provided that $^{t}$CCD(min) is met.
5. A WRITE burst to any bank inside DRAM can be interrupted.
6. A WRITE burst with auto-precharge cannot be interrupted.

## BURST TERMINATE Command

The BURST TERMINATE (BST) command is initiated with CS_n LOW, CA0 HIGH, CA1 HIGH, CA2 LOW, and CA3 LOW at the rising edge of the clock. A BST command can be issued only to terminate an active READ or WRITE burst. Therefore, a BST command can be issued only up to and including BL/2 - 1 clock cycles after a READ or WRITE command. The effective burst length of a READ or WRITE command truncated by a BST command is as follows: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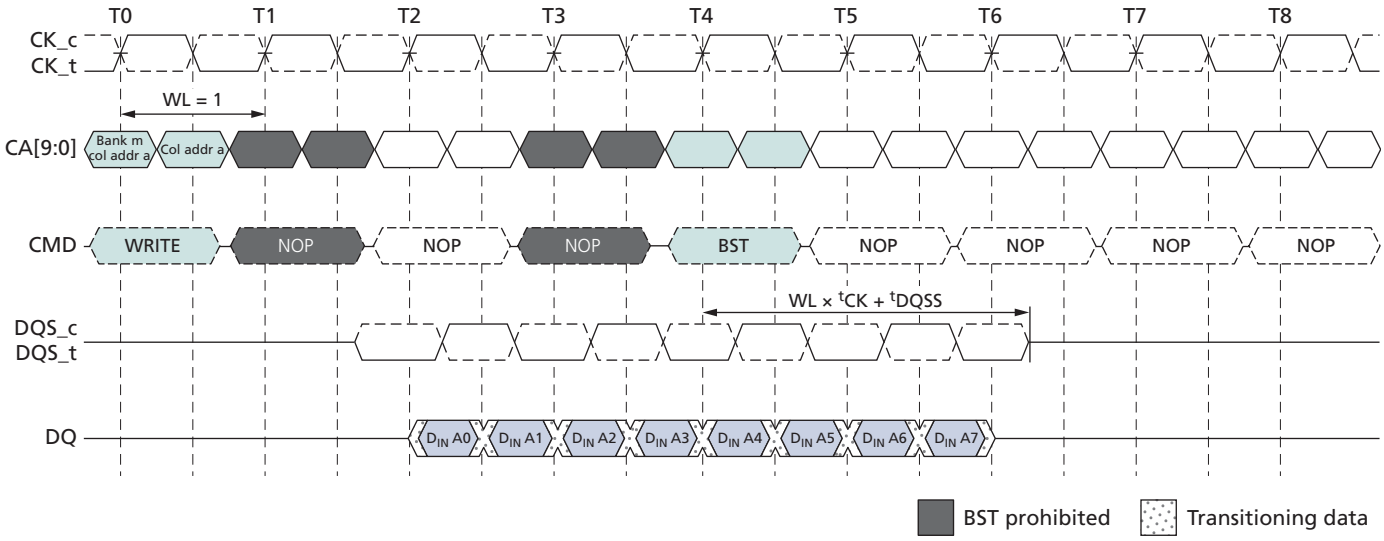
- Effective burst length = 2 × (number of clock cycles from the READ or WRITE command to the BST command).
- If a READ or WRITE burst is truncated with a BST command, the effective burst length of the truncated burst should be used for BL when calculating the minimum READ-to-WRITE or WRITE-to-READ delay.
- The BST command only affects the most recent READ or WRITE command. The BST command truncates an ongoing READ burst RL × $^{t}$CK + $^{t}$DQSCK + $^{t}$DQSQ after the rising edge of the clock where the BST command is issued. The BST command truncates an ongoing WRITE burst WL × $^{t}$CK + $^{t}$DQSS after the rising edge of the clock where the BST command is issued.
- The 4-bit prefetch architecture enables BST command assertion on even clock cycles following a WRITE or READ command. The effective burst length of a READ or WRITE command truncated by a BST command is thus an integer multiple of four.

**Figure 37: Burst WRITE Truncated by BST – WL = 1, BL = 16**




Notes:
1. The BST command truncates an ongoing WRITE burst WL × $^{t}$CK + $^{t}$DQSS after the rising edge of the clock where the BST command is issued.
2. BST can only be issued an even number of clock cycles after the WRITE command.
3. Additional BST commands are not supported after T4 and must not be issued until after the next READ or WRITE command.


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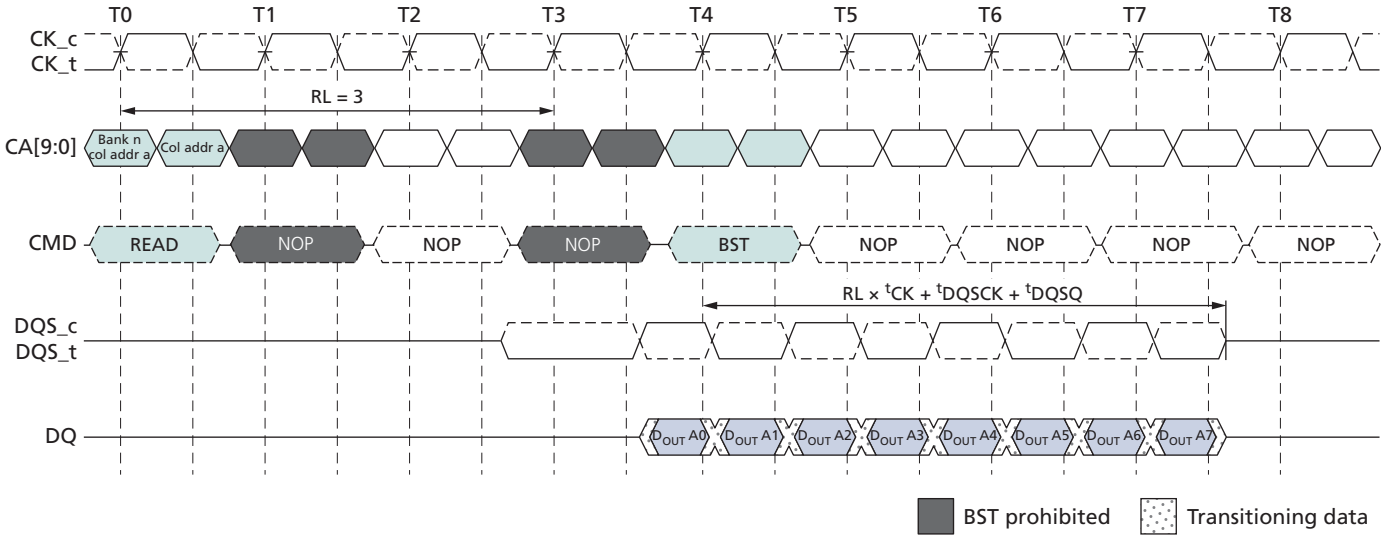
**Figure 38: Burst READ Truncated by BST – RL = 3, BL = 16**




Notes:
1. The BST command truncates an ongoing READ burst (RL × $^{t}$CK + $^{t}$DQSCK + $^{t}$DQSQ) after the rising edge of the clock where the BST command is issued.
2. BST can only be issued an even number of clock cycles after the READ command.
3. Additional BST commands are not supported after T4 and must not be issued until after the next READ or WRITE command.

## Write Data Mask

On the LPDDR2 device, one write data mask (DM) pin for each data byte (DQ) is supported, consistent with the implementation on LPDDR SDRAM. Each DM can mask its respective DQ for any given cycle of the burst. Data mask timings match data bit timing, but are inputs only. Internal data mask loading is identical to data bit loading to ensure matched system timing.

**Figure 39: Data Mask Timing**

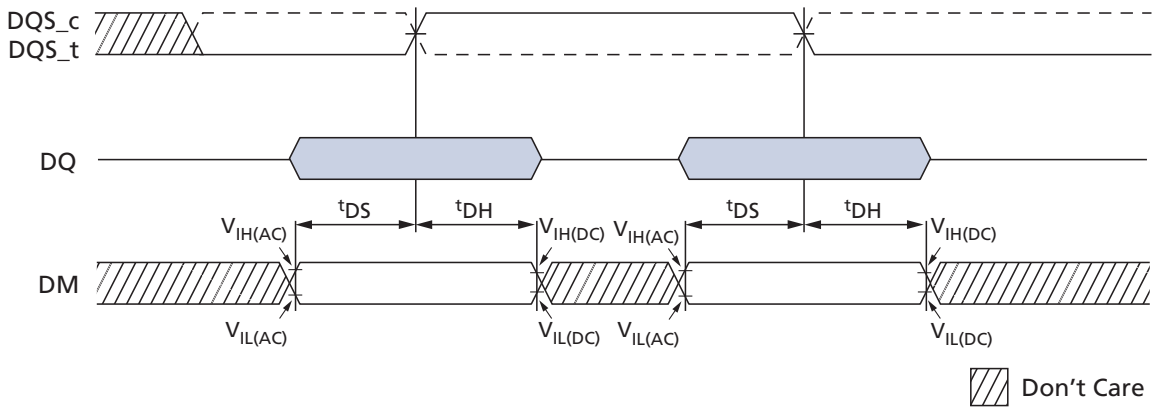




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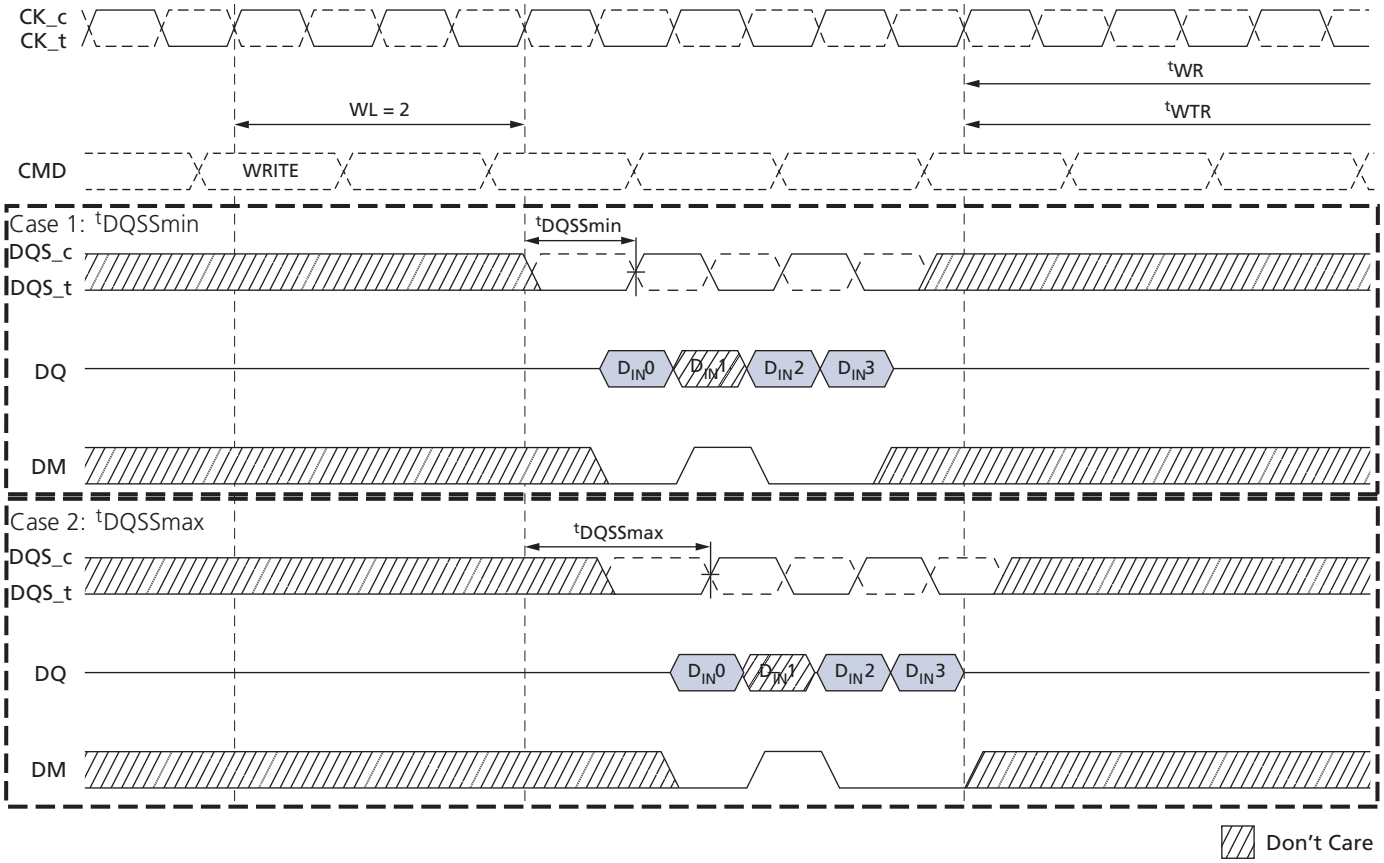
**Figure 40: Write Data Mask – Second Data Bit Masked**




Note: 1. For the data mask function, WL = 2, BL = 4 is shown; the second data bit is masked.

## PRECHARGE Command

The PRECHARGE command is used to precharge or close a bank that has been activated. The PRECHARGE command is initiated with CS_n LOW, CA0 HIGH, CA1 HIGH, CA2 LOW, and CA3 HIGH at the rising edge of the clock. The PRECHARGE command can be used to precharge each bank independently or all banks simultaneously. For a 4-bank device, the AB flag and bank address bits BA0 and BA1 are used to determine which bank(s) to precharge. For an 8-bank device, the AB flag and the bank address bits BA0, BA1, and BA2 are used to determine which bank(s) to precharge. The precharged bank(s) will be available for subsequent row access $^{t}$RPab after an all bank PRECHARGE command is issued, or $^{t}$RPpb after a single-bank PRECHARGE command is issued.

To ensure that an 8-bank device can meet the instantaneous current demand required to operate, the row precharge time ($^{t}$RP) for an all bank PRECHARGE in an 8-bank device ($^{t}$RPab) will be longer than the row precharge time for a single-bank PRECHARGE ($^{t}$RPpb). For a 4-bank device, $^{t}$RPab is equal to $^{t}$RPpb.

ACTIVATE to PRECHARGE timing is shown in ACTIVATE Command.


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**Table 56: Bank Selection for PRECHARGE by Address Bits**

| AB (CA4r) | BA2 (CA9r) | BA1 (CA8r) | BA0 (CA7r) | Precharged Bank(s) 4-Bank Device | Precharged Bank(s) 8-Bank Device |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | Bank 0 only | Bank 0 only |
| 0 | 0 | 0 | 1 | Bank 1 only | Bank 1 only |
| 0 | 0 | 1 | 0 | Bank 2 only | Bank 2 only |
| 0 | 0 | 1 | 1 | Bank 3 only | Bank 3 only |
| 0 | 1 | 0 | 0 | Bank 0 only | Bank 4 only |
| 0 | 1 | 0 | 1 | Bank 1 only | Bank 5 only |
| 0 | 1 | 1 | 0 | Bank 2 only | Bank 6 only |
| 0 | 1 | 1 | 1 | Bank 3 only | Bank 7 only |
| 1 | Don't Care | Don't Care | Don't Care | All banks | All banks |

## READ Burst Followed by PRECHARGE

For the earliest possible precharge, the PRECHARGE command can be issued BL/2 clock cycles after a READ command. A new bank ACTIVATE command can be issued to the same bank after the row precharge time ($^{t}$RP) has elapsed. A PRECHARGE command cannot be issued until after $^{t}$RAS is satisfied.

The minimum READ-to-PRECHARGE time ($^{t}$RTP) must also satisfy a minimum analog time from the rising clock edge that initiates the last 4-bit prefetch of a READ command. $^{t}$RTP begins BL/2 - 2 clock cycles after the READ command.

If the burst is truncated by a BST command, the effective BL value is used to calculate when $^{t}$RTP begins.

**Figure 41: READ Burst Followed by PRECHARGE – RL = 3, BL = 8, RU($^{t}$RTP(MIN)/$^{t}$CK) = 2**

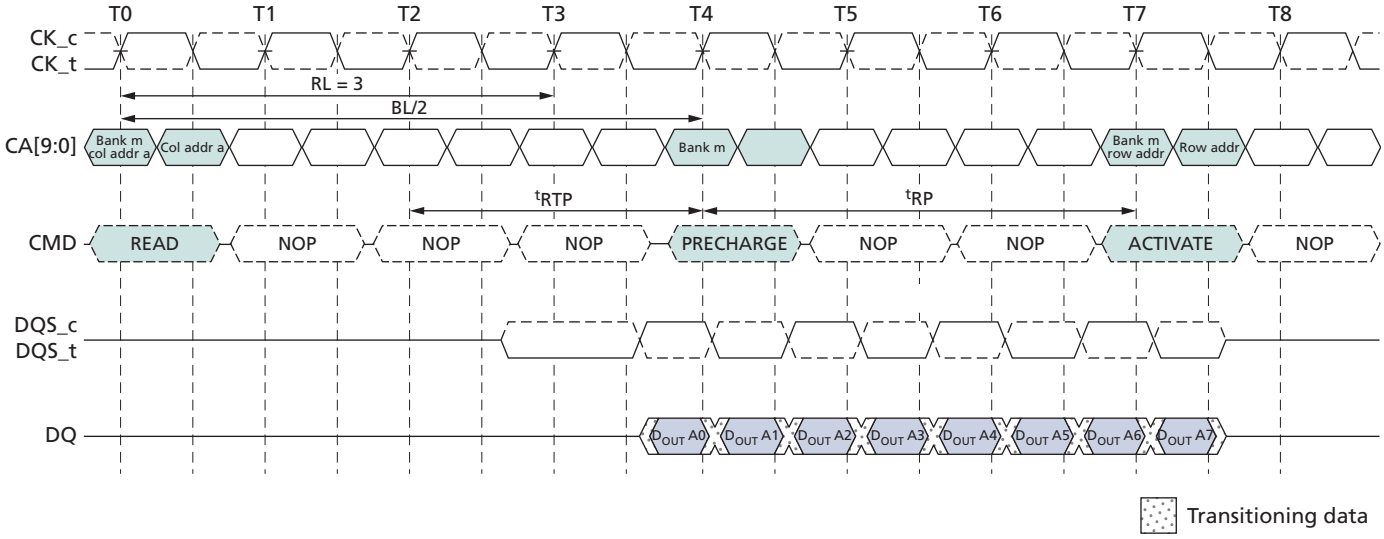



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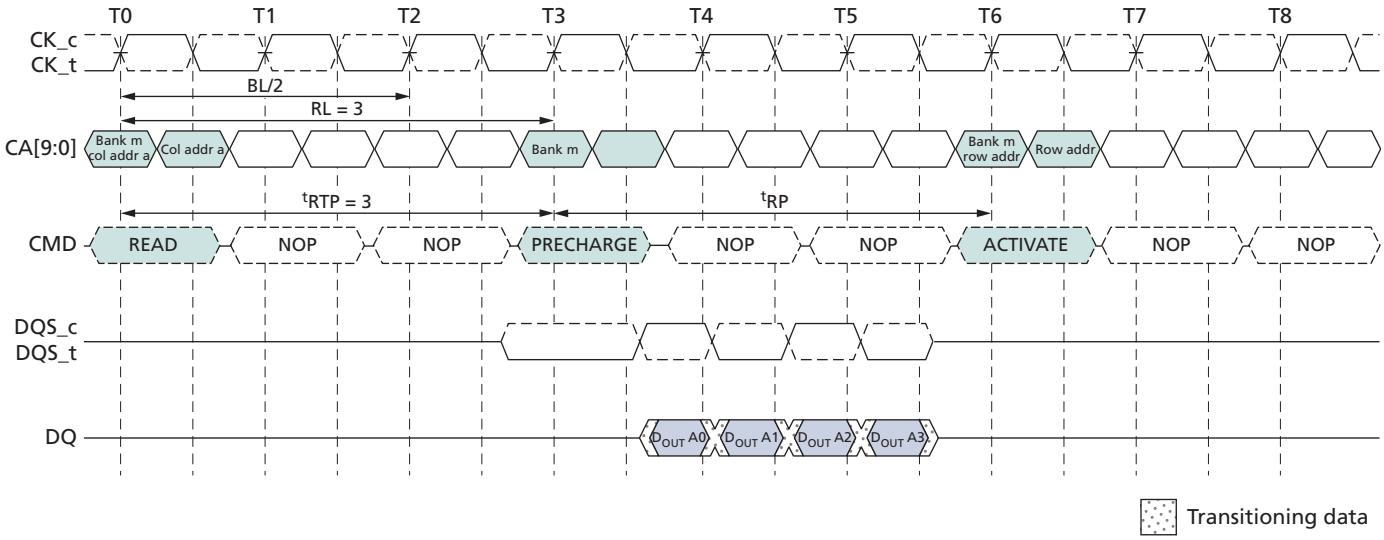
**Figure 42: READ Burst Followed by PRECHARGE – RL = 3, BL = 4, RU(tRTP(MIN)/tCK) = 3**




## WRITE Burst Followed by PRECHARGE

For WRITE cycles, a WRITE recovery time (tWR) must be provided before a PRECHARGE command can be issued. tWR delay is referenced from the completion of the burst WRITE. The PRECHARGE command must not be issued prior to the tWR delay. For WRITE-to-PRECHARGE timings, see the PRECHARGE and Auto Precharge Clarification table.

These devices write data to the array in prefetch quadruples (prefetch = 4). An internal WRITE operation can only begin after a prefetch group has been completely latched.

The minimum WRITE-to-PRECHARGE time for commands to the same bank is WL + BL/2 + 1 + RU(tWR/tCK) clock cycles. For untruncated bursts, BL is the value set in the mode register. For truncated bursts, BL is the effective burst length.


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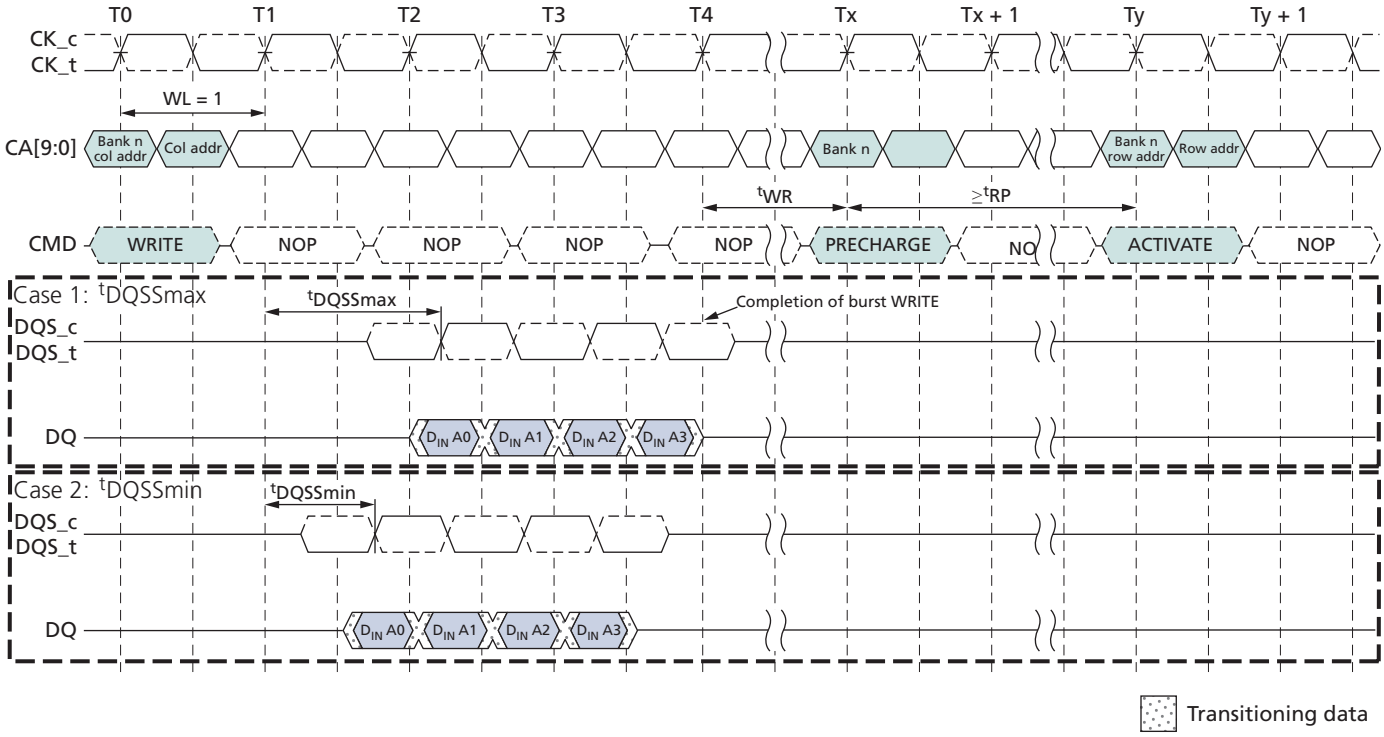
**Figure 43: WRITE Burst Followed by PRECHARGE – WL = 1, BL = 4**




## Auto Precharge operation

Before a new row can be opened in an active bank, the active bank must be precharged using either the PRECHARGE command or the auto precharge function. When a READ or WRITE command is issued to the device, the auto precharge bit (AP) can be set to enable the active bank to automatically begin precharge at the earliest possible moment during the burst READ or WRITE cycle.

If AP is LOW when the READ or WRITE command is issued, then normal READ or WRITE burst operation is executed and the bank remains active at the completion of the burst.

If AP is HIGH when the READ or WRITE command is issued, the auto precharge function is engaged. This feature enables the PRECHARGE operation to be partially or completely hidden during burst READ cycles (dependent upon READ or WRITE latency), thus improving system performance for random data access.

## READ Burst with Auto Precharge

If AP (CA0f) is HIGH when a READ command is issued, the READ with auto precharge function is engaged.

This device starts an auto precharge on the rising edge of the clock BL/2 or BL/2 - 2 + RU(tRTP/tCK) clock cycles later than the READ with auto precharge command, whichever is greater. For auto precharge calculations, see the PRECHARGE and Auto Precharge Clarification table.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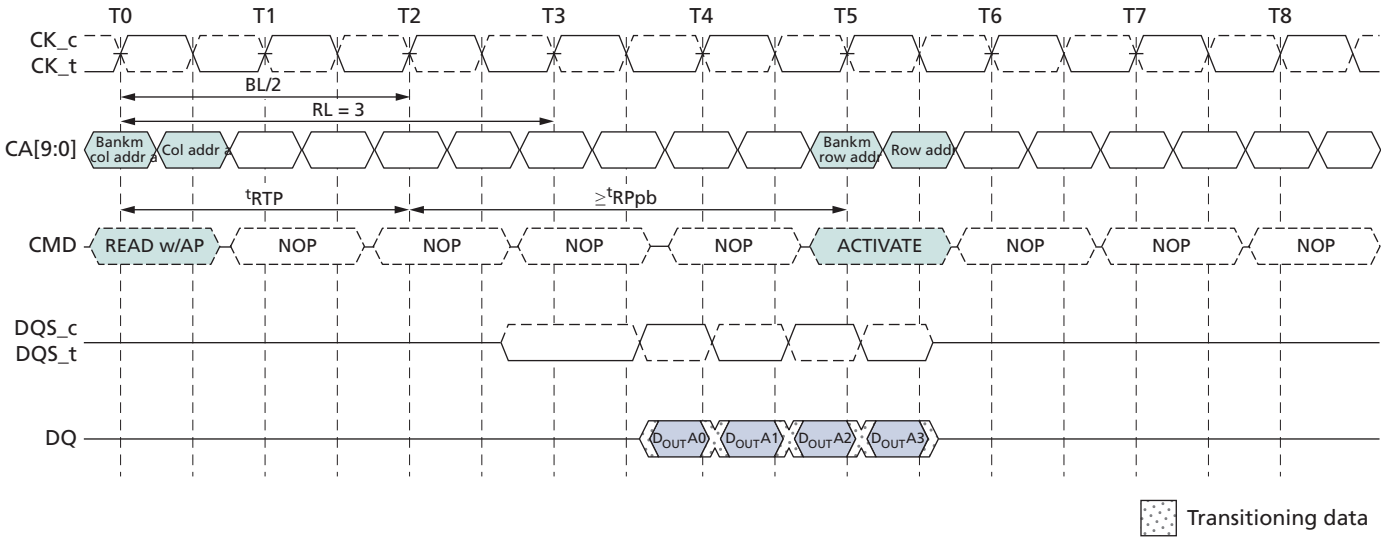
Following an auto precharge operation, an ACTIVATE command can be issued to the same bank if the following two conditions are satisfied simultaneously:

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

**Figure 44: READ Burst with Auto Precharge – RL = 3, BL = 4, RU($^{t}$RTP(MIN)/$^{t}$CK) = 2**




## WRITE Burst with Auto Precharge

If AP (CA0f) is HIGH when a WRITE command is issued, the WRITE with auto precharge function is engaged. The device starts an auto precharge at the clock rising edge $^{t}$WR cycles after the completion of the burst WRITE.

Following a WRITE with auto precharge, an ACTIVATE command can be issued to the same bank if the following two conditions are met:

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


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**Figure 45: WRITE Burst with Auto Precharge – WL = 1, BL = 4**

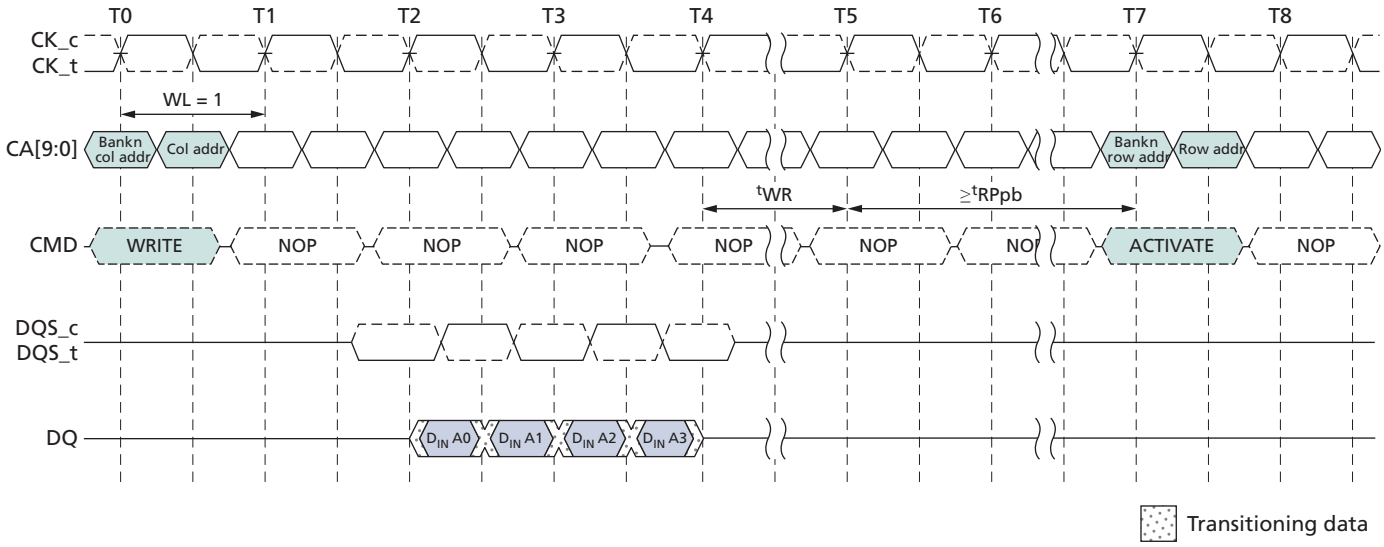


**Table 57: PRECHARGE and Auto Precharge Clarification**

| From Command | To Command | Minimum Delay Between Commands | Unit | Notes |
|---|---|---|---|---|
| READ | PRECHARGE to same bank as READ | BL/2 + MAX(2, RU($^t$RTP/$^t$CK)) - 2 | CLK | 1 |
| | PRECHARGE ALL | BL/2 + MAX(2, RU($^t$RTP/$^t$CK)) - 2 | CLK | 1 |
| BST | PRECHARGE to same bank as READ | 1 | CLK | 1 |
| | PRECHARGE ALL | 1 | CLK | 1 |
| READ w/AP | PRECHARGE to same bank as READ w/AP | BL/2 + MAX(2, RU($^t$RTP/$^t$CK)) - 2 | CLK | 1, 2 |
| | PRECHARGE ALL | BL/2 + MAX(2, RU($^t$RTP/$^t$CK)) - 2 | CLK | 1 |
| | ACTIVATE to same bank as READ w/AP | BL/2 + MAX(2, RU($^t$RTP/$^t$CK)) - 2 + RU($^t$RPpb/$^t$CK) | CLK | 1 |
| | WRITE or WRITE w/AP (same bank) | Illegal | CLK | 3 |
| | WRITE or WRITE w/AP (different bank) | RL + BL/2 + RU($^t$DQSCKmax/$^t$CK) - WL + 1 | CLK | 3 |
| | READ or READ w/AP (same bank) | Illegal | CLK | 3 |
| | READ or READ w/AP (different bank) | BL/2 | CLK | 3 |
| WRITE | PRECHARGE to same bank as WRITE | WL + BL/2 + RU($^t$WR/$^t$CK) + 1 | CLK | 1 |
| | PRECHARGE ALL | WL + BL/2 + RU($^t$WR/$^t$CK) + 1 | CLK | 1 |
| BST | PRECHARGE to same bank as WRITE | WL + RU($^t$WR/$^t$CK) + 1 | CLK | 1 |
| | PRECHARGE ALL | WL + RU($^t$WR/$^t$CK) + 1 | CLK | 1 |


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**Table 57: PRECHARGE and Auto Precharge Clarification (Continued)**

| From Command | To Command | Minimum Delay Between Commands | Unit | Notes |
|---|---|---|---|---|
| WRITE w/AP | PRECHARGE to same bank as WRITE w/AP | WL + BL/2 + RU($^t$WR/$^t$CK) + 1 | CLK | 1, 2 |
| | PRECHARGE ALL | WL + BL/2 + RU($^t$WR/$^t$CK) + 1 | CLK | 1 |
| | ACTIVATE to same bank as WRITE w/AP | WL + BL/2 + RU($^t$WR/$^t$CK) + 1 + RU($^t$RPpb/$^t$CK) | CLK | 1 |
| | WRITE or WRITE w/AP (same bank) | Illegal | CLK | 3 |
| | WRITE or WRITE w/AP (different bank) | BL/2 | CLK | 3 |
| | READ or READ w/AP (same bank) | Illegal | CLK | 3 |
| | READ or READ w/AP (different bank) | WL + BL/2 + RU($^t$WTR/$^t$CK) + 1 | CLK | 3 |
| PRECHARGE | PRECHARGE to same bank as PRECHARGE | 1 | CLK | 1 |
| | PRECHARGE ALL | 1 | CLK | 1 |
| PRECHARGE ALL | PRECHARGE | 1 | CLK | 1 |
| | PRECHARGE ALL | 1 | CLK | 1 |

Notes:
1. For a given bank, the PRECHARGE period should be counted from the latest PRECHARGE command—either a one-bank PRECHARGE or PRECHARGE ALL—issued to that bank. The PRECHARGE period is satisfied after $^t$RP, depending on the latest PRECHARGE command issued to that bank.
2. Any command issued during the specified minimum delay time is illegal.
3. After READ with auto precharge, seamless READ operations to different banks are supported. After WRITE with auto precharge, seamless WRITE operations to different banks are supported. READ with auto precharge and WRITE with auto precharge must not be interrupted or truncated.

## REFRESH Command

The REFRESH command is initiated with CS_n LOW, CA0 LOW, CA1 LOW, and CA2 HIGH at the rising edge of the clock. A per-bank REFRESH command is initiated with CA3 LOW at the rising edge of the clock. The all-bank REFRESH command is initiated with CA3 HIGH at the rising edge of the clock. A per-bank REFRESH is only supported in devices with eight banks.

A per-bank REFRESH command (REFpb) performs a per-bank REFRESH operation to the bank scheduled by the bank counter in the memory device. The bank sequence for per-bank REFRESH is fixed to be a sequential round-robin: 0-1-2-3-4-5-6-7-0-1-.... The bank count is synchronized between the controller and the SDRAM by resetting the bank count to zero. Synchronization can occur upon issuing a RESET command or at every exit from self refresh.

A bank must be idle before it can be refreshed. The controller must track the bank being refreshed by the per-bank REFRESH command.

The REFpb command must not be issued to the device until the following conditions have been met:

- $^t$RFCab has been satisfied after the prior REFab command
- $^t$RFCpb has been satisfied after the prior REFpb command
- $^t$RP has been satisfied after the prior PRECHARGE command to that bank


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tRRD has been satisfied after the prior ACTIVATE command (when applicable, for example after activating a row in a different bank than the one affected by the REFpb command)

The target bank is inaccessible during per-bank REFRESH cycle time (tRFCpb); however, other banks within the device are accessible and can be addressed during the cycle. During the REFpb operation, any of the banks other than the one being refreshed can be maintained in an active state or accessed by a READ or WRITE command.

When the per-bank REFRESH cycle has completed, the affected bank will be in the idle state.

After issuing REFpb, the following conditions must be met:

- tRFCpb must be satisfied before issuing a REFab command
- tRFCpb must be satisfied before issuing an ACTIVATE command to the same bank
- tRRD must be satisfied before issuing an ACTIVATE command to a different bank
- tRFCpb must be satisfied before issuing another REFpb command

An all-bank REFRESH command (REFab) issues a REFRESH command to all banks. All banks must be idle when REFab is issued (for instance, by issuing a PRECHARGE ALL command prior to issuing an all-bank REFRESH command). REFab also synchronizes the bank count between the controller and the SDRAM to zero. The REFab command must not be issued to the device until the following conditions have been met:

- tRFCab has been satisfied following the prior REFab command
- tRFCpb has been satisfied following the prior REFpb command
- tRP has been satisfied following the prior PRECHARGE commands

After an all-bank REFRESH cycle has completed, all banks will be idle. After issuing REFab:

- tRFCab latency must be satisfied before issuing an ACTIVATE command
- tRFCab latency must be satisfied before issuing a REFab or REFpb command

**Table 58: REFRESH Command Scheduling Separation Requirements**

| Symbol | Minimum Delay From | To | Notes |
|---|---|---|---|
| tRFCab | REFab | REFab | |
| | | ACTIVATE command to any bank | |
| | | REFpb | |
| tRFCpb | REFpb | REFab | |
| | | ACTIVATE command to same bank as REFpb | |
| | | REFpb | |
| tRRD | REFpb | ACTIVATE command to a different bank than REFpb | |
| | ACTIVATE | REFpb affecting an idle bank (different bank than activate) | 1 |
| | | ACTIVATE command to a different bank than the prior ACTIVATE command | |

Note: 1. A bank must be in the idle state before it is refreshed, so REFab is prohibited following an ACTIVATE command. REFpb is supported only if it affects a bank that is in the idle state.


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## REFRESH Requirements

**1. Minimum Number of REFRESH Commands**

Mobile LPDDR2 requires a minimum number, R, of REFRESH (REFab) commands within any rolling refresh window ($^{t}$REFW = 32 ms @ MR4[2:0] = 011 or $T_C \leq 85^{\circ}C$). For actual values per density and the resulting average refresh interval ($^{t}$REFI), see Refresh Requirements.

For $^{t}$REFW and $^{t}$REFI refresh multipliers at different MR4 settings, see the MR4 Device Temperature (MA[7:0] = 04h) table.

For devices supporting per-bank REFRESH, a REFab command can be replaced by a full cycle of eight REFpb commands.

**2. Burst REFRESH Limitation**

To limit current consumption, a maximum of eight REFab commands can be issued in any rolling $^{t}$REFBW ($^{t}$REFBW = 4 × 8 × $^{t}$RFCab). This condition does not apply if REFpb commands are used.

