

# Automotive LPDDR2 SDRAM

## MT42L32M32D1, MT42L64M32D2

### Features

- Ultra low-voltage core and I/O power supplies
  - $V_{DD2} = 1.14\text{--}1.30\text{V}$
  - $V_{DDCA}/V_{DDQ} = 1.14\text{--}1.30\text{V}$
  - $V_{DD1} = 1.70\text{--}1.95\text{V}$
- Clock frequency range
  - 533–10 MHz (data rate range: 1066–20 Mb/s/pin)
- Four-bit prefetch DDR architecture
- Eight internal banks for concurrent operation
- Multiplexed, double data rate, command/address inputs; commands entered on every CK edge
- Bidirectional/differential data strobe per byte of data (DQS/DQS#)
- Programmable READ and WRITE latencies (RL/WL)
- Programmable burst lengths: 4, 8, or 16
- Per-bank refresh for concurrent operation
- On-chip temperature sensor to control self refresh rate (SR not supported >105°C)
- Partial-array self refresh (PASR)
- Deep power-down mode (DPD)
- Selectable output drive strength (DS)
- Clock stop capability
- RoHS-compliant, “green” packaging
- AEC-Q100

### Options

- $V_{DD2}$ : 1.2V
- Configuration
  - 4 Meg x 32 x 8 banks 32M32
  - 8 Meg x 16 x 8 banks x 2 die 64M32
- Device Type
  - LPDDR2-S4, 1 die in package D1
  - LPDDR2-S4, 2 die in package D2
- FBGA “green” package
  - 134-ball FBGA (10mm x 11.5mm) HE
- Timing – cycle time
  - 1.875ns @ RL = 8 -18
- Special options
  - Automotive grade (Package-level burn-in) A
- Operating temperature range<sup>1</sup>
  - From –40°C to +105°C AT
  - From –40°C to +125°C UT<sup>2</sup>
- Revision D

- Notes:
1. When  $T_C > 105^\circ\text{C}$ , self refresh mode is not available.
  2. UT option use based on automotive usage model. Contact Micron sales representative with questions.

**Table 1: Key Timing Parameters**

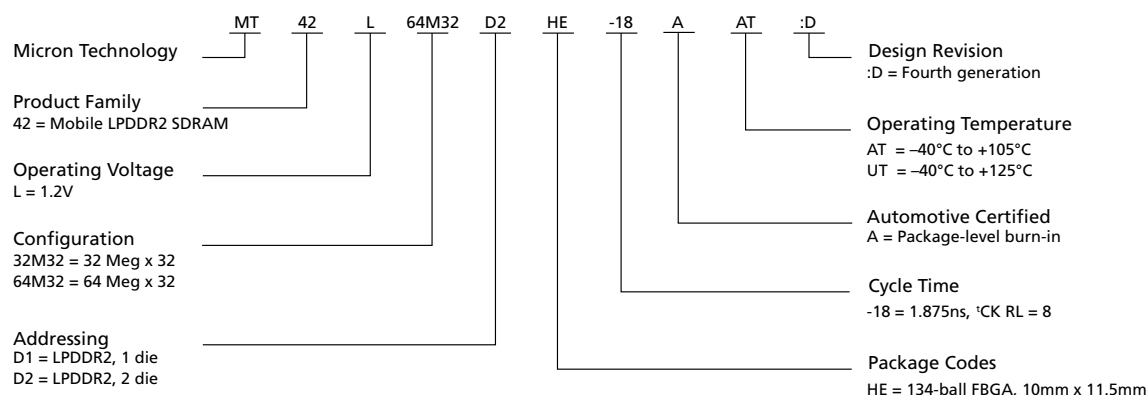
| Speed Grade | Clock Rate (MHz) | Data Rate (Mb/s/pin) | RL | WL |
|-------------|------------------|----------------------|----|----|
| -18         | 533              | 1066                 | 8  | 4  |

**Table 2: S4 Configuration Addressing**

| Architecture                   | 32 Meg x 32          | 64 Meg x 32              |
|--------------------------------|----------------------|--------------------------|
| Die configuration              | 4 Meg x 32 x 8 banks | 2 x 8 Meg x 16 x 8 banks |
| Row addressing                 | 8K (A[12:0])         | 8K (A[12:0])             |
| Column addressing              | 512 (A[8:0])         | 1K (A[9:0])              |
| Number of die                  | 1                    | 2                        |
| Die per rank                   | 1                    | 2                        |
| Ranks per channel <sup>1</sup> | 1                    | 1                        |

Note: 1. A channel is a complete LPDRAM interface, including command/address and data pins.

**Figure 1: LPDDR2 Part Numbering**



## FBGA Part Marking Decoder

Due to space limitations, FBGA-packaged components have an abbreviated part marking that is different from the part number. Micron's FBGA part marking decoder is available at [www.micron.com/decoder](http://www.micron.com/decoder).

**Table 3: Package Codes and Descriptions**

| Package Code | Ball Count | # Ranks | # Channels | Size (mm)                   | Die per Package | Solder Ball Composition |
|--------------|------------|---------|------------|-----------------------------|-----------------|-------------------------|
| HE           | 134        | 1       | 1          | 10 x 11.5 x 1.0, 0.65 pitch | SDP/DDP         | SAC302                  |

- Notes:
1. SDP = single-die package; DDP = Dual-die package
  2. Solder ball material: SAC302 (96.8% Sn, 3% Ag, 0.2% Cu).

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## Important Notes and Warnings

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## General Description

The 1Gb Mobile Low-Power DDR2 SDRAM (LPDDR2) is a high-speed CMOS, dynamic random-access memory containing 1,073,741,824 bits. The LPDDR2-S4 device is internally configured as an eight-bank DRAM. Each of the x16's 134,217,728-bit banks is organized as 8192 rows by 1024 columns by 16 bits. Each of the x32's 134,217,728-bit banks is organized as 8192 rows by 512 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, DQS# and CK, CK# 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.

## I<sub>DD</sub> Specifications

**Table 4: I<sub>DD</sub> Specifications (32 Meg x 32)**
 $V_{DD2}, V_{DDQ}, V_{DDCA} = 1.14\text{--}1.30\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

| Parameter             | Supply                               | Clock Rate | Unit |
|-----------------------|--------------------------------------|------------|------|
|                       |                                      | 533 MHz    |      |
| I <sub>DD01</sub>     | V <sub>DD1</sub>                     | 6          | mA   |
| I <sub>DD02</sub>     | V <sub>DD2</sub>                     | 35         |      |
| I <sub>DD0,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |      |
| I <sub>DD2P1</sub>    | V <sub>DD1</sub>                     | 600        | μA   |
| I <sub>DD2P2</sub>    | V <sub>DD2</sub>                     | 1600       |      |
| I <sub>DD2P,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 100        |      |
| I <sub>DD2PS1</sub>   | V <sub>DD1</sub>                     | 600        | μA   |
| I <sub>DD2PS2</sub>   | V <sub>DD2</sub>                     | 1600       |      |
| I <sub>DD2PS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 100        |      |
| I <sub>DD2N1</sub>    | V <sub>DD1</sub>                     | 0.6        | mA   |
| I <sub>DD2N2</sub>    | V <sub>DD2</sub>                     | 20         |      |
| I <sub>DD2N,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |      |
| I <sub>DD2NS1</sub>   | V <sub>DD1</sub>                     | 0.6        | mA   |
| I <sub>DD2NS2</sub>   | V <sub>DD2</sub>                     | 12         |      |
| I <sub>DD2NS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |      |
| I <sub>DD3P1</sub>    | V <sub>DD1</sub>                     | 1.4        | mA   |
| I <sub>DD3P2</sub>    | V <sub>DD2</sub>                     | 5          |      |
| I <sub>DD3P,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 0.1        |      |
| I <sub>DD3PS1</sub>   | V <sub>DD1</sub>                     | 1.4        | mA   |
| I <sub>DD3PS2</sub>   | V <sub>DD2</sub>                     | 5          |      |
| I <sub>DD3PS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 0.1        |      |
| I <sub>DD3N1</sub>    | V <sub>DD1</sub>                     | 1.5        | mA   |
| I <sub>DD3N2</sub>    | V <sub>DD2</sub>                     | 24         |      |
| I <sub>DD3N,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |      |
| I <sub>DD3NS1</sub>   | V <sub>DD1</sub>                     | 1.5        | mA   |
| I <sub>DD3NS2</sub>   | V <sub>DD2</sub>                     | 16         |      |
| I <sub>DD3NS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |      |
| I <sub>DD4R1</sub>    | V <sub>DD1</sub>                     | 2          | mA   |
| I <sub>DD4R2</sub>    | V <sub>DD2</sub>                     | 180        |      |
| I <sub>DD4R,in</sub>  | V <sub>DDCA</sub>                    | 2          |      |
| I <sub>DD4W1</sub>    | V <sub>DD1</sub>                     | 2          | mA   |
| I <sub>DD4W2</sub>    | V <sub>DD2</sub>                     | 200        |      |
| I <sub>DD4W,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |      |

**Table 4: I<sub>DD</sub> Specifications (32 Meg x 32) (Continued)**
 $V_{DD2}, V_{DDQ}, V_{DDCA} = 1.14\text{--}1.30\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

| Parameter             | Supply                               | Clock Rate | Unit    |
|-----------------------|--------------------------------------|------------|---------|
|                       |                                      | 533 MHz    |         |
| I <sub>DD51</sub>     | V <sub>DD1</sub>                     | 20         | mA      |
| I <sub>DD52</sub>     | V <sub>DD2</sub>                     | 70         |         |
| I <sub>DD5,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |         |
| I <sub>DD5PB1</sub>   | V <sub>DD1</sub>                     | 2          | mA      |
| I <sub>DD5PB2</sub>   | V <sub>DD2</sub>                     | 23         |         |
| I <sub>DD5PB,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |         |
| I <sub>DD5AB1</sub>   | V <sub>DD1</sub>                     | 2          | mA      |
| I <sub>DD5AB2</sub>   | V <sub>DD2</sub>                     | 23         |         |
| I <sub>DD5AB,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 1          |         |
| I <sub>DD61</sub>     | V <sub>DD1</sub>                     | –          | Table 5 |
| I <sub>DD62</sub>     | V <sub>DD2</sub>                     | –          |         |
| I <sub>DD6,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | –          |         |
| I <sub>DD81</sub>     | V <sub>DD1</sub>                     | 50         | μA      |
| I <sub>DD82</sub>     | V <sub>DD2</sub>                     | 50         |         |
| I <sub>DD8,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 80         |         |

**Table 5: I<sub>DD6</sub> Partial-Array Self Refresh Current (32 Meg x 32)**
 $V_{DD2}, V_{DDQ}, V_{DDCA} = 1.14\text{--}1.30\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

| PASR       | Supply           | I <sub>DD6</sub> Partial-Array Self Refresh Current |                 |                  | Unit |
|------------|------------------|-----------------------------------------------------|-----------------|------------------|------|
|            |                  | –40°C to +85°C                                      | +85°C to +105°C | +105°C to +125°C |      |
| Full array | V <sub>DD1</sub> | 350                                                 | 2100            | –                | μA   |
|            | V <sub>DD2</sub> | 2000                                                | 10700           | –                |      |
|            | V <sub>DDi</sub> | 30                                                  | 30              | –                |      |
| 1/2 array  | V <sub>DD1</sub> | 280                                                 | 2000            | –                |      |
|            | V <sub>DD2</sub> | 1450                                                | 6200            | –                |      |
|            | V <sub>DDi</sub> | 30                                                  | 30              | –                |      |
| 1/4 array  | V <sub>DD1</sub> | 240                                                 | 1800            | –                |      |
|            | V <sub>DD2</sub> | 1150                                                | 4000            | –                |      |
|            | V <sub>DDi</sub> | 30                                                  | 30              | –                |      |
| 1/8 array  | V <sub>DD1</sub> | 230                                                 | 1700            | –                |      |
|            | V <sub>DD2</sub> | 1000                                                | 3000            | –                |      |
|            | V <sub>DDi</sub> | 30                                                  | 30              | –                |      |

- Notes:
1. LPDDR2-S4 SDRAM devices support both bank-masking and segment-masking. I<sub>DD6</sub> PASR currents are measured using bank-masking only.
  2. When T<sub>C</sub> > 105°C: Self refresh mode is not available.