**3. REFRESH Requirements and Self Refresh**

If any time within a refresh window is spent in self refresh mode, the number of required REFRESH commands in that window is reduced to the following:

$$R' = R - RU\left(\frac{t_{SRF}}{t_{REFI}}\right) = R - RU\left(R \times \frac{t_{SRF}}{t_{REFW}}\right)$$

Where RU represents the round-up function



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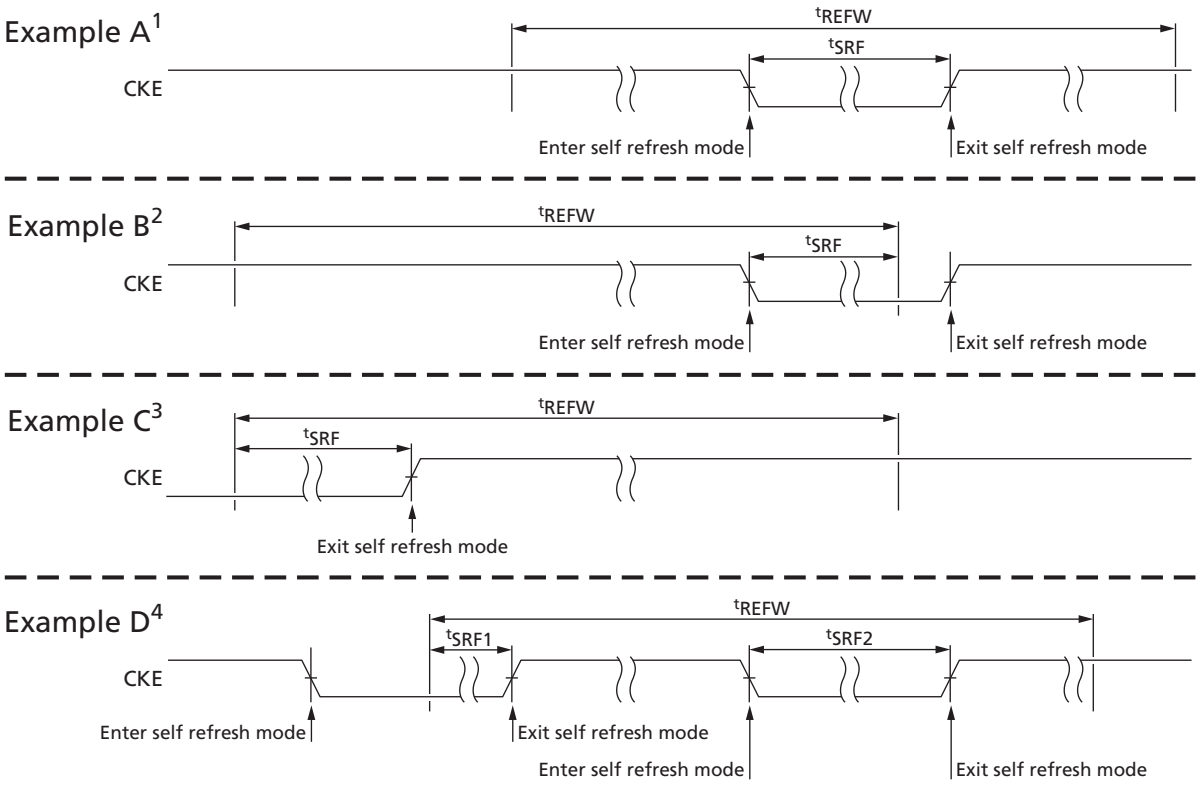
**Figure 46: tSRF Definition**




Notes:
1. Time in self refresh mode is fully enclosed in the refresh window (tREFW).
2. At self refresh entry.
3. At self refresh exit.
4. Several intervals in self refresh during one tREFW interval. In this example, tSRF = tSRF1 + tSRF2.

The mobile LPDDR2 device provides significant flexibility in scheduling a REFRESH command as long as the required boundary conditions are met (see the tSRF Definition figure).

In the most straightforward implementations, a REFRESH command should be scheduled every tREFI. In this case, self refresh can be entered at any time.

Users may choose to deviate from this regular refresh pattern, for instance, to enable a period in which no refresh is required. As an example, using a 1Gb LPDDR2 device, the user can choose to issue a refresh burst of 4096 REFRESH commands at the maximum supported rate (limited by tREFBW), followed by an extended period without issuing any REFRESH commands, until the refresh window is complete. The maximum supported time without REFRESH commands is calculated as follows: tREFW - (R/8) × tREFBW = tREFW - R × 4 × tRFCab.

For example, a 1Gb device at $T_C \leq 85^\circ C$ can be operated without a refresh for up to 32ms - 4096 × 4 × 130ns ≈ 30ms.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Both the regular and the burst/pause patterns can satisfy refresh requirements if they are repeated in every 32ms window. It is critical to satisfy the refresh requirement in *every* rolling refresh window during refresh pattern transitions. The supported transition from a burst pattern to a regular distributed pattern is shown in the Supported Transition from Repetitive REFRESH Burst figure. If this transition occurs immediately after the burst refresh phase, all rolling $^{t}$REFW intervals will meet the minimum required number of REFRESH commands.

A nonsupported transition is shown below. In this example, the regular refresh pattern starts after the completion of the pause phase of the burst/pause refresh pattern. For several rolling $^{t}$REFW intervals, the minimum number of REFRESH commands is not satisfied.

Understanding this pattern transition is extremely important, even when only one pattern is employed. In self refresh mode, a regular distributed refresh pattern must be assumed. Micron recommends entering self refresh mode immediately following the burst phase of a burst/pause refresh pattern; upon exiting self refresh, begin with the burst phase (see the Recommended Self Refresh Entry and Exit figure).



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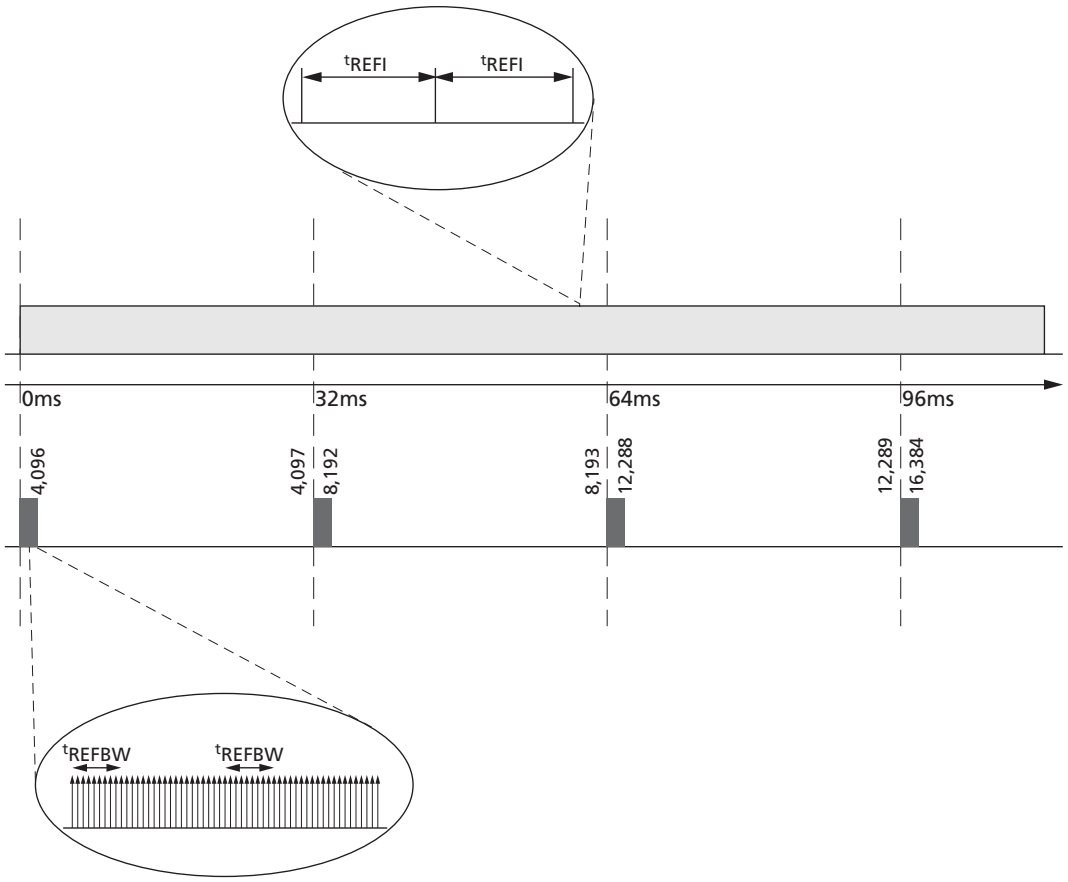
**Figure 47: Regular Distributed Refresh Pattern**




Notes:
1. Compared to repetitive burst REFRESH with subsequent REFRESH pause.
2. As an example, in a 1Gb LPDDR2 device at $T_C \leq 85^{\circ}C$, the distributed refresh pattern has one REFRESH command per 7.8µs; the burst refresh pattern has one REFRESH command per 0.52µs, followed by ≈ 30ms without any REFRESH command.


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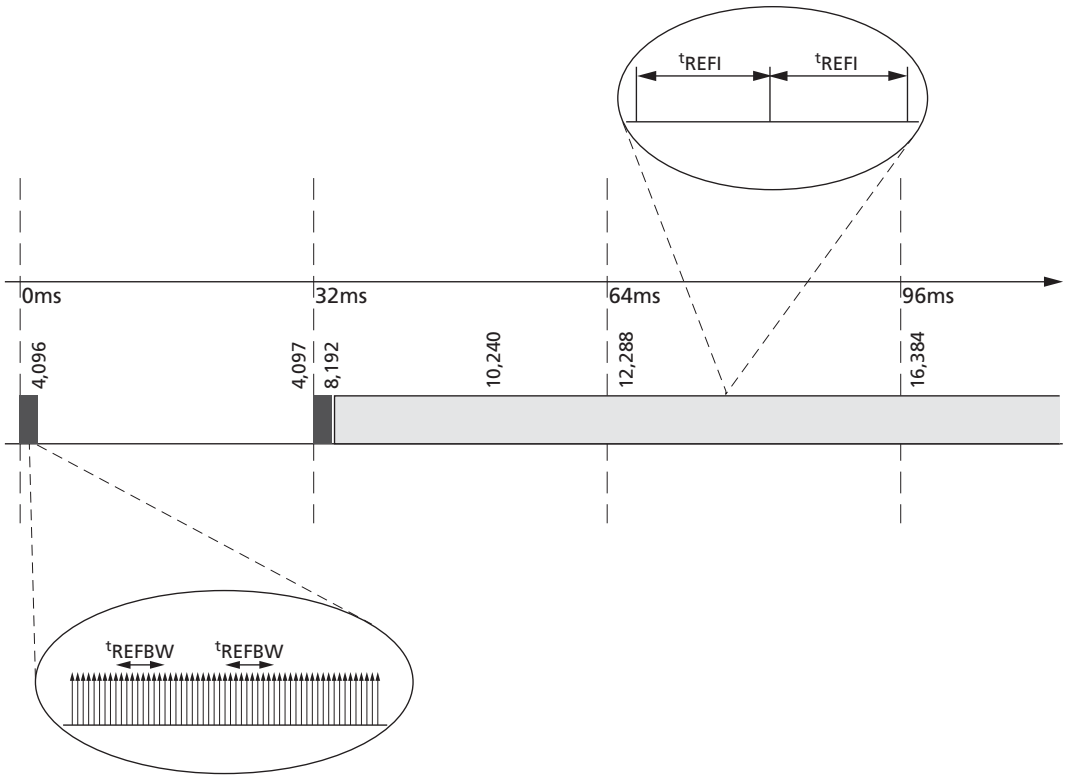
**Figure 48: Supported Transition from Repetitive REFRESH Burst**




Notes:
1. Shown with subsequent REFRESH pause to regular distributed refresh pattern.
2. As an example, in a 1Gb LPDDR2 device at $T_C \leq 85^{\circ}C$, the distributed refresh pattern has one REFRESH command per 7.8µs; the burst refresh pattern has one REFRESH command per 0.52µs, followed by ≈ 30ms without any REFRESH command.


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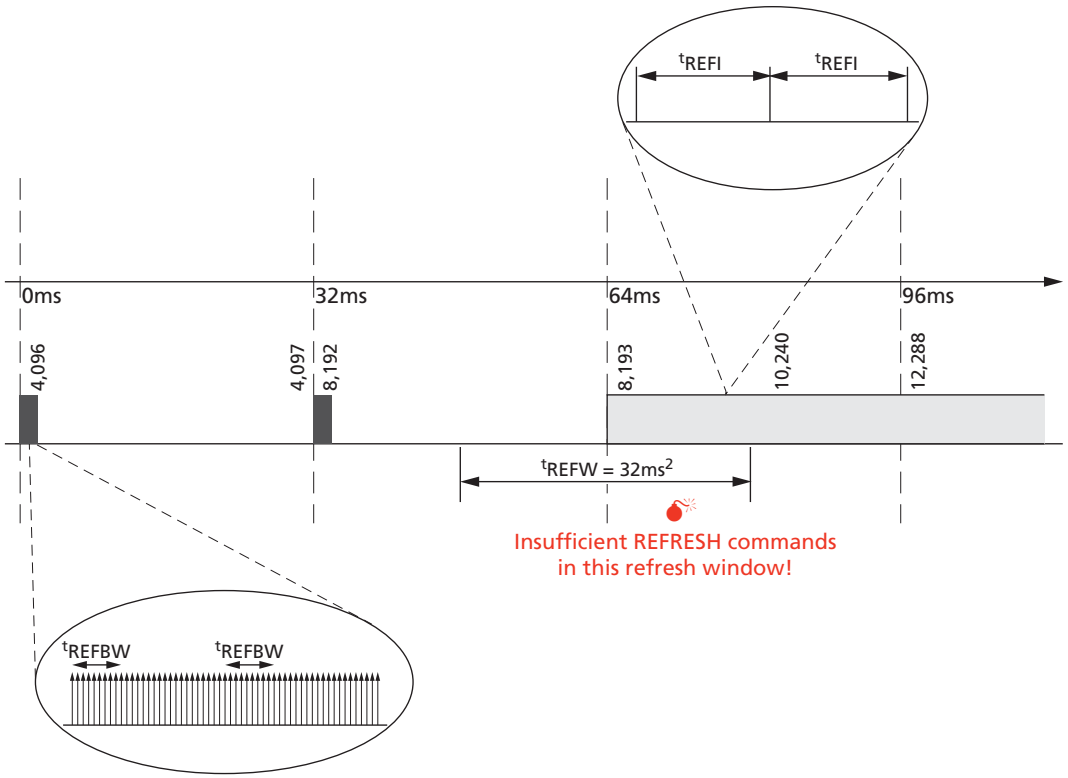
**Figure 49: Nonsupported Transition from Repetitive REFRESH Burst**




Notes:
1. Shown with subsequent REFRESH pause to regular distributed refresh pattern.
2. There are only ≈ 2048 REFRESH commands in the indicated tREFW window. This does not provide the required minimum number of REFRESH commands (R).


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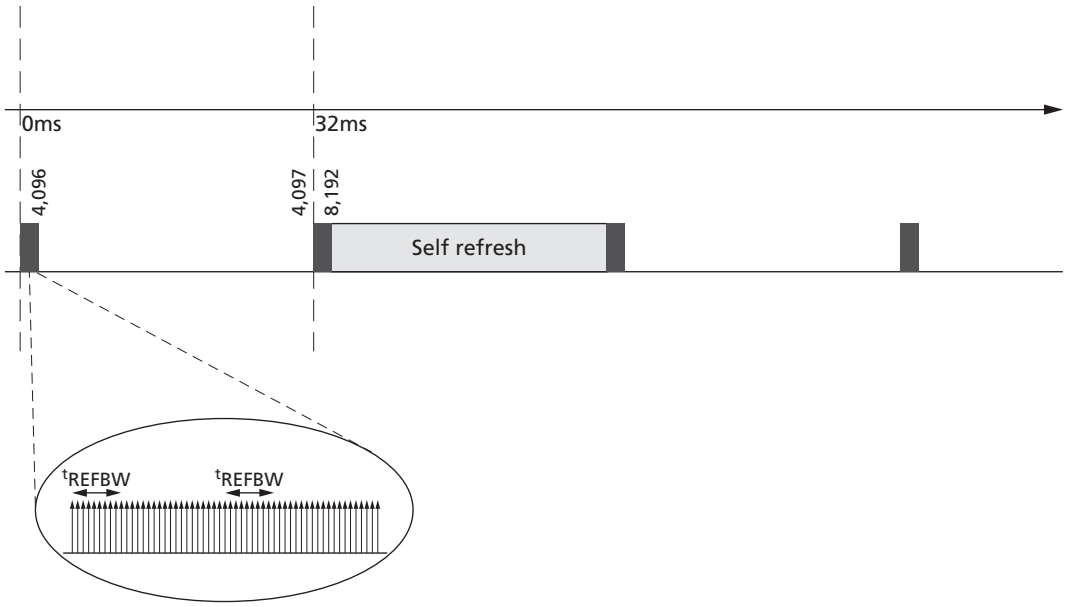
**Figure 50: Recommended Self Refresh Entry and Exit**




Note: 1. In conjunction with a burst/pause refresh pattern.


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**Figure 51: All-Bank REFRESH Operation**

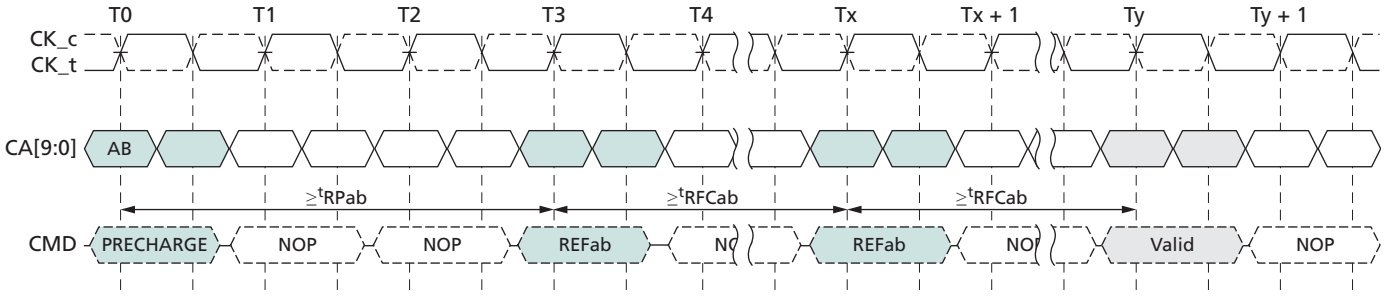
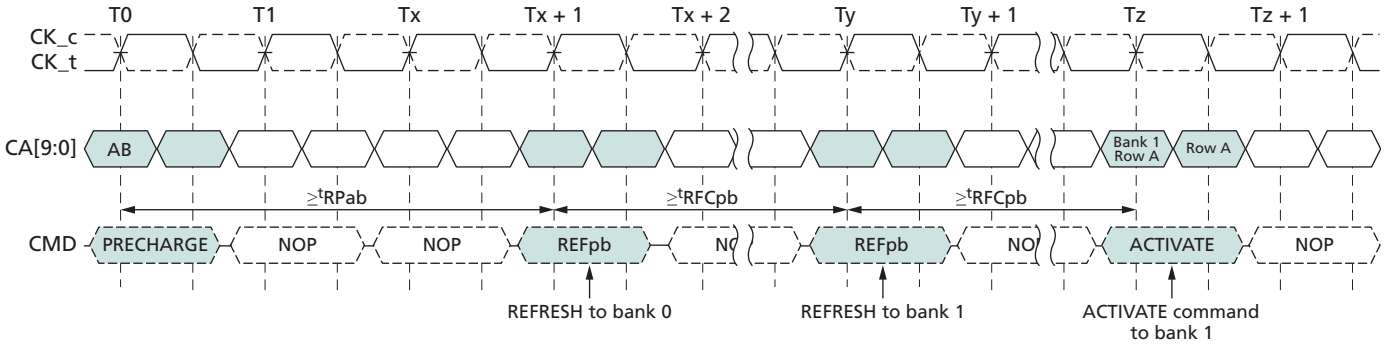



**Figure 52: Per-Bank REFRESH Operation**




Notes: 1. Prior to T0, the REFpb bank counter points to bank 0.
2. Operations to banks other than the bank being refreshed are supported during the tRFCpb period.

# SELF REFRESH Operation

The SELF REFRESH command can be used to retain data in the array, even if the rest of the system is powered down. When in the self refresh mode, the device retains data without external clocking. The device has a built-in timer to accommodate the SELF REFRESH operation.

The SELF REFRESH command is executed by taking CKE LOW, CS_n LOW, CA0 LOW, CA1 LOW, and CA2 HIGH at the rising edge of the clock. CKE must be HIGH during the previous clock cycle. A NOP command must be driven in the clock cycle following the POWER-DOWN command. Once the command is registered, CKE must be held LOW to keep the device in self-refresh mode.

The mobile LPDDR2 device can operate in self refresh mode in both the standard and extended temperature ranges. The device also manages self refresh power consumption when the operating temperature changes, resulting in the lowest possible power consumption across the operating temperature range (See IDD Specifications for details).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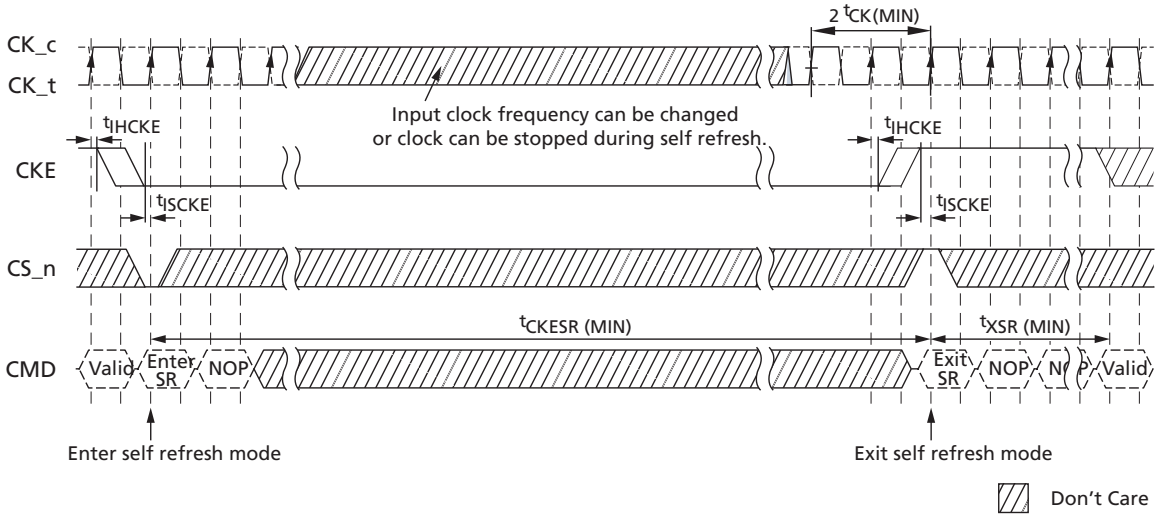
After the device has entered self refresh mode, all external signals other than CKE are "Don't Care." For proper self refresh operation, power supply pins ($V_{DD1}$, $V_{DD2}$, and $V_{DDQ}$) must be at valid levels. $V_{DDQ}$ can be turned off during self refresh. If $V_{DDQ}$ is turned off, $V_{REFDQ}$ must also be turned off. Prior to exiting self refresh, both $V_{DDQ}$ and $V_{REFDQ}$ must be within their respective minimum/maximum operating ranges (see the Single-Ended AC and DC Input Levels for DQ and DM table). $V_{REFDQ}$ can be at any level between 0 and $V_{DDQ}$; $V_{REFCA}$ can be at any level between 0 and $V_{DD2}$ during self refresh.

Before exiting self refresh, $V_{REFDQ}$ and $V_{REFCA}$ must be within specified limits (See AC and DC Logic Input Measurement Levels for Single-Ended Signals for details). After entering self refresh mode, the device initiates at least one all-bank REFRESH command internally during $^{t}$CKESR. The clock is internally disabled during SELF REFRESH operation to save power. The device must remain in self refresh mode for at least $^{t}$CKESR. The user can change the external clock frequency or halt the external clock one clock after self refresh entry is registered; however, the clock must be restarted and stable before the device can exit SELF REFRESH operation.

Exiting self refresh requires a series of commands. First, the clock must be stable prior to CKE returning HIGH. After the self refresh exit is registered, a minimum delay, at least equal to the self refresh exit interval ($^{t}$XSR), must be satisfied before a valid command can be issued to the device. This provides completion time for any internal refresh in progress. For proper operation, CKE must remain HIGH throughout $^{t}$XSR. NOP commands must be registered on each rising clock edge during $^{t}$XSR.

Using self refresh mode introduces the possibility that an internally timed refresh event could be missed when CKE is driven HIGH for exit from self refresh mode. Upon exiting self refresh, at least one REFRESH command (one all-bank command or eight per-bank commands) must be issued before issuing a subsequent SELF REFRESH command.

**Figure 53: SELF REFRESH Operation**




Notes: 1. Input clock frequency can be changed or stopped during self refresh, provided that upon exiting self-refresh, a minimum of two cycles of stable clocks are provided, and the clock frequency is between the minimum and maximum frequencies for the particular speed grade.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2. The device must be in the all banks idle state prior to entering self refresh mode.
3. $^{t}$XSR begins at the rising edge of the clock after CKE is driven HIGH.
4. A valid command can be issued only after $^{t}$XSR is satisfied. NOPs must be issued during $^{t}$XSR.

## Partial-Array Self Refresh – Bank Masking

Any device of densities of 64Mb–512Mb is comprised of four banks; a device of 1Gb density or higher is comprised of eight banks. Each bank can be configured independently whether or not a SELF REFRESH operation will occur in that bank. One 8-bit mode register (accessible via the MRW command) is assigned to program the bank-masking status of each bank up to eight banks. For bank masking bit assignments, see the MR16 PASR Bank Mask (MA[7:0] = 010h) and MR16 Op-Code Bit Definitions tables.

The mask bit to the bank enables or disables a refresh operation of the entire memory space within the bank. If a bank is masked using the bank mask register, a REFRESH operation to the entire bank is blocked and bank data retention is not guaranteed in self refresh mode. To enable a REFRESH operation to a bank, the corresponding bank mask bit must be programmed as "unmasked." When a bank mask bit is unmasked, the array space being refreshed within that bank is determined by the programmed status of the segment mask bits.

## Partial-Array Self Refresh – Segment Masking

Programming segment mask bits is similar to programming bank mask bits. For a density of 1Gb or higher, eight segments are used for masking (see the MR17 PASR Segment Mask (MA[7:0] = 011h) and MR17 PASR Segment Mask Definitions tables). A mode register is used for programming segment mask bits up to eight bits. For a density of less than 1Gb, segment masking is not supported.

When the mask bit to an address range (represented as a segment) is programmed as "masked," a REFRESH operation to that segment is blocked. Conversely, when a segment mask bit to an address range is unmasked, refresh to that segment is enabled.

A segment masking scheme can be used in place of or in combination with a bank masking scheme. Each segment mask bit setting is applied across all banks. For segment masking bit assignments, see the tables noted above.

**Table 59: Bank and Segment Masking Example**

| | Segment Mask (MR17) | Bank 0 | Bank 1 | Bank 2 | Bank 3 | Bank 4 | Bank 5 | Bank 6 | Bank 7 |
|---|---|---|---|---|---|---|---|---|---|
| **Bank Mask (MR16)** | | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **1** |
| Segment 0 | 0 | – | M | – | – | – | – | – | M |
| Segment 1 | 0 | – | M | – | – | – | – | – | M |
| Segment 2 | 1 | M | M | M | M | M | M | M | M |
| Segment 3 | 0 | – | M | – | – | – | – | – | M |
| Segment 4 | 0 | – | M | – | – | – | – | – | M |
| Segment 5 | 0 | – | M | – | – | – | – | – | M |
| Segment 6 | 0 | – | M | – | – | – | – | – | M |


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**Table 59: Bank and Segment Masking Example (Continued)**

| | Segment Mask (MR17) | Bank 0 | Bank 1 | Bank 2 | Bank 3 | Bank 4 | Bank 5 | Bank 6 | Bank 7 |
|---|---|---|---|---|---|---|---|---|---|
| Segment 7 | 1 | M | M | M | M | M | M | M | M |

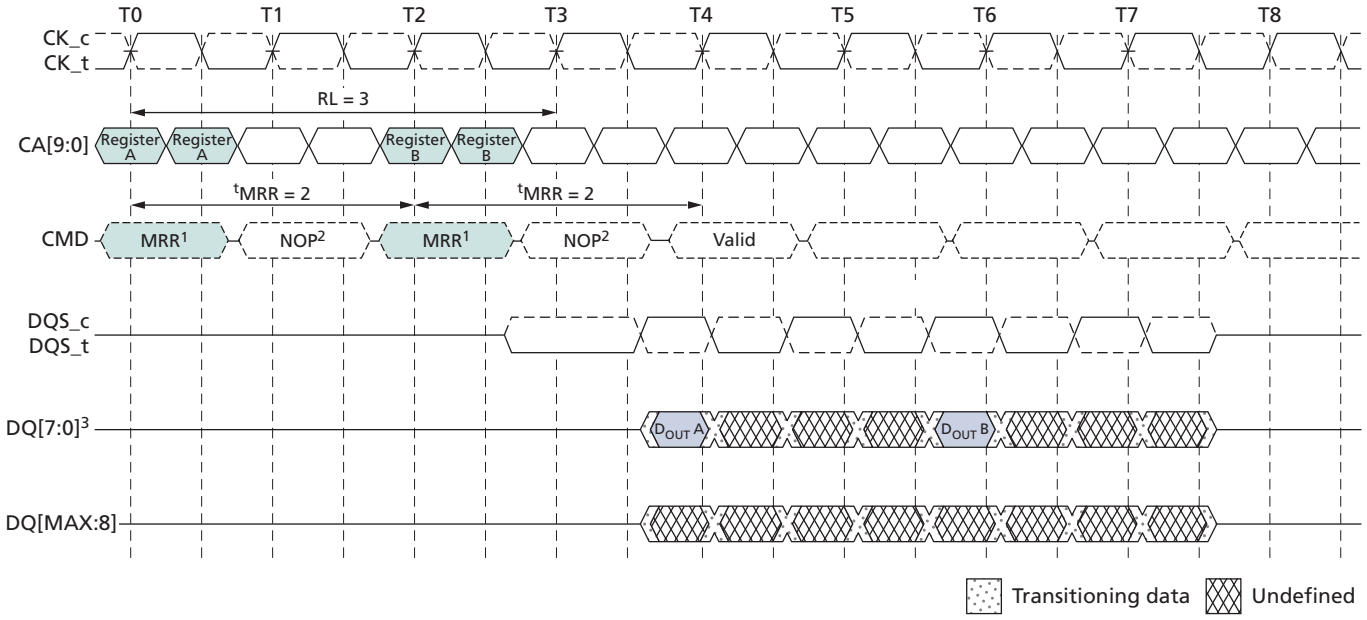
Note: 1. This table provides values for an 8-bank device with REFRESH operations masked to banks 1 and 7, and segments 2 and 7.

# MODE REGISTER READ

The MODE REGISTER READ (MRR) command is used to read configuration and status data from SDRAM mode registers. The MRR command is initiated with CS_n LOW, CA0 LOW, CA1 LOW, CA2 LOW, and CA3 HIGH at the rising edge of the clock. The mode register is selected by CA1f–CA0f and CA9r–CA4r. The mode register contents are available on the first data beat of DQ[7:0] after RL × $^{t}$CK + $^{t}$DQSCK + $^{t}$DQSQ and following the rising edge of the clock where MRR is issued. Subsequent data beats contain valid but undefined content, except in the case of the DQ calibration function, where subsequent data beats contain valid content as described in the Data Calibration Pattern Description table. All DQS_t,DQS_c are toggled for the duration of the mode register READ burst.

The MRR command has a burst length of four. MRR operation (consisting of the MRR command and the corresponding data traffic) must not be interrupted. The MRR command period ($^{t}$MRR) is two clock cycles. The MRR command issued to reserved and write-only registers should returns valid but undefined content on all data beats, and DQS_t, DQS_c should be toggled.

**Figure 54: MRR Timing – RL = 3, $^{t}$MRR = 2**





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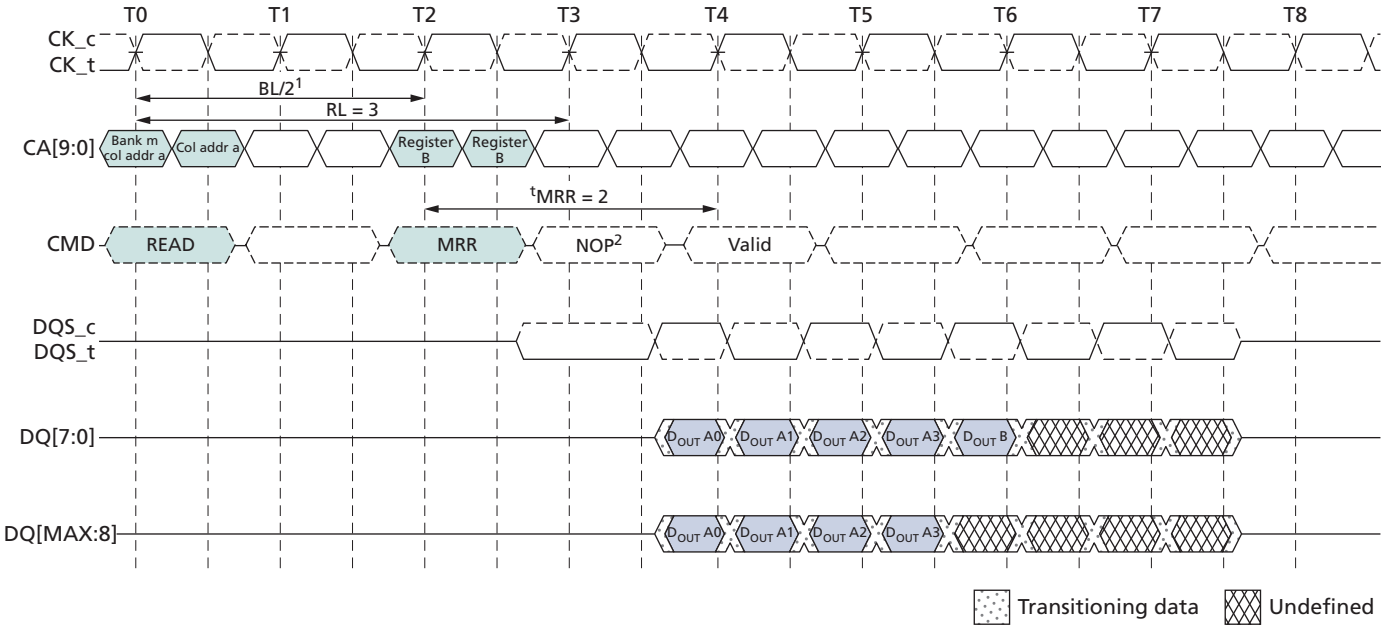
Notes:
1. MRRs to DQ calibration registers MR32 and MR40 are described in the Data Calibration Pattern Description table.
2. Only the NOP command is supported during $^{t}$MRR.
3. Mode register data is valid only on DQ[7:0] on the first beat. Subsequent beats contain valid but undefined data. DQ[MAX:8] contain valid but undefined data for the duration of the MRR burst.
4. Minimum MRR to write latency is RL + RU($^{t}$DQSCKmax/$^{t}$CK) + 4/2 + 1 - WL clock cycles.
5. Minimum MRR to MRW latency is RL + RU($^{t}$DQSCKmax/$^{t}$CK) + 4/2 + 1 clock cycles.

READ bursts and WRITE bursts cannot be truncated by MRR. Following a READ command, the MRR command must not be issued before BL/2 clock cycles have completed. Following a WRITE command, the MRR command must not be issued before WL + 1 + BL/2 + RU($^{t}$WTR/$^{t}$CK) clock cycles have completed. If a READ or WRITE burst is truncated with a BST command, the effective burst length of the truncated burst should be used for the BL value.

**Figure 55: READ to MRR Timing – RL = 3, $^{t}$MRR = 2**




Notes:
1. The minimum number of clock cycles from the burst READ command to the MRR command is BL/2.
2. Only the NOP command is supported during $^{t}$MRR.


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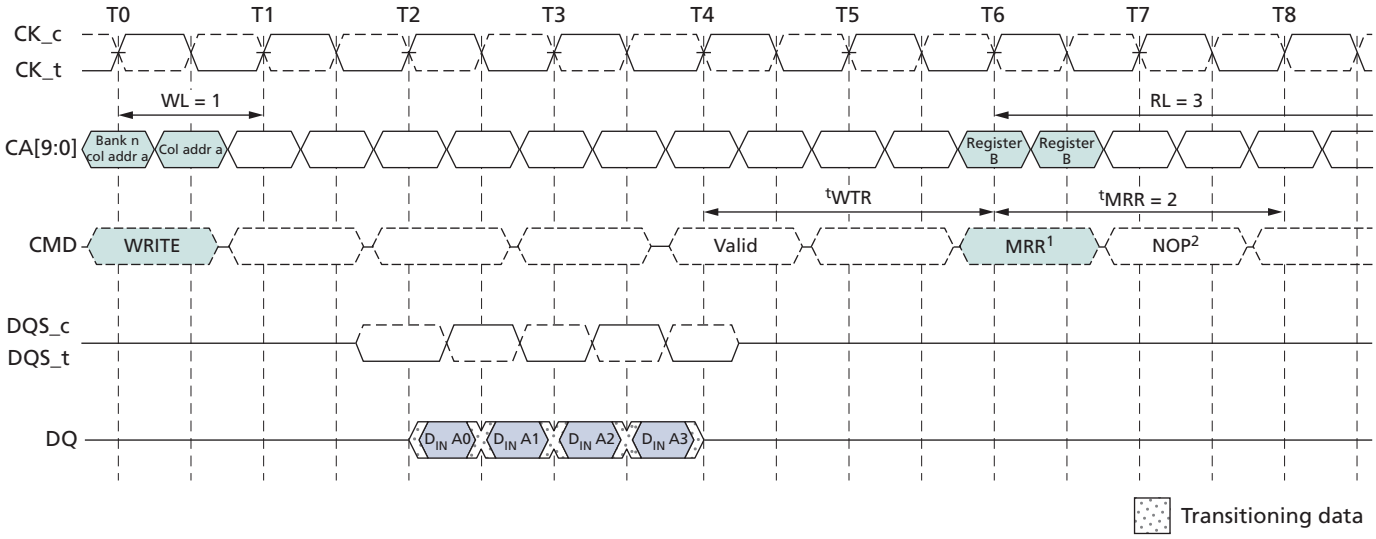
**Figure 56: Burst WRITE Followed by MRR – RL = 3, WL = 1, BL = 4**




Notes:
1. The minimum number of clock cycles from the burst WRITE command to the MRR command is [WL + 1 + BL/2 + RU($^{t}$WTR/$^{t}$CK)].
2. Only the NOP command is supported during $^{t}$MRR.

## Temperature Sensor

The mobile LPDDR2 device features a temperature sensor whose status can be read from MR4. This sensor can be used to determine an appropriate refresh rate, determine whether AC timing derating is required in the extended temperature range, and/or monitor the operating temperature. Either the temperature sensor or the device operating temperature can be used to determine whether operating temperature requirements are being met (see Operating Temperature Range table).

Temperature sensor data can be read from MR4 using the mode register read protocol. Upon exiting self-refresh or power-down, the device temperature status bits will be no older than $^{t}$TSI.

When using the temperature sensor, the actual device case temperature may be higher than the operating temperature specification that applies for the standard or extended temperature ranges (see table noted above). For example, $T_{CASE}$ could be above 85˚C when MR4[2:0] equals 011b.

To ensure proper operation using the temperature sensor, applications must accommodate the parameters in the temperature sensor definitions table.


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**Table 60: Temperature Sensor Definitions and Operating Conditions**

| Parameter | Description | Symbol | Min/Max | Value | Unit |
|---|---|---|---|---|---|
| System temperature gradient | Maximum temperature gradient experienced by the memory device at the temperature of interest over a range of 2˚C | TempGradient | MAX | System-dependent | ˚C/s |
| MR4 READ interval | Time period between MR4 READs from the system | ReadInterval | MAX | System-dependent | ms |
| Temperature sensor interval | Maximum delay between internal updates of MR4 | $^{t}$TSI | MAX | 32 | ms |
| System response delay | Maximum response time from an MR4 READ to the system response | SysRespDelay | MAX | System-dependent | ms |
| Device temperature margin | Margin above maximum temperature to support controller response | TempMargin | MAX | 2 | ˚C |

The mobile LPDDR2 device accommodates the temperature margin between the point at which the device temperature enters the extended temperature range and the point at which the controller reconfigures the system accordingly. To determine the required MR4 polling frequency, the system must use the maximum TempGradient and the maximum response time of the system according to the following equation:

$$\text{TempGradient} \times (\text{ReadInterval} + {}^{t}\text{TSI} + \text{SysRespDelay}) \leq 2°\text{C}$$

For example, if TempGradient is 10˚C/s and the SysRespDelay is 1ms:

$$\frac{10°\text{C}}{\text{s}} \times (\text{ReadInterval} + 32\text{ms} + 1\text{ms}) \leq 2°\text{C}$$

In this case, ReadInterval must not exceed 167ms.



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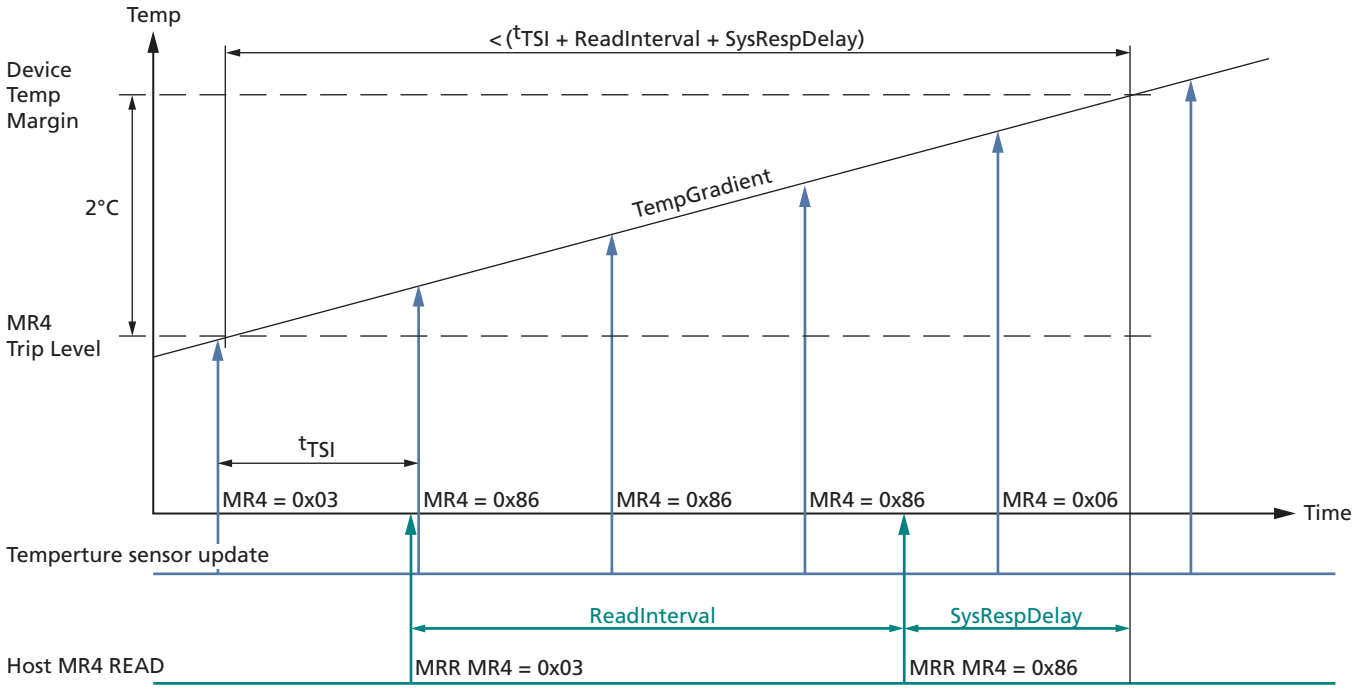
**Figure 57: Temperature Sensor Timing**




## DQ Calibration

The mobile LPDDR2 device features a DQ calibration function that outputs one of two predefined system timing calibration patterns. For a x16 device, pattern A (MRR to MRR32), and pattern B (MRR to MRR40), will return the specified pattern on DQ0 and DQ8; a x32 device returns the specified pattern on DQ0, DQ8, DQ16, and DQ24.

For a x16 device, DQ[7:1] and DQ[15:9] drive the same information as DQ0 during the MRR burst. For a x32 device, DQ[7:1], DQ[15:9], DQ[23:17], and DQ[31:25] drive the same information as DQ0 during the MRR burst. MRR DQ calibration commands can occur only in the idle state.


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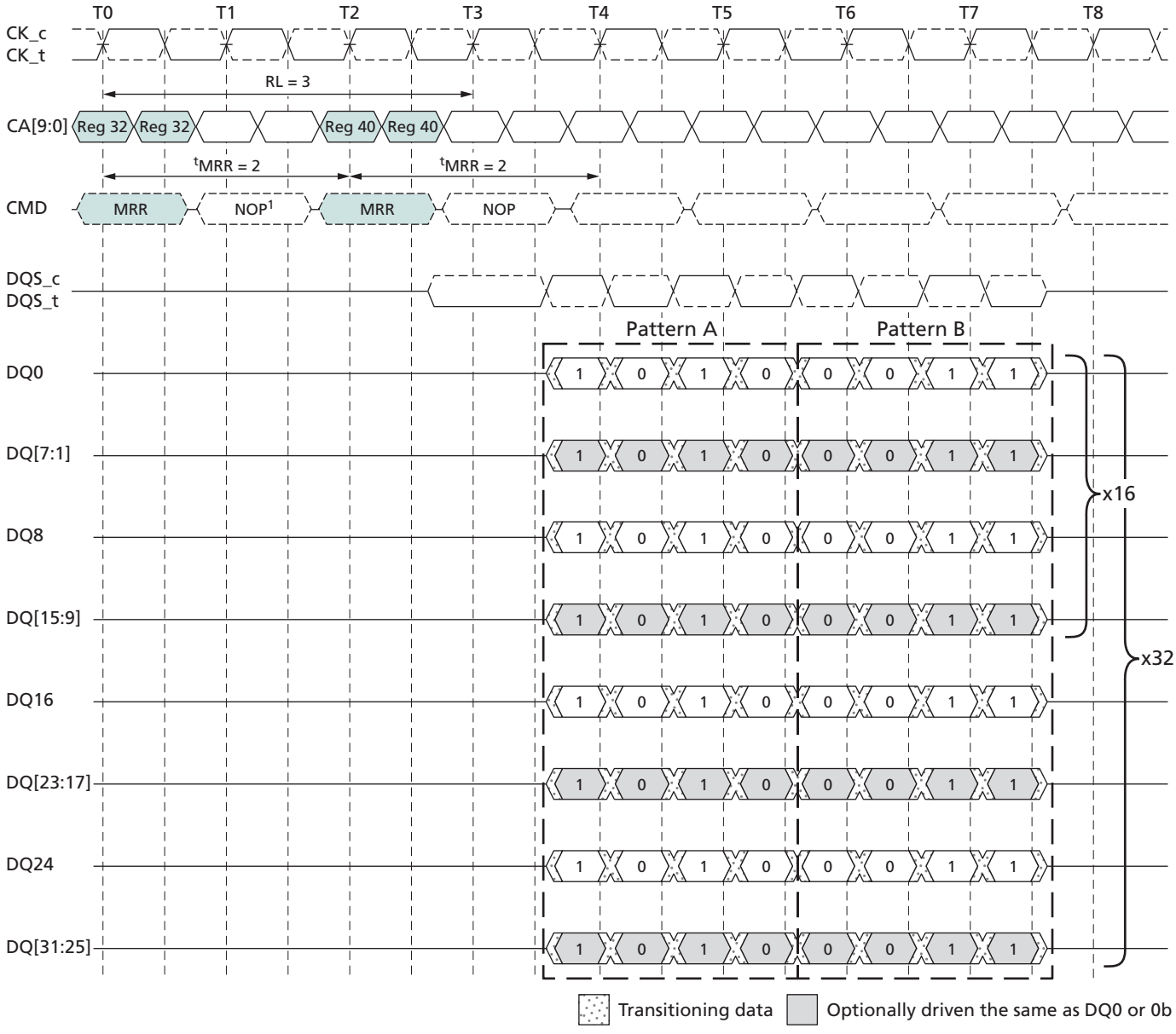
**Figure 58: MR32 and MR40 DQ Calibration Timing – RL = 3, $^{t}$MRR = 2**




Notes:
1. The MRR command has a burst length of four.
2. The MRR operation must not be interrupted.
3. A MRR to MR32 and MR40 drives valid data on DQ[0] during the entire burst. For a x16 device, DQ[8] drives the same information as DQ[0] during the burst. For a x32 device, DQ[8], DQ[16], and DQ[24] drive the same information as DQ[0] during the burst.
4. For a x16 device, DQ[7:1] and DQ[15:9] may optionally drive the same information as DQ[0], or they may drive 0b during the burst. For a x32 device, DQ[7:1], DQ[15:9], DQ[23:17], and DQ[31:25] may optionally drive the same information as DQ[0], or they may drive 0b during the burst.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5. The MODE REGISTER command period is $^{t}$MRR. No command (other than NOP) is allowed during this period.

**Table 61: Data Calibration Pattern Description**

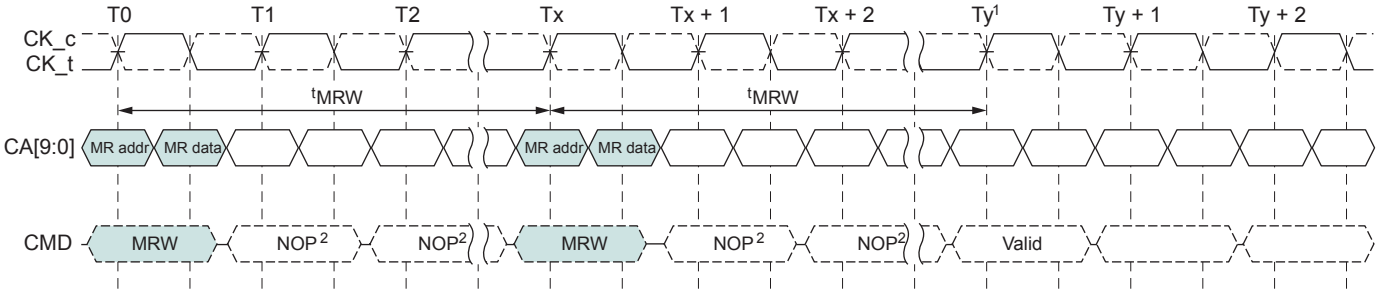
| Pattern | MR# | Bit Time 0 | Bit Time 1 | Bit Time 2 | Bit Time 3 | Description |
|---|---|---|---|---|---|---|
| Pattern A | MR32 | 1 | 0 | 1 | 0 | Reads to MR32 return DQ calibration pattern A |
| Pattern B | MR40 | 0 | 0 | 1 | 1 | Reads to MR40 return DQ calibration pattern B |

# MODE REGISTER WRITE Command

The MODE REGISTER WRITE (MRW) command is used to write configuration data to the mode registers. The MRW command is initiated with CS_n LOW, CA0 LOW, CA1 LOW, CA2 LOW, and CA3 LOW at the rising edge of the clock. The mode register is selected by CA1f–CA0f, CA9r–CA4r. The data to be written to the mode register is contained in CA9f–CA2f. The MRW command period is defined by $^{t}$MRW. A MRW command to read-only registers has no impact on the functionality of the device.

MRW can be issued only when all banks are in the idle precharge state. One method of ensuring that the banks are in this state is to issue a PRECHARGE ALL command.

**Figure 59: MODE REGISTER WRITE Timing – RL = 3, $^{t}$MRW = 5**




Notes:
1. At time Ty, the device is in the idle state.
2. Only the NOP command is supported during $^{t}$MRW.

**Table 62: Truth Table for MRR and MRW**

| Current State | Command | Intermediate State | Next State |
|---|---|---|---|
| All banks idle | MRR | Reading mode register, all banks idle | All banks idle |
| | MRW | Writing mode register, all banks idle | All banks idle |
| | MRW (RESET) | Resetting, device auto initialization | All banks idle |
| Bank(s) active | MRR | Reading mode register, bank(s) active | Bank(s) active |
| | MRW | Not allowed | Not allowed |
| | MRW (RESET) | Not allowed | Not allowed |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## MRW RESET Command

The MRW RESET command brings the device to the device auto initialization (resetting) state in the power-on initialization sequence (see step 2. of the RESET Command under Voltage Ramp and Initialization Sequence). The MRW RESET command can be issued from the idle state. This command resets all mode registers to their default values. Only the NOP command is supported during $^{t}$INIT4. After MRW RESET, boot timings must be observed until the device initialization sequence is complete and the device is in the idle state. Array data is undefined after the MRW RESET command has completed. For MRW RESET timing, see Voltage Ramp and Initialization Sequence.

## MRW ZQ Calibration Commands

The MRW command is used to initiate a ZQ calibration command that calibrates output driver impedance across process, temperature, and voltage. LPDDR2-S4 devices support ZQ calibration. To achieve tighter tolerances, proper ZQ calibration must be performed.

There are four ZQ calibration commands and related timings: $^{t}$ZQINIT, $^{t}$ZQRESET, $^{t}$ZQCL, and $^{t}$ZQCS. $^{t}$ZQINIT is used for initialization calibration; $^{t}$ZQRESET is used for resetting ZQ to the default output impedance; $^{t}$ZQCL is used for long calibration(s); and $^{t}$ZQCS is used for short calibration(s). See the MR10 Calibration (MA[7:0] = 0Ah) table for ZQ calibration command code definitions.

ZQINIT must be performed for LPDDR2 devices. ZQINIT provides an output impedance accuracy of ±15%. After initialization, the ZQ calibration long (ZQCL) can be used to recalibrate the system to an output impedance accuracy of ±15%. A ZQ calibration short (ZQCS) can be used periodically to compensate for temperature and voltage drift in the system.

ZQRESET resets the output impedance calibration to a default accuracy of ±30% across process, voltage, and temperature. This command is used to ensure output impedance accuracy to ±30% when ZQCS and ZQCL commands are not used.

One ZQCS command can effectively correct at least 1.5% (ZQ correction) of output impedance errors within $^{t}$ZQCS for all speed bins if maximum sensitivities are met as specified in Output Driver Sensitivity Definition and Output Driver Temperature and Voltage Sensitivity. The appropriate interval between ZQCS commands can be determined using these tables and system-specific parameters.

Mobile LPDDR2 devices are subject to temperature drift rate ($T_{driftrate}$) and voltage drift rate ($V_{driftrate}$) in various applications. To accommodate drift rates and calculate the necessary interval between ZQCS commands, apply the following formula:

$$\frac{ZQ_{correction}}{(T_{sens} \times T_{driftrate}) + (V_{sens} \times V_{driftrate})}$$

Where $T_{sens}$ = MAX ($dR_{ON}dT$) and $V_{sens}$ = MAX ($dR_{ON}dV$) define temperature and voltage sensitivities.

For example, if $T_{sens}$ = 0.75%/˚C, $V_{sens}$ = 0.20%/mV, $T_{driftrate}$ = 1˚C/sec, and $V_{driftrate}$ = 15 mV/sec, then the interval between ZQCS commands is calculated as:

$$\frac{1.5}{(0.75 \times 1) + (0.20 \times 15)} = 0.4s$$


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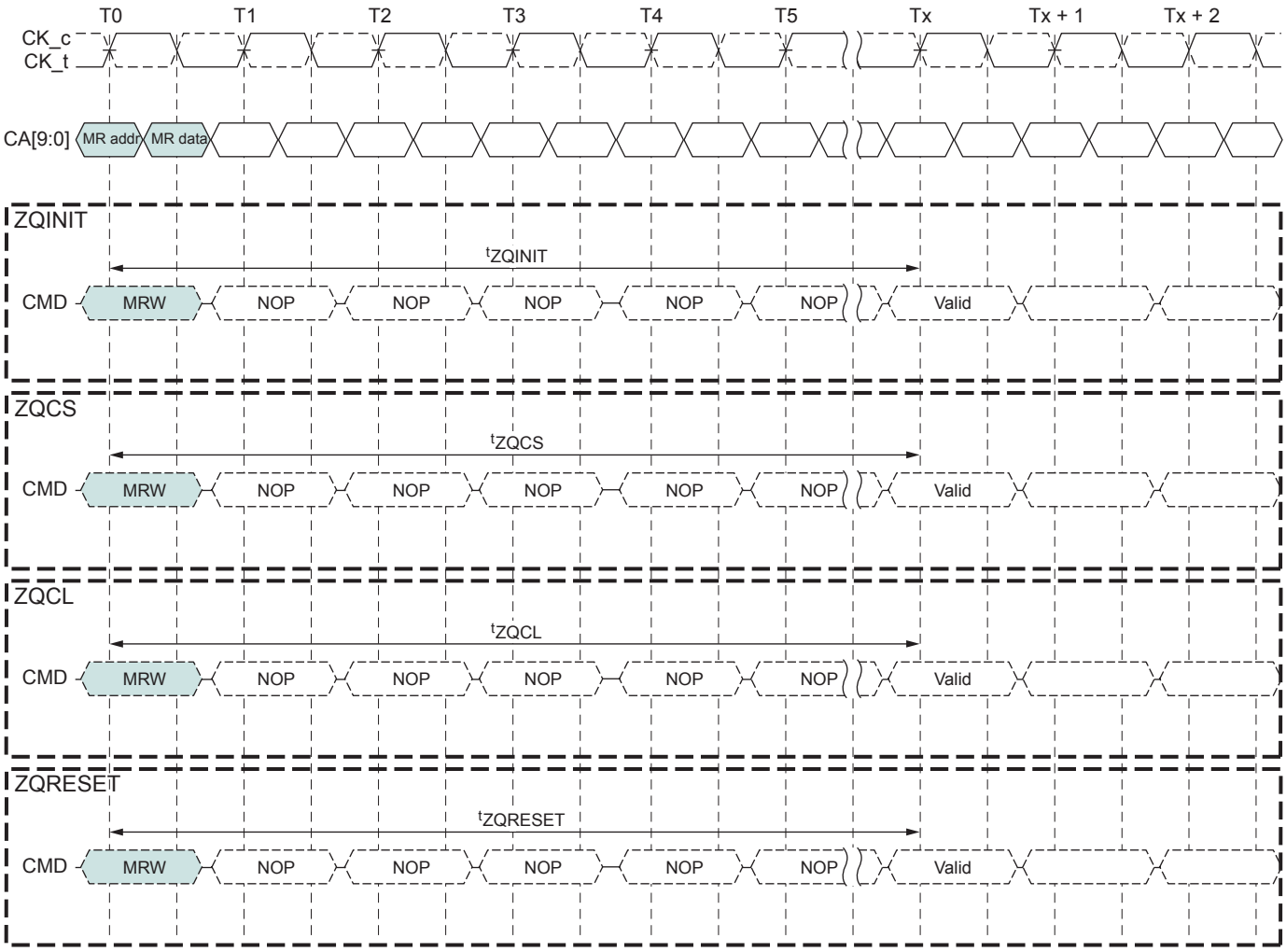
A ZQ calibration command can only be issued when the device is in the idle state with all banks precharged.

No other activities can be performed on the data bus during calibration periods ($^{t}$ZQINIT, $^{t}$ZQCL, or $^{t}$ZQCS). The quiet time on the data bus helps to calibrate output impedance accurately. There is no required quiet time after the ZQRESET command. If multiple devices share a single ZQ resistor, only one device can be calibrating at any given time. After calibration is complete, the ZQ ball circuitry is disabled to reduce power consumption.

In systems sharing a ZQ resistor between devices, the controller must prevent $^{t}$ZQINIT, $^{t}$ZQCS, and $^{t}$ZQCL overlap between the devices. ZQRESET overlap is acceptable. If the ZQ resistor is absent from the system, ZQ must be connected to $V_{DDCA}$. In this situation, the device must ignore ZQ calibration commands and the device will use the default calibration settings.

**Figure 60: ZQ Timings**




Notes: 1. Only the NOP command is supported during ZQ calibrations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$^{t}$ZQINIT: ZQ calibration initialization period
$^{t}$ZQCS: ZQ calibration short period
$^{t}$ ZQCL: ZQ calibration long period
$^{t}$ZQRESET: ZQ calibration reset period

2. CKE must be registered HIGH continuously during the calibration period.
3. All devices connected to the DQ bus should be High-Z during the calibration process.

## ZQ External Resistor Value, Tolerance, and Capacitive Loading

To use the ZQ calibration function, a 240 ohm (±1% tolerance) external resistor must be connected between the ZQ pin and ground. A single resistor can be used for each device or one resistor can be shared between multiple devices if the ZQ calibration timings for each device do not overlap. The total capacitive loading on the ZQ pin must be limited (see the Input/Output Capacitance table).

# Power-Down

Power-down is entered synchronously when CKE is registered LOW and CS_n is HIGH at the rising edge of clock. A NOP command must be driven in the clock cycle following power-down entry. CKE must not go LOW while MRR, MRW, READ, or WRITE operations are in progress. CKE can go LOW while any other operation such as ACTIVATE, PRECHARGE, auto precharge, or REFRESH are in progress, but the power-down $I_{DD}$ specification will not be applied until such operations are complete.

If power-down occurs when all banks are idle, this mode is referred to as idle power-down; if power-down occurs when there is a row active in any bank, this mode is referred to as active power-down.

Entering power-down deactivates the input and output buffers, excluding CK_t, CK_c, and CKE. In power-down mode, CKE must be held LOW; all other input signals are "Don't Care." CKE LOW must be maintained until $^{t}$CKE is satisfied. $V_{REFCA}$ must be maintained at a valid level during power-down.

$V_{DDQ}$ can be turned off during power-down. If $V_{DDQ}$ is turned off, $V_{REFDQ}$ must also be turned off. Prior to exiting power-down, both $V_{DDQ}$ and $V_{REFDQ}$ must be within their respective minimum/maximum operating ranges (see AC and DC Operating Conditions).

No refresh operations are performed in power-down mode. The maximum duration in power-down mode is limited only by the refresh requirements outlined in REFRESH Command.

The power-down state is exited when CKE is registered HIGH. The controller must drive CS_n HIGH in conjunction with CKE HIGH when exiting the power-down state. CKE HIGH must be maintained until $^{t}$CKE is satisfied. 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 Timing section.


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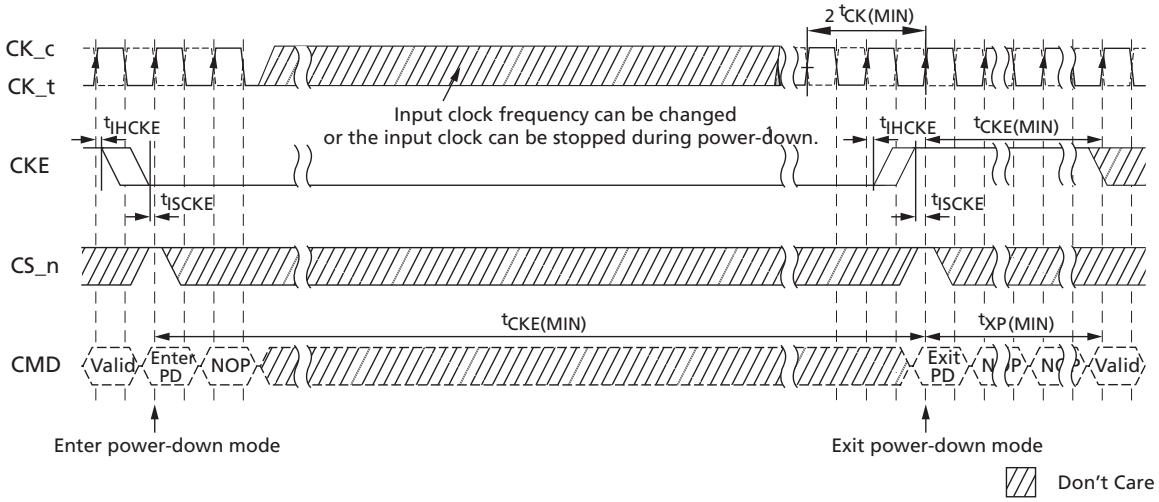
**Figure 61: Power-Down Entry and Exit Timing**




Note: 1. Input clock frequency can be changed or the input clock stopped during power-down, provided that the clock frequency is between the minimum and maximum specified frequencies for the speed grade in use, and that prior to power-down exit, a minimum of two stable clocks complete.

**Figure 62: CKE Intensive Environment**

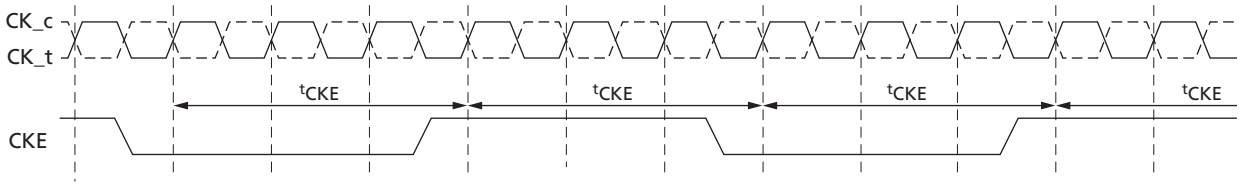
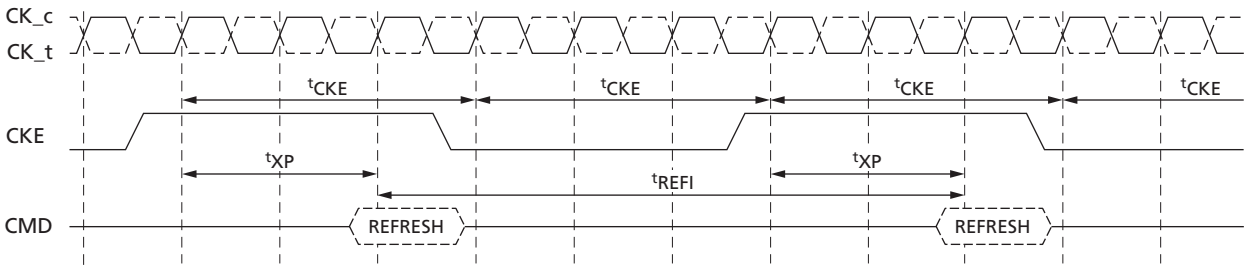



**Figure 63: REFRESH-to-REFRESH Timing in CKE Intensive Environments**




Note: 1. The pattern shown can repeat over an extended period of time. With this pattern, all AC and DC timing and voltage specifications with temperature and voltage drift are ensured.


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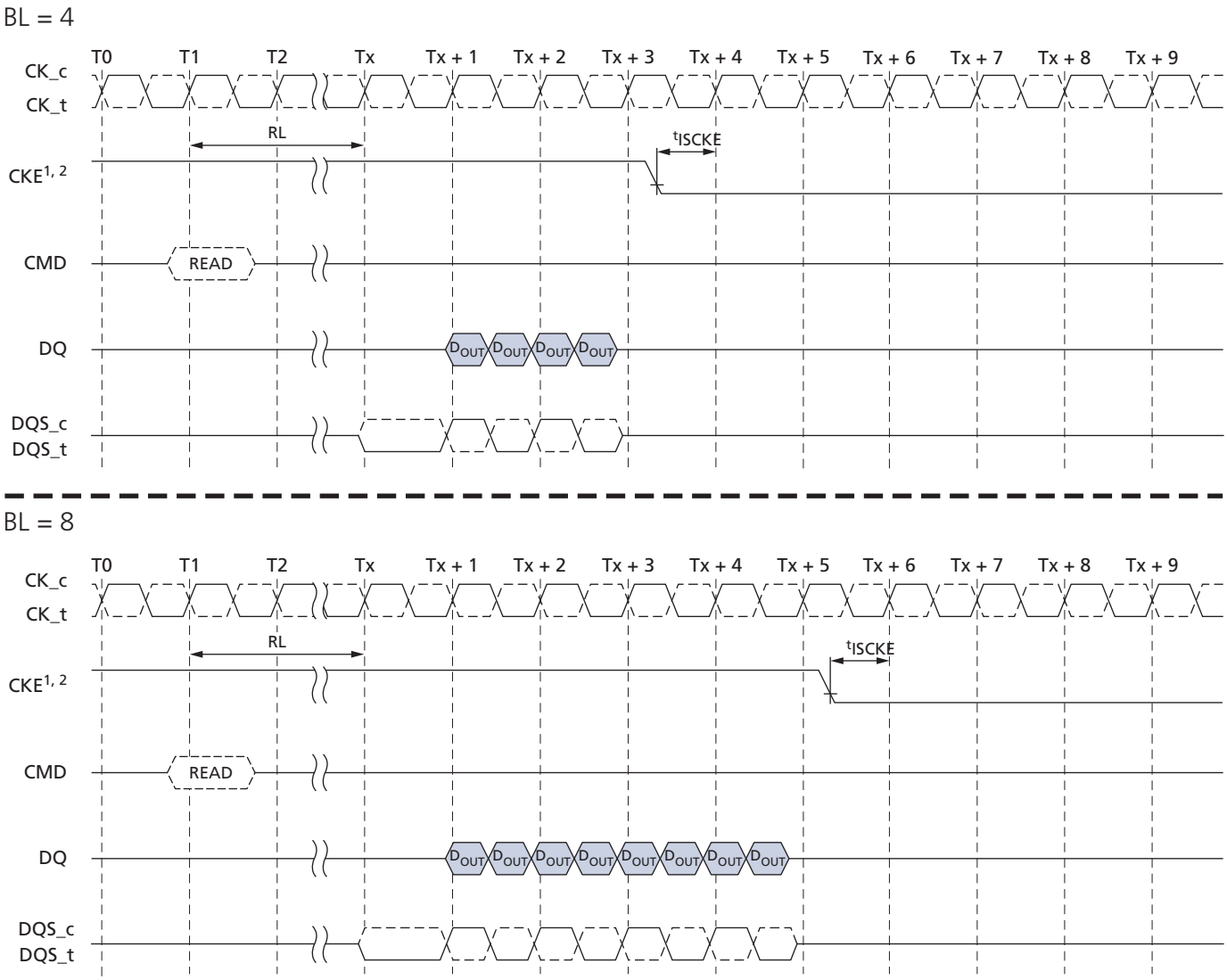
**Figure 64: READ to Power-Down Entry**




Notes:
1. CKE must be held HIGH until the end of the burst operation.
2. CKE can be registered LOW at (RL + RU($^{t}$DQSCK(MAX)/$^{t}$CK) + BL/2 + 1) clock cycles after the clock on which the READ command is registered.


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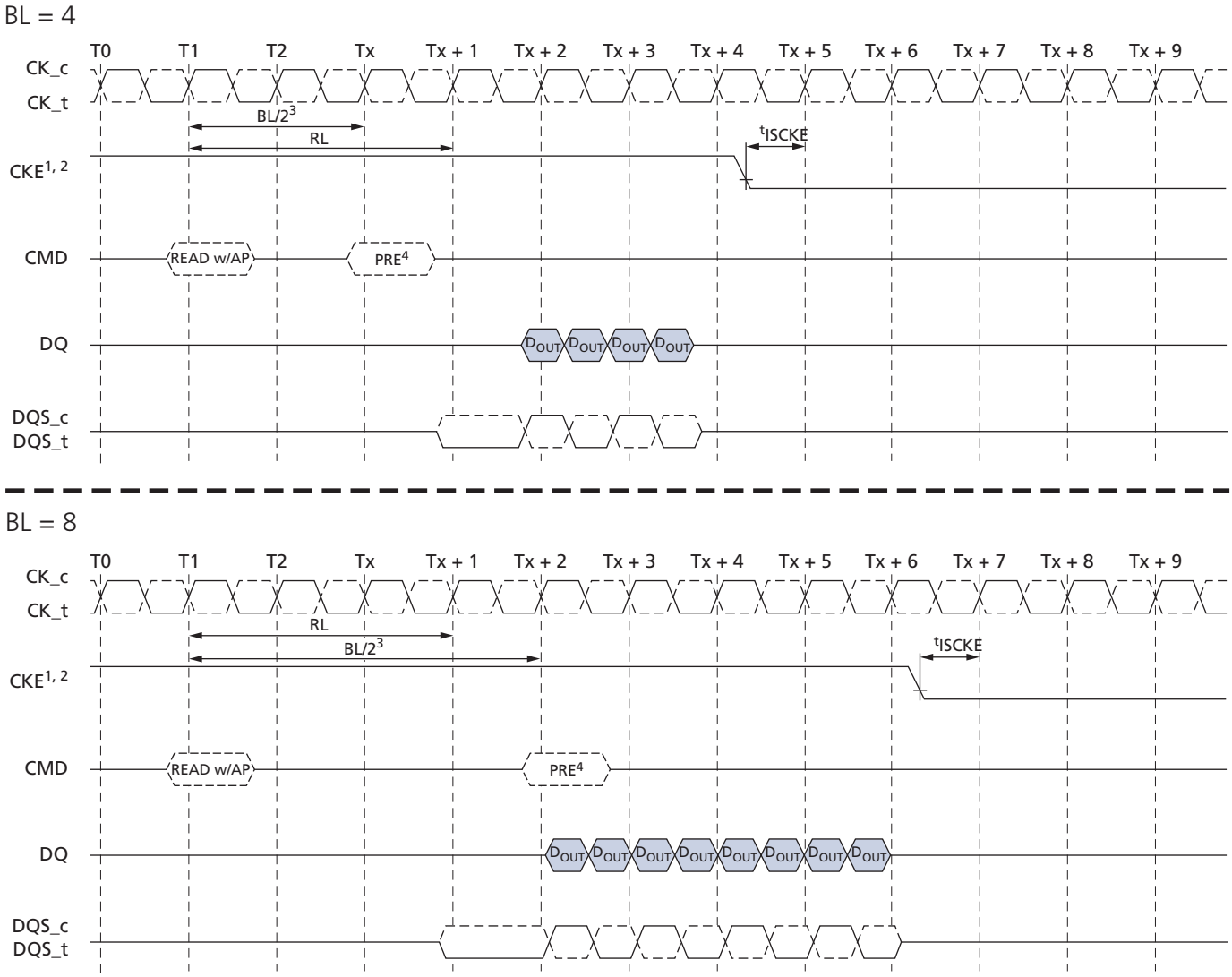
**Figure 65: READ with Auto Precharge to Power-Down Entry**




Notes:
1. CKE must be held HIGH until the end of the burst operation.
2. CKE can be registered LOW at (RL + RU($^{t}$DQSCK/$^{t}$CK)+ BL/2 + 1) clock cycles after the clock on which the READ command is registered.
3. BL/2 with $^{t}$RTP = 7.5ns and $^{t}$RAS (MIN) is satisfied.
4. Start internal PRECHARGE.


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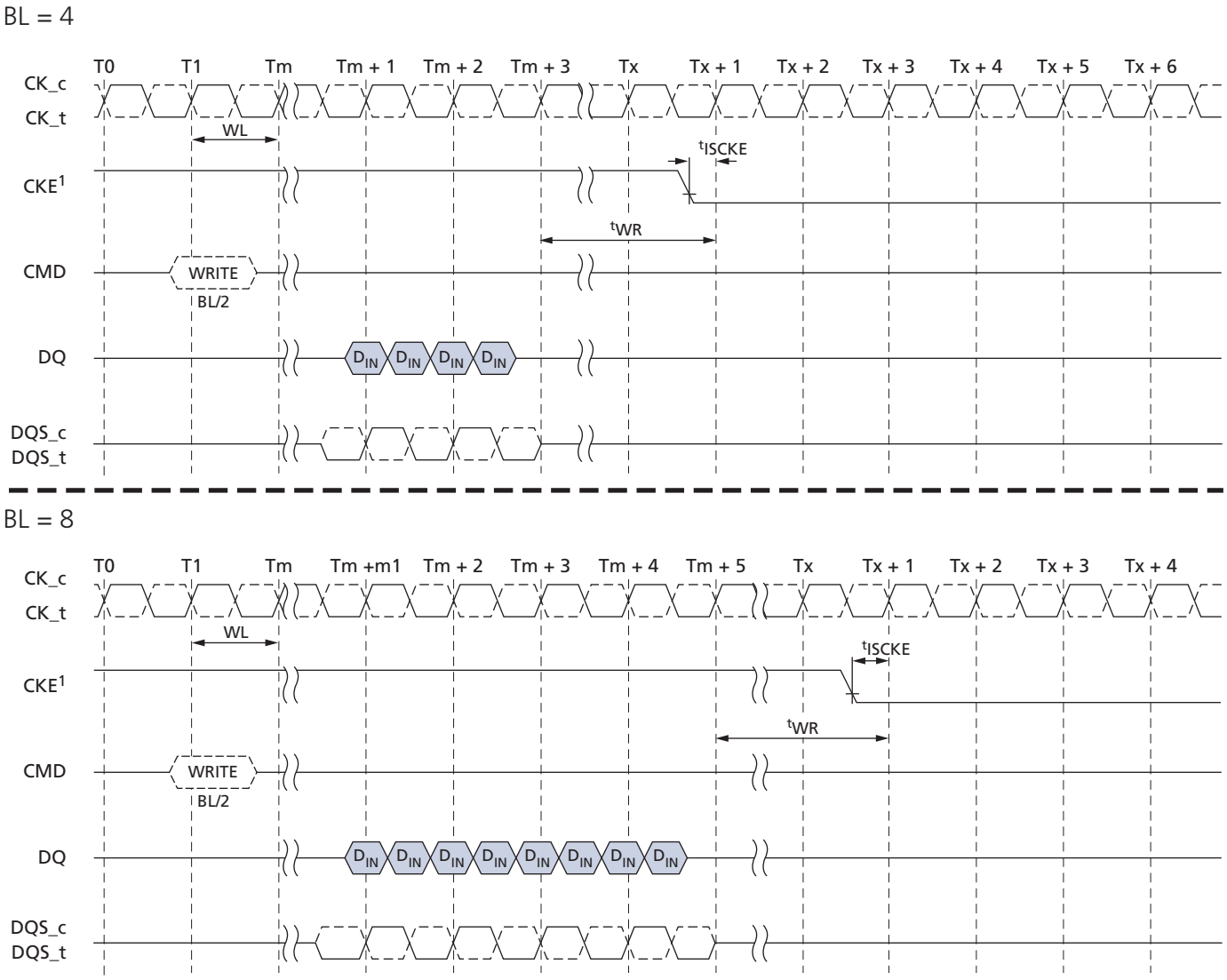
**Figure 66: WRITE to Power-Down Entry**




Note: 1. CKE can be registered LOW at (WL + 1 + BL/2 + RU($^{t}$WR/$^{t}$CK)) clock cycles after the clock on which the WRITE command is registered.