**Table 6: I<sub>DD</sub> Specifications (64 Meg x 32)**
 $V_{DD2}, V_{DDQ}, V_{DDCA} = 1.14\text{--}1.30\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

| Parameter             | Supply                               | Clock Rate | Unit |
|-----------------------|--------------------------------------|------------|------|
|                       |                                      | 533 MHz    |      |
| I <sub>DD01</sub>     | V <sub>DD1</sub>                     | 12         | mA   |
| I <sub>DD02</sub>     | V <sub>DD2</sub>                     | 70         |      |
| I <sub>DD0,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |
| I <sub>DD2P1</sub>    | V <sub>DD1</sub>                     | 1200       | μA   |
| I <sub>DD2P2</sub>    | V <sub>DD2</sub>                     | 3200       |      |
| I <sub>DD2P,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 200        |      |
| I <sub>DD2PS1</sub>   | V <sub>DD1</sub>                     | 1200       | μA   |
| I <sub>DD2PS2</sub>   | V <sub>DD2</sub>                     | 3200       |      |
| I <sub>DD2PS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 200        |      |
| I <sub>DD2N1</sub>    | V <sub>DD1</sub>                     | 1.2        | mA   |
| I <sub>DD2N2</sub>    | V <sub>DD2</sub>                     | 40         |      |
| I <sub>DD2N,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |
| I <sub>DD2NS1</sub>   | V <sub>DD1</sub>                     | 1.2        | mA   |
| I <sub>DD2NS2</sub>   | V <sub>DD2</sub>                     | 24         |      |
| I <sub>DD2NS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |
| I <sub>DD3P1</sub>    | V <sub>DD1</sub>                     | 2.8        | mA   |
| I <sub>DD3P2</sub>    | V <sub>DD2</sub>                     | 10         |      |
| I <sub>DD3P,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 0.2        |      |
| I <sub>DD3PS1</sub>   | V <sub>DD1</sub>                     | 2.8        | mA   |
| I <sub>DD3PS2</sub>   | V <sub>DD2</sub>                     | 10         |      |
| I <sub>DD3PS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 0.2        |      |
| I <sub>DD3N1</sub>    | V <sub>DD1</sub>                     | 3          | mA   |
| I <sub>DD3N2</sub>    | V <sub>DD2</sub>                     | 48         |      |
| I <sub>DD3N,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |
| I <sub>DD3NS1</sub>   | V <sub>DD1</sub>                     | 3          | mA   |
| I <sub>DD3NS2</sub>   | V <sub>DD2</sub>                     | 32         |      |
| I <sub>DD3NS,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |
| I <sub>DD4R1</sub>    | V <sub>DD1</sub>                     | 4          | mA   |
| I <sub>DD4R2</sub>    | V <sub>DD2</sub>                     | 360        |      |
| I <sub>DD4R,in</sub>  | V <sub>DDCA</sub>                    | 4          |      |
| I <sub>DD4W1</sub>    | V <sub>DD1</sub>                     | 4          | mA   |
| I <sub>DD4W2</sub>    | V <sub>DD2</sub>                     | 400        |      |
| I <sub>DD4W,in</sub>  | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |
| I <sub>DD51</sub>     | V <sub>DD1</sub>                     | 40         | mA   |
| I <sub>DD52</sub>     | V <sub>DD2</sub>                     | 140        |      |
| I <sub>DD5,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |      |

**Table 6: I<sub>DD</sub> Specifications (64 Meg x 32) (Continued)**
 $V_{DD2}, V_{DDQ}, V_{DDCA} = 1.14\text{--}1.30\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

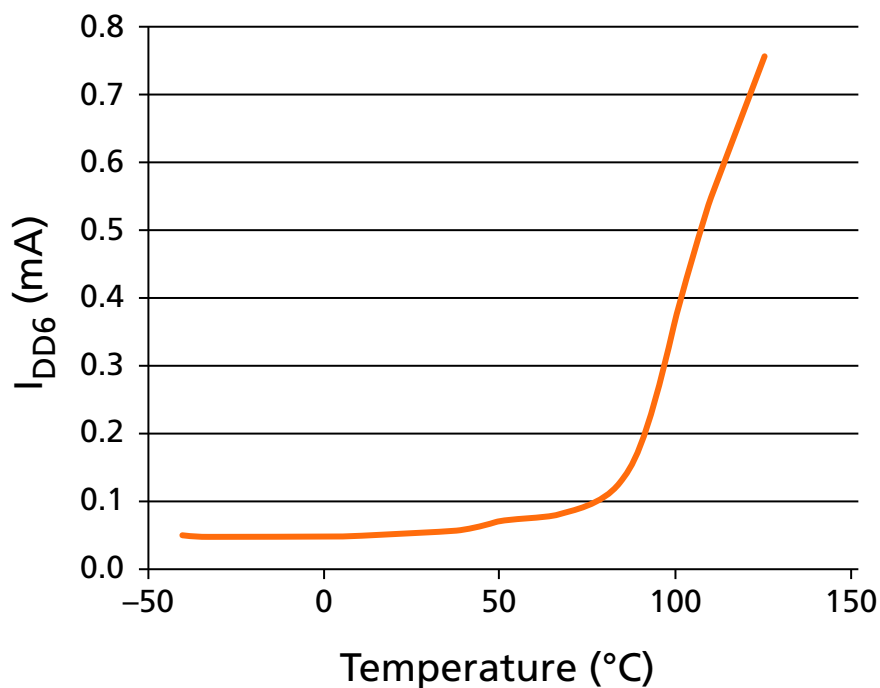
| Parameter             | Supply                               | Clock Rate | Unit    |
|-----------------------|--------------------------------------|------------|---------|
|                       |                                      | 533 MHz    |         |
| I <sub>DD5PB1</sub>   | V <sub>DD1</sub>                     | 4          | mA      |
| I <sub>DD5PB2</sub>   | V <sub>DD2</sub>                     | 46         |         |
| I <sub>DD5PB,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |         |
| I <sub>DD5AB1</sub>   | V <sub>DD1</sub>                     | 4          | mA      |
| I <sub>DD5AB2</sub>   | V <sub>DD2</sub>                     | 46         |         |
| I <sub>DD5AB,in</sub> | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 2          |         |
| I <sub>DD61</sub>     | V <sub>DD1</sub>                     | –          | Table 7 |
| I <sub>DD62</sub>     | V <sub>DD2</sub>                     | –          |         |
| I <sub>DD6,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | –          |         |
| I <sub>DD81</sub>     | V <sub>DD1</sub>                     | 100        | μA      |
| I <sub>DD82</sub>     | V <sub>DD2</sub>                     | 100        |         |
| I <sub>DD8,in</sub>   | V <sub>DDCA</sub> + V <sub>DDQ</sub> | 160        |         |

**Table 7: I<sub>DD6</sub> Partial-Array Self Refresh Current (64 Meg x 32)**
 $V_{DD2}, V_{DDQ}, V_{DDCA} = 1.14\text{--}1.30\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

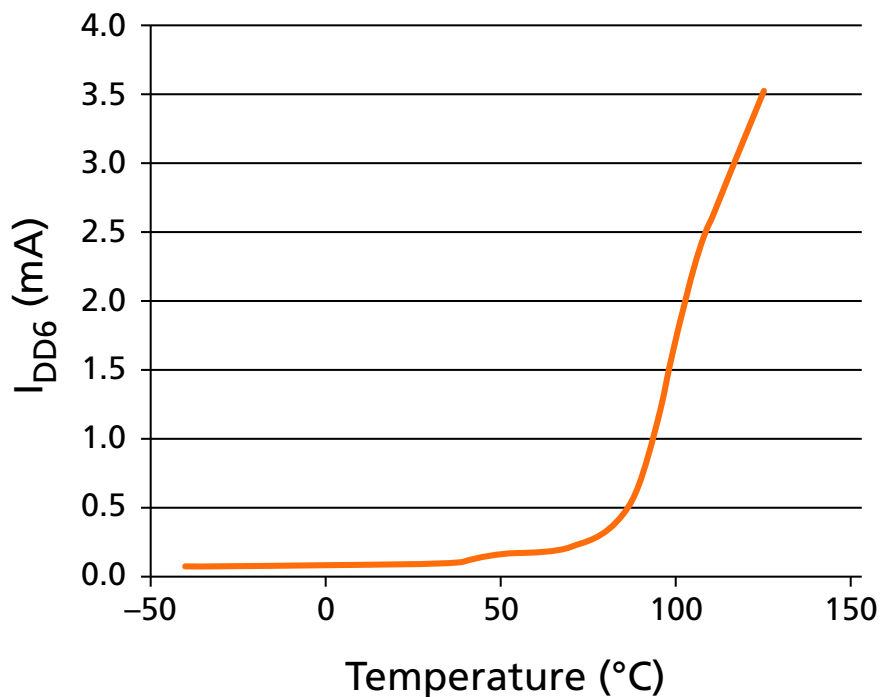
| PASR       | Supply           | I <sub>DD6</sub> Partial-Array Self Refresh Current |                 |                  | Unit |
|------------|------------------|-----------------------------------------------------|-----------------|------------------|------|
|            |                  | –40°C to +85°C                                      | +85°C to +105°C | +105°C to +125°C |      |
| Full array | V <sub>DD1</sub> | 700                                                 | 4200            | –                | μA   |
|            | V <sub>DD2</sub> | 4000                                                | 21400           | –                |      |
|            | V <sub>DDi</sub> | 60                                                  | 60              | –                |      |
| 1/2 array  | V <sub>DD1</sub> | 360                                                 | 4000            | –                |      |
|            | V <sub>DD2</sub> | 2900                                                | 12400           | –                |      |
|            | V <sub>DDi</sub> | 60                                                  | 60              | –                |      |
| 1/4 array  | V <sub>DD1</sub> | 480                                                 | 3600            | –                |      |
|            | V <sub>DD2</sub> | 2300                                                | 8000            | –                |      |
|            | V <sub>DDi</sub> | 60                                                  | 60              | –                |      |
| 1/8 array  | V <sub>DD1</sub> | 460                                                 | 3400            | –                |      |
|            | V <sub>DD2</sub> | 2000                                                | 6000            | –                |      |
|            | V <sub>DDi</sub> | 60                                                  | 60              | –                |      |

- Notes:
1. LPDDR2-S4 SDRAM devices support both bank-masking and segment-masking. I<sub>DD6</sub> PASR currents are measured using bank-masking only.
  2. When T<sub>C</sub> > 105°C: Self refresh mode is not available.