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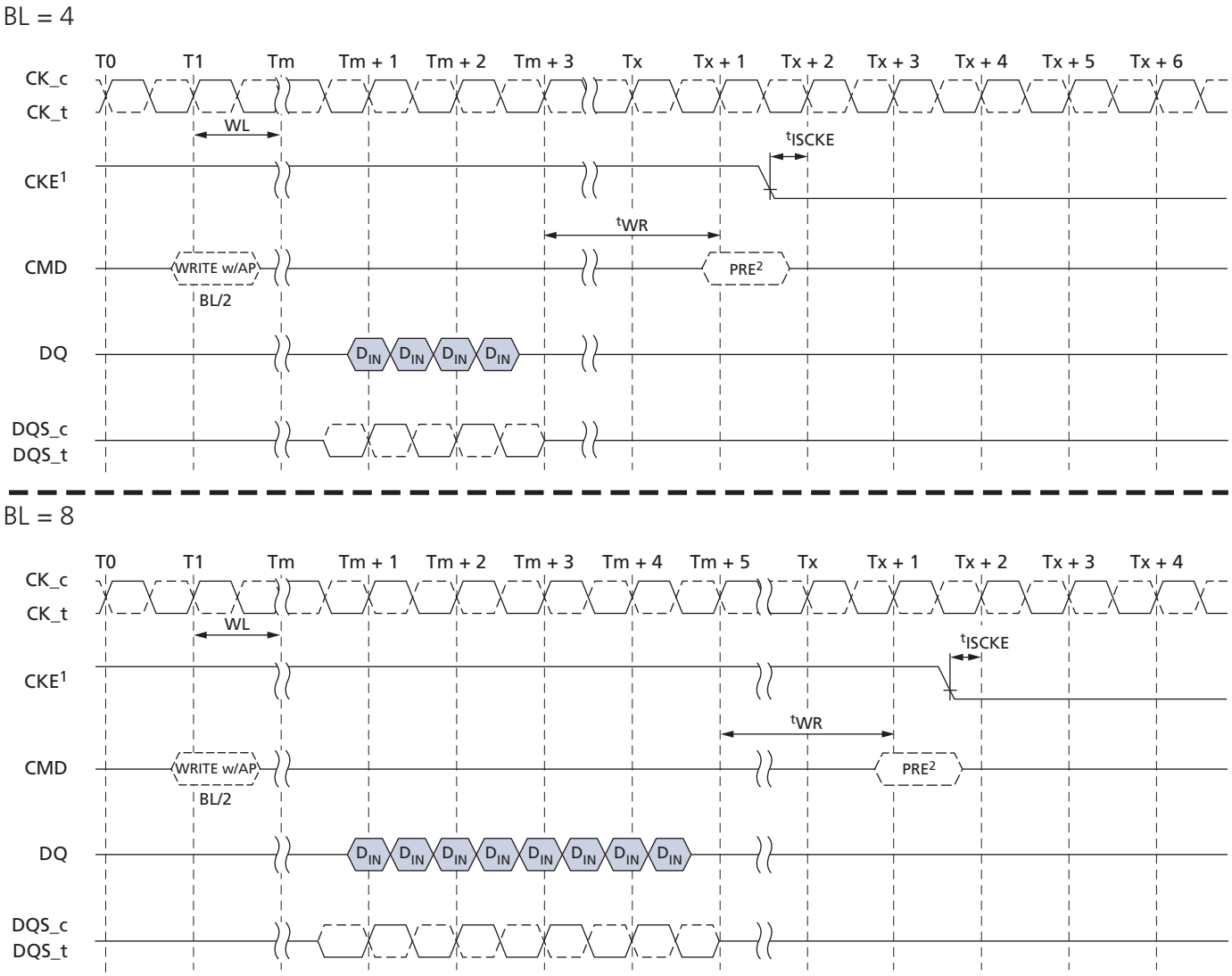
**Figure 67: WRITE with Auto Precharge to Power-Down Entry**




Notes:
1. CKE can be registered LOW at (WL + 1 + BL/2 + RU($^{t}$WR/$^{t}$CK + 1) clock cycles after the WRITE command is registered.
2. Start internal PRECHARGE.


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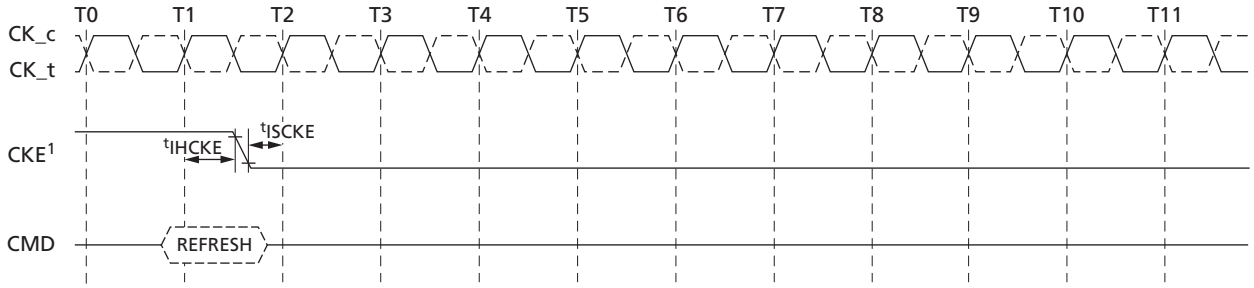
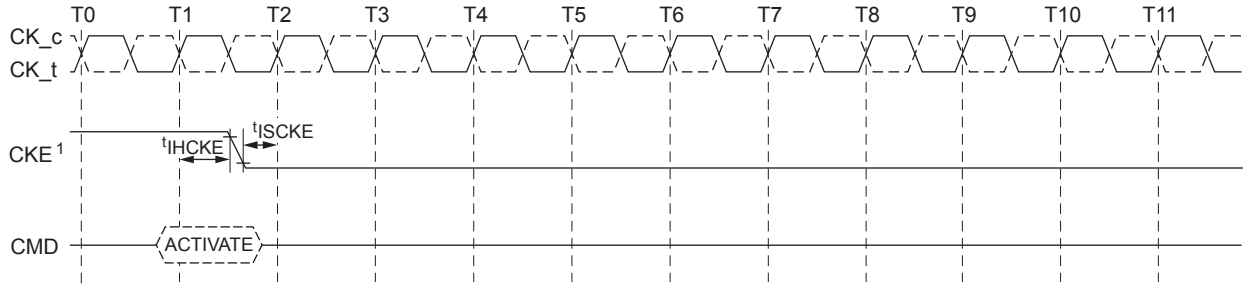
**Figure 68: REFRESH Command to Power-Down Entry**



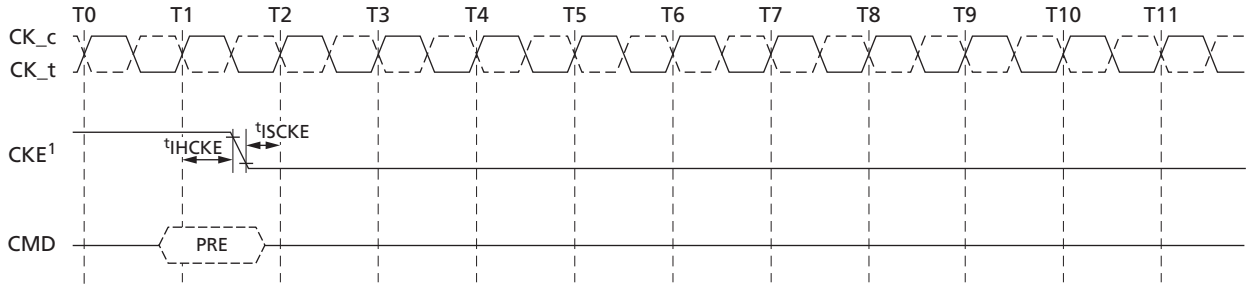

Note: 1. CKE can go LOW $^{t}$IHCKE after the clock on which the REFRESH command is registered.

**Figure 69: ACTIVATE Command to Power-Down Entry**




Note: 1. CKE can go LOW at $^{t}$IHCKE after the clock on which the ACTIVATE command is registered.

**Figure 70: PRECHARGE Command to Power-Down Entry**




Note: 1. CKE can go LOW $^{t}$IHCKE after the clock on which the PRECHARGE command is registered.


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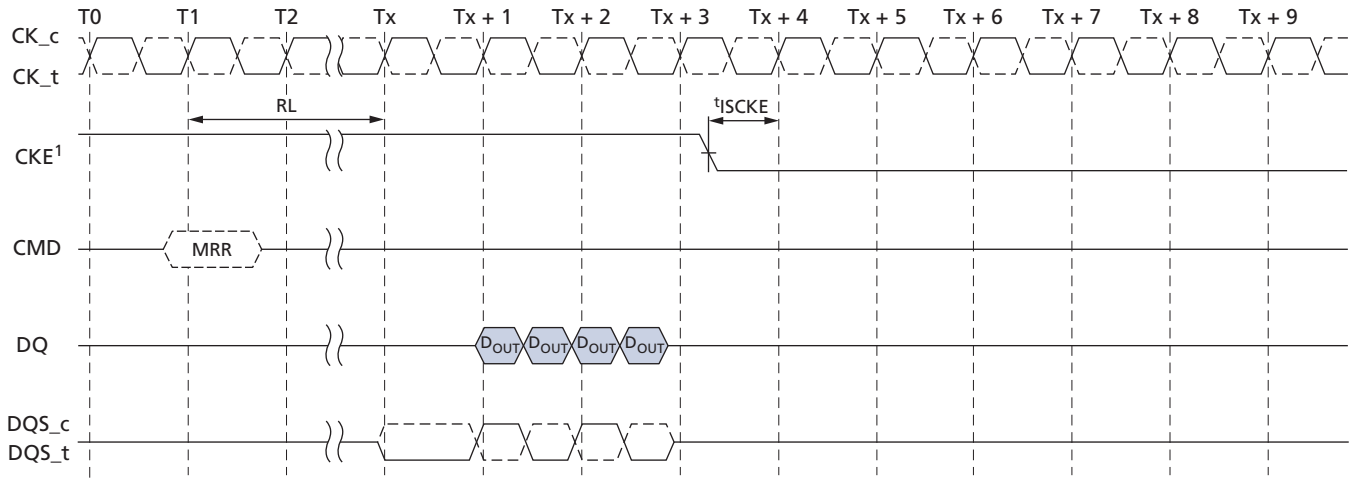
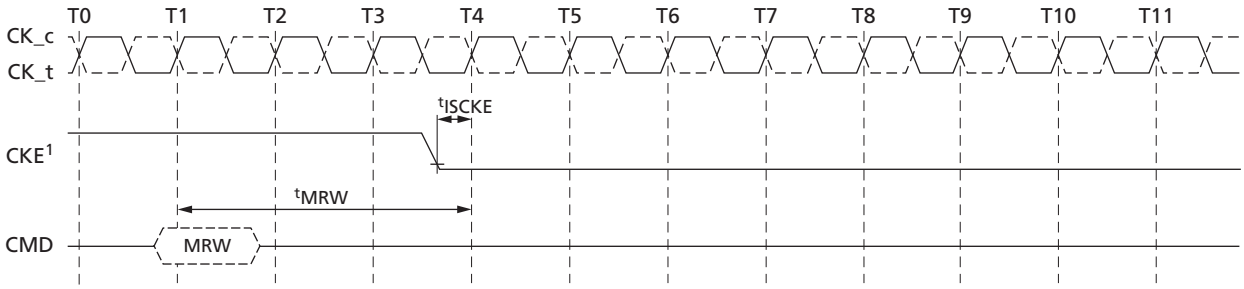
**Figure 71: MRR Command to Power-Down Entry**




Note: 1. CKE can be registered LOW at (RL + RU($^{t}$DQSCK/$^{t}$CK)+ BL/2 + 1) clock cycles after the clock on which the MRR command is registered.

**Figure 72: MRW Command to Power-Down Entry**




Note: 1. CKE can be registered LOW $^{t}$MRW after the clock on which the MRW command is registered.

## Deep Power-Down

Deep power-down (DPD) is entered when CKE is registered LOW with CS_n LOW, CA0 HIGH, CA1 HIGH, and CA2 LOW at the rising edge of the clock. The NOP command must be driven in the clock cycle following power-down entry. CKE must not go LOW while MRR or MRW operations are in progress. CKE can go LOW while other operations such as ACTIVATE, auto precharge, PRECHARGE, or REFRESH are in progress; however, deep power-down $I_{DD}$ specifications will not be applied until those operations complete. The contents of the array will be lost upon entering DPD mode.

In DPD mode, all input buffers except CKE, all output buffers, and the power supply to internal circuitry are disabled within the device. $V_{REFDQ}$ can be at any level between 0 and $V_{DDQ}$, and $V_{REFCA}$ can be at any level between 0 and $V_{DD2}$ during DPD. All power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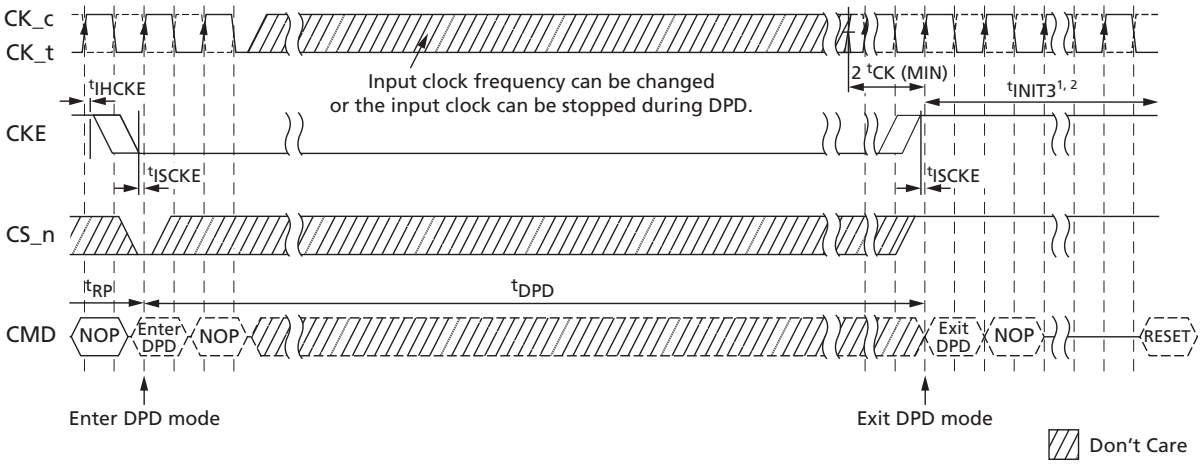
supplies (including $V_{REF}$) must be within the specified limits prior to exiting DPD (see AC and DC Operating Conditions).

To exit DPD, CKE must be HIGH, $^{t}$ISCKE must be complete, and the clock must be stable. To resume operation, the device must be fully reinitialized using the power-up initialization sequence.

**Figure 73: Deep Power-Down Entry and Exit Timing**




Notes:
1. The initialization sequence can start at any time after Tx + 1.
2. $^{t}$INIT3 and Tx + 1 refer to timings in the initialization sequence. For details, see Mode Register Definition.

# Input Clock Frequency Changes and Stop Events

## Input Clock Frequency Changes and Clock Stop with CKE LOW

During CKE LOW, the mobile LPDDR2 device supports input clock frequency changes and clock stop under the following conditions:

- Refresh requirements are met
- Only REFab or REFpb commands can be in process
- Any ACTIVATE or PRECHARGE commands have completed prior to changing the frequency
- Related timing conditions, $^{t}$RCD and $^{t}$RP, have been met prior to changing the frequency
- The initial clock frequency must be maintained for a minimum of two clock cycles after CKE goes LOW
- The clock satisfies $^{t}$CH(abs) and $^{t}$CL(abs) for a minimum of two clock cycles prior to CKE going HIGH

For input clock frequency changes, $^{t}$CK(MIN) and $^{t}$CK(MAX) must be met for each clock cycle.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After the input clock frequency is changed and CKE is held HIGH, additional MRW commands may be required to set the WR, RL, etc. These settings may require adjustment to meet minimum timing requirements at the target clock frequency.

For clock stop, CK_t is held LOW and CK_c is held HIGH.

### Input Clock Frequency Changes and Clock Stop with CKE HIGH

During CKE HIGH, the LPDDR2 device supports input clock frequency changes and clock stop under the following conditions:

- REFRESH requirements are met
- Any ACTIVATE, READ, WRITE, PRECHARGE, MRW, or MRR commands must have completed, including any associated data bursts, prior to changing the frequency
- Related timing conditions, $^{t}$RCD, $^{t}$WR, $^{t}$RP, $^{t}$MRW, and $^{t}$MRR, etc., are met
- CS_n must be held HIGH
- Only REFab or REFpb commands can be in process

The device is ready for normal operation after the clock satisfies $^{t}$CH(abs) and $^{t}$CL(abs) for a minimum of 2 × $^{t}$CK + $^{t}$XP.

For input clock frequency changes, $^{t}$CK(MIN) and $^{t}$CK(MAX) must be met for each clock cycle.

After the input clock frequency is changed, additional MRW commands may be required to set the WR, RL, etc. These settings may require adjustment to meet minimum timing requirements at the target clock frequency.

For clock stop, CK_t is held LOW and CK_c is held HIGH.

## NO OPERATION Command

The NO OPERATION (NOP) command prevents the device from registering any unwanted commands issued between operations. A NOP command can be issued only at clock cycle N when the CKE level is constant for clock cycle N-1 and clock cycle N. The NOP command has two possible encodings: CS_n HIGH at the clock rising edge N; and CS_n LOW with CA0, CA1, CA2 HIGH at the clock rising edge N.

The NOP command will not terminate a previous operation that is still in process, such as a READ burst or WRITE burst cycle.

## Truth Tables

Truth tables provide complementary information to the state diagram. They also clarify device behavior and applicable restrictions when considering the actual state of the banks.

Unspecified operations and timings are illegal. To ensure proper operation after an illegal event, the device must be powered down and then restarted using the specified initialization sequence before normal operation can continue.


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### Table 63: Command Truth Table

Notes 1–13 apply to all parameters conditions

| Command | Command Pins | | | CA Pins | | | | | | | | | | CK Edge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CKE | | | | | | | | | | | | | |
| | CK(*n*-1) | CK(*n*) | CS_n | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 | CA6 | CA7 | CA8 | CA9 | |
| MRW | H | H | L | L | L | L | L | MA0 | MA1 | MA2 | MA3 | MA4 | MA5 | ↓ |
| | H | H | X | MA6 | MA7 | OP0 | OP1 | OP2 | OP3 | OP4 | OP5 | OP6 | OP7 | ↓ |
| MRR | H | H | L | L | L | L | H | MA0 | MA1 | MA2 | MA3 | MA4 | MA5 | ↓ |
| | H | H | X | MA6 | MA7 | X | | | | | | | | ↓ |
| REFRESH (per bank) | H | H | L | L | L | H | L | X | | | | | | ↓ |
| | H | H | X | X | | | | | | | | | | ↓ |
| REFRESH (all banks) | H | H | L | L | L | H | H | X | | | | | | ↓ |
| | H | H | X | X | | | | | | | | | | ↓ |
| Enter self refresh | H | L | L | L | L | H | X | | | | | | | ↓ |
| | X | L | X | X | | | | | | | | | | ↓ |
| ACTIVATE (bank) | H | H | L | L | H | R8 | R9 | R10 | R11 | R12 | BA0 | BA1 | BA2 | ↓ |
| | H | H | X | R0 | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R13 | R14 | ↓ |
| WRITE (bank) | H | H | L | H | L | L | RFU | RFU | C1 | C2 | BA0 | BA1 | BA2 | ↓ |
| | H | H | X | AP | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | ↓ |
| READ (bank) | H | H | L | H | L | H | RFU | RFU | C1 | C2 | BA0 | BA1 | BA2 | ↓ |
| | H | H | X | AP | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | ↓ |
| PRECHARGE (bank) | H | H | L | H | H | L | H | AB | X | X | BA0 | BA1 | BA2 | ↓ |
| | H | H | X | X | | | | | | | | | | ↓ |
| BST | H | H | L | H | H | L | L | X | | | | | | ↓ |
| | H | H | X | X | | | | | | | | | | ↓ |
| Enter DPD | H | L | L | H | H | L | X | | | | | | | ↓ |
| | X | L | X | X | | | | | | | | | | ↓ |
| NOP | H | H | L | H | H | H | X | | | | | | | ↓ |
| | H | H | X | X | | | | | | | | | | ↓ |
| Maintain PD, SREF, DPD, (NOP) | L | L | L | H | H | H | X | | | | | | | ↓ |
| | L | L | X | X | | | | | | | | | | ↓ |
| NOP | H | H | H | X | | | | | | | | | | ↓ |
| | H | H | X | X | | | | | | | | | | ↓ |
| Maintain PD, SREF, DPD, (NOP) | L | L | H | X | | | | | | | | | | ↓ |
| | L | L | X | X | | | | | | | | | | ↓ |
| Enter power-down | H | L | H | X | | | | | | | | | | ↓ |
| | X | L | X | X | | | | | | | | | | ↓ |



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### Table 63: Command Truth Table (Continued)

Notes 1–13 apply to all parameters conditions

| Command | Command Pins | | | CA Pins | | | | | | | | | | CK Edge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CKE | | | | | | | | | | | | | |
| | CK(*n*-1) | CK(*n*) | CS_n | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 | CA6 | CA7 | CA8 | CA9 | |
| Exit PD, SREF, DPD | L | H | H | X | | | | | | | | | | ↑ |
| | X | H | X | X | | | | | | | | | | ↓ |

Notes:
1. All commands are defined by the current state of CS_n, CA0, CA1, CA2, CA3, and CKE at the rising edge of the clock.
2. Bank addresses (BA) determine which bank will be operated upon.
3. AP HIGH during a READ or WRITE command indicates that an auto precharge will occur to the bank associated with the READ or WRITE command.
4. X indicates a "Don't Care" state, with a defined logic level, either HIGH (H) or LOW (L).
5. Self refresh exit and DPD exit are asynchronous.
6. $V_{REF}$ must be between 0 and $V_{DDQ}$ during self refresh and DPD operation.
7. CAxr refers to command/address bit "x" on the rising edge of clock.
8. CAxf refers to command/address bit "x" on the falling edge of clock.
9. CS_n and CKE are sampled on the rising edge of the clock.
10. Per-bank refresh is supported only in devices with eight banks.
11. The least-significant column address C0 is not transmitted on the CA bus, and is inferred to be zero.
12. RFU needs to input "H" or "L" (but a defined logic level).
13. AB "high"during Precharge command indicates that all bank Precharge will occur. In this case, Bank Address is don't care.

### Table 64: CKE Truth Table

Notes 1–5 apply to all parameters and conditions; L = LOW, H = HIGH, X = "Don't Care"

| Current State | CKE*n*-1 | CKE*n* | CS_n | Command *n* | Operation *n* | Next State | Notes |
|---|---|---|---|---|---|---|---|
| Active power-down | L | L | X | X | Maintain active power-down | Active power-down | |
| | L | H | H | NOP | Exit active power-down | Active | 6, 7 |
| Idle power-down | L | L | X | X | Maintain idle power-down | Idle power-down | |
| | L | H | H | NOP | Exit idle power-down | Idle | 6, 7 |
| Resetting idle power-down | L | L | X | X | Maintain resetting power-down | Resetting power-down | |
| | L | H | H | NOP | Exit resetting power-down | Idle or resetting | 6, 7, 8 |
| Deep power-down | L | L | X | X | Maintain deep power-down | Deep power-down | |
| | L | H | H | NOP | Exit deep power-down | Power-on | 9 |
| Self refresh | L | L | X | X | Maintain self refresh | Self refresh | |
| | L | H | H | NOP | Exit self refresh | Idle | 10, 11 |
| Bank(s) active | H | L | H | NOP | Enter active power-down | Active power-down | |


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**Table 64: CKE Truth Table (Continued)**

Notes 1–5 apply to all parameters and conditions; L = LOW, H = HIGH, X = "Don't Care"

| Current State | CKE*n*-1 | CKE*n* | CS_n | Command *n* | Operation *n* | Next State | Notes |
|---|---|---|---|---|---|---|---|
| All banks idle | H | L | H | NOP | Enter idle power-down | Idle power-down | |
| | H | L | L | Enter self refresh | Enter self refresh | Self refresh | |
| | H | L | L | DPD | Enter deep power-down | Deep power-down | |
| Resetting | H | L | H | NOP | Enter resetting power-down | Resetting power-down | |
| Other states | H | H | Refer to the command truth table | | | | |

Notes:
1. Current state = the state of the device immediately prior to the clock rising edge *n*.
2. All states and sequences not shown are illegal or reserved unless explicitly described elsewhere in this document.
3. CKE*n* = the logic state of CKE at clock rising edge *n*; CKE*n*-1 was the state of CKE at the previous clock edge.
4. CS_n= the logic state of CS_n at the clock rising edge *n*.
5. Command *n* = the command registered at clock edge *n*, and operation *n* is a result of command *n*.
6. Power-down exit time ($^{t}$XP) must elapse before any command other than NOP is issued.
7. The clock must toggle at least twice prior to the $^{t}$XP period.
8. Upon exiting the resetting power-down state, the device will return to the idle state if $^{t}$INIT5 has expired.
9. The DPD exit procedure must be followed as described in Deep Power Down.
10. Self refresh exit time ($^{t}$XSR) must elapse before any command other than NOP is issued.
11. The clock must toggle at least twice prior to the $^{t}$XSR time.

**Table 65: Current State Bank *n* to Command to Bank *n* Truth Table**

Notes 1–5 apply to all parameters and conditions

| Current State | Command | Operation | Next State | Notes |
|---|---|---|---|---|
| Any | NOP | Continue previous operation | Current state | |
| Idle | ACTIVATE | Select and activate row | Active | |
| | Refresh (per bank) | Begin to refresh | Refreshing (per bank) | 6 |
| | Refresh (all banks) | Begin to refresh | Refreshing (all banks) | 7 |
| | MRW | Load value to mode register | MR writing | 7 |
| | MRR | Read value from mode register | Idle, MR reading | |
| | RESET | Begin device auto initialization | Resetting | 7, 8 |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 9, 10 |
| Row active | READ | Select column and start read burst | Reading | |
| | WRITE | Select column and start write burst | Writing | |
| | MRR | Read value from mode register | Active MR reading | |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 9 |


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**Table 65: Current State Bank *n* to Command to Bank *n* Truth Table (Continued)**

Notes 1–5 apply to all parameters and conditions

| Current State | Command | Operation | Next State | Notes |
|---|---|---|---|---|
| Reading | READ | Select column and start new read burst | Reading | 11, 12 |
| | WRITE | Select column and start write burst | Writing | 11, 12, 13 |
| | BST | Read burst terminate | Active | 14 |
| Writing | WRITE | Select column and start new write burst | Writing | 11, 12 |
| | READ | Select column and start read burst | Reading | 11, 12, 15 |
| | BST | Write burst terminate | Active | 14 |
| Power-on | RESET | Begin device auto initialization | Resetting | 7, 9 |
| Resetting | MRR | Read value from mode register | Resetting MR reading | |

Notes:

1. Values in this table apply when both CKE*n* -1 and CKE*n* are HIGH, and after $^{t}$XSR or $^{t}$XP has been met, if the previous state was power-down.
2. All states and sequences not shown are illegal or reserved.
3. Current state definitions:

   Idle: The bank or banks have been precharged, and $^{t}$RP has been met.

   Active: A row in the bank has been activated, and $^{t}$RCD has been met. No data bursts or accesses and no register accesses are in progress.

   Reading: A READ burst has been initiated with auto precharge disabled and has not yet terminated or been terminated.

   Writing: A WRITE burst has been initiated with auto precharge disabled and has not yet terminated or been terminated.
4. These states must not be interrupted by a command issued to the same bank. NOP commands or supported commands to the other bank must be issued on any clock edge occurring during these states. Supported commands to the other banks are determined by that bank's current state and the definitions given here.

   Precharge: Starts with registration of a PRECHARGE command and ends when $^{t}$RP is met. After $^{t}$RP is met, the bank is in the idle state.

   Row activate: Starts with registration of an ACTIVATE command and ends when $^{t}$RCD is met. After $^{t}$RCD is met, the bank is in the active state.

   READ with AP enabled: Starts with registration of a READ command with auto precharge enabled and ends when $^{t}$RP is met. After $^{t}$RP is met, the bank is in the idle state.

   WRITE with AP enabled: Starts with registration of a WRITE command with auto precharge enabled and ends when $^{t}$RP is met. After $^{t}$RP is met, the bank is in the idle state.
5. These states must not be interrupted by any executable command. NOP commands must be applied to each rising clock edge during these states.

   Refresh (per bank): Starts with registration of a REFRESH (per bank) command and ends when $^{t}$RFCpb is met. After $^{t}$RFCpb is met, the bank is in the idle state.

   Refresh (all banks): Starts with registration of a REFRESH (all banks) command and ends when $^{t}$RFCab is met. After $^{t}$RFCab is met, the device is in the all banks idle state.

   Idle MR reading: Starts with registration of the MRR command and ends when $^{t}$MRR is met. After $^{t}$MRR is met, the device is in the all banks idle state.

   Resetting MR reading: Starts with registration of the MRR command and ends when $^{t}$MRR is met. After $^{t}$MRR is met, the device is in the all banks idle state.


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Active MR reading: Starts with registration of the MRR command and ends when $^{t}$MRR is met. After $^{t}$MRR is met, the bank is in the active state.

MR writing: Starts with registration of the MRW command and ends when $^{t}$MRW is met. After $^{t}$MRW is met, the device is in the all banks idle state.

Precharging all: Starts with registration of a PRECHARGE ALL command and ends when $^{t}$RP is met. After $^{t}$RP is met, the device is in the all banks idle state.

6. Bank-specific; requires that the bank is idle and no bursts are in progress.
7. Not bank-specific; requires that all banks are idle and no bursts are in progress.
8. Not bank-specific.
9. This command may or may not be bank specific. If all banks are being precharged, they must be in a valid state for precharging.
10. If a PRECHARGE command is issued to a bank in the idle state, $^{t}$RP still applies.
11. A command other than NOP should not be issued to the same bank while a burst READ or burst WRITE with auto precharge is enabled.
12. The new READ or WRITE command could be auto precharge enabled or auto precharge disabled.
13. A WRITE command can be issued after the completion of the READ burst; otherwise, a BST must be issued to end the READ prior to asserting a WRITE command.
14. Not bank-specific. The BST command affects the most recent READ/WRITE burst started by the most recent READ/WRITE command, regardless of bank.
15. A READ command can be issued after completion of the WRITE burst; otherwise, a BST must be used to end the WRITE prior to asserting another READ command.

### Table 66: Current State Bank *n* to Command to Bank *m* Truth Table

Notes 1–6 apply to all parameters and conditions

| Current State of Bank *n* | Command to Bank *m* | Operation | Next State for Bank *m* | Notes |
|---|---|---|---|---|
| Any | NOP | Continue previous operation | Current state of bank *m* | |
| Idle | Any | Any command supported to bank *m* | – | 7 |
| Row activating, active, or pre-charging | ACTIVATE | Select and activate row in bank *m* | Active | 8 |
| | READ | Select column and start READ burst from bank *m* | Reading | 9 |
| | WRITE | Select column and start WRITE burst to bank *m* | Writing | 9 |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 10 |
| | MRR | READ value from mode register | Idle MR reading or active MR reading | 11, 12, 13 |
| | BST | READ or WRITE burst terminates an on-going READ/WRITE from/to bank *m* | Active | 7 |
| Reading (auto precharge disabled) | READ | Select column and start READ burst from bank *m* | Reading | 9 |
| | WRITE | Select column and start WRITE burst to bank *m* | Writing | 9, 14 |
| | ACTIVATE | Select and activate row in bank *m* | Active | |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 10 |


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**Table 66: Current State Bank *n* to Command to Bank *m* Truth Table (Continued)**

Notes 1–6 apply to all parameters and conditions

| Current State of Bank *n* | Command to Bank *m* | Operation | Next State for Bank *m* | Notes |
|---|---|---|---|---|
| Writing (auto precharge disabled) | READ | Select column and start READ burst from bank *m* | Reading | 9, 15 |
| | WRITE | Select column and start WRITE burst to bank *m* | Writing | 9 |
| | ACTIVATE | Select and activate row in bank *m* | Active | |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 10 |
| Reading with auto precharge | READ | Select column and start READ burst from bank *m* | Reading | 9, 16 |
| | WRITE | Select column and start WRITE burst to bank *m* | Writing | 9, 14, 16 |
| | ACTIVATE | Select and activate row in bank *m* | Active | |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 10 |
| Writing with auto precharge | READ | Select column and start READ burst from bank *m* | Reading | 9, 15, 16 |
| | WRITE | Select column and start WRITE burst to bank *m* | Writing | 9, 16 |
| | ACTIVATE | Select and activate row in bank *m* | Active | |
| | PRECHARGE | Deactivate row(s) in bank or banks | Precharging | 10 |
| Power-on | RESET | Begin device auto initialization | Resetting | 17, 18 |
| Resetting | MRR | Read value from mode register | Resetting MR reading | |

Notes:

1. This table applies when: the previous state was self refresh or power-down; after $^{t}$XSR or $^{t}$XP has been met; *and* both CKE*n* -1 and CKE*n* are HIGH.
2. All states and sequences not shown are illegal or reserved.
3. Current state definitions:

   Idle: The bank has been precharged and $^{t}$RP has been met.

   Active: A row in the bank has been activated, $^{t}$RCD has been met, no data bursts or accesses and no register accesses are in progress.

   Read: A READ burst has been initiated with auto precharge disabled and the READ has not yet terminated or been terminated.

   Write: A WRITE burst has been initiated with auto precharge disabled and the WRITE has not yet terminated or been terminated.
4. Refresh, self refresh, and MRW commands can be issued only when all banks are idle.
5. A BST command cannot be issued to another bank; it applies only to the bank represented by the current state.
6. These states must not be interrupted by any executable command. NOP commands must be applied during each clock cycle while in these states:

   Idle MRR: Starts with registration of the MRR command and ends when $^{t}$MRR has been met. After $^{t}$MRR is met, the device is in the all banks idle state.

   Reset MRR: Starts with registration of the MRR command and ends when $^{t}$MRR has been met. After $^{t}$MRR is met, the device is in the all banks idle state.


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Active MRR: Starts with registration of the MRR command and ends when $^{t}$MRR has been met. After $^{t}$MRR is met, the bank is in the active state.

MRW: Starts with registration of the MRW command and ends when $^{t}$MRW has been met. After $^{t}$MRW is met, the device is in the all banks idle state.

7. BST is supported only if a READ or WRITE burst is ongoing.
8. $^{t}$RRD must be met between the ACTIVATE command to bank *n* and any subsequent ACTIVATE command to bank *m*.
9. READs or WRITEs listed in the command column include READs and WRITEs with or without auto precharge enabled.
10. This command may or may not be bank-specific. If all banks are being precharged, they must be in a valid state for precharging.
11. MRR is supported in the row-activating state.
12. MRR is supported in the precharging state.
13. The next state for bank *m* depends on the current state of bank *m* (idle, row-activating, precharging, or active).
14. A WRITE command can be issued after the completion of the READ burst; otherwise a BST must be issued to end the READ prior to asserting a WRITE command.
15. A READ command can be issued after the completion of the WRITE burst; otherwise, a BST must be issued to end the WRITE prior to asserting another READ command.
16. A READ with auto precharge enabled or a WRITE with auto precharge enabled can be followed by any valid command to other banks provided that the timing restrictions in the PRECHARGE and Auto Precharge Clarification table are met.
17. Not bank-specific; requires that all banks are idle and no bursts are in progress.
18. RESET command is achieved through MODE REGISTER WRITE command.

**Table 67: DM Truth Table**

| Functional Name | DM | DQ | Notes |
|---|---|---|---|
| Write enable | L | Valid | 1 |
| Write inhibit | H | X | 1 |

Note: 1. Used to mask write data, and is provided simultaneously with the corresponding input data.

# Electrical Conditions

- All voltages are referenced to VSS (GND).
- Power-up and Initialization sequence must be executed before proper device operation is achieved.


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# Absolute Maximum Ratings

Stresses greater than those listed below 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 document is not implied. Exposure to absolute maximum rating conditions for extended periods may adversely affect reliability.

**Table 68: Absolute Maximum DC Ratings**

| Parameter | Symbol | Min | Max | Unit | Notes |
|---|---|---|---|---|---|
| $V_{DD1}$ supply voltage relative to $V_{SS}$ | $V_{DD1}$ | –0.4 | +2.3 | V | 1 |
| $V_{DD2}$ supply voltage relative to $V_{SS}$ | $V_{DD2}$ (1.2V) | –0.4 | +1.6 | V | 1 |
| $V_{DDQ}$ supply voltage relative to $V_{SSQ}$ | $V_{DDQ}$ | –0.4 | +1.6 | V | 1, 3 |
| Voltage on any ball relative to $V_{SS}$ | $V_{IN}$, $V_{OUT}$ | –0.4 | +1.6 | V | |
| Storage temperature | $T_{STG}$ | –55 | +125 | °C | 4 |

Notes:
1. See 1. Voltage Ramp under Power Up.
2. $V_{REFCA}$ 0.6 ≤ $V_{DD2}$; however, $V_{REFCA}$ may be ≥ $V_{DD2}$ provided that $V_{REFCA}$ ≤ 300mV.
3. $V_{REFDQ}$ 0.6 ≤ $V_{DDQ}$; however, $V_{REFDQ}$ may be ≥ $V_{DDQ}$ provided that $V_{REFDQ}$ ≤ 300mV.
4. Storage temperature is the case surface temperature on the center/top side of the device. For measurement conditions, refer to the JESD51-2 standard.

# AC and DC Operating Conditions

An operation or timing that is not specified is illegal. To ensure proper operation, the device must be initialized properly.

**Table 69: Recommended DC Operating Conditions**

| Symbol | LPDDR2-S4B | | | Power Supply | Unit |
|---|---|---|---|---|---|
| | Min | Typ | Max | | |
| $V_{DD1}$[1] | 1.70 | 1.80 | 1.95 | Core power 1 | V |
| $V_{DD2}$ | 1.14 | 1.20 | 1.30 | Core power 2 | V |
| $V_{DDQ}$ | 1.14 | 1.20 | 1.30 | I/O buffer power | V |

Note:
1. $V_{DD1}$ uses significantly less power than $V_{DD2}$.

**Table 70: Input Leakage Current**

| Parameter/Condition | Symbol | Min | Max | Unit | Notes |
|---|---|---|---|---|---|
| **Input leakage current:** For CA, CKE, CS_n, CK_t, CK_c; Any input 0V ≤ $V_{IN}$ ≤ $V_{DD2}$; (All other pins not under test = 0V) | $I_L$ | –2 | 2 | µA | 1 |
| **$V_{REF}$ supply leakage current:** $V_{REFDQ}$ = $V_{DDQ}$/2, or $V_{REFCA}$ = $V_{DD2}$/2; (All other pins not under test = 0V) | $I_{VREF}$ | –1 | 1 | µA | 2 |

Notes:
1. Although DM is for input only, the DM leakage must match the DQ and DQS_t/DQS_c output leakage specification.
2. The minimum limit requirement is for testing purposes. The leakage current on $V_{REFCA}$ and $V_{REFDQ}$ pins should be minimal.