**Figure 2:  $V_{DD1}$  Typical Self-Refresh Current vs. Temperature (Per Die)**

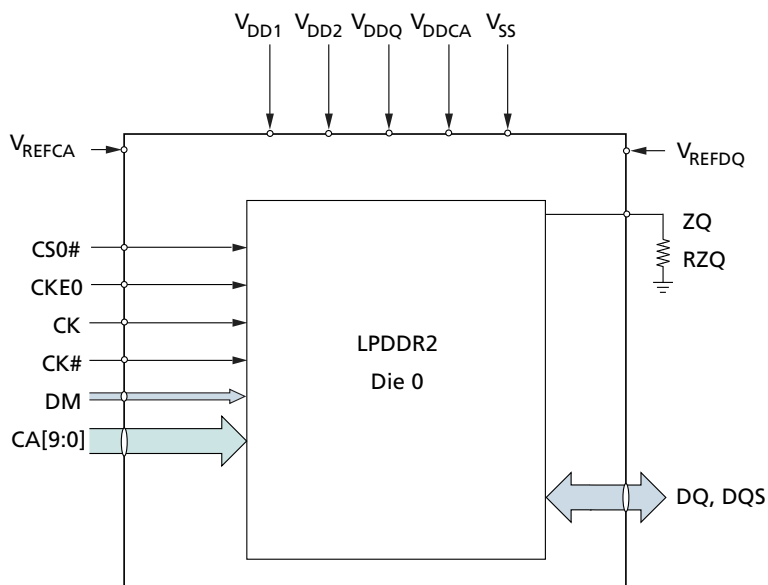


**Figure 3:  $V_{DD2}$  Typical Self-Refresh Current vs. Temperature (Per Die)**

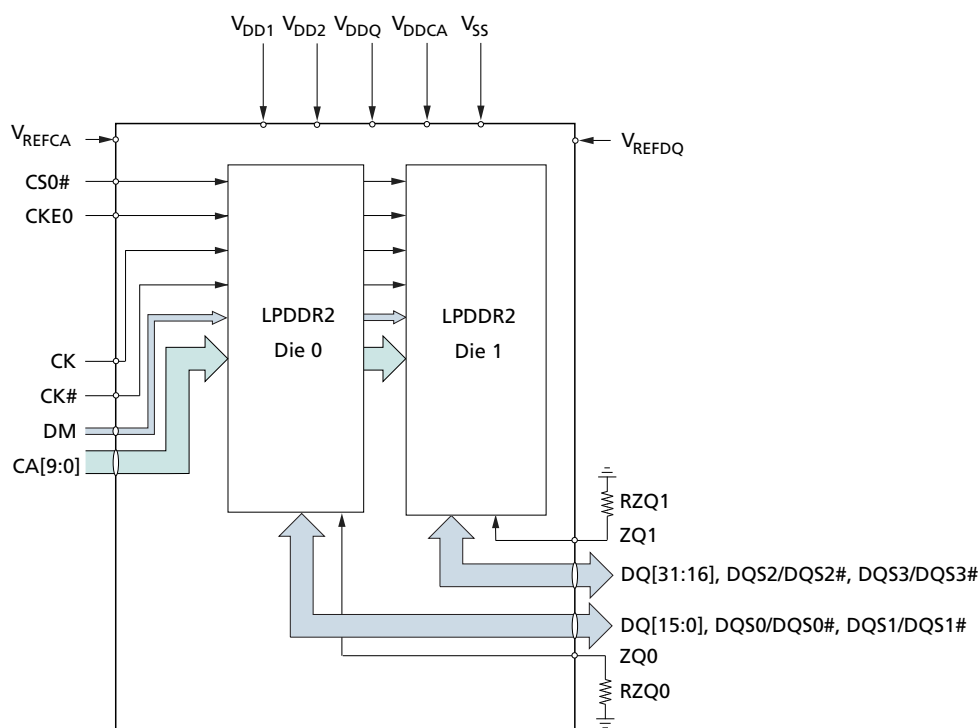


## Package Block Diagrams

**Figure 4: Single Die, Single Rank, Single Channel Package Block Diagram**

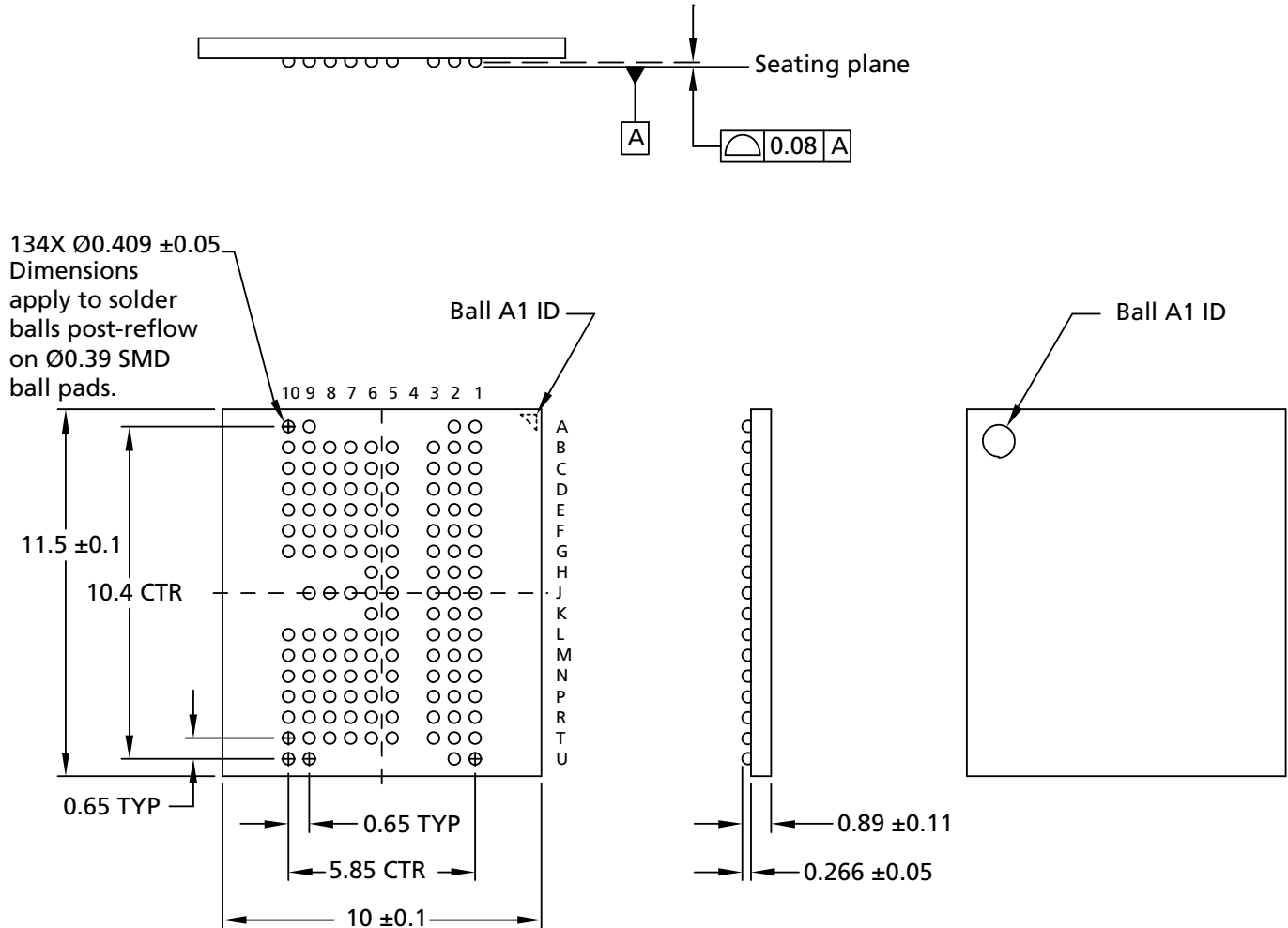


**Figure 5: Dual Die, Single Rank, Single Channel Package Block Diagram**



## Package Dimensions

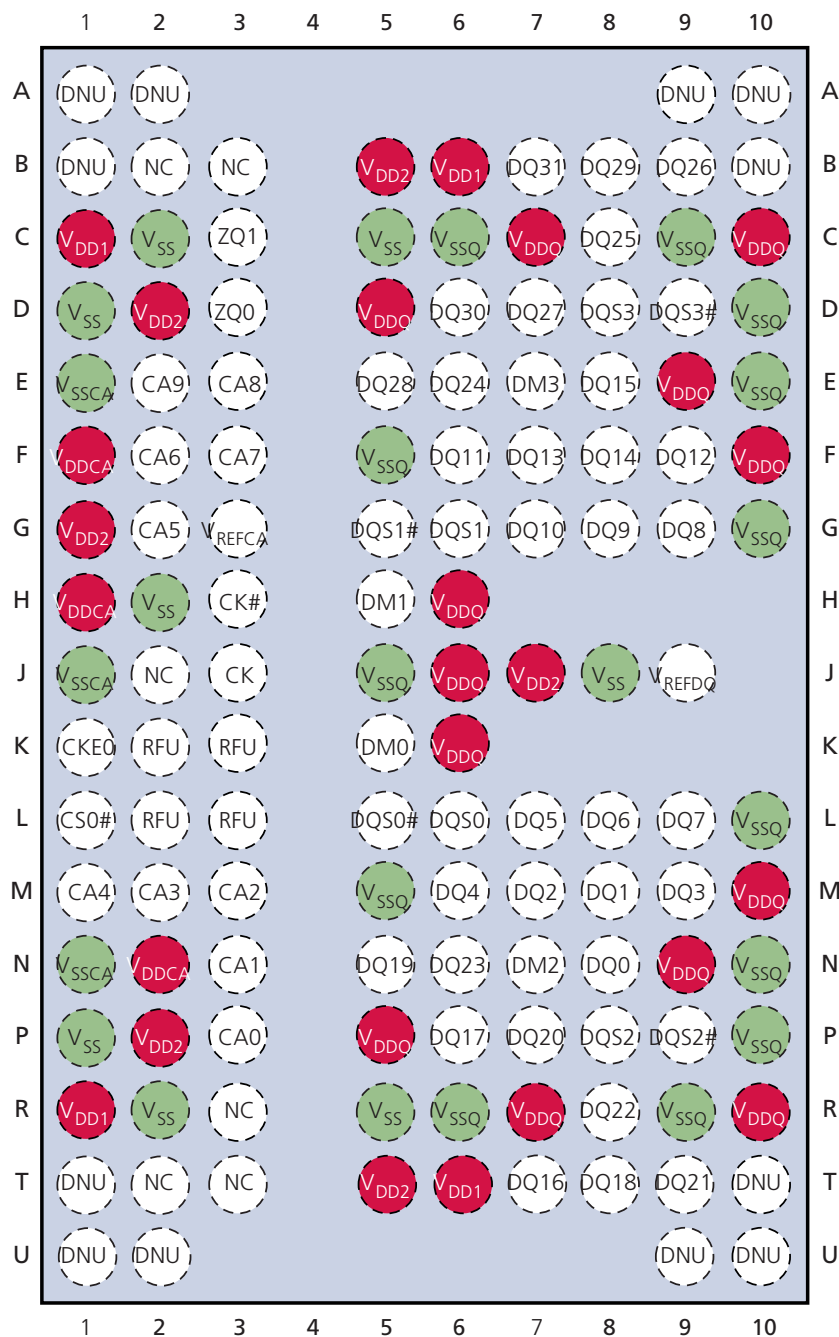
**Figure 6: 134-Ball VFBGA – 10mm x 11.5mm (Package Code: HE)**



Note: 1. All dimensions are in millimeters.

## Ball Assignments

**Figure 7: 134-Ball FBGA (32 Meg x 32, 64 Meg x 32)**



- Notes:
1. V<sub>DDCA</sub> is unnecessary. F1, H1, and N2 pins should be left unconnected.
  2. C3 pin is RFU for 32 Meg x 32, and is ZQ1 for 64 Meg x 32.

## 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 8: Ball/Pad Descriptions**

| Symbol                                  | Type      | Description                                                                                                                                                                                                                                                                        |
|-----------------------------------------|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CA[9:0]                                 | Input     | <b>Command/address inputs:</b> Provide the command and address inputs according to the command truth table.                                                                                                                                                                        |
| CK, CK#                                 | Input     | <b>Clock:</b> CK and CK# are 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     | <b>Clock enable:</b> 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 at the rising edge of CK. |
| CS[1:0]#                                | Input     | <b>Chip select:</b> CS# is considered part of the command code and is sampled at the rising edge of CK.                                                                                                                                                                            |
| DM[3:0]                                 | Input     | <b>Input data mask:</b> DM is an 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       | <b>Data input/output:</b> Bidirectional data bus.                                                                                                                                                                                                                                  |
| DQS[3:0],<br>DQS[3:0]#                  | I/O       | <b>Data strobe:</b> The data strobe is bidirectional (used for read and write data) and complementary (DQS and DQS#). It is edge-aligned output with read data and centered input with write data. DQS[3:0]/DQS[3:0]# is DQS for each of the four data bytes, respectively.        |
| V <sub>DDQ</sub>                        | Supply    | <b>DQ power supply:</b> Isolated on the die for improved noise immunity.                                                                                                                                                                                                           |
| V <sub>SSQ</sub>                        | Supply    | <b>DQ ground:</b> Isolated on the die for improved noise immunity.                                                                                                                                                                                                                 |
| V <sub>DDCA</sub>                       | Supply    | <b>Command/address power supply:</b> Command/address power supply.                                                                                                                                                                                                                 |
| V <sub>SSCA</sub>                       | Supply    | <b>Command/address ground:</b> Isolated on the die for improved noise immunity.                                                                                                                                                                                                    |
| V <sub>DD1</sub>                        | Supply    | <b>Core power:</b> Supply 1.                                                                                                                                                                                                                                                       |
| V <sub>DD2</sub>                        | Supply    | <b>Core power:</b> Supply 2.                                                                                                                                                                                                                                                       |
| V <sub>SS</sub>                         | Supply    | <b>Common ground</b>                                                                                                                                                                                                                                                               |
| V <sub>REFCA</sub> , V <sub>REFDQ</sub> | Supply    | <b>Reference voltage:</b> V <sub>REFCA</sub> is reference for command/address input buffers, V <sub>REFDQ</sub> is reference for DQ input buffers.                                                                                                                                 |
| ZQ                                      | Reference | <b>External impedance (240 ohm):</b> This signal is used to calibrate the device output impedance.                                                                                                                                                                                 |
| RFU                                     | –         | <b>Reserved for future use:</b> Must be left floating.                                                                                                                                                                                                                             |
| DNU                                     | –         | <b>Do not use:</b> Must be grounded or left floating.                                                                                                                                                                                                                              |
| NC                                      | –         | <b>No connect:</b> Not internally connected.                                                                                                                                                                                                                                       |
| (NC)                                    | –         | <b>No connect:</b> Balls indicated as (NC) are no connects, however, they could be connected together internally.                                                                                                                                                                  |

Mobile LPDDR2 is a high-speed SDRAM internally configured as a 4- or 8-bank memory device. LPDDR2 devices use 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.

LPDDR2-S4 devices use a double data rate architecture on the DQ pins to achieve high-speed operation. The double data rate architecture is essentially a  $4n$  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  $4n$ -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 accesses are burst oriented; accesses start at a selected location and continue for a programmed number of locations in a programmed sequence.

Accesses begin with the registration of an **ACTIVATE** command followed by a **READ** or **WRITE** command. The address and BA bits registered coincident with the **ACTIVATE** command are used to select the row and bank to be accessed. The address bits registered coincident with the **READ** or **WRITE** command are used to select the bank and the starting column location for the burst access.

## Power-Up

The following sequence must be used to power up the device. Unless specified otherwise, this procedure is mandatory (see Figure 9 (page 23)). Power-up and initialization by means other than those specified will result in undefined operation.

### 1. Voltage Ramp

While applying power (after  $T_a$ ), CKE must be held LOW ( $\leq 0.2 \times V_{DDCA}$ ), 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 ( $T_b$ ), CKE must be held LOW. DQ, DM, DQS, and DQS# voltage levels must be between  $V_{SSQ}$  and  $V_{DDQ}$  during voltage ramp to avoid latchup. CK, CK#, CS#, and CA input levels must be between  $V_{SSCA}$  and  $V_{DDCA}$  during voltage ramp to avoid latchup.

The following conditions apply for voltage ramp:

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

#### Voltage Ramp Completion

After  $T_a$  is reached:

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

Beginning at  $T_b$ , 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 ( $T_c$ ). CKE, CS#, 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  $t_{INIT3} = 200\mu s$  ( $T_d$ ).

### 2. RESET Command

After  $t_{INIT3}$  is satisfied, the MRW RESET command must be issued ( $T_d$ ). 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.

### 3. MRRs and Device Auto Initialization (DAI) Polling

After  $t_{\text{INIT4}}$  is satisfied ( $T_e$ ), only MRR commands and power-down entry/exit commands are supported. After  $T_e$ , 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  $t_{\text{INIT5}}$ , or until the DAI bit is set, before proceeding.

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

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

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

### 4. ZQ Calibration

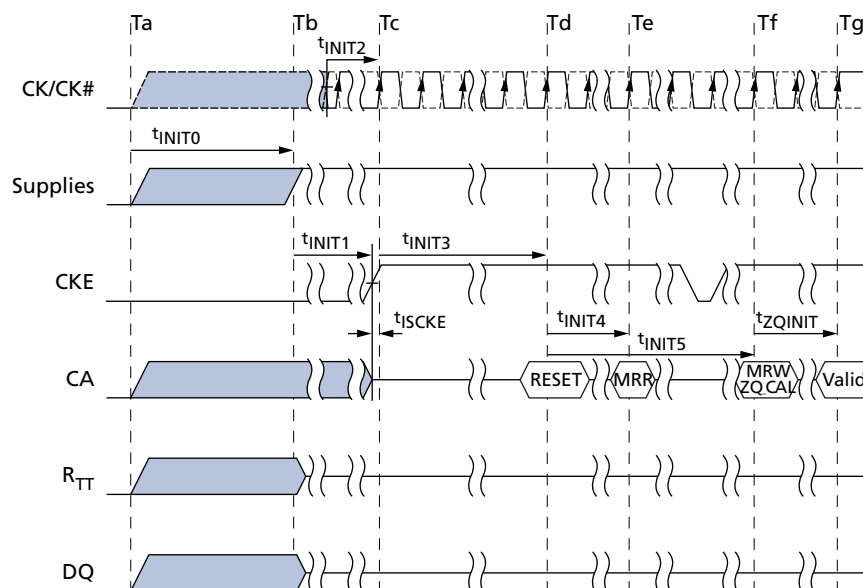
After  $t_{\text{INIT5}}$  ( $T_f$ ), the MRW initialization calibration (ZQ calibration) command can be issued to the memory (MR10).

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  $t_{\text{ZQINIT}}$ .

### 5. Normal Operation

After ( $T_g$ ), MRW commands must be used to properly configure the memory (output buffer drive strength, latencies, etc.). 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  $T_g$ , the clock frequency can be changed using the procedure described in Input Clock Frequency Changes and Stop Events.

**Figure 9: Voltage Ramp and Initialization Sequence**


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

**Table 9: 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   | –   | $\mu s$  | Minimum idle time after first CKE assertion           |
| $t_{INIT4}$  | 1     | –   | $\mu s$  | Minimum idle time after RESET command                 |
| $t_{INIT5}$  | –     | 10  | $\mu s$  | Maximum duration of device auto initialization        |
| $t_{ZQINIT}$ | 1     | –   | $\mu s$  | 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, please 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

While powering off, CKE must be held LOW ( $\leq 0.2 \times V_{DDCA}$ ); all other inputs must be between  $V_{ILmin}$  and  $V_{IHmax}$ . The device outputs remain at High-Z while CKE is held LOW.

DQ, DM, DQS, and DQS# voltage levels must be between  $V_{SSQ}$  and  $V_{DDQ}$  during the power-off sequence to avoid latchup. CK, CK#, CS#, and CA input levels must be between  $V_{SSCA}$  and  $V_{DDCA}$  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  $V_{DD2} - 200\text{mV}$
- $V_{DD1}$  must be greater than  $V_{DDCA} - 200\text{mV}$
- $V_{DD1}$  must be greater than  $V_{DDQ} - 200\text{mV}$
- $V_{REF}$  must always be less than all other supply voltages

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

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

## Uncontrolled Power-Off

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  $0.5\text{ V}/\mu\text{s}$  between Tx and Tz.

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

**Table 10: Power-Off Timing**

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

## Mode Register Definition

LPDDR2 devices contain 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.

**Table 11: 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      |              | DNVI | DI  | DAI | go to MR0   |
| 1       | 01h       | Device feature 1         | W      | nWR (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  |
| 18–19   | 12h–13h   | Reserved                 | –      | RFU                       |     |         |           |              |      |     |     | go to MR18  |
| 20–31   | 14h–1Fh   | Reserved for NVM         |        |                           |     |         |           |              |      |     |     | MR20–MR30   |
| 32      | 20h       | DQ calibration pattern A | R      | See Table 48 (page 71).   |     |         |           |              |      |     |     | go to MR32  |
| 33–39   | 21h–27h   | Do not use               |        |                           |     |         |           |              |      |     |     | go to MR33  |
| 40      | 28h       | DQ calibration pattern B | R      | See Table 48 (page 71).   |     |         |           |              |      |     |     | 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.

**Table 12: MR0 Device Information (MA[7:0] = 00h)**

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

**Table 13: 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                                                                   |
|                                        |      |           |         | 1b: NVM                                                              |
| Data not valid information             | DNVI | Read-only | OP2     | 0b: DNVI not supported                                               |
| Built-in self test for RZQ information | RZQI | Read-only | OP[4:3] | 00b: RZQ self test not supported                                     |
|                                        |      |           |         | 01b: ZQ pin might be connected to V <sub>DDCA</sub> or left floating |
|                                        |      |           |         | 10b: ZQ pin might be shorted to ground                               |
|                                        |      |           |         | 11b: ZQ pin self test complete; no error condition detected          |

- 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<sub>DDCA</sub> to set default calibration, OP[4:3] must be set to 01. If ZQ is not connected to V<sub>DDCA</sub>, 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<sub>ON</sub> 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 14: MR1 Device Feature 1 (MA[7:0] = 01h)**

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

**Table 15: MR1 Op-Code Bit Definitions**

| Feature                          | Type       | OP      | Definition               | Notes |
|----------------------------------|------------|---------|--------------------------|-------|
| BL = burst length                | Write-only | OP[2:0] | 010b: BL4 (default)      |       |
|                                  |            |         | 011b: BL8                |       |
|                                  |            |         | 100b: BL16               |       |
|                                  |            |         | All others: Reserved     |       |
| BT = burst type                  | Write-only | OP3     | 0b: Sequential (default) |       |
|                                  |            |         | 1b: Interleaved          |       |
| WC = wrap control                | Write-only | OP4     | 0b: Wrap (default)       |       |
|                                  |            |         | 1b: No wrap              |       |
| nWR = number of tWR clock cycles | Write-only | OP[7:5] | 001b: nWR = 3 (default)  | 1     |
|                                  |            |         | 010b: nWR = 4            |       |
|                                  |            |         | 011b: nWR = 5            |       |
|                                  |            |         | 100b: nWR = 6            |       |
|                                  |            |         | 101b: nWR = 7            |       |
|                                  |            |         | 110b: nWR = 8            |       |
|                                  |            |         | All others: Reserved     |       |

Note: 1. The programmed value in nWR 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 16: Burst Sequence by Burst Length (BL), Burst Type (BT), and Wrap Control (WC)**

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 |
| 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 | Wrap    | 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)                       |       |       |       |   |   |   |   |   |    |    |    |    |    |    |    |
|    |     |    |    |    |    |         |                                               |       |       |       |   |   |   |   |   |    |    |    |    |    |    |    |
|    |     |    |    |    |    |         |                                               |       |       |       |   |   |   |   |   |    |    |    |    |    |    |    |

**Table 16: 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 | Illegal (not supported) |                                               |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |
|    |     |    |    |    |    | No wrap                 |                                               |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |

- 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 17: 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 18: MR2 Device Feature 2 (MA[7:0] = 02h)**

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

**Table 19: 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 20: MR3 I/O Configuration 1 (MA[7:0] = 03h)**

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

**Table 21: 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 22: MR4 Device Temperature (MA[7:0] = 04h)**

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

**Table 23: MR4 Op-Code Bit Definitions**

Notes 1–10 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: $4 \times t_{REFI}$ , $4 \times t_{REFIpb}$ , $4 \times t_{REFW}$                                          |
|                               |           |         | 010b: $2 \times t_{REFI}$ , $2 \times t_{REFIpb}$ , $2 \times t_{REFW}$                                          |
|                               |           |         | 011b: $1 \times t_{REFI}$ , $1 \times t_{REFIpb}$ , $1 \times t_{REFW}$ ( $\leq 85^{\circ}\text{C}$ )            |
|                               |           |         | 100b: Reserved                                                                                                   |
|                               |           |         | 101b: $0.25 \times t_{REFI}$ , $0.25 \times t_{REFIpb}$ , $0.25 \times t_{REFW}$ , do not derate SDRAM AC timing |
|                               |           |         | 110b: $0.25 \times t_{REFI}$ , $0.25 \times t_{REFIpb}$ , $0.25 \times t_{REFW}$ , 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  $85^{\circ}\text{C}$ .
  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 (page 68).
  9. While the AT grade product is guaranteed to operate from  $T_{CASE} -40^{\circ}\text{C}$  to  $105^{\circ}\text{C}$ , the temperature sensor accuracy relative to this is not guaranteed. The temperature sensor embedded in the LPDDR2 device is not an accurate reflection of the DRAM  $T_{CASE}$  operating temperature. Sampling of the sensor has shown up to a  $\pm 7^{\circ}\text{C}$  variance from actual  $T_{CASE}$ .
  10. The temperature sensor does not work above  $105^{\circ}\text{C}$ , but the functionalities here described in this datasheet are guaranteed for products range up to  $125^{\circ}\text{C}$  (AUT).

**Table 24: MR5 Basic Configuration 1 (MA[7:0] = 05h)**

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

**Table 25: MR5 Op-Code Bit Definitions**

| Feature         | Type      | OP      | Definition           |
|-----------------|-----------|---------|----------------------|
| Manufacturer ID | Read-only | OP[7:0] | 1111 1111b: Micron   |
|                 |           |         | All others: Reserved |

**Table 26: MR6 Basic Configuration 2 (MA[7:0] = 06h)**

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

Note: 1. MR6 is vendor-specific.

**Table 27: MR6 Op-Code Bit Definitions**

| Feature      | Type      | OP      | Definition            |
|--------------|-----------|---------|-----------------------|
| Revision ID1 | Read-only | OP[7:0] | 0000 0000b: Version A |

**Table 28: MR7 Basic Configuration 3 (MA[7:0] = 07h)**

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

**Table 29: MR7 Op-Code Bit Definitions**

| Feature      | Type      | OP      | Definition            |
|--------------|-----------|---------|-----------------------|
| Revision ID2 | Read-only | OP[7:0] | 0000 0000b: Version A |

Note: 1. MR7 is vendor-specific.

**Table 30: MR8 Basic Configuration 4 (MA[7:0] = 08h)**

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

**Table 31: MR8 Op-Code Bit Definitions**

| Feature | Type      | OP      | Definition    |
|---------|-----------|---------|---------------|
| Type    | Read-only | OP[1:0] | 00b: S4 SDRAM |
|         |           |         | 01b: S2 SDRAM |
|         |           |         | 10b: NVM      |
|         |           |         | 11b: Reserved |

**Table 31: MR8 Op-Code Bit Definitions (Continued)**

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

**Table 32: MR9 Test Mode (MA[7:0] = 09h)**

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

**Table 33: MR10 Calibration (MA[7:0] = 0Ah)**

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

**Table 34: MR10 Op-Code Bit Definitions**

Notes 1–4 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  $V_{SSCA}$  through  $R_{ZQ}$ , either the ZQ calibration function (see MRW ZQ Calibration Commands (page 73)) or default calibration (through the ZQRESET command) is supported. If ZQ is connected to  $V_{DDCA}$ , 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.

**Table 35: MR[11:15] Reserved (MA[7:0] = 0Bh–0Fh)**

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

**Table 36: MR16 PASR Bank Mask (MA[7:0] = 010h)**

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

**Table 37: 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 38: 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 39: MR17 PASR Segment Mask Definitions**

| 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                           |

**Table 40: 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  | XXXXXXXX1    | 000b     |          |          |
| 1       | 1  | XXXXXX1X     | 001b     |          |          |
| 2       | 2  | XXXXX1XX     | 010b     |          |          |
| 3       | 3  | XXXX1XXX     | 011b     |          |          |

**Table 40: MR17 PASR Row Address Ranges in Masked Segments (Continued)**

| Segment | OP | Segment Mask | 1Gb      | 2Gb, 4Gb | 8Gb      |
|---------|----|--------------|----------|----------|----------|
|         |    |              | R[12:10] | R[13:11] | R[14:12] |
| 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 41: 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 <sup>1</sup> |          |     |     |     |     |     |     |     |
| MR[33:39]     |         | 21h–27h | DNU <sup>1</sup> |          |     |     |     |     |     |     |     |
| 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 <sup>1</sup> |          |     |     |     |     |     |     |     |
| 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 42: MR63 RESET (MA[7:0] = 3Fh) – MRW Only**

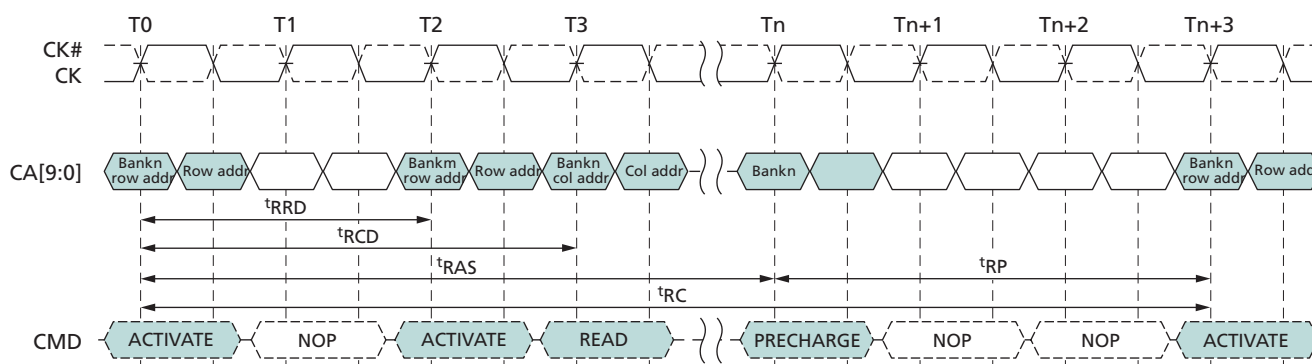
| OP7 | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
|-----|-----|-----|-----|-----|-----|-----|-----|
| X   |     |     |     |     |     |     |     |

Note: 1. For additional information on MRW RESET see MODE REGISTER WRITE Command (page 72).