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**Table 71: Operating Temperature Range**

| Parameter/Condition | Symbol | Min | Max | Unit |
|---|---|---|---|---|
| Standard (WT) temperature range | $T_{CASE}$[1] | –30 | +85 | °C |
| Wide temperature range | | –30 | +105 | °C |

Notes:
1. Operating temperature is the case surface temperature at the center of the top side of the device. For measurement conditions, refer to the JESD51-2 standard.
2. Some applications require operation in the maximum case temperature range, between 85°C and 105°C. For some LPDDR2 devices, derating may be necessary to operate in this range (see the MR4 Device Temperature (MA[7:0] = 04h) table).
3. Either the device operating temperature or the temperature sensor can be used to set an appropriate refresh rate, determine the need for AC timing derating, and/or monitor the operating temperature (see Temperature Sensor). When using the temperature sensor, the actual device case temperature may be higher than the $T_{CASE}$ rating that applies for the operating temperature range. For example, $T_{CASE}$ could be above 85°C when the temperature sensor indicates a temperature of less than 85°C.

# AC and DC Logic Input Measurement Levels for Single-Ended Signals

**Table 72: Single-Ended AC and DC Input Levels for CA and CS_n Inputs**

| Symbol | Parameter | LPDDR2-1066 to LPDDR2-466 | | LPDDR2-400 to LPDDR2-200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| $V_{IHCA(AC)}$ | AC input logic HIGH | $V_{REF}$ + 0.220 | Note 2 | $V_{REF}$ + 0.300 | Note 2 | V | 1, 2 |
| $V_{ILCA(AC)}$ | AC input logic LOW | Note 2 | $V_{REF}$ - 0.220 | Note 2 | $V_{REF}$ - 0.300 | V | 1, 2 |
| $V_{IHCA(DC)}$ | DC input logic HIGH | $V_{REF}$ + 0.130 | $V_{DD2}$ | $V_{REF}$ + 0.200 | $V_{DD2}$ | V | 1 |
| $V_{ILCA(DC)}$ | DC input logic LOW | $V_{SS}$ | $V_{REF}$ - 0.130 | $V_{SS}$ | $V_{REF}$ - 0.200 | V | 1 |
| $V_{REFCA(DC)}$ | Reference voltage for CA and CS_n inputs | 0.49 × $V_{DD2}$ | 0.51 × $V_{DD2}$ | 0.49 × $V_{DD2}$ | 0.51 × $V_{DD2}$ | V | 3, 4 |

Notes:
1. For CA and CS_n input-only pins. $V_{REF}$ = $V_{REFCA(DC)}$.
2. See Overshoot and Undershoot Definition.
3. The AC peak noise on $V_{REFCA}$ could prevent $V_{REFCA}$ from deviating more than ±1% $V_{DD2}$ from $V_{REFCA(DC)}$ (for reference, approximately ±12mV).
4. For reference, approximately $V_{DD2}$/2 ±12mV.

**Table 73: Single-Ended AC and DC Input Levels for CKE**

| Symbol | Parameter | Min | Max | Unit | Notes |
|---|---|---|---|---|---|
| $V_{IHCKE}$ | CKE input HIGH level | 0.8 × $V_{DD2}$ | Note 1 | V | 1 |
| $V_{ILCKE}$ | CKE input LOW level | Note 1 | 0.2 × $V_{DD2}$ | V | 1 |

Note:
1. See Overshoot and Undershoot Definition.


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**Table 74: Single-Ended AC and DC Input Levels for DQ and DM**

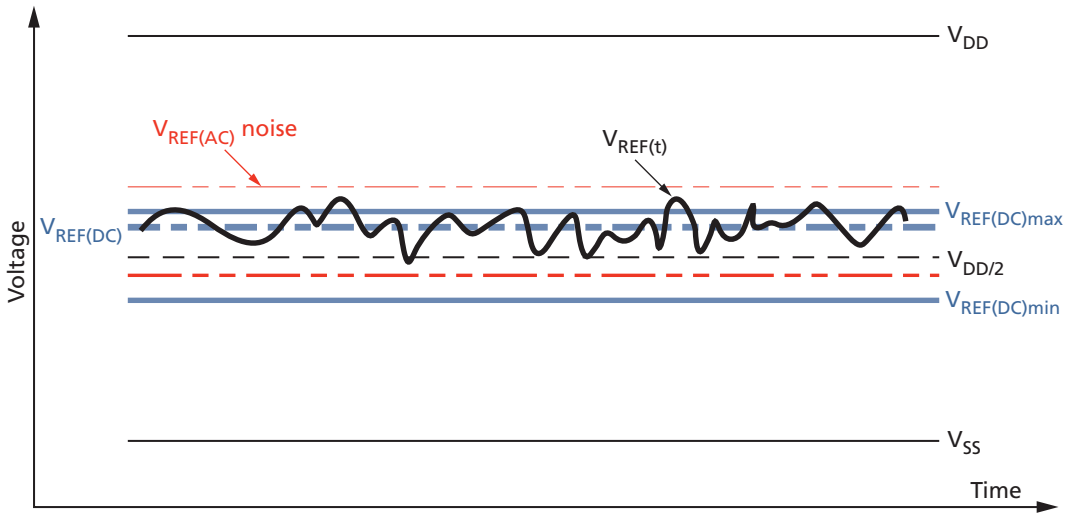
| Symbol | Parameter | LPDDR2-1066 to LPDDR2-466 | | LPDDR2-400 to LPDDR2-200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| $V_{IHDQ(AC)}$ | AC input logic HIGH | $V_{REF}$ + 0.220 | Note 2 | $V_{REF}$ + 0.300 | Note 2 | V | 1, 2 |
| $V_{ILDQ(AC)}$ | AC input logic LOW | Note 2 | $V_{REF}$ - 0.220 | Note 2 | $V_{REF}$ - 0.300 | V | 1, 2 |
| $V_{IHDQ(DC)}$ | DC input logic HIGH | $V_{REF}$ + 0.130 | $V_{DDQ}$ | $V_{REF}$ + 0.200 | $V_{DDQ}$ | V | 1 |
| $V_{ILDQ(DC)}$ | DC input logic LOW | $V_{SS}$ | $V_{REF}$ - 0.130 | $V_{SS}$ | $V_{REF}$ - 0.200 | V | 1 |
| $V_{REFDQ(DC)}$ | Reference voltage for DQ and DM inputs | 0.49 × $V_{DDQ}$ | 0.51 × $V_{DDQ}$ | 0.49 × $V_{DDQ}$ | 0.51 × $V_{DDQ}$ | V | 3, 4 |

Notes:
1. For DQ input-only pins. $V_{REF} = V_{REFDQ(DC)}$.
2. See Overshoot and Undershoot Definition.
3. The AC peak noise on $V_{REFDQ}$ could prevent $V_{REFDQ}$ from deviating more than ±1% $V_{DDQ}$ from $V_{REFDQ(DC)}$ (for reference, approximately ±12mV).
4. For reference, approximately. $V_{DDQ}/2$ ±12mV.

## $V_{REF}$ Tolerances

The DC tolerance limits and AC noise limits for the reference voltages $V_{REFCA}$ and $V_{REFDQ}$ are illustrated below. This figure shows a valid reference voltage $V_{REF}(t)$ as a function of time. $V_{DD}$ is used in place of $V_{DD2}$ for $V_{REFCA}$, and $V_{DDQ}$ for $V_{REFDQ}$. $V_{REF(DC)}$ is the linear average of $V_{REF}(t)$ over a very long period of time (for example, 1 second) and is specified as a fraction of the linear average of $V_{DDQ}$ or $V_{DD2}$, also over a very long period of time (for example, 1 second). This average must meet the MIN/MAX requirements in the Single-Ended AC and DC Input Levels for CA and CS_n Inputs table. Additionally, $V_{REF}(t)$ can temporarily deviate from $V_{REF(DC)}$ by no more than ±1% $V_{DD}$. $V_{REF}(t)$ cannot track noise on $V_{DDQ}$ or $V_{DD2}$ if doing so would force $V_{REF}$ outside these specifications.

**Figure 74: $V_{REF}$ DC Tolerance and $V_{REF}$ AC Noise Limits**





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The voltage levels for setup and hold time measurements $V_{IH(AC)}$, $V_{IH(DC)}$, $V_{IL(AC)}$, and $V_{IL(DC)}$ are dependent on $V_{REF}$.

$V_{REF}$ DC variations affect the absolute voltage a signal must reach to achieve a valid HIGH or LOW, as well as the time from which setup and hold times are measured. When $V_{REF}$ is outside the specified levels, devices will function correctly with appropriate timing deratings as long as:

- $V_{REF}$ is maintained between 0.44 x $V_{DDQ}$ (or $V_{DD2}$) and 0.56 x $V_{DDQ}$ (or $V_{DD2}$), *and*
- the controller achieves the required single-ended AC and DC input levels from instantaneous $V_{REF}$ (see the Single-Ended AC and DC Input Levels for CA and CS_n Inputs table).

System timing and voltage budgets must account for $V_{REF}$ deviations outside this range.

The setup/hold specification and derating values must 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% $V_{DD}$) are included in LPDDR2 timings and their associated deratings.


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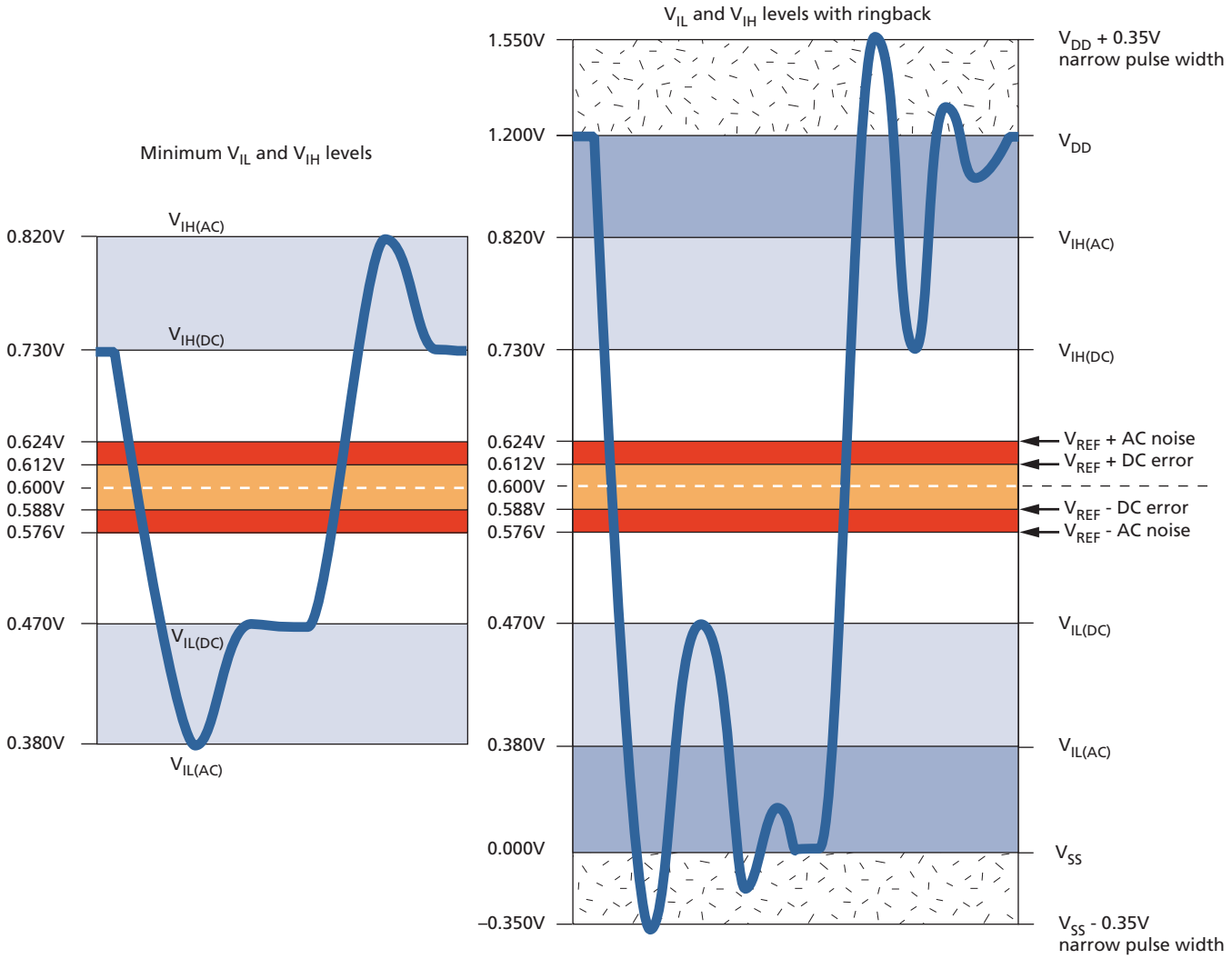
## Input Signal

**Figure 75: LPDDR2-466 to LPDDR2-1066 Input Signal**




Notes:
1. Numbers reflect typical values.
2. For CA[9:0], CK_t, CK_c, and CS_n $V_{DD}$ stands for $V_{DD2}$. For DQ, DM, DQS_t, and DQS_c, $V_{DD}$ stands for $V_{DDQ}$.
3. For CA[9:0], CK_t, CK_c, and CS_n are $V_{SS}$ . For DQ, DM, DQS_t, and DQS_c, $V_{SS}$ stands for $V_{SSQ}$.


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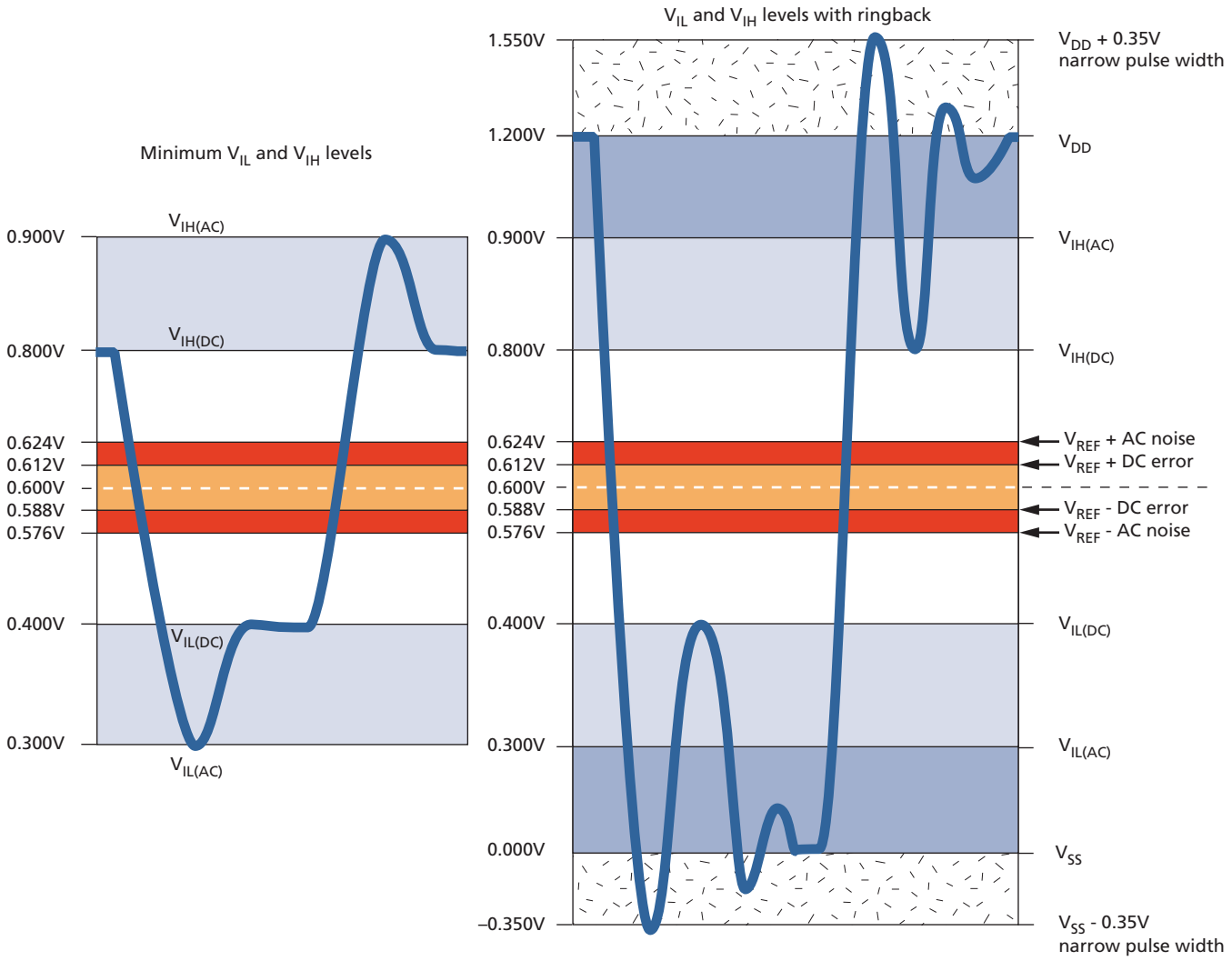
**Figure 76: LPDDR2-200 to LPDDR2-400 Input Signal**




Notes:
1. Numbers reflect typical values.
2. For CA[9:0], CK_t, CK_c, and CS_n $V_{DD}$ stands for $V_{DD2}$. For DQ, DM, DQS_t, and DQS_c, $V_{DD}$ stands for $V_{DDQ}$.
3. For CA[9:0], CK_t, CK_c, and CS_n are $V_{SS}$. For DQ, DM, DQS_t, and DQS_c, $V_{SS}$ stands for $V_{SSQ}$.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# AC and DC Logic Input Measurement Levels for Differential Signals

**Figure 77: Differential AC Swing Time and $^{t}$DVAC**

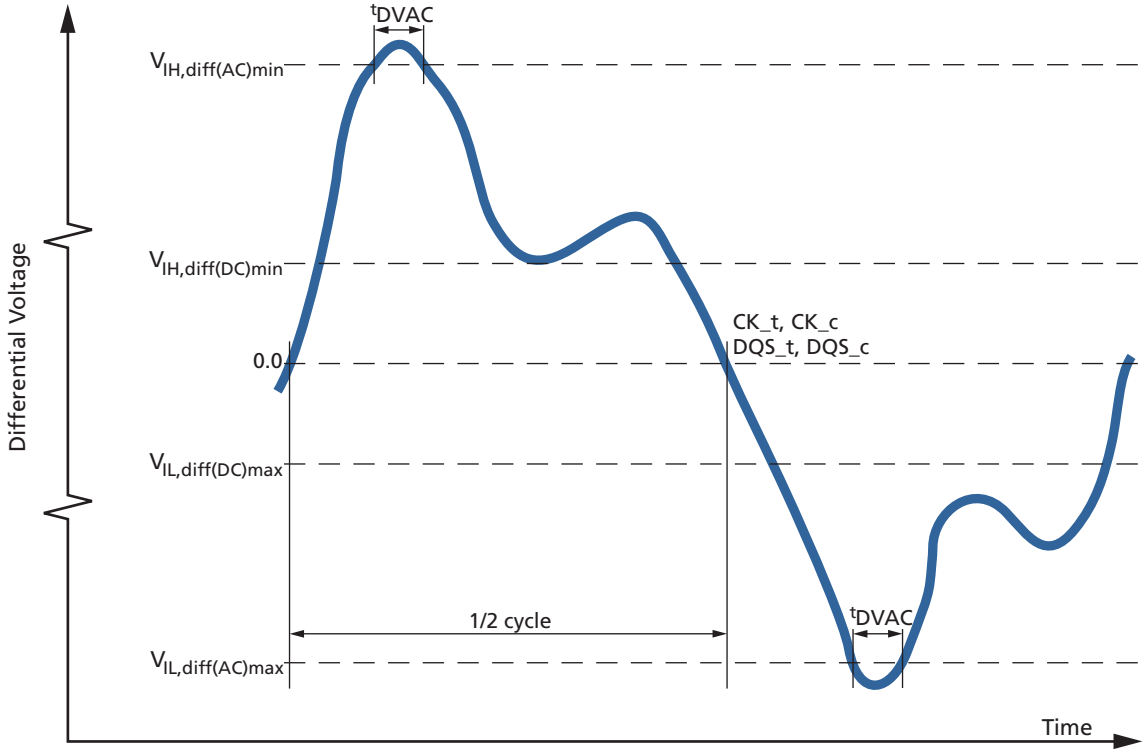


**Table 75: Differential AC and DC Input Levels**

For CK_t and CK_c, $V_{REF} = V_{REFCA(DC)}$; For DQS_t and DQS_c $V_{REF} = V_{REFDQ(DC)}$

| Symbol | Parameter | LPDDR2-1066 to LPDDR2-466 | | LPDDR2-400 to LPDDR2-200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| $V_{IH,diff(AC)}$ | Differential input HIGH AC | $2 \times (V_{IH(AC)} - V_{REF})$ | Note 1 | $2 \times (V_{IH(AC)} - V_{REF})$ | Note 1 | V | 2 |
| $V_{IL,diff(AC)}$ | Differential input LOW AC | Note 1 | $2 \times (V_{IL(AC)} - V_{REF})$ | Note 1 | $2 \times (V_{IL(AC)} - V_{REF})$ | V | 2 |
| $V_{IH,diff(DC)}$ | Differential input HIGH | $2 \times (V_{IH(DC)} - V_{REF})$ | Note 1 | $2 \times (V_{IH(DC)} - V_{REF})$ | Note 1 | V | 3 |
| $V_{IL,diff(DC)}$ | Differential input LOW | Note 1 | $2 \times (V_{IL(DC)} - V_{REF})$ | Note 1 | $2 \times (V_{IL(DC)} - V_{REF})$ | V | 3 |

Notes: 1. These values are not defined, however the single-ended signals CK_t, CK_c, DQS_t, and DQS_c must be within the respective limits ($V_{IH(DC)max}$, $V_{IL(DC)min}$) for single-ended signals and must comply with the specified limitations for overshoot and undershoot (see Overshoot and Undershoot Definitions).


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2. For CK_t and CK_c, use $V_{IH}/V_{IL(AC)}$ of CA and $V_{REFCA}$; for DQS_t and DQS_c, use $V_{IH}/V_{IL(AC)}$ of DQ and $V_{REFDQ}$. If a reduced AC HIGH or AC LOW is used for a signal group, the reduced voltage level also applies.
3. Used to define a differential signal slew rate. For CK_t - CK_c use VIH/VIL(dc) of CA and VREFCA; for DQS_t - DQS_c, use VIH/VIL(dc) of DQs and VREFDQ; if a reduced dc-high or dc-low level is used for a signal group,then the reduced level applies also here.

**Table 76: CK_t/CK_c and DQS_t/DQS_c Time Requirements Before Ringback ($^{t}$DVAC)**

| Slew Rate (V/ns) | $^{t}$DVAC (ps) at $V_{IH}/V_{ILdiff(AC)}$ = 440mV | $^{t}$DVAC (ps) at $V_{IH}/V_{ILdiff(AC)}$ = 600mV |
|---|---|---|
| | Min | Min |
| > 4.0 | 175 | 75 |
| 4.0 | 170 | 57 |
| 3.0 | 167 | 50 |
| 2.0 | 163 | 38 |
| 1.8 | 162 | 34 |
| 1.6 | 161 | 29 |
| 1.4 | 159 | 22 |
| 1.2 | 155 | 13 |
| 1.0 | 150 | 0 |
| < 1.0 | 150 | 0 |

## Single-Ended Requirements for Differential Signals

Each individual component of a differential signal (CK_t, CK_c, DQS_t, and DQS_c) must also comply with certain requirements for single-ended signals.

CK_t and CK_c must meet $V_{SEH(AC)min}/V_{SEL(AC)max}$ in every half cycle. DQS_t, DQS_c must meet $V_{SEH(AC)min}/V_{SEL(AC)max}$ in every half cycle preceding and following a valid transition.

The applicable AC levels for CA and DQ differ by speed bin.


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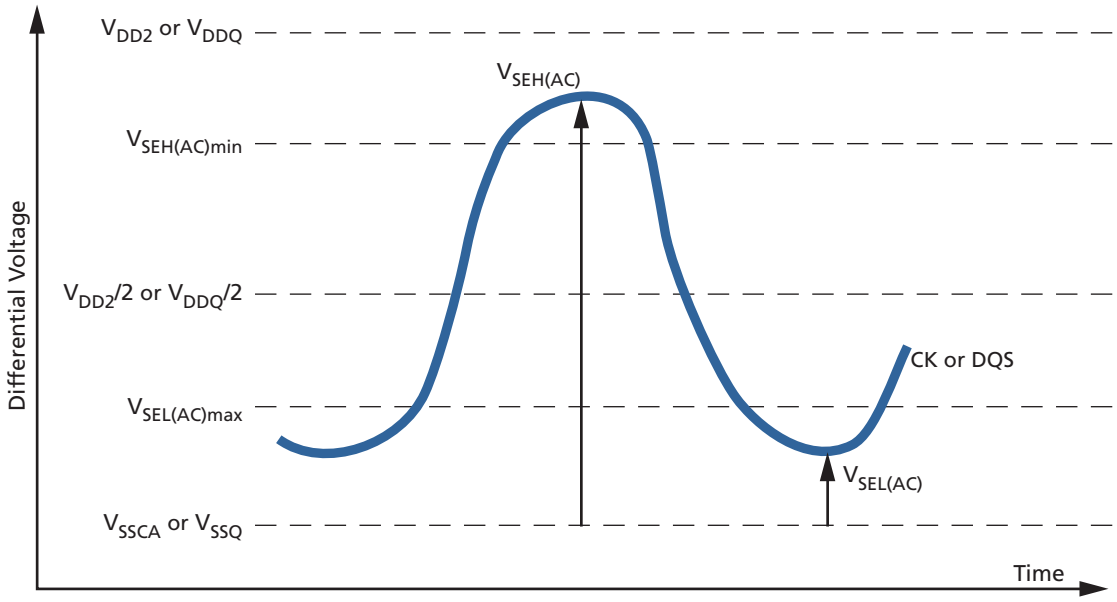
**Figure 78: Single-Ended Requirements for Differential Signals**




While CA and DQ signal requirements are referenced to $V_{REF}$, the single-ended components of differential signals also have a requirement with respect to $V_{DDQ}/2$ for DQS, and $V_{DD2}/2$ for CK.

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 $V_{SEL(AC)max}$ or $V_{SEH(AC)min}$ has no bearing on timing. This requirement does, however, add a restriction on the common mode characteristics of these signals (see Single-Ended AC and DC Input Levels for CA and CS_n Inputs for CK_t/CK_c single-ended requirements, and Single-Ended AC and DC Input Levels for DQ and DM for DQ and DQM single-ended requirements).

**Table 77: Single-Ended Levels for CK_t, CK_c, DQS_t, DQS_c**

| Symbol | Parameter | LPDDR2-1066 to LPDDR2-466 | | LPDDR2-400 to LPDDR2-200 | | Unit | Notes |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| $V_{SEH(AC)}$ | Single-ended HIGH level for strobes | $(V_{DDQ}/2) + 0.220$ | Note 1 | $(V_{DDQ}/2) + 0.300$ | Note 1 | V | 2, 3 |
| | Single-ended HIGH level for CK_t, CK_c | $(V_{DD2}/2) + 0.220$ | Note 1 | $(V_{DD2}/2) + 0.300$ | Note 1 | V | 2, 3 |
| $V_{SEL(AC)}$ | Single-ended LOW level for strobes | Note 1 | $(V_{DDQ}/2) - 0.220$ | Note 1 | $(V_{DDQ}/2) + 0.300$ | V | 2, 3 |
| | Single-ended LOW level for CK_t, CK_c | Note 1 | $(V_{DD2}/2) - 0.220$ | Note 1 | $(V_{DD2}/2) + 0.300$ | V | 2, 3 |

Notes: 1. These values are not defined; however, the single-ended signals CK_t, CK_c, DQS0_t, DQS0_c, DQS1_t, DQS1_c, DQS2_t, DQS2_c, DQS3_t, DQS3_c must be within the respective limits ($V_{IH(DC)max}$/ $V_{IL(DC)min}$) for single-ended signals, and must comply with the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specified limitations for overshoot and undershoot (see Overshoot and Undershoot Definition).

2. For CK_t and CK_c, use $V_{SEH}/V_{SEL(AC)}$ of CA; for strobes (DQS[3:0]_t and DQS[3:0]_c), use $V_{IH}/V_{IL(AC)}$ of DQ.
3. $V_{IH(AC)}$ and $V_{IL(AC)}$ for DQ are based on $V_{REFDQ}$; $V_{SEH(AC)}$ and $V_{SEL(AC)}$ for CA are based on $V_{REFCA}$. If a reduced AC HIGH or AC LOW is used for a signal group, the reduced level applies.

## Differential Input Crosspoint Voltage

To ensure tight setup and hold times as well as output skew parameters with respect to clock and strobe, each crosspoint voltage of differential input signals (CK_t, CK_c, DQS_t, and DQS_c) must meet the specifications listed in the Single-Ended Levels for CK_t, CK_c, DQS_t, DQS_c table. The differential input crosspoint voltage ($V_{IX}$) is measured from the actual crosspoint of the true signal and its and complement to the midlevel between $V_{DD}$ and $V_{SS}$.

**Figure 79: $V_{IX}$ Definition**

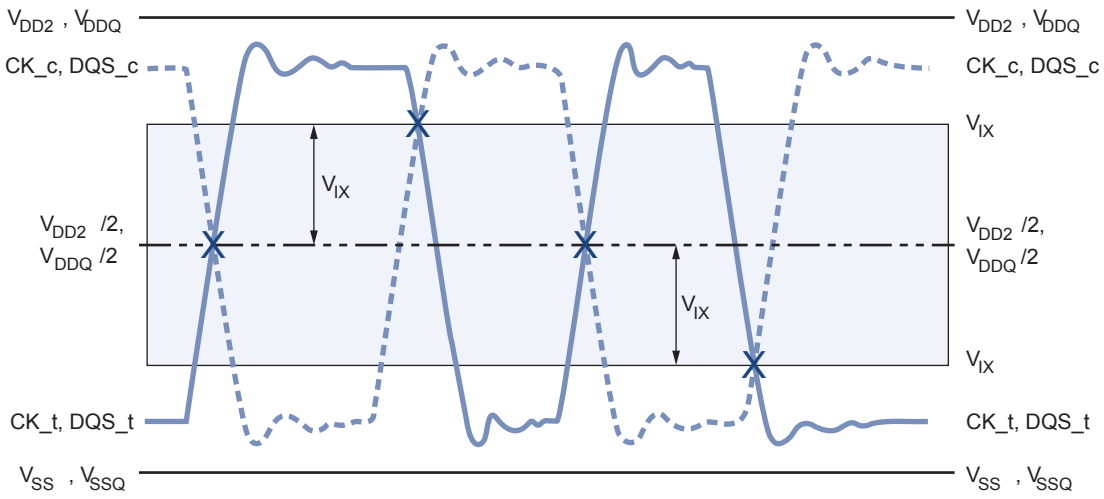


**Table 78: Crosspoint Voltage for Differential Input Signals (CK_t, CK_c, DQS_t, DQS_c)**

| Symbol | Parameter | LPDDR2-1066 to LPDDR2-200 | | Unit | Notes |
|---|---|---|---|---|---|
| | | Min | Max | | |
| $V_{IXCA(AC)}$ | Differential input crosspoint voltage relative to $V_{DD2}/2$ for CK_t and CK_c | –120 | 120 | mV | 1, 2 |
| $V_{IXDQ(AC)}$ | Differential input crosspoint voltage relative to $V_{DDQ}/2$ for DQS_t and DQS_c | –120 | 120 | mV | 1, 2 |

Notes:
1. The typical value of $V_{IX(AC)}$ is expected to be about 0.5 × $V_{DD}$ of the transmitting device, and it is expected to track variations in $V_{DD}$. $V_{IX(AC)}$ indicates the voltage at which differential input signals must cross.
2. For CK_t and CK_c, $V_{REF} = V_{REFCA(DC)}$. For DQS_t and DQS_c, $V_{REF} = V_{REFDQ(DC)}$.


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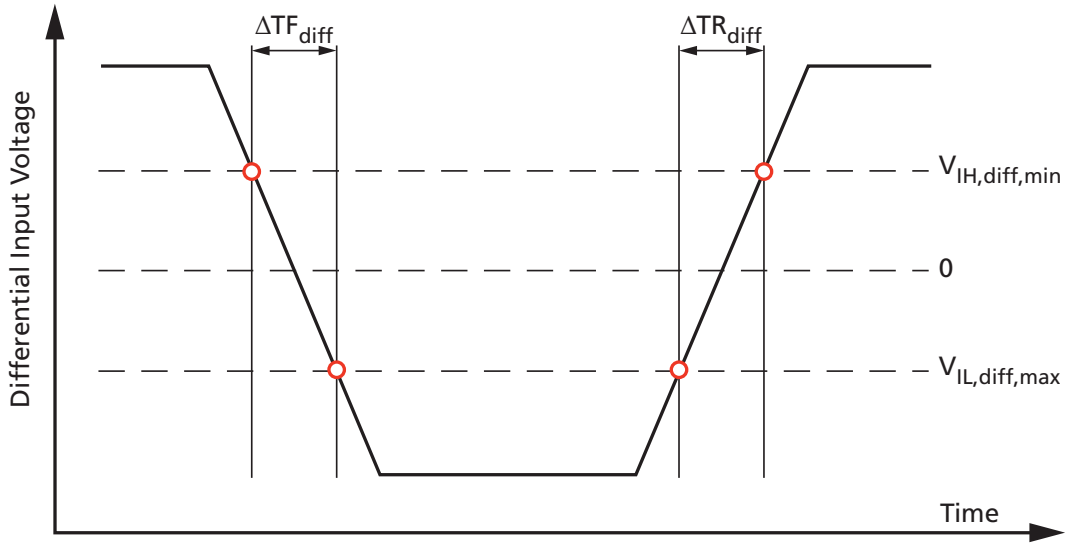
## Input Slew Rate

### Table 79: Differential Input Slew Rate Definition

| Description | Measured[1] | | Defined by |
|---|---|---|---|
| | From | To | |
| Differential input slew rate for rising edge (CK_t/CK_c and DQS_t/DQS_c) | $V_{IL,diff,max}$ | $V_{IH,diff,min}$ | $[V_{IH,diff,min} - V_{IL,diff,max}] / \Delta TR_{diff}$ |
| Differential input slew rate for falling edge (CK_t/CK_c and DQS_t/DQS_c) | $V_{IH,diff,min}$ | $V_{IL,diff,max}$ | $[V_{IH,diff,min} - V_{IL,diff,max}] / \Delta TF_{diff}$ |

Note: 1. The differential signals (CK_t/CK_c and DQS_t/DQS_c) must be linear between these thresholds.

### Figure 80: Differential Input Slew Rate Definition for CK_t, CK_c, DQS_t, and DQS_c




# Output Characteristics and Operating Conditions

### Table 80: Single-Ended AC and DC Output Levels

| Symbol | Parameter | | Value | Unit | Notes |
|---|---|---|---|---|---|
| $V_{OH(AC)}$ | AC output HIGH measurement level (for output slew rate) | | $V_{REF}$ + 0.12 | V | |
| $V_{OL(AC)}$ | AC output LOW measurement level (for output slew rate) | | $V_{REF}$ - 0.12 | V | |
| $V_{OH(DC)}$ | DC output HIGH measurement level (for I-V curve linearity) | | 0.9 x $V_{DDQ}$ | V | 1 |
| $V_{OL(DC)}$ | DC output LOW measurement level (for I-V curve linearity) | | 0.1 x $V_{DDQ}$ | V | 2 |
| $I_{OZ}$ | Output leakage current (DQ, DM, DQS_t, DQS_c); DQ, DQS_t, DQS_c are disabled; 0V ≤ $V_{OUT}$ ≤ $V_{DDQ}$ | MIN | –5 | µA | |
| | | MAX | +5 | µA | |


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**Table 80: Single-Ended AC and DC Output Levels (Continued)**

| Symbol | Parameter | | Value | Unit | Notes |
|---|---|---|---|---|---|
| MMpupd | Delta output impedance between pull-up and pull-down for DQ/DM | MIN | –15 | % | |
| | | MAX | +15 | % | |

Notes: 1. $I_{OH}$ = –0.1mA.
2. $I_{OL}$ = 0.1mA.

**Table 81: Differential AC and DC Output Levels**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| $V_{OHdiff(AC)}$ | AC differential output HIGH measurement level (for output SR) | + 0.2 x $V_{DDQ}$ | V |
| $V_{OLdiff(AC)}$ | AC differential output LOW measurement level (for output SR) | - 0.2 x $V_{DDQ}$ | V |

## Single-Ended Output Slew Rate

With the reference load for timing measurements, the 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 82: 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 | $V_{OH(AC)}$ | $V_{OL(AC)}$ | $[V_{OH(AC)} - V_{OL(AC)}] / \Delta TF_{SE}$ |

Note: 1. Output slew rate is verified by design and characterization and may not be subject to production testing.


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**Figure 81: Single-Ended Output Slew Rate Definition**

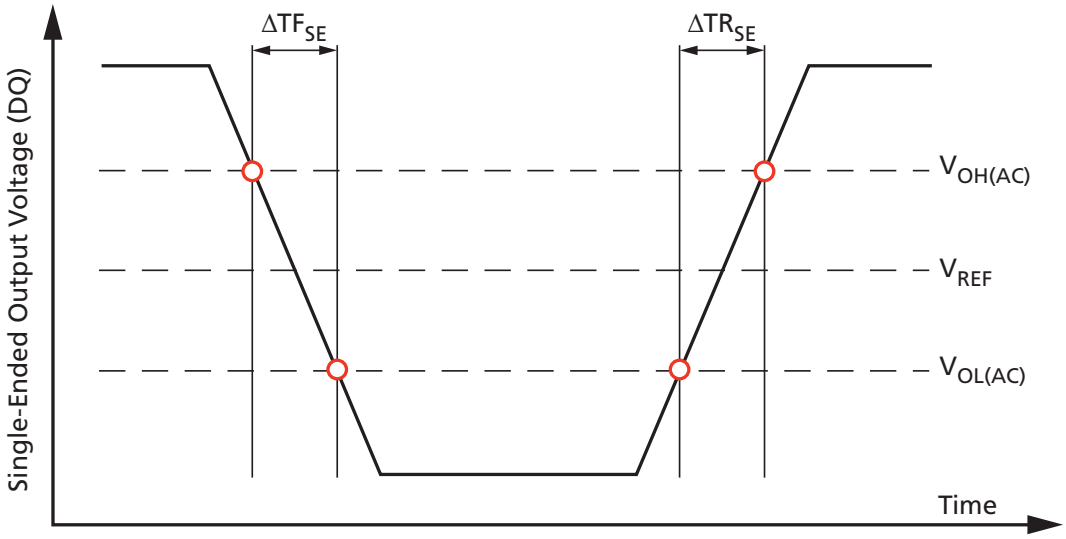


**Table 83: Single-Ended Output Slew Rate**

Notes 1–5 apply to all parameters conditions

| Parameter | Symbol | Value | | Unit |
|---|---|---|---|---|
| | | Min | Max | |
| Single-ended output slew rate (output impedance = 40Ω ±30%) | $SRQ_{SE}$ | 1.5 | 3.5 | V/ns |
| Single-ended output slew rate (output impedance = 60Ω ±30%) | $SRQ_{SE}$ | 1.0 | 2.5 | V/ns |
| Output slew-rate-matching ratio (pull-up to pull-down) | | 0.7 | 1.4 | – |

Notes:
1. Definitions: SR = slew rate; Q = output (similar to DQ = data-in, data-out); SE = single-ended signals.
2. Measured with output reference load.
3. The ratio of pull-up to pull-down slew rate is specified for the same temperature and voltage over the entire temperature and voltage range. For a given output, the ratio represents the maximum difference between pull-up and pull-down drivers due to process variation.
4. The output slew rate for falling and rising edges is defined and measured between $V_{OL(AC)}$ and $V_{OH(AC)}$.
5. Slew rates are measured under typical simultaneous switching output (SSO) conditions, with one-half of DQ signals per data byte driving HIGH and one-half of DQ signals per data byte driving LOW.