## ACTIVATE Command

The ACTIVATE command is issued by holding CS# 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 10: ACTIVATE Command**



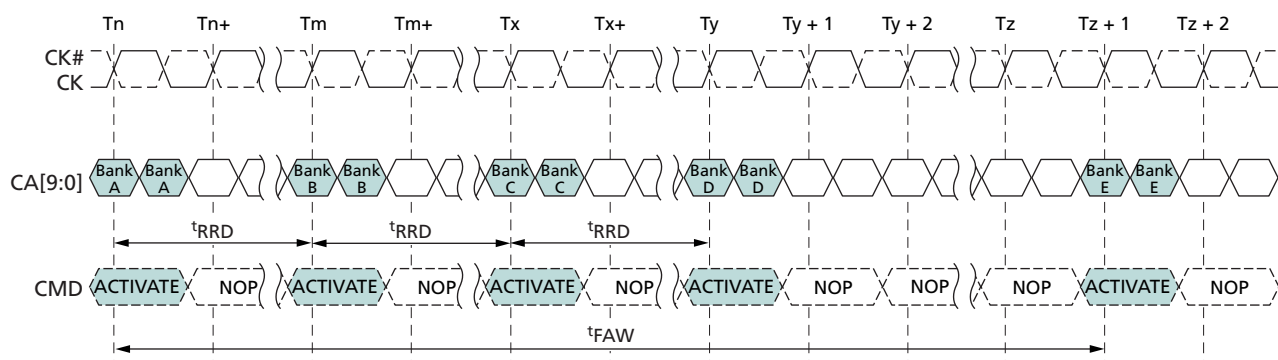
- Notes:
1.  $t_{RCD} = 3$ ,  $t_{RP} = 3$ ,  $t_{RRD} = 2$ .
  2. A PRECHARGE ALL command uses  $t_{RPab}$  timing, and a single-bank PRECHARGE command uses  $t_{RPpb}$  timing. In this figure,  $t_{RP}$  is used to denote either an all-bank PRECHARGE or a single-bank PRECHARGE.

## 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 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 example, if  $RU(t_{FAW}/t_{CK})$  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  $t_{FAW}$ .

**The 8-Bank Device PRECHARGE ALL Provision:**  $t_{RP}$  for a PRECHARGE ALL command must equal  $t_{RPab}$ , which is greater than  $t_{RPpb}$ .

**Figure 11:  $t_{FAW}$  Timing (8-Bank Devices)**


Note: 1. Exclusively for 8-bank devices.

## Read and Write Access Modes

After a bank is activated, a READ or WRITE command can be issued with CS# 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.

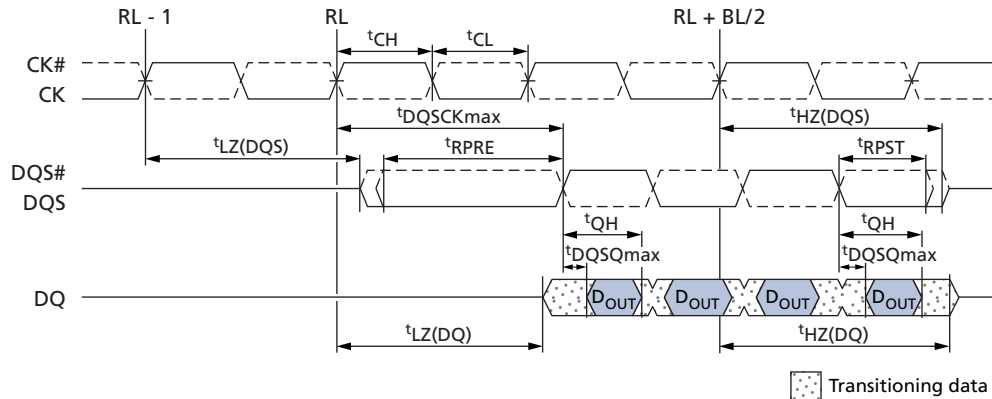
A new burst access must not interrupt the previous 4-bit burst operation when BL = 4. When BL = 8 or BL = 16, READs can be interrupted by READs and WRITEs can be interrupted by WRITEs, provided that the interrupt occurs on a 4-bit boundary and that  $t_{CCD}$  is met.

## Burst READ Command

The burst READ command is initiated with CS# 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  $RL \times t_{CK} + t_{DQSCK} + t_{DQSQ}$  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.

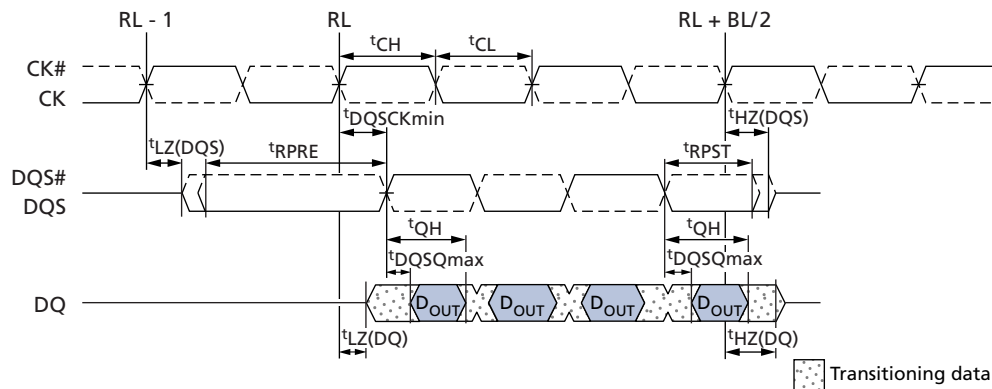
Pin input timings for the data strobe are measured relative to the crosspoint of DQS and its complement, DQS#.

**Figure 12: READ Output Timing –  $t_{DQSCK}$  (MAX)**



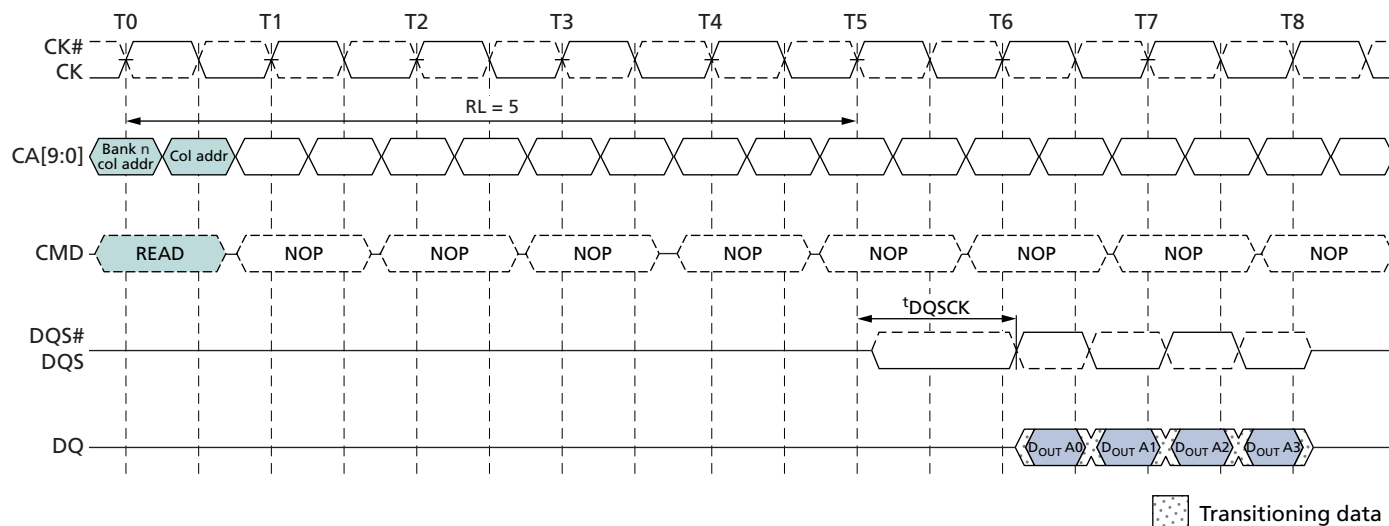
- Notes:
1.  $t_{DQSCK}$  can span multiple clock periods.
  2. An effective burst length of 4 is shown.

**Figure 13: READ Output Timing –  $t_{DQSCK}$  (MIN)**

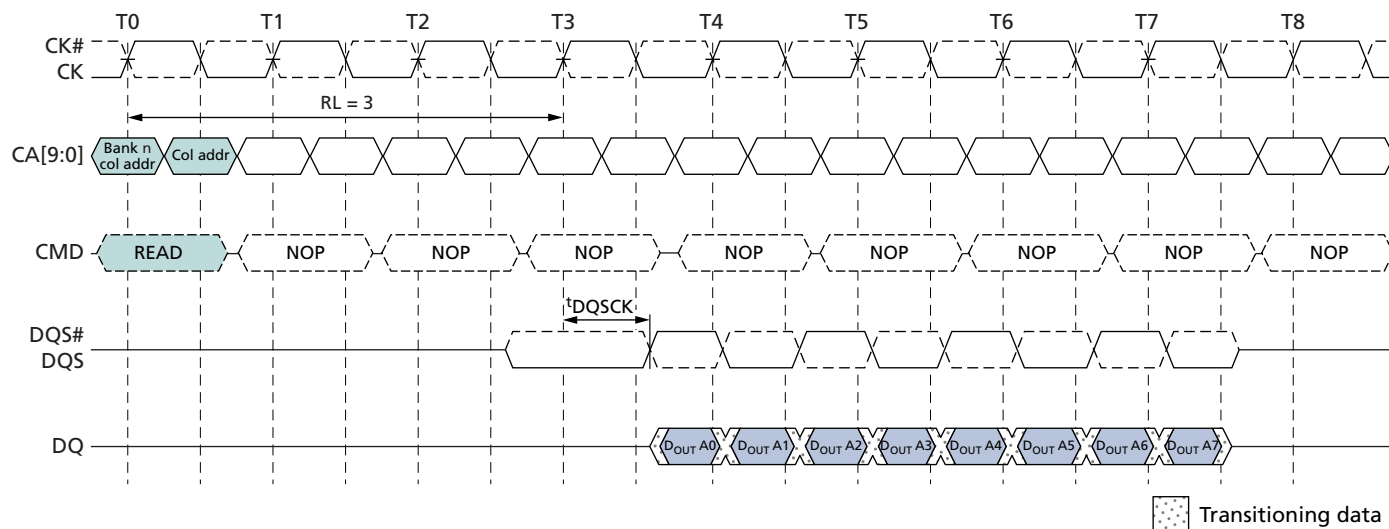


- Note:
1. An effective burst length of 4 is shown.

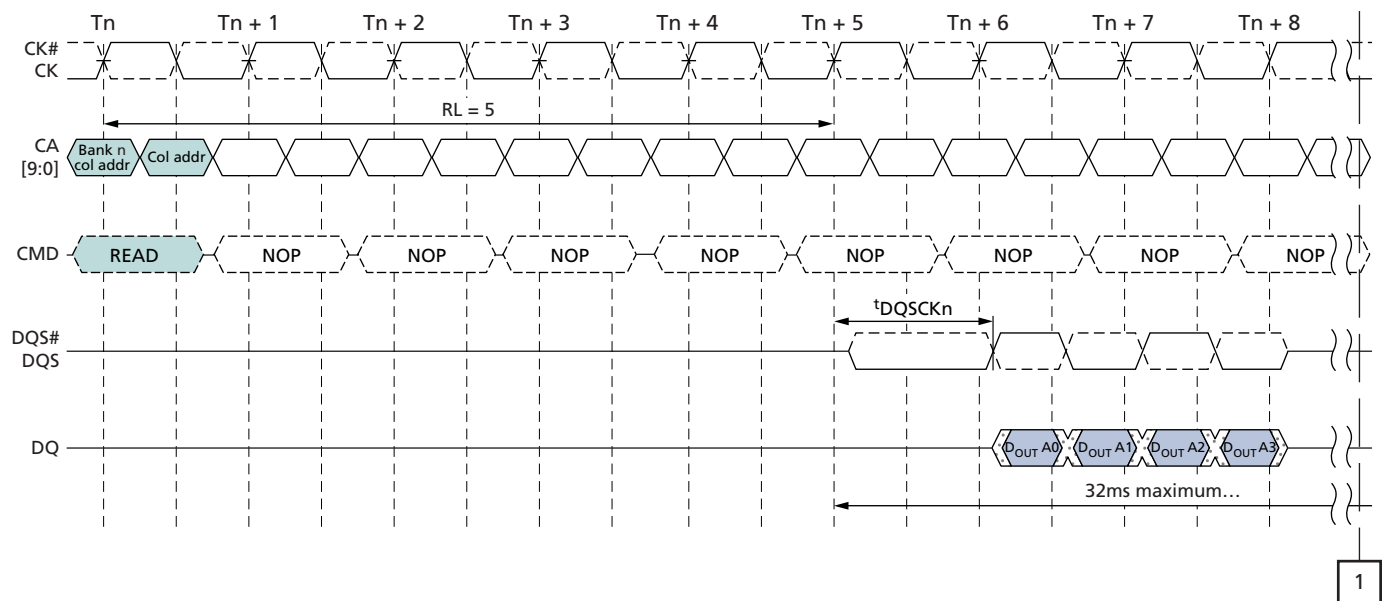
**Figure 14: Burst READ – RL = 5, BL = 4,  $t_{DQSCK} > t_{CK}$**