## Differential Output Slew Rate

With the reference load for timing measurements, the output slew rate for falling and rising edges is defined and measured between $V_{OL,diff(AC)}$ and $V_{OH,diff(AC)}$ for differential signals.


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**Table 84: 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 | $V_{OH,diff(AC)}$ | $V_{OL,diff(AC)}$ | $[V_{OH,diff(AC)} - V_{OL,diff(AC)}] / \Delta TF_{diff}$ |

Note: 1. Output slew rate is verified by design and characterization and may not be subject to production testing.

**Figure 82: Differential Output Slew Rate Definition**

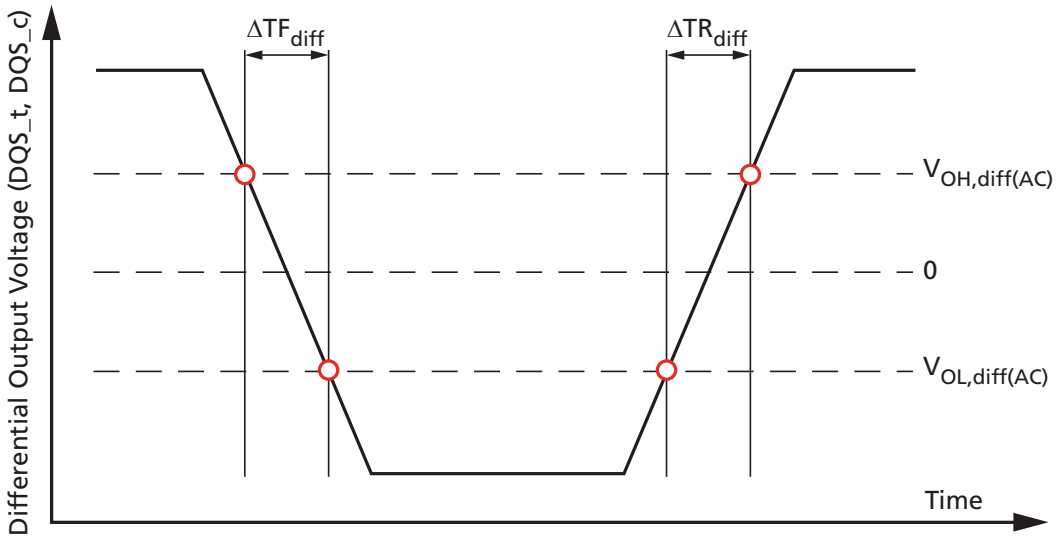


**Table 85: Differential Output Slew Rate**

| Parameter | Symbol | Value | | Unit |
|---|---|---|---|---|
| | | Min | Max | |
| Differential output slew rate (output impedance = 40Ω ±30%) | $SRQ_{diff}$ | 3.0 | 7.0 | V/ns |
| Differential output slew rate (output impedance = 60Ω ±30%) | $SRQ_{diff}$ | 2.0 | 5.0 | V/ns |

Notes:
1. Definitions: SR = slew rate; Q = output (similar to DQ = data-in, data-out); SE = single-ended signals.
2. Measured with output reference load.
3. The output slew rate for falling and rising edges is defined and measured between $V_{OL(AC)}$ and $V_{OH(AC)}$.
4. Slew rates are measured under typical simultaneous switching output (SSO) conditions, with one-half of DQ signals per data byte driving HIGH and one-half of DQ signals per data byte driving LOW.


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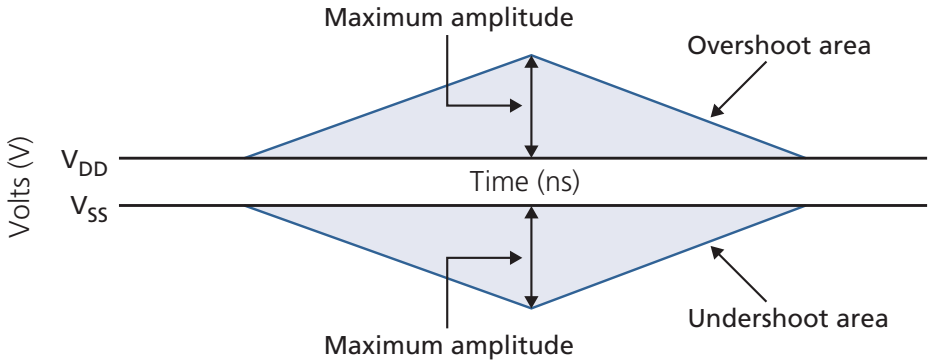
**Table 86: AC Overshoot/Undershoot Specification**

Applies for CA[9:0], CS_n, CKE, CK_t, CK_c, DQ, DQS_t, DQS_c, DM

| Parameter | 1066 | 933 | 800 | 667 | 533 | 466 | 400 | 333 | 266 | 200 | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum peak amplitude provided for overshoot area | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | V |
| Maximum peak amplitude provided for undershoot area | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | V |
| Maximum area above $V_{DD}$[1] | 0.15 | 0.17 | 0.20 | 0.24 | 0.30 | 0.35 | 0.40 | 0.48 | 0.60 | 0.80 | V-ns |
| Maximum area below $V_{SS}$[2] | 0.15 | 0.17 | 0.20 | 0.24 | 0.30 | 0.35 | 0.40 | 0.48 | 0.60 | 0.80 | V-ns |

Notes:
1. $V_{DD}$ stands for $V_{DD2}$ for CA[9:0], CK_t, CK_c, CS_n, and CKE. $V_{DD}$ stands for $V_{DDQ}$ for DQ, DM, DQS_t, and DQS_c.
2. $V_{SS}$ is for CA[9:0], CK_t, CK_c, CS_n, and CKE. $V_{SS}$ stands for $V_{SSQ}$ for DQ, DM, DQS_t, and DQS_c.

**Figure 83: Overshoot and Undershoot Definition**




Notes:
1. $V_{DD}$ stands for $V_{DD2}$ for CA[9:0], CK_t, CK_c, CS_n, and CKE. $V_{DD}$ stands for $V_{DDQ}$ for DQ, DM, DQS_t, and DQS_c.
2. $V_{SS}$ is for CA[9:0], CK_t, CK_c, CS_n, and CKE. $V_{SS}$ stands for $V_{SSQ}$ for DQ, DM, DQS_t, and DQS_c.

## HSUL_12 Driver Output Timing Reference Load

The timing reference loads are not intended as a precise representation of any particular system environment or a depiction of the actual load presented by a production tester. System designers should use IBIS or other simulation tools to correlate the timing reference load to a system environment. Manufacturers correlate to their production test conditions, generally with one or more coaxial transmission lines terminated at the tester electronics.


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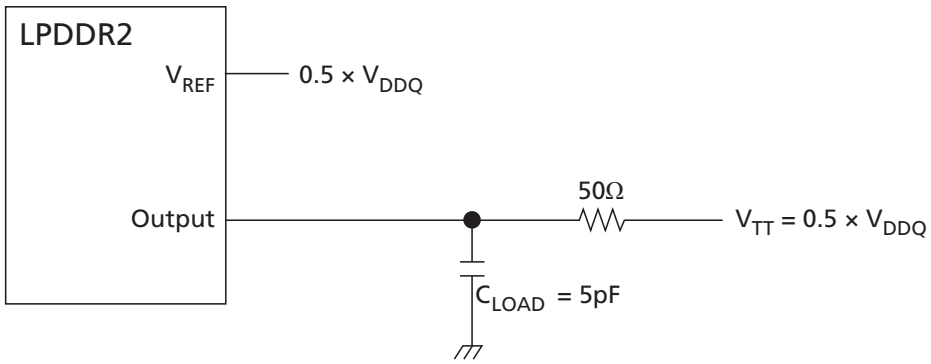
**Figure 84: HSUL_12 Driver Output Reference Load for Timing and Slew Rate**




Note: 1. All output timing parameter values ($^{t}$DQSCK, $^{t}$DQSQ, $^{t}$QHS, $^{t}$HZ, $^{t}$RPRE etc.) are reported with respect to this reference load. This reference load is also used to report slew rate.

## Output Driver Impedance

Output driver impedance is selected by a mode register during initialization. To achieve tighter tolerances, ZQ calibration is required. Output specifications refer to the default output drive unless specifically stated otherwise. The output driver impedance $R_{ON}$ is defined by the value of the external reference resistor $R_{ZQ}$ as follows:

$$R_{ONPU} = \frac{V_{DDQ} - V_{OUT}}{ABS(I_{OUT})}$$

When $R_{ONPD}$ is turned off.

$$R_{ONPD} = \frac{V_{OUT}}{ABS(I_{OUT})}$$

When $R_{ONPU}$ is turned off.


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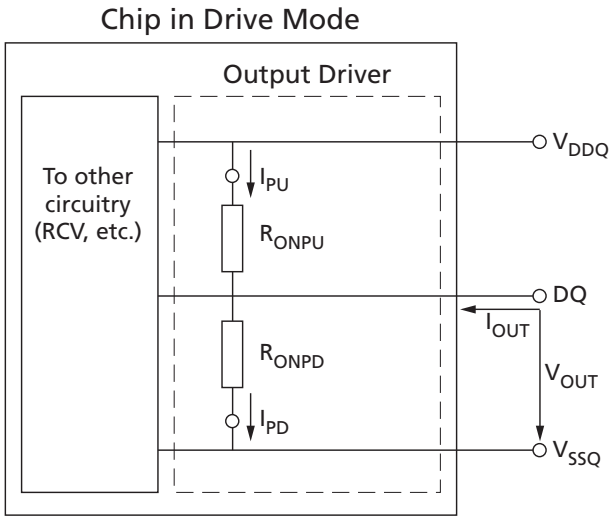
**Figure 85: Output Driver**




## Output Driver Impedance Characteristics with ZQ Calibration

Output driver impedance is defined by the value of the external reference resistor $R_{ZQ}$. Typical $R_{ZQ}$ is 240 ohms.

### Table 87: Output Driver DC Electrical Characteristics with ZQ Calibration

Notes 1–4 apply to all parameters and conditions

| $R_{ONnom}$ | Resistor | $V_{OUT}$ | Min | Typ | Max | Unit | Notes |
|---|---|---|---|---|---|---|---|
| 34.3Ω | $R_{ON34PD}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/7$ | |
| | $R_{ON34PU}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/7$ | |
| 40.0Ω | $R_{ON40PD}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/6$ | |
| | $R_{ON40PU}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/6$ | |
| 48.0Ω | $R_{ON48PD}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/5$ | |
| | $R_{ON48PU}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/5$ | |
| 60.0Ω | $R_{ON60PD}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/4$ | |
| | $R_{ON60PU}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/4$ | |
| 80.0Ω | $R_{ON80PD}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/3$ | |
| | $R_{ON80PU}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/3$ | |
| 120.0Ω (optional) | $R_{ON120PD}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/2$ | |
| | $R_{ON120PU}$ | 0.5 × $V_{DDQ}$ | 0.85 | 1.00 | 1.15 | $R_{ZQ}/2$ | |
| Mismatch between pull-up and pull-down | $MM_{PUPD}$ | | –15.00 | | +15.00 | % | 5 |

Notes: 1. Applies across entire operating temperature range after calibration.
2. $R_{ZQ}$ = 240Ω.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3. The tolerance limits are specified after calibration, with fixed voltage and temperature. For behavior of the tolerance limits if temperature or voltage changes after calibration, see Output Driver Temperature and Voltage Sensitivity.
4. Pull-down and pull-up output driver impedances should be calibrated at 0.5 x $V_{DDQ}$.
5. Measurement definition for mismatch between pull-up and pull-down, $MM_{PUPD}$: Measure $R_{ONPU}$ and $R_{ONPD}$, both at 0.5 × $V_{DDQ}$:

$$MM_{PUPD} = \frac{R_{ONPU} - R_{ONPD}}{R_{ON,nom}} \times 100$$

For example, with $MM_{PUPD}$ (MAX) = 15% and $R_{ONPD}$ = 0.85, $RON_{PU}$ must be less than 1.0.

## Output Driver Temperature and Voltage Sensitivity

If temperature and/or voltage change after calibration, the tolerance limits widen.

**Table 88: Output Driver Sensitivity Definition**

| Resistor | $V_{OUT}$ | Min | Max | Unit |
|---|---|---|---|---|
| $R_{ONPD}$ | 0.5 × $V_{DDQ}$ | $85 - (dR_{ON}dT \cdot \lvert\Delta T\rvert) - (dR_{ON}dV \cdot \lvert\Delta V\rvert)$ | $115 + (dR_{ON}dT \cdot \lvert\Delta T\rvert) + (dR_{ON}dV \cdot \lvert\Delta V\rvert)$ | % |
| $R_{ONPU}$ | | | | |

Notes:
1. $\Delta T = T - T$ (at calibration). $\Delta V = V - V$ (at calibration).
2. $dR_{ON}dT$ and $dR_{ON}dV$ are not subject to production testing; they are verified by design and characterization.

**Table 89: Output Driver Temperature and Voltage Sensitivity**

| Symbol | Parameter | Min | Max | Unit |
|---|---|---|---|---|
| $R_{ONdT}$ | $R_{ON}$ temperature sensitivity | 0.00 | 0.75 | %/°C |
| $R_{ONdV}$ | $R_{ON}$ voltage sensitivity | 0.00 | 0.20 | %/mV |

## Output Impedance Characteristics Without ZQ Calibration

Output driver impedance is defined by design and characterization as the default setting.

**Table 90: Output Driver DC Electrical Characteristics Without ZQ Calibration**

| $RON_{nom}$ | Resistor | $V_{OUT}$ | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| 34.3Ω | $R_{ON34PD}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/7$ |
| | $R_{ON34PU}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/7$ |
| 40.0Ω | $R_{ON40PD}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/6$ |
| | $R_{ON40PU}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/6$ |
| 48.0Ω | $R_{ON48PD}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/5$ |
| | $R_{ON48PU}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/5$ |
| 60.0Ω | $R_{ON60PD}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/4$ |
| | $R_{ON60PU}$ | 0.5 × $V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/4$ |


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**Table 90: Output Driver DC Electrical Characteristics Without ZQ Calibration (Continued)**

| $RON_{nom}$ | Resistor | $V_{OUT}$ | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| 80.0Ω | $R_{ON80PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/3$ |
| | $R_{ON80PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/3$ |
| 120.0Ω (optional) | $R_{ON120PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/2$ |
| | $R_{ON120PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/2$ |

Notes: 1. Applies across entire operating temperature range without calibration.
2. $R_{ZQ} = 240\Omega$.

**Table 91: I-V Curves**

| | $R_{ON} = 240\Omega$ ($R_{ZQ}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pull-Down | | | | Pull-Up | | | |
| | Current (mA) / $R_{ON}$ (ohms) | | | | Current (mA) / $R_{ON}$ (ohms) | | | |
| | Default Value after ZQRESET | | With Calibration | | Default Value after ZQRESET | | With Calibration | |
| Voltage (V) | Min (mA) | Max (mA) | Min (mA) | Max (mA) | Min (mA) | Max (mA) | Min (mA) | Max (mA) |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.05 | 0.19 | 0.32 | 0.21 | 0.26 | –0.19 | –0.32 | –0.21 | –0.26 |
| 0.10 | 0.38 | 0.64 | 0.40 | 0.53 | –0.38 | –0.64 | –0.40 | –0.53 |
| 0.15 | 0.56 | 0.94 | 0.60 | 0.78 | –0.56 | –0.94 | –0.60 | –0.78 |
| 0.20 | 0.74 | 1.26 | 0.79 | 1.04 | –0.74 | –1.26 | –0.79 | –1.04 |
| 0.25 | 0.92 | 1.57 | 0.98 | 1.29 | –0.92 | –1.57 | –0.98 | –1.29 |
| 0.30 | 1.08 | 1.86 | 1.17 | 1.53 | –1.08 | –1.86 | –1.17 | –1.53 |
| 0.35 | 1.25 | 2.17 | 1.35 | 1.79 | –1.25 | –2.17 | –1.35 | –1.79 |
| 0.40 | 1.40 | 2.46 | 1.52 | 2.03 | –1.40 | –2.46 | –1.52 | –2.03 |
| 0.45 | 1.54 | 2.74 | 1.69 | 2.26 | –1.54 | –2.74 | –1.69 | –2.26 |
| 0.50 | 1.68 | 3.02 | 1.86 | 2.49 | –1.68 | –3.02 | –1.86 | –2.49 |
| 0.55 | 1.81 | 3.30 | 2.02 | 2.72 | –1.81 | –3.30 | –2.02 | –2.72 |
| 0.60 | 1.92 | 3.57 | 2.17 | 2.94 | –1.92 | –3.57 | –2.17 | –2.94 |
| 0.65 | 2.02 | 3.83 | 2.32 | 3.15 | –2.02 | –3.83 | –2.32 | –3.15 |
| 0.70 | 2.11 | 4.08 | 2.46 | 3.36 | –2.11 | –4.08 | –2.46 | –3.36 |
| 0.75 | 2.19 | 4.31 | 2.58 | 3.55 | –2.19 | –4.31 | –2.58 | –3.55 |
| 0.80 | 2.25 | 4.54 | 2.70 | 3.74 | –2.25 | –4.54 | –2.70 | –3.74 |
| 0.85 | 2.30 | 4.74 | 2.81 | 3.91 | –2.30 | –4.74 | –2.81 | –3.91 |
| 0.90 | 2.34 | 4.92 | 2.89 | 4.05 | –2.34 | –4.92 | –2.89 | –4.05 |
| 0.95 | 2.37 | 5.08 | 2.97 | 4.23 | –2.37 | –5.08 | –2.97 | –4.23 |
| 1.00 | 2.41 | 5.20 | 3.04 | 4.33 | –2.41 | –5.20 | –3.04 | –4.33 |
| 1.05 | 2.43 | 5.31 | 3.09 | 4.44 | –2.43 | –5.31 | –3.09 | –4.44 |
| 1.10 | 2.46 | 5.41 | 3.14 | 4.52 | –2.46 | –5.41 | –3.14 | –4.52 |
| 1.15 | 2.48 | 5.48 | 3.19 | 4.59 | –2.48 | –5.48 | –3.19 | –4.59 |


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**Table 91: I-V Curves (Continued)**

| | $R_{ON} = 240\Omega$ ($R_{ZQ}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pull-Down | | | | Pull-Up | | | |
| | Current (mA) / $R_{ON}$ (ohms) | | | | Current (mA) / $R_{ON}$ (ohms) | | | |
| | Default Value after ZQRESET | | With Calibration | | Default Value after ZQRESET | | With Calibration | |
| Voltage (V) | Min (mA) | Max (mA) | Min (mA) | Max (mA) | Min (mA) | Max (mA) | Min (mA) | Max (mA) |
| 1.20 | 2.50 | 5.55 | 3.23 | 4.65 | –2.50 | –5.55 | –3.23 | –4.65 |


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**Figure 86: Output Impedance = 240 Ohms, I-V Curves After ZQRESET**

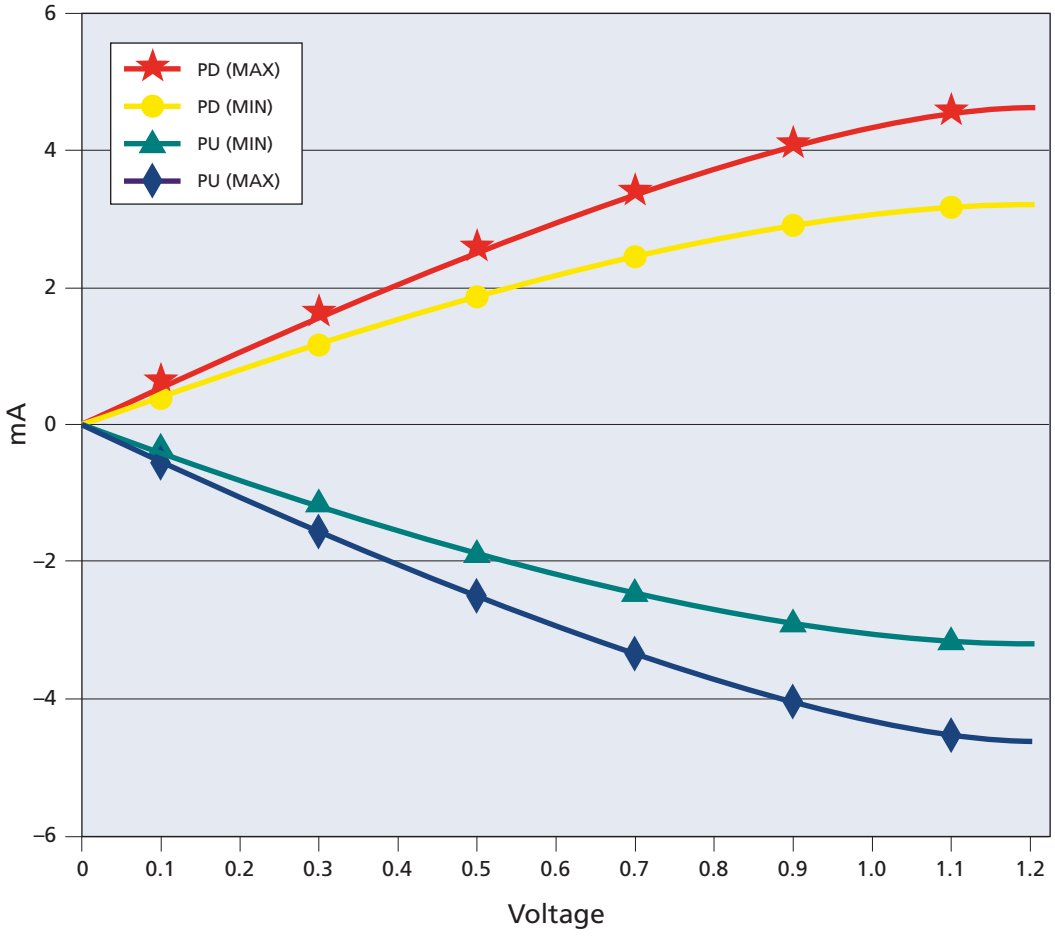



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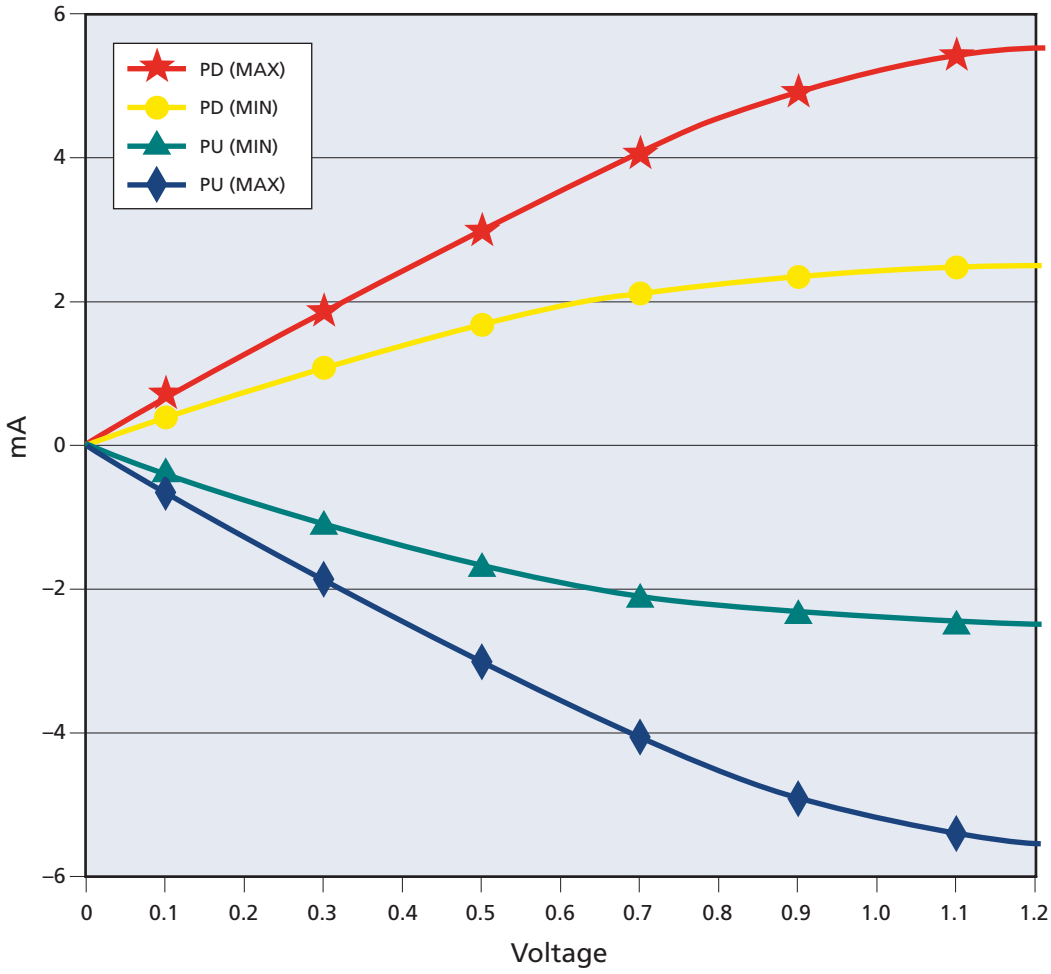
**Figure 87: Output Impedance = 240 Ohms, I-V Curves After Calibration**





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# Electrical Specifications – $I_{DD}$ Specifications and Conditions

The following definitions and conditions are used in the $I_{DD}$ measurement tables unless stated otherwise:

- LOW: $V_{IN} \leq V_{IL(DC)max}$
- HIGH: $V_{IN} \geq V_{IH(DC)min}$
- STABLE: Inputs are stable at a HIGH or LOW level
- SWITCHING: See the following three tables

### Table 92: Switching for CA Input Signals

Notes 1–3 apply to all parameters and conditions

| | CK_t Rising/ CK_c Falling | CK_t Falling/ CK_c Rising | CK_t Rising/ CK_c Falling | CK_t Falling/ CK_c Rising | CK_t Rising/ CK_c Falling | CK_t Falling/ CK_c Rising | CK_t Rising/ CK_c Falling | CK_t Falling/ CK_c Rising |
|---|---|---|---|---|---|---|---|---|
| **Cycle** | **N** | | **N + 1** | | **N + 2** | | **N + 3** | |
| CS_n | HIGH | | HIGH | | HIGH | | HIGH | |
| CA0 | H | L | L | L | L | H | H | H |
| CA1 | H | H | H | L | L | L | L | H |
| CA2 | H | L | L | L | L | H | H | H |
| CA3 | H | H | H | L | L | L | L | H |
| CA4 | H | L | L | L | L | H | H | H |
| CA5 | H | H | H | L | L | L | L | H |
| CA6 | H | L | L | L | L | H | H | H |
| CA7 | H | H | H | L | L | L | L | H |
| CA8 | H | L | L | L | L | H | H | H |
| CA9 | H | H | H | L | L | L | L | H |

Notes:
1. CS# must always be driven HIGH.
2. For each clock cycle, 50% of the CA bus is changing between HIGH and LOW.
3. The noted pattern (N, N + 1, N + 2, N + 3...) is used continuously during $I_{DD}$ measurement for $I_{DD}$ values that require switching on the CA bus.

### Table 93: Switching for $I_{DD4R}$

| Clock | CKE | CS_n | Clock Cycle Number | Command | CA[2:0] | CA[9:3] | All DQ |
|---|---|---|---|---|---|---|---|
| Rising | H | L | N | Read_Rising | HLH | LHLHLHL | L |
| Falling | H | L | N | Read_Falling | LLL | LLLLLLL | L |
| Rising | H | H | N +1 | NOP | LLL | LLLLLLL | H |
| Falling | H | H | N + 1 | NOP | HLH | HLHLLHL | L |
| Rising | H | L | N + 2 | Read_Rising | HLH | HLHLLHL | H |
| Falling | H | L | N + 2 | Read_Falling | LLL | HHHHHHH | H |
| Rising | H | H | N + 3 | NOP | LLL | HHHHHHH | H |


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**Table 93: Switching for $I_{DD4R}$ (Continued)**

| Clock | CKE | CS_n | Clock Cycle Number | Command | CA[2:0] | CA[9:3] | All DQ |
|---|---|---|---|---|---|---|---|
| Falling | H | H | N + 3 | NOP | HLH | LHLHLHL | L |

Notes:
1. Data strobe (DQS) is changing between HIGH and LOW with every clock cycle.
2. The noted pattern (N, N + 1...) is used continuously during $I_{DD}$ measurement for $I_{DD4R}$.

**Table 94: Switching for $I_{DD4W}$**

| Clock | CKE | CS_n | Clock Cycle Number | Command | CA[2:0] | CA[9:3] | All DQ |
|---|---|---|---|---|---|---|---|
| Rising | H | L | N | Write_Rising | HLL | LHLHLHL | L |
| Falling | H | L | N | Write_Falling | LLL | LLLLLLL | L |
| Rising | H | H | N +1 | NOP | LLL | LLLLLLL | H |
| Falling | H | H | N + 1 | NOP | HLH | HLHLLHL | L |
| Rising | H | L | N + 2 | Write_Rising | HLL | HLHLLHL | H |
| Falling | H | L | N + 2 | Write_Falling | LLL | HHHHHHH | H |
| Rising | H | H | N + 3 | NOP | LLL | HHHHHHH | H |
| Falling | H | H | N + 3 | NOP | HLH | LHLHLHL | L |

Notes:
1. Data strobe (DQS) is changing between HIGH and LOW with every clock cycle.
2. Data masking (DM) must always be driven LOW.
3. The noted pattern (N, N + 1...) is used continuously during $I_{DD}$ measurement for $I_{DD4W}$.

**Table 95: $I_{DD}$ Specification Parameters and Operating Conditions**

Notes 1–3 apply to all parameters and conditions

| Parameter/Condition | Symbol | Power Supply | Notes |
|---|---|---|---|
| **Operating one bank active-precharge current (SDRAM):** $^{t}CK = {}^{t}CKmin$; $^{t}RC = {}^{t}RCmin$; CKE is HIGH; CS_n is HIGH between valid commands; CA bus inputs are switching; Data bus inputs are stable | $I_{DD01}$ | $V_{DD1}$ | |
| | $I_{DD02}$ | $V_{DD2}$ | |
| | $I_{DD0in}$ | $V_{DDQ}$ | 4 |
| **Idle power-down standby current:** $^{t}CK = {}^{t}CKmin$; CKE is LOW; CS_n is HIGH; All banks are idle; CA bus inputs are switching; Data bus inputs are stable | $I_{DD2P1}$ | $V_{DD1}$ | |
| | $I_{DD2P2}$ | $V_{DD2}$ | |
| | $I_{DD2P,in}$ | $V_{DDQ}$ | 4 |
| **Idle power-down standby current with clock stop:** CK_t = LOW, CK_c = HIGH; CKE is LOW; CS_n is HIGH; All banks are idle; CA bus inputs are stable; Data bus inputs are stable | $I_{DD2PS1}$ | $V_{DD1}$ | |
| | $I_{DD2PS2}$ | $V_{DD2}$ | |
| | $I_{DD2PS,in}$ | $V_{DDQ}$ | 4 |
| **Idle non-power-down standby current:** $^{t}CK = {}^{t}CKmin$; CKE is HIGH; CS_n is HIGH; All banks are idle; CA bus inputs are switching; Data bus inputs are stable | $I_{DD2N1}$ | $V_{DD1}$ | |
| | $I_{DD2N2}$ | $V_{DD2}$ | |
| | $I_{DD2N,in}$ | $V_{DDQ}$ | 4 |
| **Idle non-power-down standby current with clock stopped:** CK_t = LOW; CK_c = HIGH; CKE is HIGH; CS_n is HIGH; All banks are idle; CA bus inputs are stable; Data bus inputs are stable | $I_{DD2NS1}$ | $V_{DD1}$ | |
| | $I_{DD2NS2}$ | $V_{DD2}$ | |
| | $I_{DD2NS,in}$ | $V_{DDQ}$ | 4 |


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**Table 95: $I_{DD}$ Specification Parameters and Operating Conditions (Continued)**

Notes 1–3 apply to all parameters and conditions

| Parameter/Condition | Symbol | Power Supply | Notes |
|---|---|---|---|
| **Active power-down standby current:** $^{t}$CK = $^{t}$CKmin; CKE is LOW; CS_n is HIGH; One bank is active; CA bus inputs are switching; Data bus inputs are stable | $I_{DD3P1}$ | $V_{DD1}$ | |
| | $I_{DD3P2}$ | $V_{DD2}$ | |
| | $I_{DD3P,in}$ | $V_{DDQ}$ | 4 |
| **Active power-down standby current with clock stop:** CK_t = LOW, CK_c = HIGH; CKE is LOW; CS_n is HIGH; One bank is active; CA bus inputs are stable; Data bus inputs are stable | $I_{DD3PS1}$ | $V_{DD1}$ | |
| | $I_{DD3PS2}$ | $V_{DD2}$ | |
| | $I_{DD3PS,in}$ | $V_{DDQ}$ | 4 |
| **Active non-power-down standby current:** $^{t}$CK = $^{t}$CKmin; CKE is HIGH; CS_n is HIGH; One bank is active; CA bus inputs are switching; Data bus inputs are stable | $I_{DD3N1}$ | $V_{DD1}$ | |
| | $I_{DD3N2}$ | $V_{DD2}$ | |
| | $I_{DD3N,in}$ | $V_{DDQ}$ | 4 |
| **Active non-power-down standby current with clock stopped:** CK_t = LOW, CK_c = HIGH CKE is HIGH; CS_n is HIGH; One bank is active; CA bus inputs are stable; Data bus inputs are stable | $I_{DD3NS1}$ | $V_{DD1}$ | |
| | $I_{DD3NS2}$ | $V_{DD2}$ | |
| | $I_{DD3NS,in}$ | $V_{DDQ}$ | 4 |
| **Operating burst READ current:** $^{t}$CK = $^{t}$CKmin; CS_n is HIGH between valid commands; One bank is active; BL = 4; RL = RL (MIN); CA bus inputs are switching; 50% data change each burst transfer | $I_{DD4R1}$ | $V_{DD1}$ | |
| | $I_{DD4R2}$ | $V_{DD2}$ | |
| **Operating burst WRITE current:** $^{t}$CK = $^{t}$CKmin; CS_n is HIGH between valid commands; One bank is active; BL = 4; WL = WLmin; CA bus inputs are switching; 50% data change each burst transfer | $I_{DD4W1}$ | $V_{DD1}$ | |
| | $I_{DD4W2}$ | $V_{DD2}$ | |
| | $I_{DD4W,in}$ | $V_{DDQ}$ | 4 |
| **All-bank REFRESH burst current:** $^{t}$CK = $^{t}$CKmin; CKE is HIGH between valid commands; $^{t}$RC = $^{t}$RFCabmin; Burst refresh; CA bus inputs are switching; Data bus inputs are stable | $I_{DD51}$ | $V_{DD1}$ | |
| | $I_{DD52}$ | $V_{DD2}$ | |
| | $I_{DD5IN}$ | $V_{DDQ}$ | 4 |
| **All-bank REFRESH average current:** $^{t}$CK = $^{t}$CKmin; CKE is HIGH between valid commands; $^{t}$RC = $^{t}$REFI; CA bus inputs are switching; Data bus inputs are stable | $I_{DD5AB1}$ | $V_{DD1}$ | |
| | $I_{DD5AB2}$ | $V_{DD2}$ | |
| | $I_{DD5AB,in}$ | $V_{DDQ}$ | 4 |
| **Per-bank REFRESH average current:** $^{t}$CK = $^{t}$CKmin; CKE is HIGH between valid commands; $^{t}$RC = $^{t}$REFI/8; CA bus inputs are switching; Data bus inputs are stable | $I_{DD5PB1}$ | $V_{DD1}$ | 5 |
| | $I_{DD5PB2}$ | $V_{DD2}$ | 5 |
| | $I_{DD5PB,in}$ | $V_{DDQ}$ | 4, 5 |
| **Self refresh current (–30˚C to +85˚C):** CK_t = LOW, CK_c = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable; Maximum 1x self refresh rate | $I_{DD61}$ | $V_{DD1}$ | 6 |
| | $I_{DD62}$ | $V_{DD2}$ | 6 |
| | $I_{DD6IN}$ | $V_{DDQ}$ | 4, 6 |
| **Self refresh current (+85˚C to +105˚C):** CK_t = LOW, CK_c = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable | $I_{DD6ET1}$ | $V_{DD1}$ | 6, 7 |
| | $I_{DD6ET2}$ | $V_{DD2}$ | 6, 7 |
| | $I_{DD6ET,in}$ | $V_{DDQ}$ | 4, 6, 7 |
| **Deep power-down current:** CK_t = LOW, CK_c = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable | $I_{DD81}$ | $V_{DD1}$ | 7 |
| | $I_{DD82}$ | $V_{DD2}$ | 7 |
| | $I_{DD8IN}$ | $V_{DDQ}$ | 4, 7 |

Notes:
1. $I_{DD}$ values are the maximum of the distribution of the arithmetic mean.
2. $I_{DD}$ current specifications are tested after the device is properly initialized.


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3. The 1x self refresh rate is the rate at which the device is refreshed internally during self refresh before going into the extended temperature range.
4. Measured currents are the sum of $V_{DDQ}$ and $V_{DD2}$.
5. Per-bank REFRESH is only applicable for LPDDR2-S4 device densities 1Gb or higher.
6. This is the general definition that applies to full-array self refresh. Refer to "IDD6 Full and Partial Array Self-Refresh Current" for details of Partial Array Self Refresh IDD6 specification.
7. $I_{DD6ET}$ and $I_{DD8}$ are typical values, sampled only and not tested.

# Clock Specification

The specified clock jitter is a random jitter with Gaussian distribution. Input clocks violating minimum or maximum values may result in device malfunction.

**Table 96: Definitions and Calculations**

| Symbol | Description | Calculation | Notes |
|---|---|---|---|
| $^{t}$CK(avg) and *n*CK | The average clock period across any consecutive 200-cycle window. Each clock period is calculated from rising clock edge to rising clock edge.<br><br>Unit $^{t}$CK(avg) represents the actual clock average $^{t}$CK(avg)of the input clock under operation. Unit *n*CK represents one clock cycle of the input clock, counting from actual clock edge to actual clock edge.<br><br>$^{t}$CK(avg)can change no more than ±1% within a 100-clock-cycle window, provided that all jitter and timing specifications are met. | $^{t}CK(avg) = \left(\sum_{j=1}^{N} {}^{t}CK_{j}\right)/N$<br>Where N = 200 | |
| $^{t}$CK(abs) | The absolute clock period, as measured from one rising clock edge to the next consecutive rising clock edge. | | 1 |
| $^{t}$CH(avg) | The average HIGH pulse width, as calculated across any 200 consecutive HIGH pulses. | $^{t}CH(avg) = \left(\sum_{j=1}^{N} {}^{t}CH_{j}\right)/(N \times {}^{t}CK(avg))$<br>Where N = 200 | |
| $^{t}$CL(avg) | The average LOW pulse width, as calculated across any 200 consecutive LOW pulses. | $^{t}CL(avg) = \left(\sum_{j=1}^{N} {}^{t}CL_{j}\right)/(N \times {}^{t}CK(avg))$<br>Where N = 200 | |
| $^{t}$JIT(per) | The single-period jitter defined as the largest deviation of any signal $^{t}$CK from $^{t}$CK(avg). | $^{t}JIT(per) = \text{min/max of } \left({}^{t}CK_{i} - {}^{t}CK(avg)\right)$<br>Where i = 1 to 200 | 1 |
| $^{t}$JIT(per),act | The actual clock jitter for a given system. | | |
| $^{t}$JIT(per), allowed | The specified clock period jitter allowance. | | |
| $^{t}$JIT(cc) | The absolute difference in clock periods between two consecutive clock cycles. $^{t}$JIT(cc) defines the cycle-to-cycle jitter. | $^{t}JIT(cc) = \text{max of } \left({}^{t}CK_{i+1} - {}^{t}CK_{i}\right)$ | 1 |



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**Table 96: Definitions and Calculations (Continued)**

| Symbol | Description | Calculation | Notes |
|---|---|---|---|
| $^{t}$ERR(nper) | The cumulative error across *n* multiple consecutive cycles from $^{t}$CK(avg). | $^{t}ERR(nper) = \left(\sum_{j=i}^{i+n-1} {}^{t}CK_j\right) - (n \times {}^{t}CK(avg))$ | 1 |
| $^{t}$ERR(nper),act | The actual cumulative error over *n* cycles for a given system. | | |
| $^{t}$ERR(nper), allowed | The specified cumulative error allowance over *n* cycles. | | |
| $^{t}$ERR(nper),min | The minimum $^{t}$ERR(nper). | $^{t}ERR(nper),min = (1 + 0.68LN(n)) \times {}^{t}JIT(per),min$ | 2 |
| $^{t}$ERR(nper),max | The maximum $^{t}$ERR(nper). | $^{t}ERR(nper),max = (1 + 0.68LN(n)) \times {}^{t}JIT(per),max$ | 2 |
| $^{t}$JIT(duty) | Defined with absolute and average specifications for $^{t}$CH and $^{t}$CL, respectively. | $^{t}JIT(duty),min = MIN(({}^{t}CH(abs),min - {}^{t}CH(avg),min), ({}^{t}CL(abs),min - {}^{t}CL(avg),min)) \times {}^{t}CK(avg)$<br><br>$^{t}JIT(duty),max = MAX(({}^{t}CH(abs),max - {}^{t}CH(avg),max), ({}^{t}CL(abs),max - {}^{t}CL(avg),max)) \times {}^{t}CK(avg)$ | |

Notes: 1. Not subject to production testing.
2. Using these equations, $^{t}$ERR(nper) tables can be generated for each $^{t}$JIT(per),act value.

## $^{t}$CK(abs), $^{t}$CH(abs), and $^{t}$CL(abs)

These parameters are specified with their average values; however, the relationship between the average timing and the absolute instantaneous timing (defined in the following table) is applicable at all times.

**Table 97: $^{t}$CK(abs), $^{t}$CH(abs), and $^{t}$CL(abs) Definitions**

| Parameter | Symbol | Minimum | Unit |
|---|---|---|---|
| Absolute clock period | $^{t}$CK(abs) | $^{t}CK(avg),min + {}^{t}JIT(per),min$ | ps[1] |
| Absolute clock HIGH pulse width | $^{t}$CH(abs) | $^{t}CH(avg),min + {}^{t}JIT(duty),min^2/{}^{t}CK(avg)min$ | $^{t}$CK(avg) |
| Absolute clock LOW pulse width | $^{t}$CL(abs) | $^{t}CL(avg),min + {}^{t}JIT(duty),min^2/{}^{t}CK(avg)min$ | $^{t}$CK(avg) |

Notes: 1. $^{t}$CK(avg),min is expressed in ps for this table.
2. $^{t}$JIT(duty),min is a negative value.

# Clock Period Jitter

The LPDDR2 device can tolerate some clock period jitter without core timing parameter derating. This section describes device timing requirements with clock period jitter ($^{t}$JIT(per)) in excess of the values found in the AC Timing section. Calculating cycle time derating and clock cycle derating are also described.


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## Clock Period Jitter Effects on Core Timing Parameters

Core timing parameters ($^{t}$RCD, $^{t}$RP, $^{t}$RTP, $^{t}$WR, $^{t}$WRA, $^{t}$WTR, $^{t}$RC, $^{t}$RAS, $^{t}$RRD, $^{t}$FAW) extend across multiple clock cycles. Clock period jitter impacts these parameters when measured in numbers of clock cycles. Within the specification limits, the device is characterized and verified to support $^{t}n$PARAM = RU[$^{t}$PARAM/$^{t}$CK(avg)]. During device operation where clock jitter is outside specification limits, the number of clocks or $^{t}$CK(avg), may need to be increased based on the values for each core timing parameter.

## Cycle Time Derating for Core Timing Parameters

For a given number of clocks ($^{t}n$PARAM), when $^{t}$CK(avg) and $^{t}$ERR($^{t}n$PARAM),act exceed $^{t}$ERR($^{t}n$PARAM),allowed, cycle time derating may be required for core timing parameters.

$$\text{CycleTimeDerating} = \max\left\{\left(\frac{^{t}\text{PARAM} + ^{t}\text{ERR}(^{t}\text{nPARAM}),\text{act} - ^{t}\text{ERR}(^{t}\text{nPARAM}),\text{allowed}}{^{t}\text{nPARAM}} - ^{t}\text{CK(avg)}\right), 0\right\}$$

Cycle time derating analysis should be conducted for each core timing parameter. The amount of cycle time derating required is the maximum of the cycle time deratings determined for each individual core timing parameter.

## Clock Cycle Derating for Core Timing Parameters

For each core timing parameter and a given number of clocks ($^{t}n$PARAM), clock cycle derating should be specified with $^{t}$JIT(per).

For a given number of clocks ($^{t}n$PARAM), when $^{t}$CK(avg) plus ($^{t}$ERR($^{t}n$PARAM),act) exceed the supported cumulative $^{t}$ERR($^{t}n$PARAM),allowed, derating is required. If the equation below results in a positive value for a core timing parameter ($^{t}$CORE), the required clock cycle derating will be that positive value (in clocks).

$$\text{ClockCycleDerating} = \text{RU}\left\{\frac{^{t}\text{PARAM} + ^{t}\text{ERR}(^{t}\text{nPARAM}),\text{act} - ^{t}\text{ERR}(^{t}\text{nPARAM}),\text{allowed}}{^{t}\text{CK(avg)}}\right\} - ^{t}\text{nPARAM}$$

Cycle-time derating analysis should be conducted for each core timing parameter.

## Clock Jitter Effects on Command/Address Timing Parameters

Command/address timing parameters ($^{t}$IS, $^{t}$IH, $^{t}$ISCKE, $^{t}$IHCKE, $^{t}$ISb, $^{t}$IHb, $^{t}$ISCKEb, $^{t}$IHCKEb) are measured from a command/address signal (CKE, CS_n, or CA[9:0]) transition edge to its respective clock signal (CK_t/CK_c) crossing. The specification values are not affected by the $^{t}$JIT(per) applied, because the setup and hold times are relative to the clock signal crossing that latches the command/address. Regardless of clock jitter values, these values must be met.

## Clock Jitter Effects on READ Timing Parameters

**$^{t}$RPRE**

When the device is operated with input clock jitter, $^{t}$RPRE must be derated by the $^{t}$JIT(per),act,max of the input clock that exceeds $^{t}$JIT(per),allowed,max. Output deratings are relative to the input clock:


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$$^{t}RPRE(min,derated) = 0.9 - \left(\frac{^{t}JIT(per),act,max - ^{t}JIT(per),allowed,max}{^{t}CK(avg)}\right)$$

For example, if the measured jitter into a LPDDR2-800 device has $^{t}$CK(avg) = 2500ps, $^{t}$JIT(per),act,min = –172ps, and $^{t}$JIT(per),act,max = +193ps, then $^{t}$RPRE,min,derated = 0.9 - ($^{t}$JIT(per),act,max - $^{t}$JIT(per),allowed,max)/$^{t}$CK(avg) = 0.9 - (193 - 100)/2500 = 0.8628 $^{t}$CK(avg).

**$^{t}$LZ(DQ), $^{t}$HZ(DQ), $^{t}$DQSCK, $^{t}$LZ(DQS), $^{t}$HZ(DQS)**

These parameters are measured from a specific clock edge to a data signal transition (DM*n* or DQ*m*, where: *n* = 0, 1, 2, or 3; and *m* = DQ[31:0]), and specified timings must be met with respect to that clock edge. Therefore, they are not affected by $^{t}$JIT(per).

**$^{t}$QSH, $^{t}$QSL**

These parameters are affected by duty cycle jitter, represented by $^{t}$CH(abs)min and $^{t}$CL(abs)min. These parameters determine the absolute data valid window at the device pin. The absolute minimum data valid window at the device pin = min [($^{t}$QSH(abs)min × $^{t}$CK(avg)min - $^{t}$DQSQmax - $^{t}$QHSmax), ($^{t}$QSL(abs)min × $^{t}$CK(avg)min - $^{t}$DQSQmax - $^{t}$QHSmax)]. This minimum data valid window must be met at the target frequency regardless of clock jitter.

**$^{t}$RPST**

$^{t}$RPST is affected by duty cycle jitter, represented by $^{t}$CL(abs). Therefore, $^{t}$RPST(abs)min can be specified by $^{t}$CL(abs)min. $^{t}$RPST(abs)min = $^{t}$CL(abs)min - 0.05 = $^{t}$QSL(abs)min.

## Clock Jitter Effects on WRITE Timing Parameters

**$^{t}$DS, $^{t}$DH**

These parameters are measured from a data signal (DM*n* *or* DQ*m*, where *n* = 0, 1, 2, 3; and *m* = DQ[31:0]) transition edge to its respective data strobe signal (DQS*n*_t, DQS*n*_c: *n* = 0,1,2,3) crossing. The specification values are not affected by the amount of $^{t}$JIT(per) applied, because the setup and hold times are relative to the clock signal crossing that latches the command/address. Regardless of clock jitter values, these values must be met.

**$^{t}$DSS, $^{t}$DSH**

These parameters are measured from a data strobe signal crossing (DQS*x*_t, DQS*x*_c) to its clock signal crossing (CK_t/CK_c). The specification values are not affected by the amount of $^{t}$JIT(per)) applied, because the setup and hold times are relative to the clock signal crossing that latches the command/address. Regardless of clock jitter values, these values must be met.

**$^{t}$DQSS**

$^{t}$DQSS is measured from the clock signal crossing (CK_t/CK_c) to the first latching data strobe signal crossing (DQS*x*_t, DQS*x*_c). When the device is operated with input clock jitter, this parameter must be derated by the actual $^{t}$JIT(per),act of the input clock in excess of $^{t}$JIT(per),allowed.

$$^{t}DQSS(min,derated) = 0.75 - \left(\frac{^{t}JIT(per),act,min - ^{t}JIT(per),allowed,min}{^{t}CK(avg)}\right)$$


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$$^{t}DQSS(max,derated) = 1.25 - \left(\frac{^{t}JIT(per),act,max - ^{t}JIT(per),allowed,max}{^{t}CK(avg)}\right)$$

For example, if the measured jitter into an LPDDR2-800 device has $^{t}$CK(avg) = 2500ps, $^{t}$JIT(per),act,min = -172ps, and $^{t}$JIT(per),act,max = +193ps, then:

$^{t}$DQSS,(min,derated) = 0.75 - ($^{t}$JIT(per),act,min - $^{t}$JIT(per),allowed,min)/$^{t}$CK(avg) = 0.75 - (-172 + 100)/2500 = 0.7788 $^{t}$CK(avg), *and*

$^{t}$DQSS,(max,derated) = 1.25 - ($^{t}$JIT(per),act,max - $^{t}$JIT(per),allowed,max)/$^{t}$CK(avg) = 1.25 - (193 - 100)/2500 = 1.2128 $^{t}$CK(avg).

# Refresh Requirements Parameters

### Table 98: Refresh Requirement Parameters (Per Density)

| Parameter | | Symbol | 64Mb | 128Mb | 256Mb | 512Mb | 1Gb | 2Gb | 4Gb | 8Gb | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of banks | | | 4 | 4 | 4 | 4 | 8 | 8 | 8 | 8 | |
| Refresh window: $T_{CASE} \leq 85^{\circ}$ | | $^{t}$REFW | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | ms |
| Refresh window: $85^{\circ}C < T_{CASE} \leq 105^{\circ}C$ | | $^{t}$REFW | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | ms |
| Required number of REFRESH commands (MIN) | | R | 2048 | 2048 | 4096 | 4096 | 4096 | 8192 | 8192 | 8192 | |
| Average time between REFRESH commands (for reference only) $T_{CASE} \leq 85^{\circ}C$ | REFab | $^{t}$REFI | 15.6 | 15.6 | 7.8 | 7.8 | 7.8 | 3.9 | 3.9 | 3.9 | µs |
| | REFpb | $^{t}$REFIpb | (REFpb not supported below 1Gb) | | | | 0.975 | 0.4875 | 0.4875 | 0.4875 | µs |
| Refresh cycle time | | $^{t}$RFCab | 90 | 90 | 90 | 90 | 130 | 130 | 130 | 210 | ns |
| Per-bank REFRESH cycle time | | $^{t}$RFCpb | na | | | | 60 | 60 | 60 | 90 | ns |
| Burst REFRESH window = 4 × 8 × $^{t}$RFCab | | $^{t}$REFBW | 2.88 | 2.88 | 2.88 | 2.88 | 4.16 | 4.16 | 4.16 | 6.72 | µs |

# AC Timing

### Table 99: AC Timing

Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the $^{t}$CK minimum conditions (in multiples of $^{t}$CK) as well as the timing specifications when values for both are indicated.

| Parameter | Symbol | Min/ Max | $^{t}$CK Min | Data Rate | | | | | | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1066 | 933 | 800 | 667 | 533 | 400 | 333 | | |
| Maximum frequency | | – | – | 533 | 466 | 400 | 333 | 266 | 200 | 166 | MHz | |
| **Clock Timing** | | | | | | | | | | | | |
| Average clock period | $^{t}$CK(avg) | MIN | – | 1.875 | 2.15 | 2.5 | 3 | 3.75 | 5 | 6 | ns | |
| | | MAX | – | 100 | 100 | 100 | 100 | 100 | 100 | 100 | | |
| Average HIGH pulse width | $^{t}$CH(avg) | MIN | – | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | $^{t}$CK (avg) | |
| | | MAX | – | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | | |


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**Table 99: AC Timing (Continued)**

Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the $^{t}$CK minimum conditions (in multiples of $^{t}$CK) as well as the timing specifications when values for both are indicated.

| Parameter | Symbol | Min/ Max | $^{t}$CK Min | Data Rate | | | | | | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1066 | 933 | 800 | 667 | 533 | 400 | 333 | | |
| Average LOW pulse width | $^{t}$CL(avg) | MIN | – | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | $^{t}$CK (avg) | |
| | | MAX | – | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | | |
| Absolute clock period | $^{t}$CK(abs) | MIN | – | $^{t}$CK(avg)min ± $^{t}$JIT(per)min | | | | | | | ps | |
| Absolute clock HIGH pulse width (with allowed jitter) | $^{t}$CH(abs), allowed | MIN | – | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | $^{t}$CK (avg) | |
| | | MAX | – | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | | |
| Absolute clock LOW pulse width (with allowed jitter) | $^{t}$CL(abs), allowed | MIN | – | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | $^{t}$CK (avg) | |
| | | MAX | – | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | | |
| Clock period jitter (with supported jitter) | $^{t}$JIT(per), allowed | MIN | – | -90 | -95 | -100 | -110 | -120 | -140 | -150 | ps | |
| | | MAX | – | 90 | 95 | 100 | 110 | 120 | 140 | 150 | | |
| Maximum clock jitter between two consectuive clock cycles (with allowed jitter) | $^{t}$JIT(cc), allowed | MAX | – | 180 | 190 | 200 | 220 | 240 | 280 | 300 | ps | |
| Duty cycle jitter (with allowed jitter) | $^{t}$JIT(duty), allowed | MIN | – | MIN (($^{t}$CH(abs),min - $^{t}$CH(avg),min), ($^{t}$CL(abs),min - $^{t}$CL(avg),min)) × $^{t}$CK(avg) | | | | | | | ps | |
| | | MAX | – | MAX (($^{t}$CH(abs),max - $^{t}$CH(avg),max), ($^{t}$CL(abs),max - $^{t}$CL(avg),max)) × $^{t}$CK(avg) | | | | | | | | |
| Cumulative errors across 2 cycles | $^{t}$ERR(2per), allowed | MIN | – | -132 | -140 | -147 | -162 | -177 | -206 | -221 | ps | |
| | | MAX | – | 132 | 140 | 147 | 162 | 177 | 206 | 221 | | |
| Cumulative errors across 3 cycles | $^{t}$ERR(3per), allowed | MIN | – | -157 | -166 | -175 | -192 | -210 | -245 | -262 | ps | |
| | | MAX | – | 157 | 166 | 175 | 192 | 210 | 245 | 262 | | |
| Cumulative errors across 4 cycles | $^{t}$ERR(4per), allowed | MIN | – | -175 | -185 | -194 | -214 | -233 | -272 | -291 | ps | |
| | | MAX | – | 175 | 185 | 194 | 214 | 233 | 272 | 291 | | |
| Cumulative errors across 5 cycles | $^{t}$ERR(5per), allowed | MIN | – | -188 | -199 | -209 | -230 | -251 | -293 | -314 | ps | |
| | | MAX | – | 188 | 199 | 209 | 230 | 251 | 293 | 314 | | |
| Cumulative errors across 6 cycles | $^{t}$ERR(6per), allowed | MIN | – | -200 | -211 | -222 | -244 | -266 | -311 | -333 | ps | |
| | | MAX | – | 200 | 211 | 222 | 244 | 266 | 311 | 333 | | |
| Cumulative errors across 7 cycles | $^{t}$ERR(7per), allowed | MIN | – | -209 | -221 | -232 | -256 | -279 | -325 | -348 | ps | |
| | | MAX | – | 209 | 221 | 232 | 256 | 279 | 325 | 348 | | |
| Cumulative errors across 8 cycles | $^{t}$ERR(8per), allowed | MIN | – | -217 | -229 | -241 | -266 | -290 | -338 | -362 | ps | |
| | | MAX | – | 217 | 229 | 241 | 266 | 290 | 338 | 362 | | |
| Cumulative errors across 9 cycles | $^{t}$ERR(9per), allowed | MIN | – | -224 | -237 | -249 | -274 | -299 | -349 | -374 | ps | |
| | | MAX | – | 224 | 237 | 249 | 274 | 299 | 349 | 374 | | |
| Cumulative errors across 10 cycles | $^{t}$ERR(10per), allowed | MIN | – | -231 | -244 | -257 | -282 | -308 | -359 | -385 | ps | |
| | | MAX | – | 231 | 244 | 257 | 282 | 308 | 359 | 385 | | |
| Cumulative errors across 11 cycles | $^{t}$ERR(11per), allowed | MIN | – | -237 | -250 | -263 | -289 | -316 | -368 | -395 | ps | |
| | | MAX | – | 237 | 250 | 263 | 289 | 316 | 368 | 395 | | |



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**Table 99: AC Timing (Continued)**

Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the $^{t}$CK minimum conditions (in multiples of $^{t}$CK) as well as the timing specifications when values for both are indicated.

| Parameter | Symbol | Min/ Max | $^{t}$CK Min | Data Rate | | | | | | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1066 | 933 | 800 | 667 | 533 | 400 | 333 | | |
| Cumulative errors across 12 cycles | $^{t}$ERR(12per), allowed | MIN | – | -242 | -256 | -269 | -296 | -323 | -377 | -403 | ps | |
| | | MAX | – | 242 | 256 | 269 | 296 | 323 | 377 | 403 | | |
| Cumulative errors across *n* = 13, 14, 15…, 49, 50 cycles | $^{t}$ERR(nper), allowed | MIN | $^{t}$ERR(nper),allowed,min = (1 + 0.68ln(n)) × $^{t}$JIT(per),allowed,min | | | | | | | | ps | |
| | | MAX | $^{t}$ERR(nper), allowed,max = (1 + 0.68ln(n)) × $^{t}$JIT(per),allowed,max | | | | | | | | | |
| **ZQ Calibration Parameters** | | | | | | | | | | | | |
| Initialization calibration time | $^{t}$ZQINIT | MIN | – | 1 | 1 | 1 | 1 | 1 | 1 | 1 | µs | |
| Long calibration time | $^{t}$ZQCL | MIN | 6 | 360 | 360 | 360 | 360 | 360 | 360 | 360 | ns | |
| Short calibration time | $^{t}$ZQCS | MIN | 6 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | ns | |
| Calibration RESET time | $^{t}$ZQRESET | MIN | 3 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | ns | |
| **READ Parameters**[3] | | | | | | | | | | | | |
| DQS output access time from CK_t/CK_c | $^{t}$DQSCK | MIN | – | 2500 | 2500 | 2500 | 2500 | 2500 | 2500 | 2500 | ps | |
| | | MAX | – | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | | |
| DQSCK delta short | $^{t}$DQSCKDS | MAX | – | 330 | 380 | 450 | 540 | 670 | 900 | 1080 | ps | 4 |
| DQSCK delta medium | $^{t}$DQSCKDM | MAX | – | 680 | 780 | 900 | 1050 | 1350 | 1800 | 1900 | ps | 5 |
| DQSCK delta long | $^{t}$DQSCKDL | MAX | – | 920 | 1050 | 1200 | 1400 | 1800 | 2400 | – | ps | 6 |
| DQS-DQ skew | $^{t}$DQSQ | MAX | – | 200 | 220 | 240 | 280 | 340 | 400 | 500 | ps | |
| Data-hold skew factor | $^{t}$QHS | MAX | – | 230 | 260 | 280 | 340 | 400 | 480 | 600 | ps | |
| DQS output HIGH pulse width | $^{t}$QSH | MIN | – | $^{t}$CH(abs) - 0.05 | | | | | | | $^{t}$CK (avg) | |
| DQS output LOW pulse width | $^{t}$QSL | MIN | – | $^{t}$CL(abs) - 0.05 | | | | | | | $^{t}$CK (avg) | |
| Data half period | $^{t}$QHP | MIN | – | MIN ($^{t}$QSH, $^{t}$QSL) | | | | | | | $^{t}$CK (avg) | |
| DQ/DQS output hold time from DQS | $^{t}$QH | MIN | – | $^{t}$QHP - $^{t}$QHS | | | | | | | ps | |
| READ preamble | $^{t}$RPRE | MIN | – | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | $^{t}$CK (avg) | 7 |
| READ postamble | $^{t}$RPST | MIN | – | $^{t}$CL(abs) - 0.05 | | | | | | | $^{t}$CK (avg) | 8 |
| DQS Low-Z from clock | $^{t}$LZ(DQS) | MIN | – | $^{t}$DQSCK (MIN) - 300 | | | | | | | ps | |
| DQ Low-Z from clock | $^{t}$LZ(DQ) | MIN | – | $^{t}$DQSCK(MIN) - (1.4 × $^{t}$QHS(MAX)) | | | | | | | ps | |
| DQS High-Z from clock | $^{t}$HZ(DQS) | MAX | – | $^{t}$DQSCK (MAX) - 100 | | | | | | | ps | |
| DQ High-Z from clock | $^{t}$HZ(DQ) | MAX | – | $^{t}$DQSCK(MAX) + (1.4 × $^{t}$DQSQ(MAX)) | | | | | | | ps | |
| **WRITE Parameters**[3] | | | | | | | | | | | | |



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**Table 99: AC Timing (Continued)**

Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the $^{t}$CK minimum conditions (in multiples of $^{t}$CK) as well as the timing specifications when values for both are indicated.

| Parameter | Symbol | Min/ Max | $^{t}$CK Min | Data Rate | | | | | | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1066 | 933 | 800 | 667 | 533 | 400 | 333 | | |
| DQ and DM input hold time ($V_{REF}$ based) | $^{t}$DH | MIN | – | 210 | 235 | 270 | 350 | 430 | 480 | 600 | ps | |
| DQ and DM input setup time ($V_{REF}$ based) | $^{t}$DS | MIN | – | 210 | 235 | 270 | 350 | 430 | 480 | 600 | ps | |
| DQ and DM input pulse width | $^{t}$DIPW | MIN | – | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | $^{t}$CK (avg) | |
| Write command to first DQS latching transition | $^{t}$DQSS | MIN | – | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | $^{t}$CK (avg) | |
| | | MAX | – | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | $^{t}$CK (avg) | |
| DQS input high-level width | $^{t}$DQSH | MIN | – | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | $^{t}$CK (avg) | |
| DQS input low-level width | $^{t}$DQSL | MIN | – | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | $^{t}$CK (avg) | |
| DQS falling edge to CK setup time | $^{t}$DSS | MIN | – | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | $^{t}$CK (avg) | |
| DQS falling edge hold time from CK | $^{t}$DSH | MIN | – | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | $^{t}$CK (avg) | |
| Write postamble | $^{t}$WPST | MIN | – | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | $^{t}$CK (avg) | |
| Write preamble | $^{t}$WPRE | MIN | – | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | $^{t}$CK (avg) | |
| **CKE Input Parameters** | | | | | | | | | | | | |
| CKE minimum pulse width (HIGH and LOW pulse width) | $^{t}$CKE | MIN | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | $^{t}$CK (avg) | |
| CKE input setup time | $^{t}$ISCKE | MIN | – | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | $^{t}$CK (avg) | 9 |
| CKE input hold time | $^{t}$IHCKE | MIN | – | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | $^{t}$CK (avg) | 10 |
| **Command Address Input Parameters**[3] | | | | | | | | | | | | |
| Address and control input setup time ( Vref based ) | $^{t}$IS | MIN | – | 220 | 250 | 290 | 370 | 460 | 600 | 740 | ps | 11 |
| Address and control input hold time ( Vref based ) | $^{t}$IH | MIN | – | 220 | 250 | 290 | 370 | 460 | 600 | 740 | ps | 11 |
| Address and control input pulse width | $^{t}$IPW | MIN | – | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | $^{t}$CK (avg) | |
| **Boot Parameters (10 MHz–55 MHz)**[12, 13, 14] | | | | | | | | | | | | |
| Clock cycle time | $^{t}$CKb | MAX | – | 100 | 100 | 100 | 100 | 100 | 100 | 100 | ns | |
| | | MIN | – | 18 | 18 | 18 | 18 | 18 | 18 | 18 | | |



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**Table 99: AC Timing (Continued)**

Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the tCK minimum conditions (in multiples of tCK) as well as the timing specifications when values for both are indicated.

| Parameter | Symbol | Min/ Max | tCK Min | Data Rate | | | | | | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1066 | 933 | 800 | 667 | 533 | 400 | 333 | | |
| CKE input setup time | tISCKEb | MIN | – | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | ns | |
| CKE input hold time | tIHCKEb | MIN | – | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | ns | |
| Address and control input setup time | tISb | MIN | – | 1150 | 1150 | 1150 | 1150 | 1150 | 1150 | 1150 | ps | |
| Address and control input hold time | tIHb | MIN | – | 1150 | 1150 | 1150 | 1150 | 1150 | 1150 | 1150 | ps | |
| DQS output data access time from CK_t/CK_c | tDQSCKb | MIN | – | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | ns | |
| | | MAX | – | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | | |
| Data strobe edge to output data edge tDQSQb - 1.2 | tDQSQb | MAX | – | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | ns | |
| Data hold skew factor | tQHSb | MAX | – | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | ns | |
| **Mode Register Parameters** | | | | | | | | | | | | |
| MODE REGISTER WRITE command period | tMRW | MIN | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | tCK (avg) | |
| MODE REGISTER READ command period | tMRR | MIN | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | tCK (avg) | |
| **Core Parameters**[15] | | | | | | | | | | | | |
| READ latency | RL | MIN | 3 | 8 | 7 | 6 | 5 | 4 | 3 | 3 | tCK (avg) | |
| WRITE latency | WL | MIN | 1 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | tCK (avg) | |
| ACTIVATE-to-ACTIVATE command period | tRC | MIN | – | tRAS + tRPab (with all-bank precharge), tRAS + tRPpb (with per-bank precharge) | | | | | | | ns | 17 |
| CKE minimum pulse width during SELF REFRESH (low pulse width during SELF REFRESH) | tCKESR | MIN | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | ns | |
| SELF REFRESH exit to next valid command delay | tXSR | MIN | 2 | tRFCab + 10 | | | | | | | ns | |
| Exit power-down to next valid command delay | tXP | MIN | 2 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | ns | |
| CAS-to-CAS delay | tCCD | MIN | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | tCK (avg) | |
| Internal READ to PRECHARGE command delay | tRTP | MIN | 2 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | ns | |
| RAS-to-CAS delay | tRCD | MIN | 3 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | ns | |
| Row precharge time (single bank) | tRPpb | MIN | 3 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | ns | |
| Row precharge time (all banks) | tRPab 4-bank | MIN | 3 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | ns | |


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**Table 99: AC Timing (Continued)**

Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the tCK minimum conditions (in multiples of tCK) as well as the timing specifications when values for both are indicated.

| Parameter | Symbol | Min/ Max | tCK Min | Data Rate | | | | | | | Unit | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1066 | 933 | 800 | 667 | 533 | 400 | 333 | | |
| Row precharge time (all banks) | tRPab 8-bank | MIN | 3 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | ns | |
| Row active time | tRAS | MIN | 3 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | ns | |
| | | MAX | – | 70 | 70 | 70 | 70 | 70 | 70 | 70 | µs | |
| WRITE recovery time | tWR | MIN | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | ns | |
| Internal WRITE-to-READ command delay | tWTR | MIN | 2 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 10 | 10 | ns | |
| Active bank *a* to active bank *b* | tRRD | MIN | 2 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | ns | |
| Four-bank activate window | tFAW | MIN | 8 | 50 | 50 | 50 | 50 | 50 | 50 | 60 | ns | |
| Minimum deep power-down time | tDPD | MIN | – | 500 | 500 | 500 | 500 | 500 | 500 | 500 | µs | |
| **Temperature Derating**[16] | | | | | | | | | | | | |
| tDQSCK derating | tDQSCK (derated) | MAX | – | 5620 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | ps | |
| Core timing temperature derating | tRCD (derated) | MIN | – | tRCD + 1.875 | | | | | | | ns | |
| | tRC (derated) | MIN | – | tRC + 1.875 | | | | | | | ns | |
| | tRAS (derated) | MIN | – | tRAS + 1.875 | | | | | | | ns | |
| | tRP (derated) | MIN | – | tRP + 1.875 | | | | | | | ns | |
| | tRRD (derated) | MIN | – | tRRD + 1.875 | | | | | | | ns | |

Notes:
1. Frequency values are for reference only. Clock cycle time (tCK) is used to determine device capabilities.
2. All AC timings assume an input slew rate of 1 V/ns.
3. READ, WRITE, and input setup and hold values are referenced to $V_{REF}$.
4. tDQSCKDS is the absolute value of the difference between any two tDQSCK measurements (in a byte lane) within a contiguous sequence of bursts in a 160ns rolling window. tDQSCKDS is not tested and is guaranteed by design. Temperature drift in the system is <10˚C/s. Values do not include clock jitter.
5. tDQSCKDM is the absolute value of the difference between any two tDQSCK measurements (in a byte lane) within a 1.6µs rolling window. tDQSCKDM is not tested and is guaranteed by design. Temperature drift in the system is <10˚C/s. Values do not include clock jitter.
6. tDQSCKDL is the absolute value of the difference between any two tDQSCK measurements (in a byte lane) within a 32ms rolling window. tDQSCKDL is not tested and is guaranteed by design. Temperature drift in the system is <10˚C/s. Values do not include clock jitter.
   For LOW-to-HIGH and HIGH-to-LOW transitions, the timing reference is at the point when the signal crosses the transition threshold ($V_{TT}$). tHZ and tLZ transitions occur in


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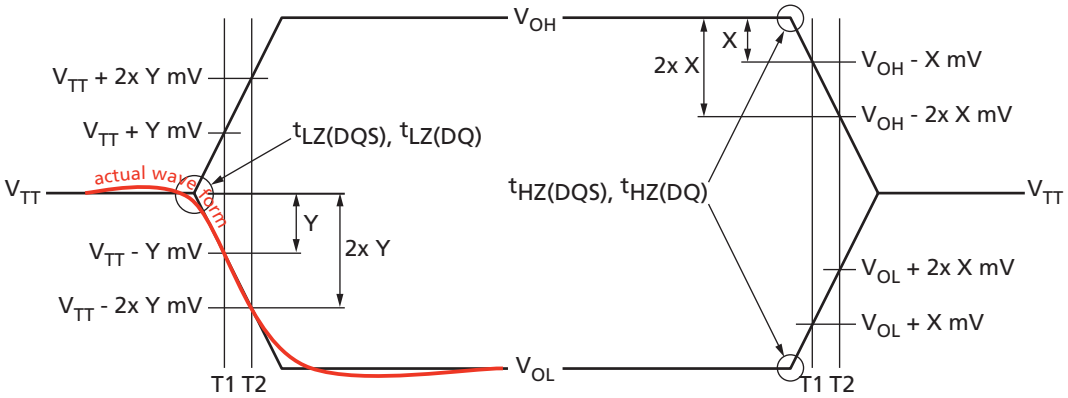
the same access time (with respect to clock) as valid data transitions. These parameters are not referenced to a specific voltage level but to the time when the device output is no longer driving (for $^{t}$RPST, $^{t}$HZ(DQS) and $^{t}$HZ(DQ)), or begins driving (for $^{t}$RPRE, $^{t}$LZ(DQS), $^{t}$LZ(DQ)). 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. The parameters $^{t}$LZ(DQS), $^{t}$LZ(DQ), $^{t}$HZ(DQS), and $^{t}$HZ(DQ) are defined as single-ended. The timing parameters $^{t}$RPRE and $^{t}$RPST are determined from the differential signal DQS_t/DQS_c.

**Output Transition Timing**




7. Measured from the point when DQS_t/DQS_c begins driving the signal, to the point when DQS_t/DQS_c begins driving the first rising strobe edge.
8. Measured from the last falling strobe edge of DQS_t/DQS_c to the point when DQS_t/DQS_c finishes driving the signal.
9. CKE input setup time is measured from CKE reaching a HIGH/LOW voltage level to CK_t/CK_c crossing.
10. CKE input hold time is measured from CK_t/CK_n crossing to CKE reaching a HIGH/LOW voltage level.
11. Input setup/hold time for signal (CA[9:0], CS_n).
12. To ensure device operation before the device is configured, a number of AC boot timing parameters are defined in this table. The letter b is appended to the boot parameter symbols (for example, $^{t}$CK during boot is $^{t}$CKb).
13. Mobile LPDDR2 devices set some mode register default values upon receiving a RESET (MRW) command, as specified in Mode Register Definition.
14. The output skew parameters are measured with default output impedance settings using the reference load.
15. The minimum $^{t}$CK column applies only when $^{t}$CK is greater than 6ns.
16. Timing derating applies for operation at 85˚C to 105˚C when the requirement to derate is indicated by mode register 4 op-code (see the MR4 Device Temperature (MA[7:0] = 04h) table).
17. DRAM devices should be evenly addressed when being accessed. Disproportionate accesses to a particular row address may result in reduction of the product lifetime.

# CA and CS_n Setup, Hold, and Derating

For all input signals (CA and CS_n), the total required setup time ($^{t}$IS) and hold time ($^{t}$IH) are calculated by adding the data sheet $^{t}$IS (base) and $^{t}$IH (base) values to the $\Delta^{t}$IS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and $\Delta^{t}$IH derating values, respectively. Example: $^{t}$IS (total setup time) = $^{t}$IS(base) + $\Delta^{t}$IS. (See the series of tables following this section.)

The typical setup slew rate ($^{t}$IS) for a rising signal is defined as the slew rate between the last crossing of $V_{REF(DC)}$ and the first crossing of $V_{IH(AC)min}$. The typical setup slew rate for a falling signal is defined as the slew rate between the last crossing of $V_{REF(DC)}$ and the first crossing of $V_{IL(AC)max}$. If the actual signal is consistently earlier than the typical slew rate line between the shaded $V_{REF(DC)}$-to-(AC) region, use the typical slew rate for the derating value (see Figure 88 (page 158)). If the actual signal is later than the typical slew rate line anywhere between the shaded $V_{REF(DC)}$-to-AC region, the slew rate of a tangent line to the actual signal from the AC level to the DC level is used for the derating value (see Figure 90 (page 160)).

The hold ($^{t}$IH) typical 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 $V_{REF(DC)}$. The hold ($^{t}$IH) typical 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 $V_{REF(DC)}$. If the actual signal is consistently later than the typical slew rate line between the shaded DC-to-$V_{REF(DC)}$ region, use the typical slew rate for the derating value (see Figure 89 (page 159)). If the actual signal is earlier than the typical slew rate line anywhere between the shaded DC-to-$V_{REF(DC)}$ region, the slew rate of a tangent line to the actual signal from the DC level to $V_{REF(DC)}$ level is used for the derating value (see Figure 91 (page 161)).

For a valid transition, the input signal must remain above or below $V_{IH}/V_{IL(AC)}$ for a specified time, $^{t}$VAC (see Table 104 (page 156)).

For slow slew rates the total setup time could be a negative value; that is, a valid input signal will not have reached $V_{IH}/V_{IL(AC)}$ at the time of the rising clock transition. A valid input signal is still required to complete the transition and reach $V_{IH}/V_{IL(AC)}$.

For slew rates between the values listed in Table 102, the derating values are obtained using linear interpolation. Typically, slew rate values are not subject to production testing. They are verified by design and characterization.

**Table 100: CA and CS_n Setup and Hold Base Values (>400 MHz, 1 V/ns Slew Rate)**

| Parameter | Data Rate | | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | 1066 | 933 | 800 | 667 | 533 | 466 | |
| $^{t}$IS (base) | 0 | 30 | 70 | 150 | 240 | 300 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)}$ ±220mV |
| $^{t}$IH (base) | 90 | 120 | 160 | 240 | 330 | 390 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)}$ ±130mV |

Note: 1. AC/DC referenced for 1 V/ns CA and CS_n slew rate, and 2 V/ns differential CK_t/CK_c slew rate.

**Table 101: CA and CS_n Setup and Hold Base Values (<400 MHz, 1 V/ns Slew Rate)**

| Parameter | Data Rate | | | | Reference |
|---|---|---|---|---|---|
| | 400 | 333 | 266 | 200 | |
| $^{t}$IS (base) | 300 | 440 | 600 | 850 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)}$ ±300mV |
| $^{t}$IH (base) | 400 | 540 | 700 | 950 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)}$ ±200mV |

Note: 1. AC/DC referenced for 1 V/ns CA and CS_n slew rate, and 2 V/ns differential CK_t/CK_c slew rate.


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### Table 102: Derating Values for AC/DC-Based $^{t}$IS/$^{t}$IH (AC220)

$\Delta^{t}$IS, $\Delta^{t}$IH derating in ps
AC220 Threshold -> VIH(ac)=VREF(dc)+220mV, VIL(ac)=VREF(dc)-220mV
DC100 Threshold -> VIH(dc)=VREF(dc)+130mV, VIL(dc)=VREF(dc)-130mV

| | | CK_t, CK_c Differential Slew Rate | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.8 V/ns | | 1.6 V/ns | | 1.4 V/ns | | 1.2 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 | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH |
| CA, CS_n slew rate V/ns | 2.0 | 110 | 65 | 110 | 65 | 110 | 65 | | | | | | | | | | |
| | 1.5 | 74 | 43 | 73 | 43 | 73 | 43 | 89 | 59 | | | | | | | | |
| | 1.0 | 0 | 0 | 0 | 0 | **0** | **0** | 16 | 16 | 32 | 32 | | | | | | |
| | 0.9 | | | -3 | -5 | -3 | -5 | 13 | 11 | 29 | 27 | 45 | 43 | | | | |
| | 0.8 | | | | | -8 | -13 | 8 | 3 | 24 | 19 | 40 | 35 | 56 | 55 | | |
| | 0.7 | | | | | | | 2 | -6 | 18 | 10 | 34 | 26 | 50 | 46 | 66 | 78 |
| | 0.6 | | | | | | | | | 10 | -3 | 26 | 13 | 42 | 33 | 58 | 65 |
| | 0.5 | | | | | | | | | | | 4 | -4 | 20 | 16 | 36 | 48 |
| | 0.4 | | | | | | | | | | | | | -7 | 2 | 17 | 34 |

Note: 1. Shaded cells are not supported.