**Figure 15: Burst READ – RL = 3, BL = 8,  $t_{DQSCK} < t_{CK}$**

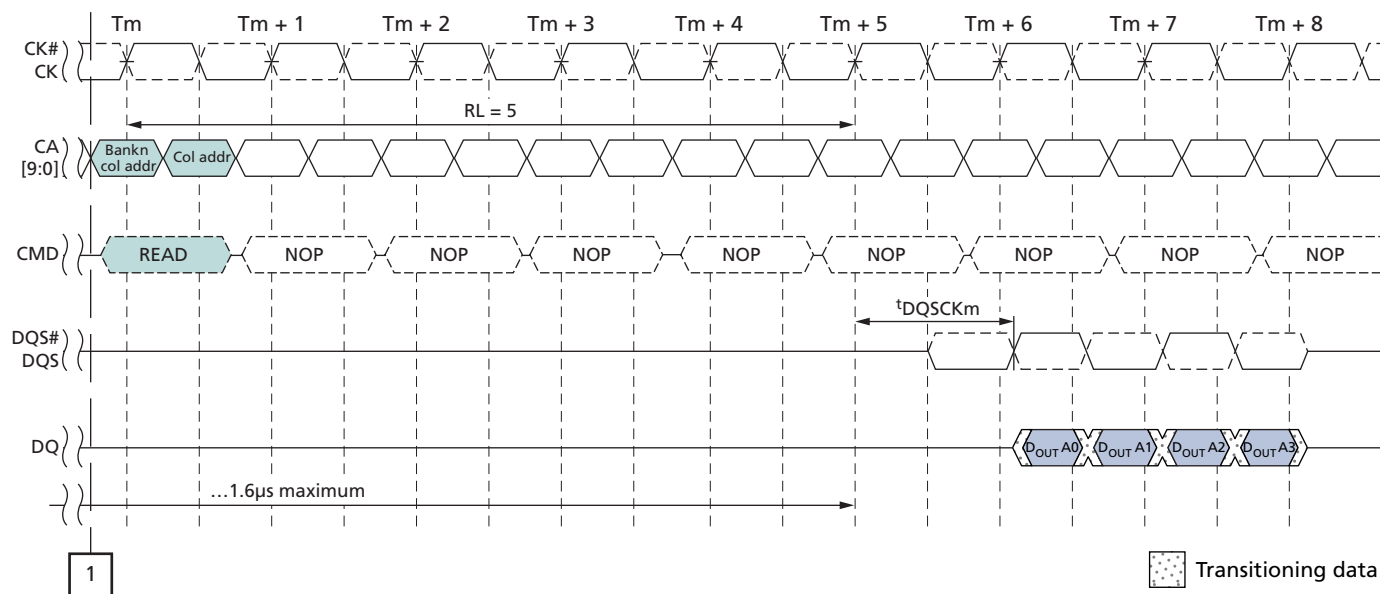
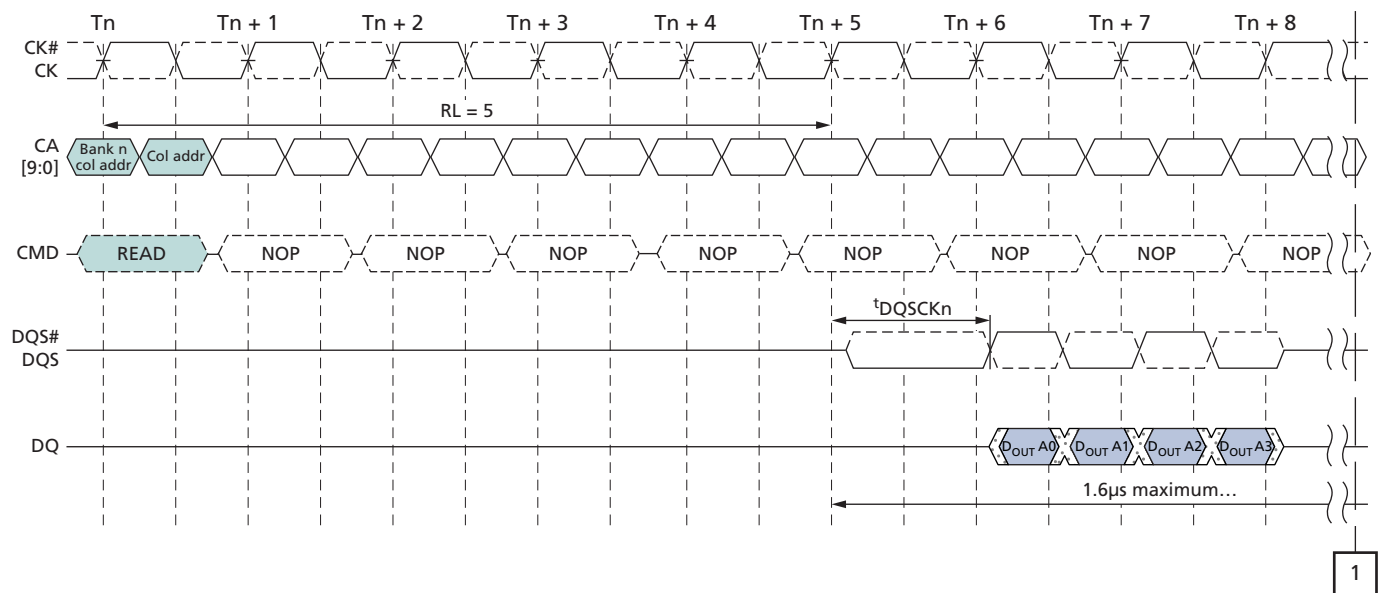


**Figure 16:  $t_{DQSKDL}$  Timing**



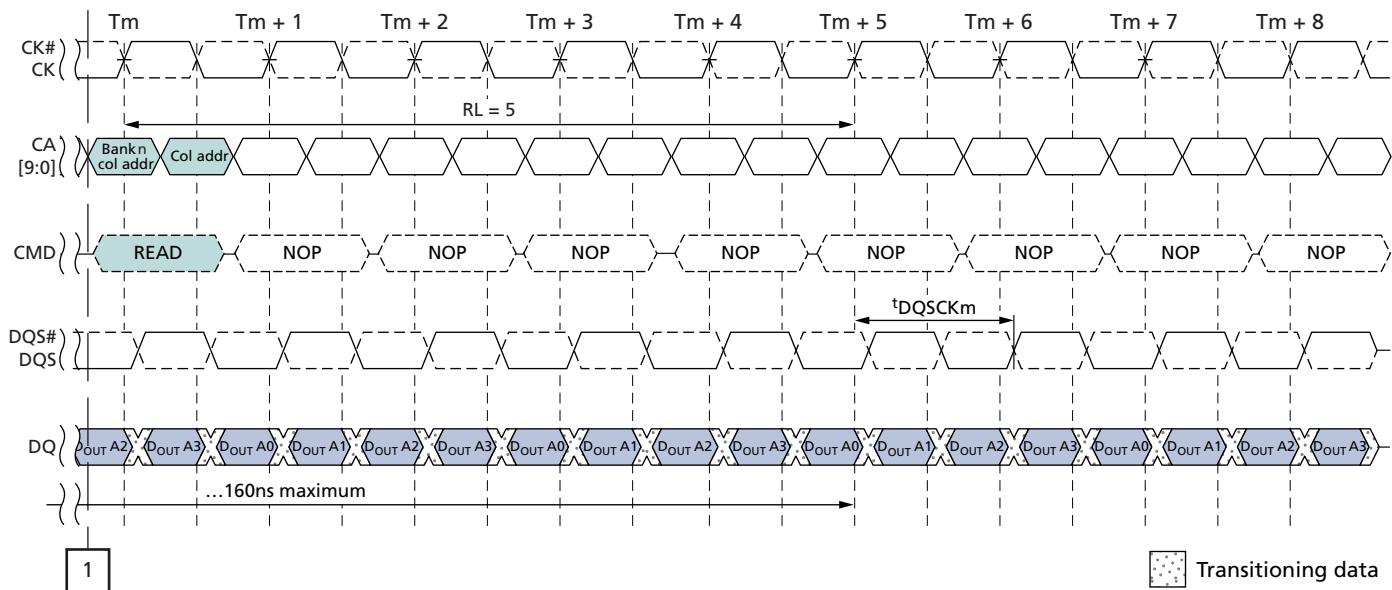
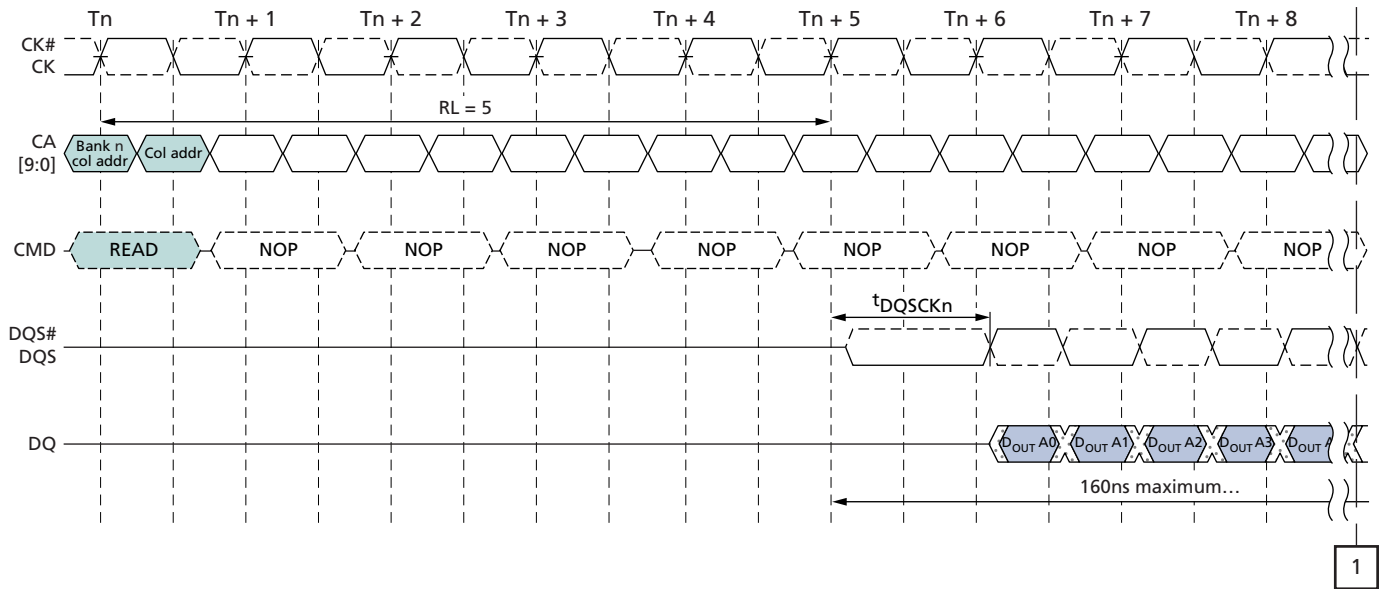
- Notes:
1.  $t_{DQSKDL} = (t_{DQSKn} - t_{DQSKm})$ .
  2.  $t_{DQSKDL} (MAX)$  is defined as the maximum of ABS ( $t_{DQSKn} - t_{DQSKm}$ ) for any ( $t_{DQSKn}$ ,  $t_{DQSKm}$ ) pair within any 32ms rolling window.

**Figure 17:  $t_{DQSCDM}$  Timing**



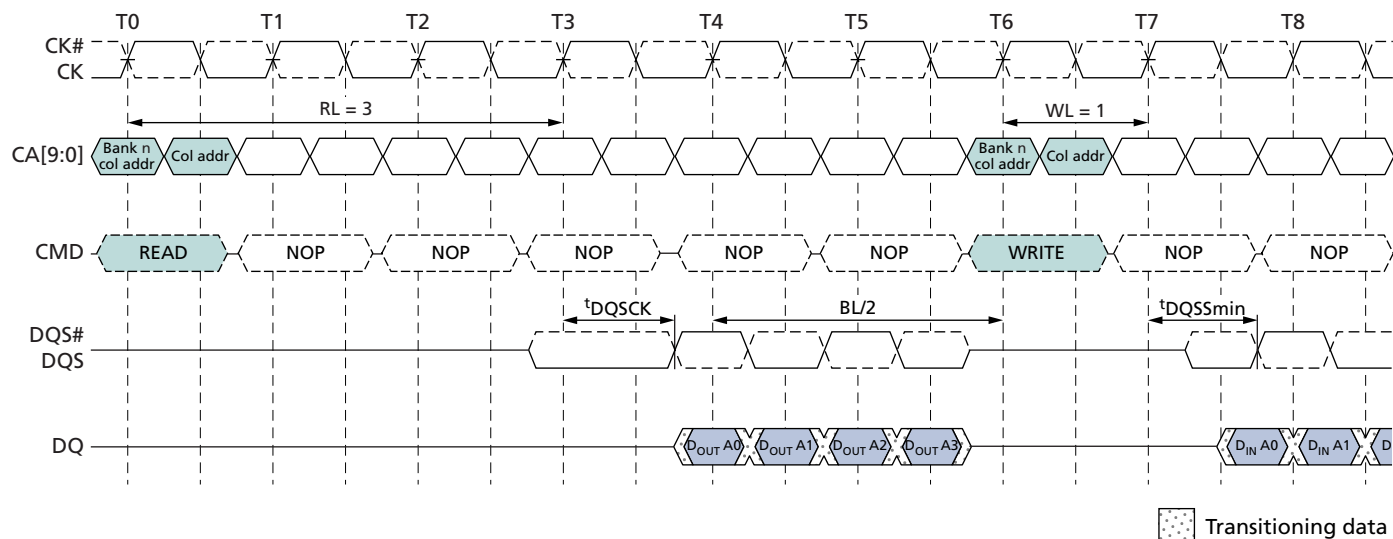
- Notes:
1.  $t_{DQSCDM} = (t_{DQSCn} - t_{DQSCm})$ .
  2.  $t_{DQSCDM} (MAX)$  is defined as the maximum of ABS ( $t_{DQSCn} - t_{DQSCm}$ ) for any ( $t_{DQSCn}$ ,  $t_{DQSCm}$ ) pair within any 1.6µs rolling window.

**Figure 18:  $t_{DQCKDS}$  Timing**



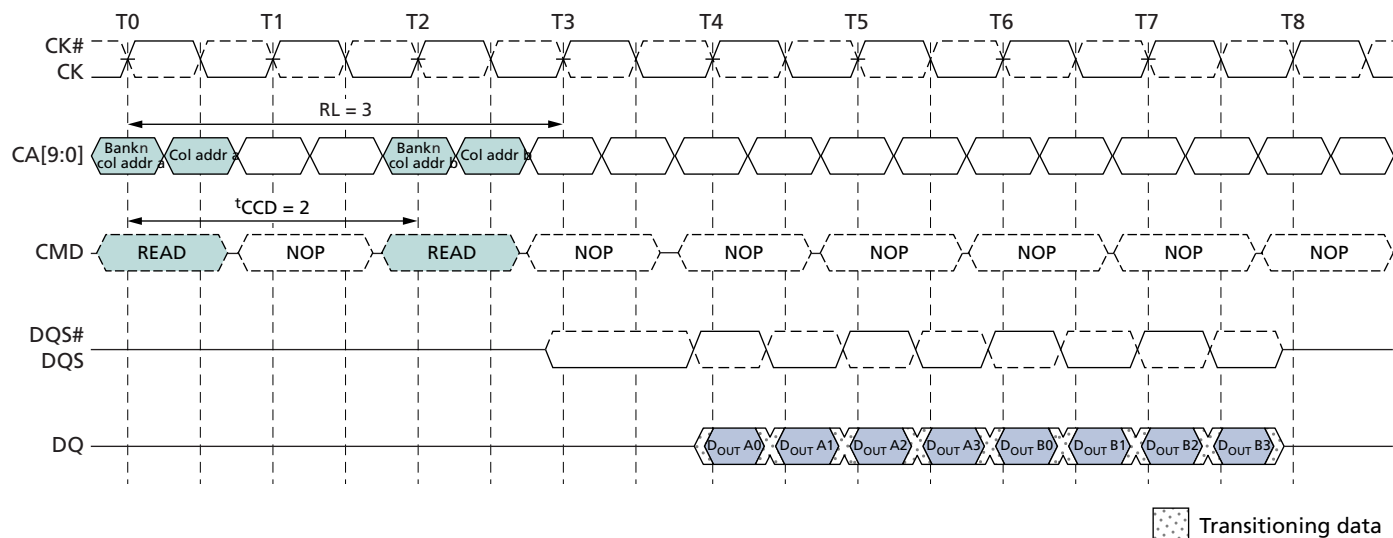
- Notes:
1.  $t_{DQCKDS} = (t_{DQCKn} - t_{DQCKm})$ .
  2.  $t_{DQCKDS} (MAX)$  is defined as the maximum of ABS ( $t_{DQCKn} - t_{DQCKm}$ ) for any ( $t_{DQCKn}$ ,  $t_{DQCKm}$ ) pair for READs within a consecutive burst, within any 160ns rolling window.

**Figure 19: 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  $RL + RU(^{tDQSCK}(MAX)/^{tCK}) + BL/2 + 1 - WL$  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 20: Seamless Burst READ – RL = 3, BL = 4,  $t_{CCD} = 2$**

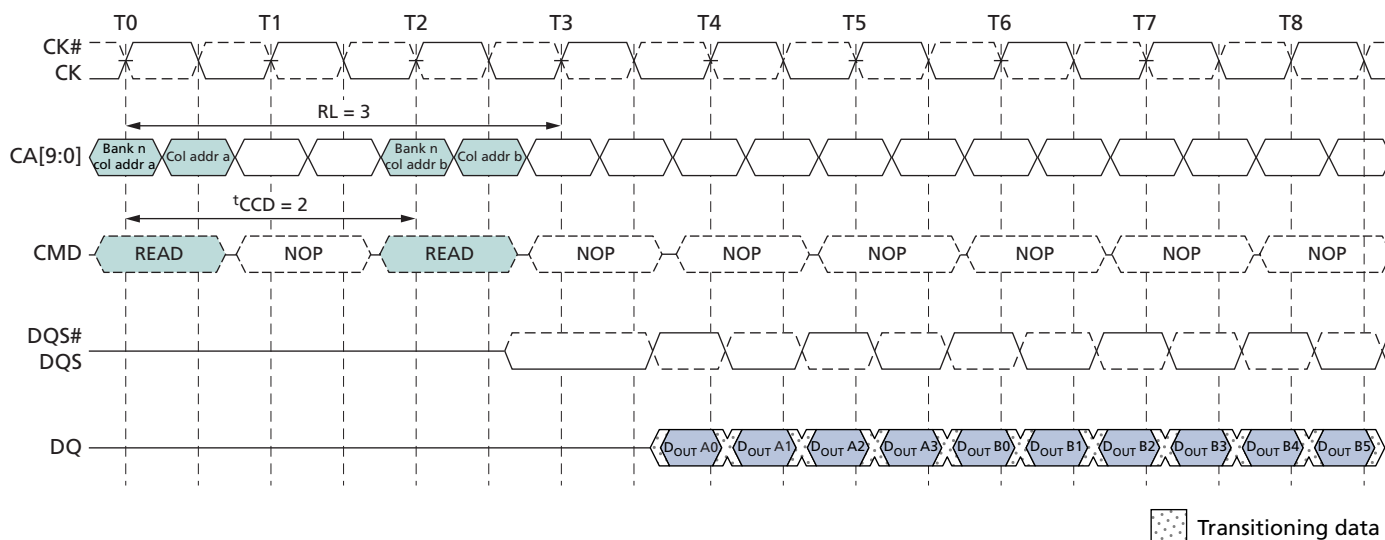


A seamless burst READ operation is supported by enabling a READ command at every other clock cycle for BL = 4 operation, every fourth clock cycle for BL = 8 operation, and every eighth clock cycle for BL = 16 operation. This operation is supported as long as the banks are activated, whether the accesses 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 21: READ Burst Interrupt Example – RL = 3, BL = 8,  $t_{CCD} = 2$**



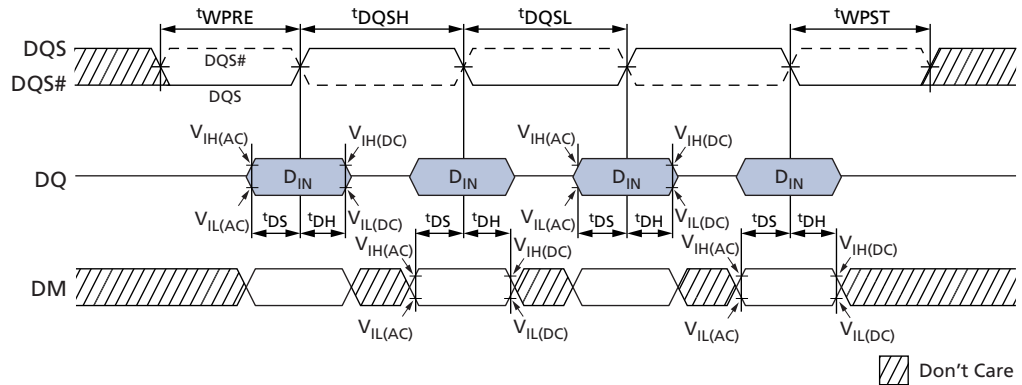
Note: 1. READs can only be interrupted by other READs or the BST command.

## Burst WRITE Command

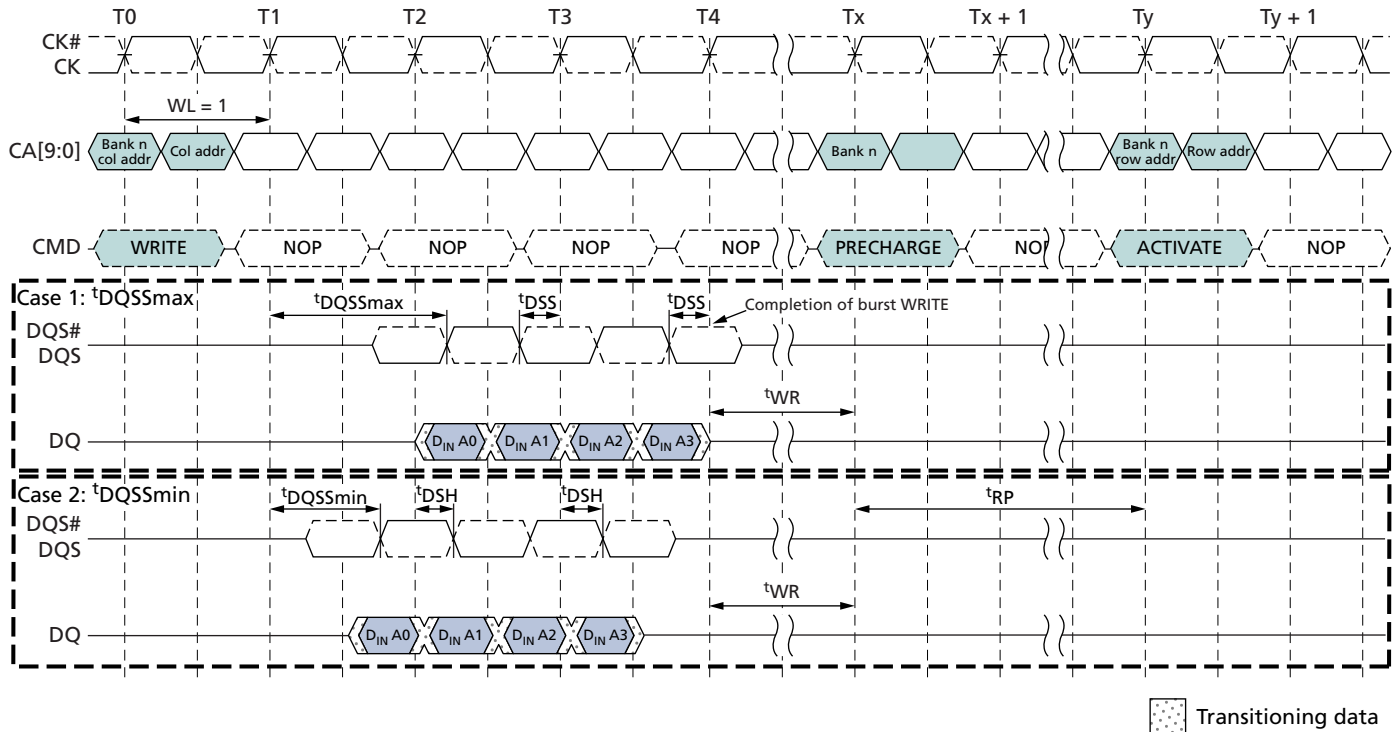
The burst WRITE command is initiated with CS# LOW, CA0 HIGH, CA1 LOW, and CA2 LOW at the rising edge of the clock. The command address bus inputs, CA5r–CA6r and CA1f–CA9f, determine the starting column address for the burst. Write latency (WL) is defined from the rising edge of the clock on which the 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  $WL \times t_{CK} + t_{DQSS}$  from the rising edge of the clock from which the WRITE command is issued. The data strobe signal (DQS) 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 and held valid until  $t_{DH}$  after that edge. Burst data is sampled on successive edges of the DQS until the 4-, 8-, or 16-bit burst length is completed. After a burst WRITE operation,  $t_{WR}$  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 and its complement, DQS#.