### Table 103: Derating Values for AC/DC-Based $^{t}$IS/$^{t}$IH (AC300)

$\Delta^{t}$IS, $\Delta^{t}$IH derating in ps
AC300 Threshold -> VIH(ac)=VREF(dc)+300mV, VIL(ac)=VREF(dc)-300mV
DC200 Threshold -> VIH(dc)=VREF(dc)+200mV, VIL(dc)=VREF(dc)-200mV

| | | CK_t, CK_c Differential Slew Rate | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.8 V/ns | | 1.6 V/ns | | 1.4 V/ns | | 1.2 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 | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH | $\Delta^{t}$IS | $\Delta^{t}$IH |
| CA, CS_n slew rate V/ns | 2.0 | 150 | 100 | 150 | 100 | 150 | 100 | | | | | | | | | | |
| | 1.5 | 100 | 67 | 100 | 67 | 100 | 67 | 116 | 83 | | | | | | | | |
| | 1.0 | 0 | 0 | 0 | 0 | **0** | **0** | 16 | 16 | 32 | 32 | | | | | | |
| | 0.9 | | | -4 | -8 | -4 | -8 | 12 | 8 | 28 | 24 | 44 | 40 | | | | |
| | 0.8 | | | | | -12 | -20 | 4 | -4 | 20 | 12 | 36 | 28 | 52 | 48 | | |
| | 0.7 | | | | | | | -3 | -18 | 13 | -2 | 29 | 14 | 45 | 34 | 61 | 66 |
| | 0.6 | | | | | | | | | 2 | -21 | 18 | -5 | 34 | 15 | 50 | 47 |
| | 0.5 | | | | | | | | | | | -12 | -32 | 4 | -12 | 20 | 20 |
| | 0.4 | | | | | | | | | | | | | -35 | -40 | -11 | -8 |

Note: 1. Shaded cells are not supported.

### Table 104: Required Time for Valid Transition – $^{t}$VAC > $V_{IH(AC)}$ and < $V_{IL(AC)}$

| Slew Rate (V/ns) | $^{t}$VAC at 300mV (ps) | | $^{t}$VAC at 220mV (ps) | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| >2.0 | 75 | – | 175 | – |
| 2.0 | 57 | – | 170 | – |


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**Table 104: Required Time for Valid Transition – $^{t}VAC > V_{IH(AC)}$ and $< V_{IL(AC)}$ (Continued)**

| Slew Rate (V/ns) | $^{t}VAC$ at 300mV (ps) | | $^{t}VAC$ at 220mV (ps) | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| 1.5 | 50 | – | 167 | – |
| 1.0 | 38 | – | 163 | – |
| 0.9 | 34 | – | 162 | – |
| 0.8 | 29 | – | 161 | – |
| 0.7 | 22 | – | 159 | – |
| 0.6 | 13 | – | 155 | – |
| 0.5 | 0 | – | 150 | – |
| <0.5 | 0 | – | 150 | – |



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**Figure 88: Typical Slew Rate and $^{t}$VAC – $^{t}$IS for CA and CS_n Relative to Clock**

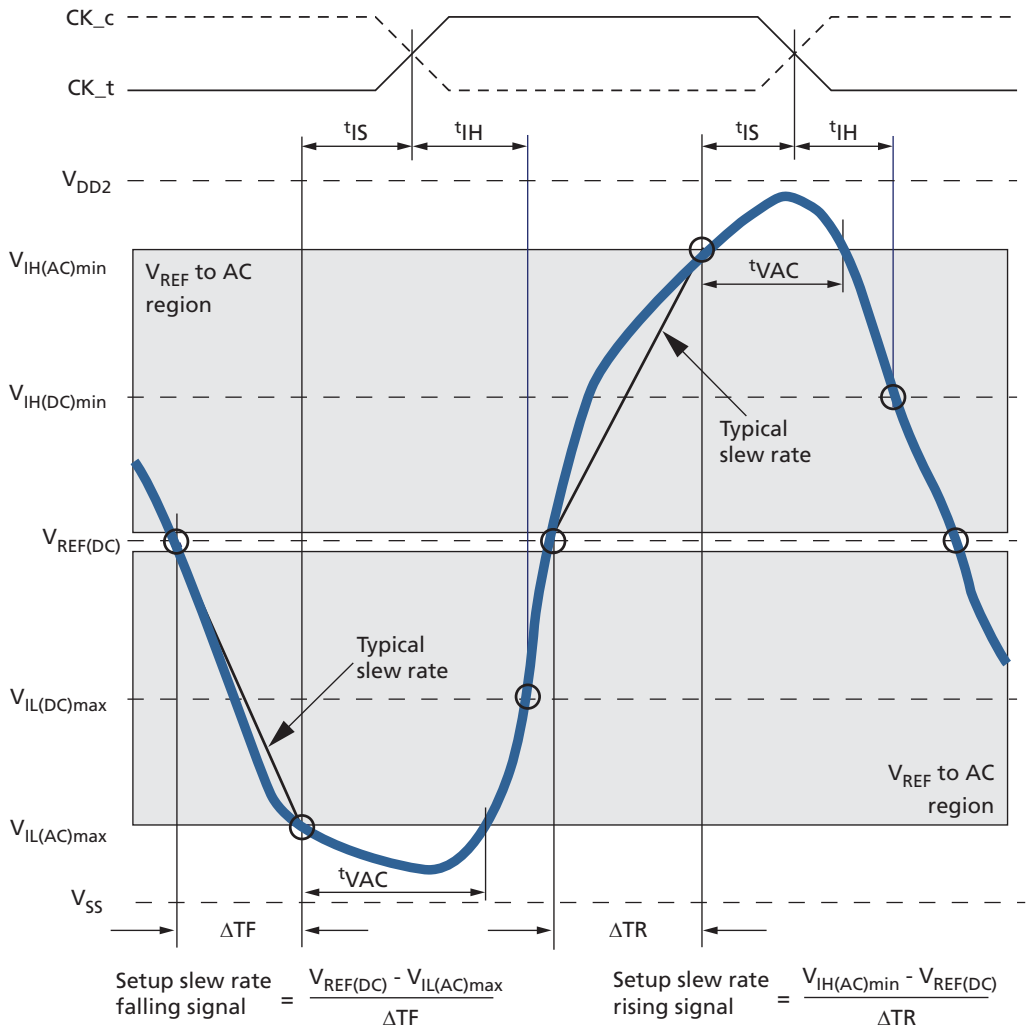



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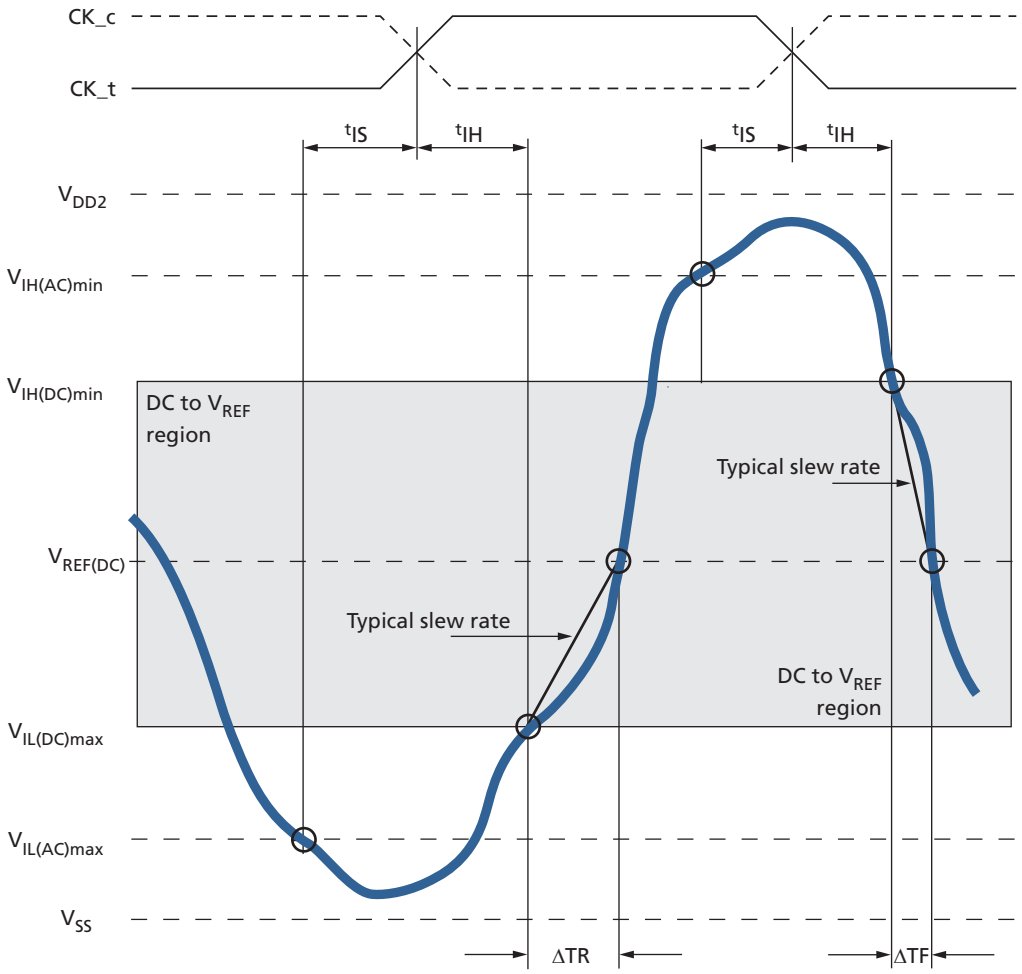
**Figure 89: Typical Slew Rate – $^{t}IH$ for CA and CS_n Relative to Clock**




$$\text{Hold slew rate falling signal} = \frac{V_{IH(DC)min} - V_{REF(DC)}}{\Delta TF}$$

$$\text{Hold slew rate rising signal} = \frac{V_{REF(DC)} - V_{IL(DC)max}}{\Delta TR}$$


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**Figure 90: Tangent Line – $^{t}IS$ for CA and CS_n Relative to Clock**

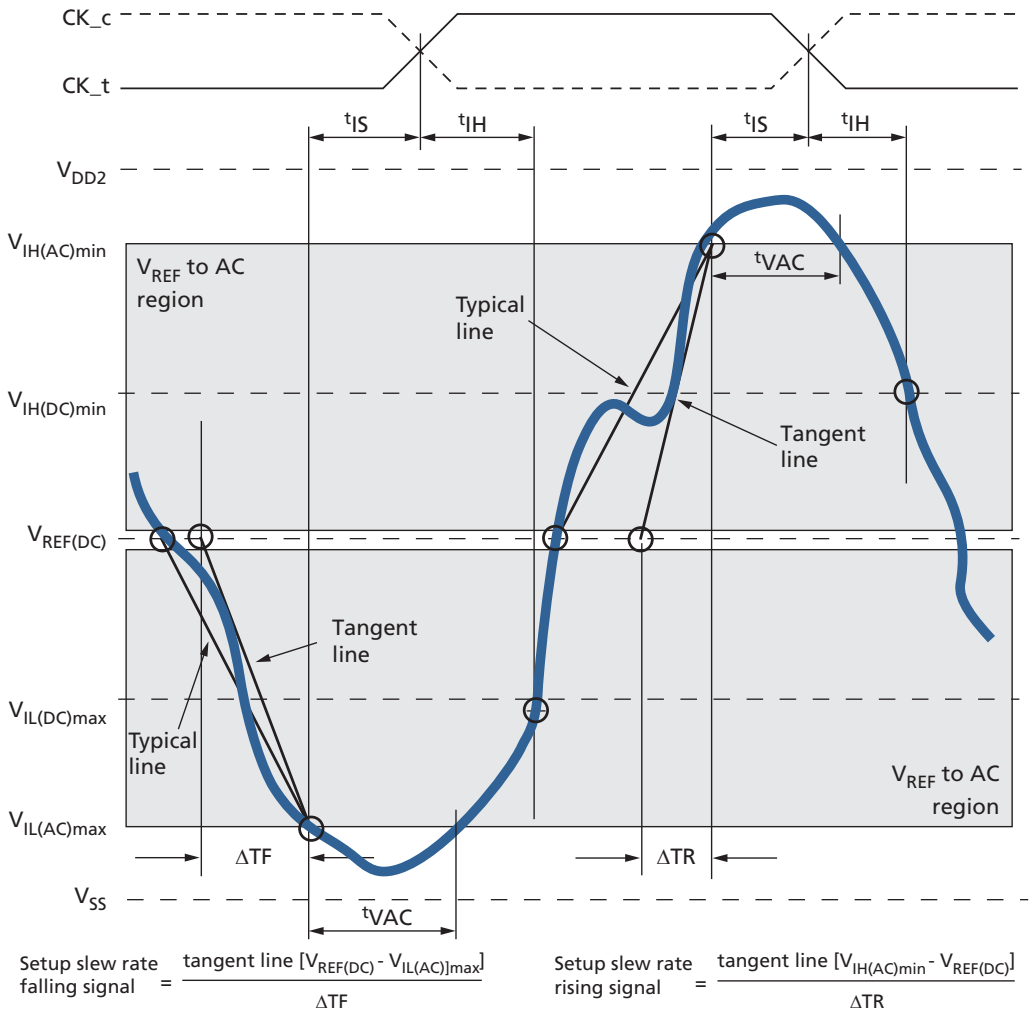



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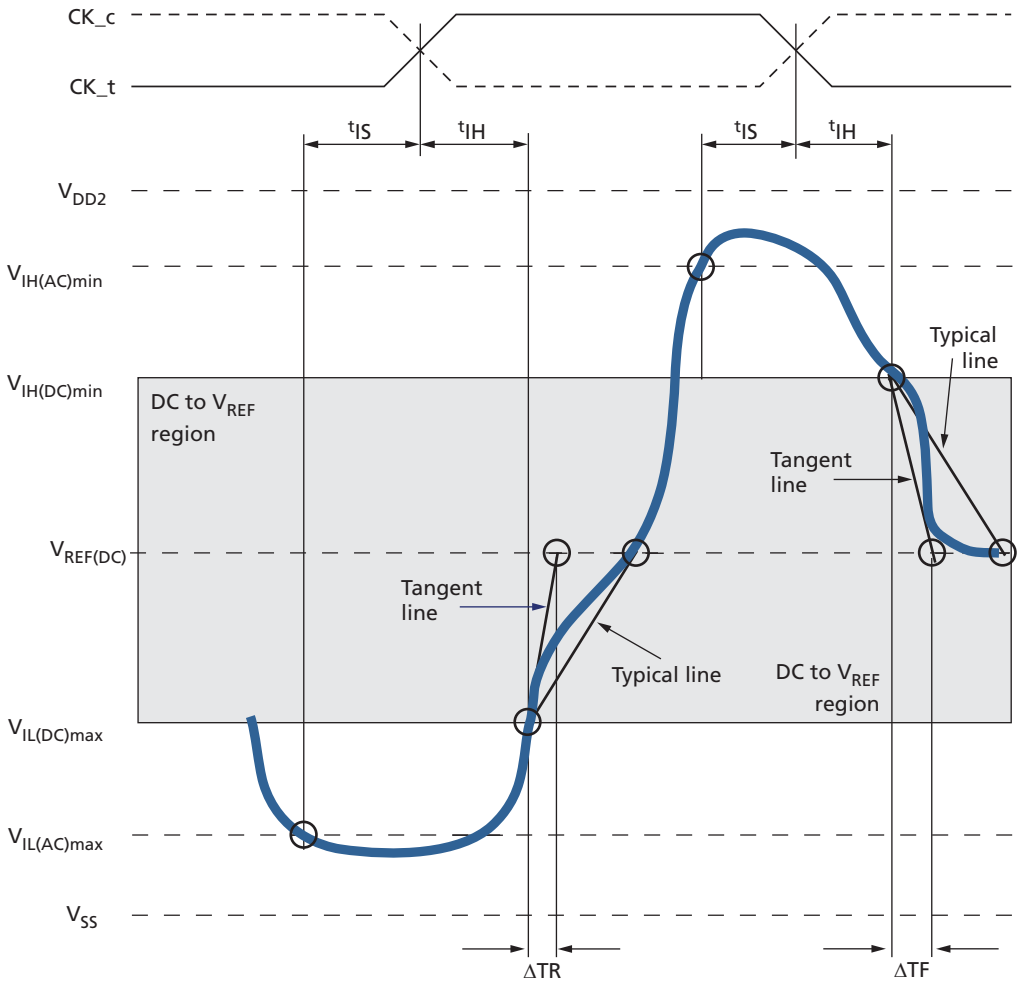
**Figure 91: Tangent Line – $^{t}IH$ for CA and CS_n Relative to Clock**




$$\text{Hold slew rate falling signal} = \frac{\text{tangent line } [V_{IH(DC)min} - V_{REF(DC)}]}{\Delta TF}$$

$$\text{Hold slew rate rising signal} = \frac{\text{tangent line } [V_{REF(DC)} - V_{IL(DC)max}]}{\Delta TR}$$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# Data Setup, Hold, and Slew Rate Derating

For all input signals (DQ, DM) the total required setup time ($^{t}$DS) and hold time ($^{t}$DH) are calculated by adding the data sheet $^{t}$DS(base) and $^{t}$DH(base) values (see the following table) to the $\Delta^{t}$DS and $\Delta^{t}$DH derating values, respectively (see the following derating tables). Example: $^{t}$DS = $^{t}$DS(base) + $\Delta^{t}$DS.

The typical $^{t}$DS slew rate for a rising signal is defined as the slew rate between the last crossing of $V_{REF(DC)}$ and the first crossing of $V_{IH(AC)min}$. The typical $^{t}$DS slew rate for a falling signal is defined as the slew rate between the last crossing of $V_{REF(DC)}$ and the first crossing of $V_{IL(AC)max}$ (see the Typical Slew Rate and $^{t}$VAC – $^{t}$DS for DQ Relative to Strobe figure).

If the actual signal is consistently earlier than the typical slew rate line in the figure, "Typical Slew Rate and $^{t}$VAC – $^{t}$IS for CA and CS_n Relative to Clock (CA and CS_n Setup, Hold, and Derating), the area shaded gray between the $V_{REF(DC)}$ region and the AC region, use the typical slew rate for the derating value. If the actual signal is later than the typical slew rate line anywhere between the shaded $V_{REF(DC)}$ region and the AC region, the slew rate of a tangent line to the actual signal from the AC level to the DC level is used for the derating value (see figure "Tangent Line – $^{t}$IS for CA and CS_n Relative to Clock" in CA and CS_n Setup, Hold, and Derating).

The typical $^{t}$DH 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 $V_{REF(DC)}$. The typical $^{t}$DH 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 $V_{REF(DC)}$ (see the Typical Slew Rate – DH for DQ Relative to Strobe figure).

If the actual signal is consistently later than the typical slew rate line between the shaded DC-level-to-$V_{REF(DC)}$ region, the typical slew rate should be used for the derating value. If the actual signal is earlier than the typical slew rate line anywhere between shaded DC-to-$V_{REF(DC)}$ region, the slew rate of a tangent line to the actual signal from the DC level to the $V_{REF(DC)}$ level is used for the derating value (see the Tangent Line – $^{t}$DH for DQ with Respect to Strobe figure).

For a valid transition, the input signal must remain above or below $V_{IH}/V_{IL(AC)}$ for the specified time, $^{t}$VAC (see the Required Time for Valid Transition – $^{t}$VAC > $V_{IH(AC)}$ or < $V_{IL(AC)}$ table).

The total setup time for slow slew rates could be negative; that is, a valid input signal may not have reached $V_{IH}/V_{IL(AC)}$ at the time of the rising clock transition. A valid input signal is still required to complete the transition and reach $V_{IH}/V_{IL(AC)}$.

For slew rates between the values listed in the following tables, the derating values can be obtained using linear interpolation. Typically, slew rate values are not subject to production testing. They are verified by design and characterization.

**Table 105: Data Setup and Hold Base Values (>400 MHz, 1 V/ns Slew Rate)**

| Parameter | Data Rate | | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | 1066 | 933 | 800 | 667 | 533 | 466 | |
| $^{t}$DS (base) | -10 | 15 | 50 | 130 | 210 | 230 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)}$ ±220mV |


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**Table 105: Data Setup and Hold Base Values (>400 MHz, 1 V/ns Slew Rate) (Continued)**

| Parameter | Data Rate | | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | 1066 | 933 | 800 | 667 | 533 | 466 | |
| $^{t}$DH (base) | 80 | 105 | 140 | 220 | 300 | 320 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)}$ ±130mV |

Note: 1. AC/DC referenced for 1 V/ns DQ, DM slew rate, and 2 V/ns differential DQS_t/DQS_c slew rate.

**Table 106: Data Setup and Hold Base Values (<400 MHz, 1 V/ns Slew Rate)**

| Parameter | Data Rate | | | | Reference |
|---|---|---|---|---|---|
| | 400 | 333 | 266 | 200 | |
| $^{t}$DS (base) | 180 | 300 | 450 | 700 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)}$ ±300mV |
| $^{t}$DH (base) | 280 | 400 | 550 | 800 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)}$ ±200mV |

Note: 1. AC/DC referenced for 1 V/ns DQ, DM slew rate, and 2 V/ns differential DQS_t/DQS_c slew rate.

**Table 107: Derating Values for AC/DC-Based $^{t}$DS/$^{t}$DH (AC220)**

$\Delta^{t}$DS, $\Delta^{t}$DH derating in ps
AC220 Threshold -> VIH(ac)=VREF(dc)+220mV, VIL(ac)=VREF(dc)-220mV
DC130 Threshold -> VIH(dc)=VREF(dc)+130mV, VIL(dc)=VREF(dc)-130mV

| | | DQS_t, DQS_c Differential Slew Rate | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.8 V/ns | | 1.6 V/ns | | 1.4 V/ns | | 1.2 V/ns | | 1.0 V/ns | |
| | | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH |
| DQ, DM slew rate V/ns | 2.0 | 110 | 65 | 110 | 65 | 110 | 65 | | | | | | | | | | |
| | 1.5 | 74 | 43 | 73 | 43 | 73 | 43 | 89 | 59 | | | | | | | | |
| | 1.0 | 0 | 0 | 0 | 0 | **0** | **0** | 16 | 16 | 32 | 32 | | | | | | |
| | 0.9 | | | -3 | -5 | -3 | -5 | 13 | 11 | 29 | 27 | 45 | 43 | | | | |
| | 0.8 | | | | | -8 | -13 | 8 | 3 | 24 | 19 | 40 | 35 | 56 | 55 | | |
| | 0.7 | | | | | | | 2 | -6 | 18 | 10 | 34 | 26 | 50 | 46 | 66 | 78 |
| | 0.6 | | | | | | | | | 10 | -3 | 26 | 13 | 42 | 33 | 58 | 65 |
| | 0.5 | | | | | | | | | | | 4 | -4 | 20 | 16 | 36 | 48 |
| | 0.4 | | | | | | | | | | | | | -7 | 2 | 17 | 34 |

Note: 1. Shaded cells are not supported.


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### Table 108: Derating Values for AC/DC-Based $^{t}$DS/$^{t}$DH (AC300)

$\Delta^{t}$DS, $\Delta^{t}$DH derating in ps
AC300 Threshold -> VIH(ac)=VREF(dc)+300mV, VIL(ac)=VREF(dc)-300mV
DC200 Threshold -> VIH(dc)=VREF(dc)+200mV, VIL(dc)=VREF(dc)-200mV

| | | DQS_t, DQS_c Differential Slew Rate | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.8 V/ns | | 1.6 V/ns | | 1.4 V/ns | | 1.2 V/ns | | 1.0 V/ns | |
| | | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH | $\Delta^{t}$DS | $\Delta^{t}$DH |
| DQ, DM slew rate V/ns | 2.0 | 150 | 100 | 150 | 100 | 150 | 100 | | | | | | | | | | |
| | 1.5 | 100 | 67 | 100 | 67 | 100 | 67 | 116 | 83 | | | | | | | | |
| | 1.0 | 0 | 0 | 0 | 0 | **0** | **0** | 16 | 16 | 32 | 32 | | | | | | |
| | 0.9 | | | -4 | -8 | -4 | -8 | 12 | 8 | 28 | 24 | 44 | 40 | | | | |
| | 0.8 | | | | | -12 | -20 | 4 | -4 | 20 | 12 | 36 | 28 | 52 | 48 | | |
| | 0.7 | | | | | | | -3 | -18 | 13 | -2 | 29 | 14 | 45 | 34 | 61 | 66 |
| | 0.6 | | | | | | | | | 2 | -21 | 18 | -5 | 34 | 15 | 50 | 47 |
| | 0.5 | | | | | | | | | | | -12 | -32 | 4 | -12 | 20 | 20 |
| | 0.4 | | | | | | | | | | | | | -35 | -40 | -11 | -8 |

Note: 1. Shaded cells are not supported.

### Table 109: Required Time for Valid Transition – $^{t}$VAC > $V_{IH(AC)}$ or < $V_{IL(AC)}$

| Slew Rate (V/ns) | $^{t}$VAC at 300mV (ps) | | $^{t}$VAC at 220mV (ps) | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| >2.0 | 75 | – | 175 | – |
| 2.0 | 57 | – | 170 | – |
| 1.5 | 50 | – | 167 | – |
| 1.0 | 38 | – | 163 | – |
| 0.9 | 34 | – | 162 | – |
| 0.8 | 29 | – | 161 | – |
| 0.7 | 22 | – | 159 | – |
| 0.6 | 13 | – | 155 | – |
| 0.5 | 0 | – | 150 | – |
| <0.5 | 0 | – | 150 | – |


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**Figure 92: Typical Slew Rate and $^{t}$VAC – $^{t}$DS for DQ Relative to Strobe**

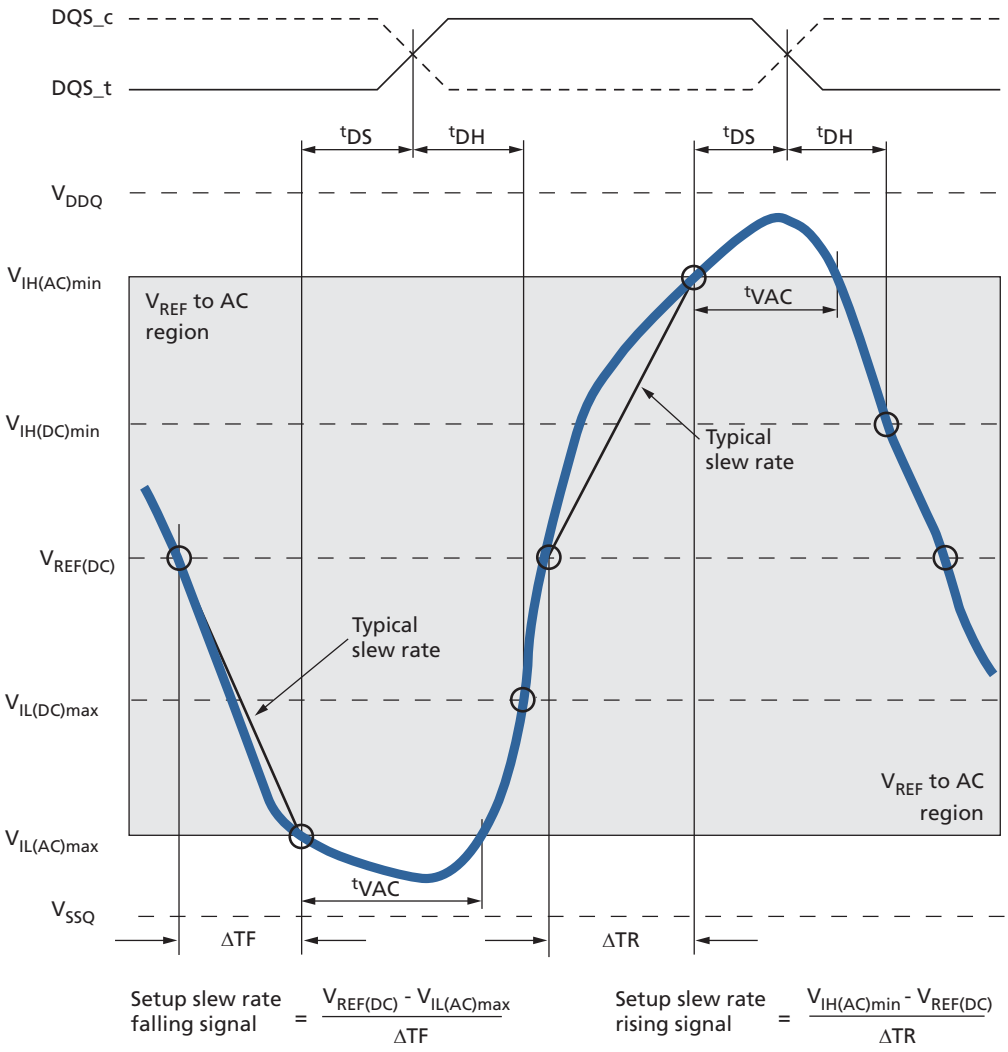



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**Figure 93: Typical Slew Rate – $^{t}$DH for DQ Relative to Strobe**

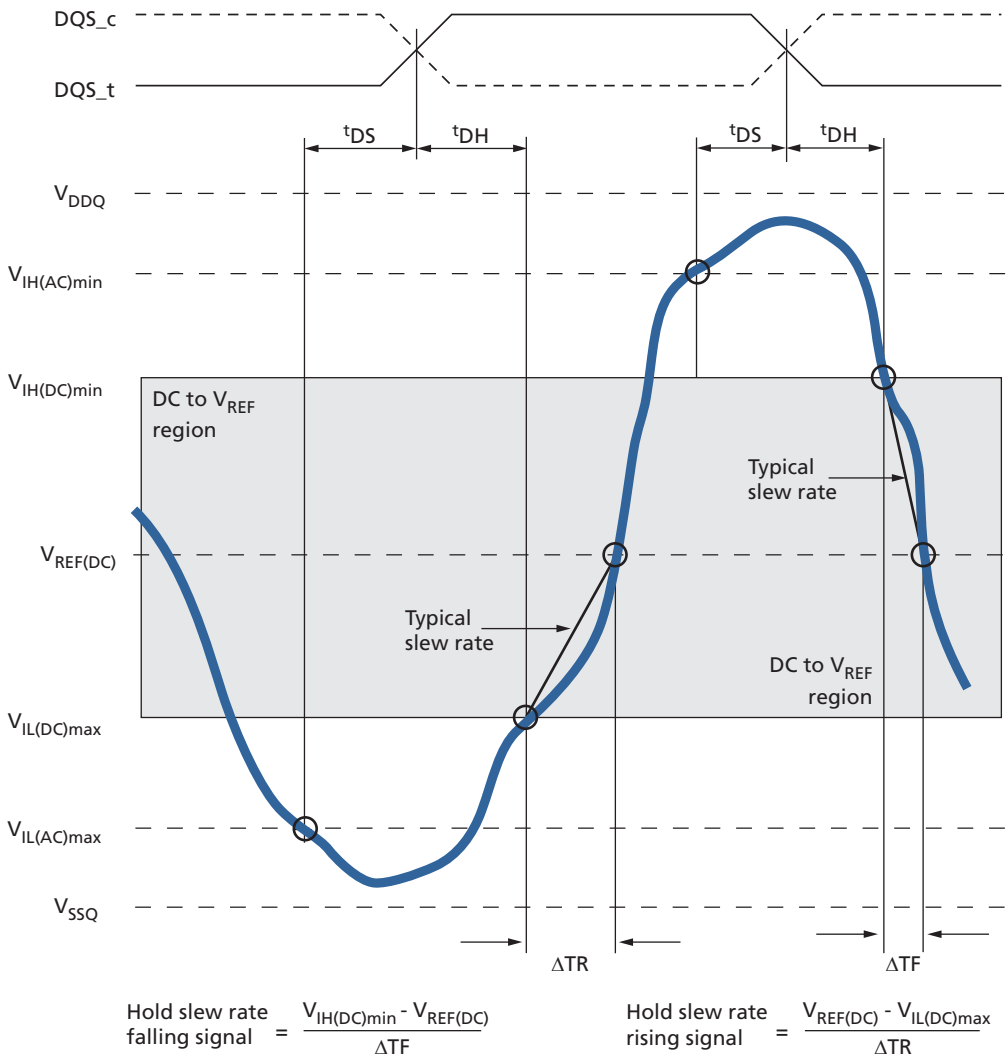



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**Figure 94: Tangent Line – $^{t}DS$ for DQ with Respect to Strobe**

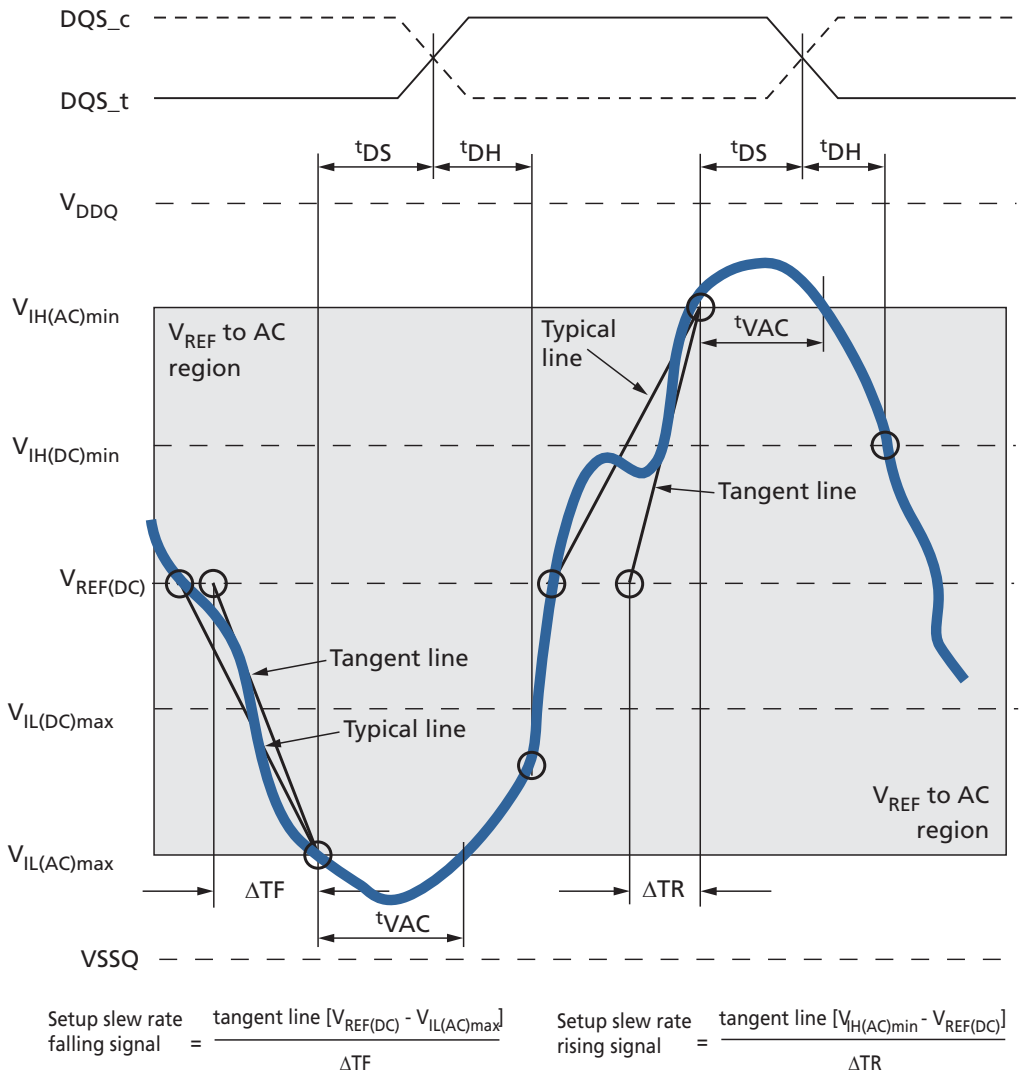



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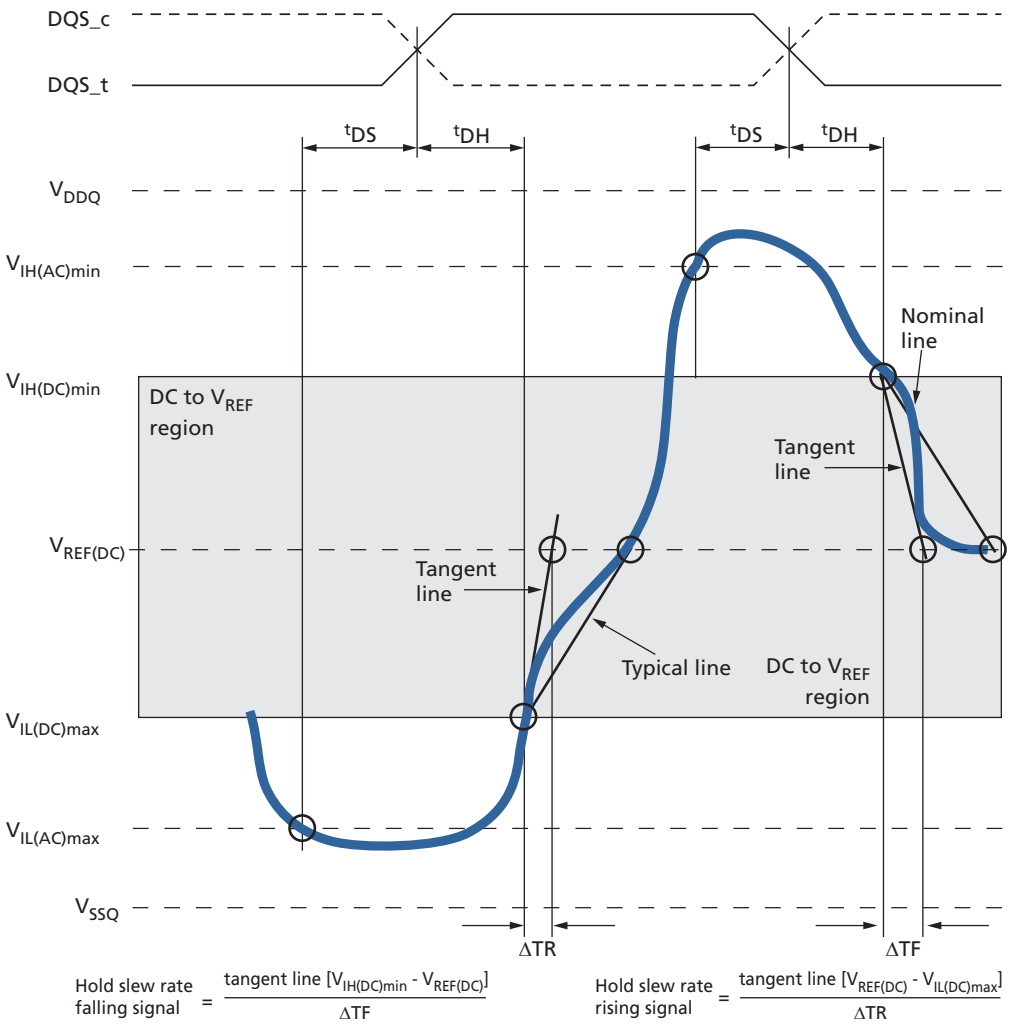
**Figure 95: Tangent Line – $^{t}$DH for DQ with Respect to Strobe**





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# Revision History

## Rev. A – 07/14

- Initial release

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