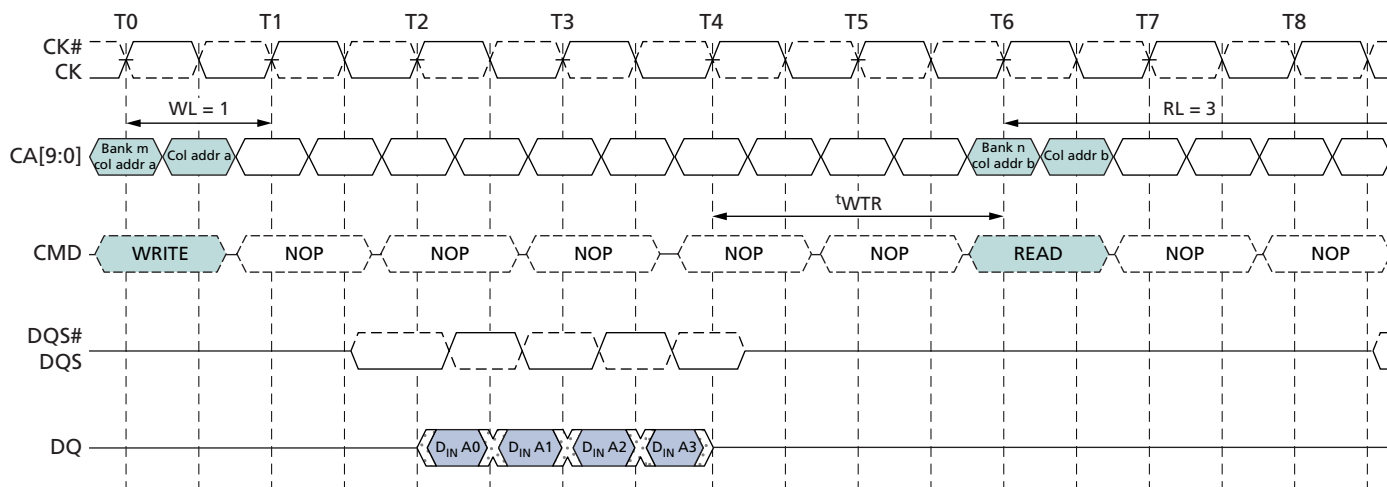
**Figure 22: Data Input (WRITE) Timing**



**Figure 23: Burst WRITE – WL = 1, BL = 4**



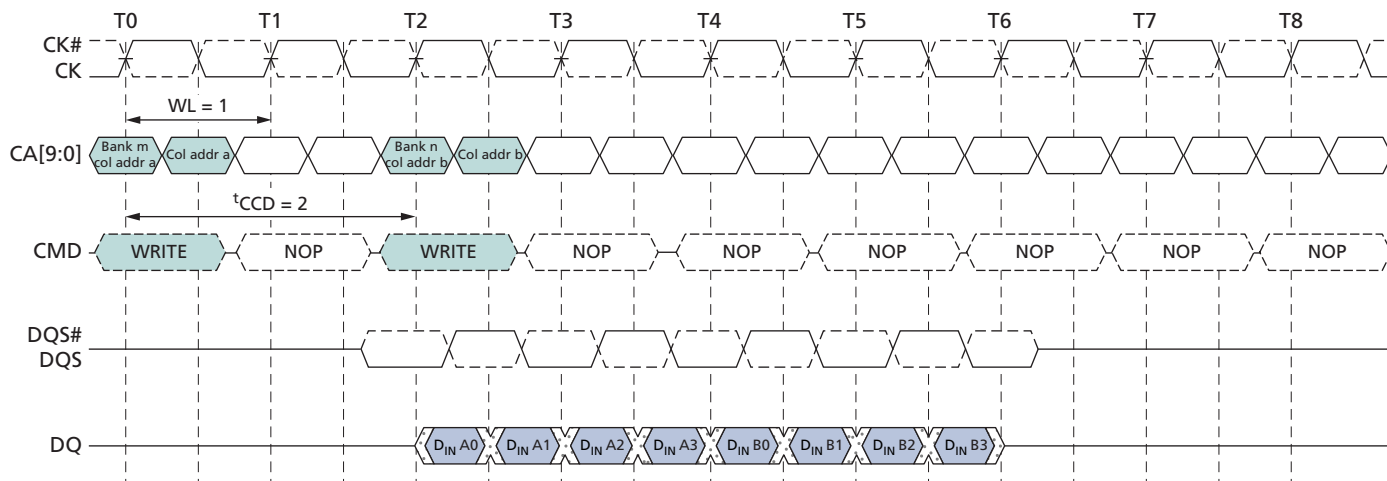
**Figure 24: Burst WRITE Followed by Burst READ – RL = 3, WL = 1, BL = 4**



Transitioning data

- 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 25: Seamless Burst WRITE – WL = 1, BL = 4,  $t_{CCD} = 2$**



Transitioning data

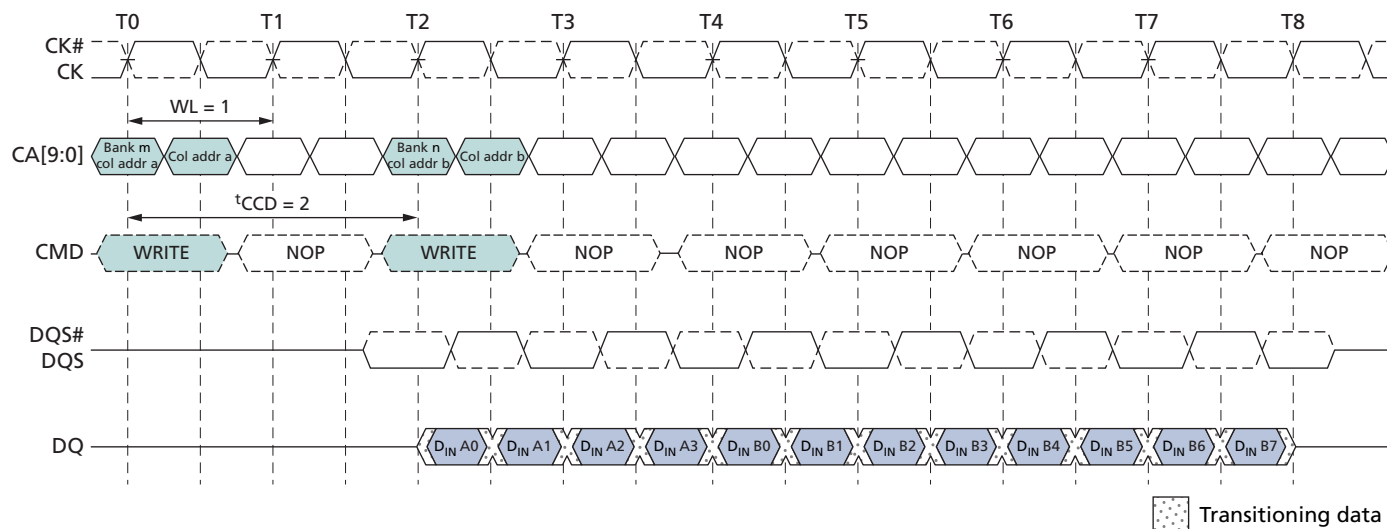
- Note:
1. The seamless burst WRITE operation is supported by enabling a WRITE command every other clock for BL = 4 operation, every four clocks for BL = 8 operation, or every eight clocks for BL = 16 operation. This operation is supported for any activated bank.

## WRITES Interrupted by a WRITE

A burst WRITE can only be interrupted 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 26: WRITE Burst Interrupt Timing – WL = 1, BL = 8,  $t_{CCD} = 2$**



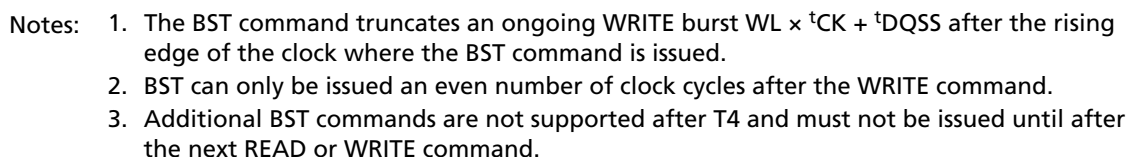
- Notes:
1. WRITES can only be interrupted by other WRITES or the BST command.
  2. The effective burst length of the first WRITE equals two times the number of clock cycles between the first WRITE and the interrupting WRITE.

## BURST TERMINATE Command

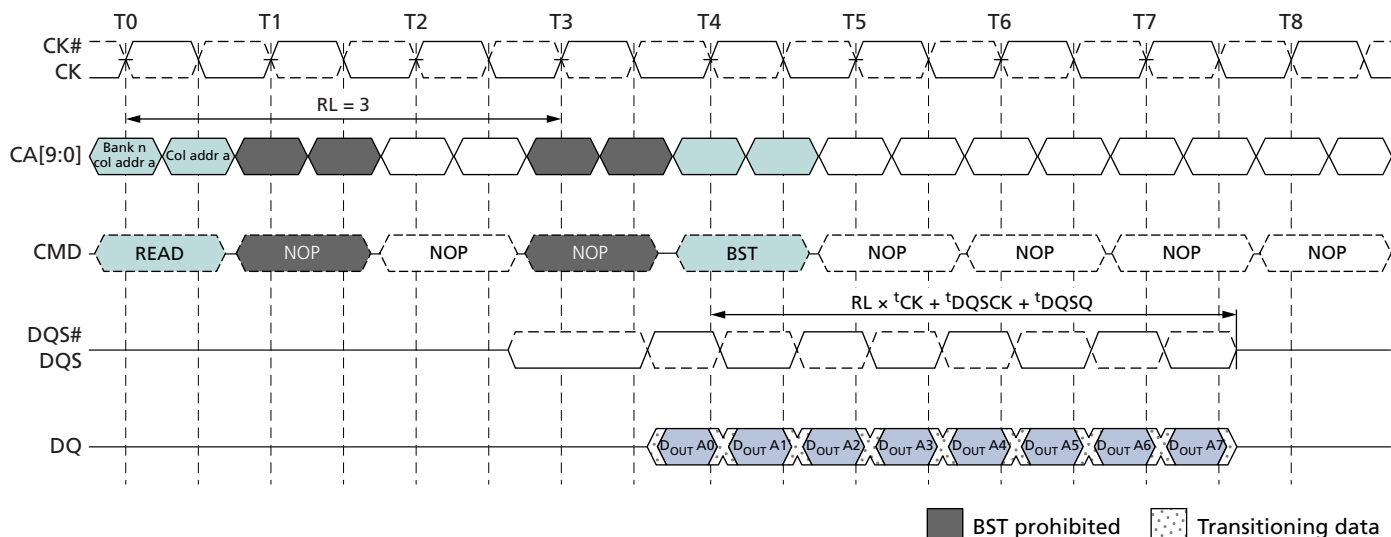
The BURST TERMINATE (BST) command is initiated with CS# LOW, CA0 HIGH, CA1 HIGH, CA2 LOW, and CA3 LOW at the rising edge of the clock. A BST command can only be issued to terminate an active READ or WRITE burst. Therefore, a BST command can only be issued up to and including  $BL/2 - 1$  clock cycles after a READ or WRITE command. The effective burst length of a READ or WRITE command truncated by a BST command is as follows:

- Effective burst length =  $2 \times (\text{number of clock cycles from the READ or WRITE command to the BST command})$ .
- 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  $RL \times t_{CK} + t_{DQSK} + t_{DQSQ}$  after the rising edge of the clock where the BST command is issued. The BST command truncates an ongoing WRITE burst  $WL \times t_{CK} + t_{DQSS}$  after the rising edge of the clock where the BST command is issued.

- Figure 27: Burst WRITE Truncated by BST – WL = 1, BL = 16**



**Figure 28: Burst READ Truncated by BST – RL = 3, BL = 16**

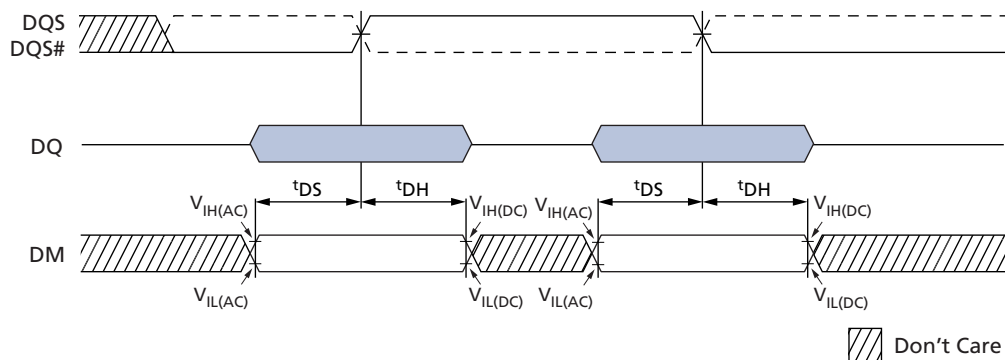


- Notes:
1. The BST command truncates an ongoing READ burst ( $RL \times t_{CK} + t_{DQSK} + t_{DQSQ}$ ) after the rising edge of the clock where the BST command is issued.
  2. BST can only be issued an even number of clock cycles after the READ command.
  3. Additional BST commands are not supported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

## Write Data Mask

On LPDDR2 devices, 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 29: Data Mask Timing**



The diagram illustrates two timing scenarios for a memory write operation:

- Case 1:  $t_{DQSSmin}$** 
  - CK#**: Clock signal with a period of  $WL = 2$ .
  - CMD**: Write command signal.
  - DQS#**: Data Strobe (inverted) signal. The time from the falling edge of DQS# to the first data output is  $t_{DQSSmin}$ .
  - DQ**: Data bus signal showing four data words ( $D_{OUT0}$  to  $D_{OUT3}$ ).
  - DM**: Data Mask signal, shown as a pulse during the write operation.
  - Annotations**:  $t_{WR}$  (Write Recovery Time) and  $t_{WTR}$  (Write Turnaround Time) are indicated for the clock signal.
- Case 2:  $t_{DQSSmax}$** 
  - DQS#**: Data Strobe (inverted) signal. The time from the falling edge of DQS# to the first data output is  $t_{DQSSmax}$ .
  - DQ**: Data bus signal showing four data words ( $D_{OUT0}$  to  $D_{OUT3}$ ).
  - DM**: Data Mask signal, shown as a pulse during the write operation.

A legend at the bottom right indicates that hatched areas represent "Don't Care" states.

## PRECHARGE Command

ACTIVATE to PRECHARGE timing is shown in ACTIVATE Command.

**Table 43: Bank Selection for PRECHARGE by Address Bits**

| AB (CA4r) | BA2 (CA9r) | BA1 (CA8r) | BA0 (CA7r) | Precharged Bank(s)<br>4-Bank Device | Precharged Bank(s)<br>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                           |

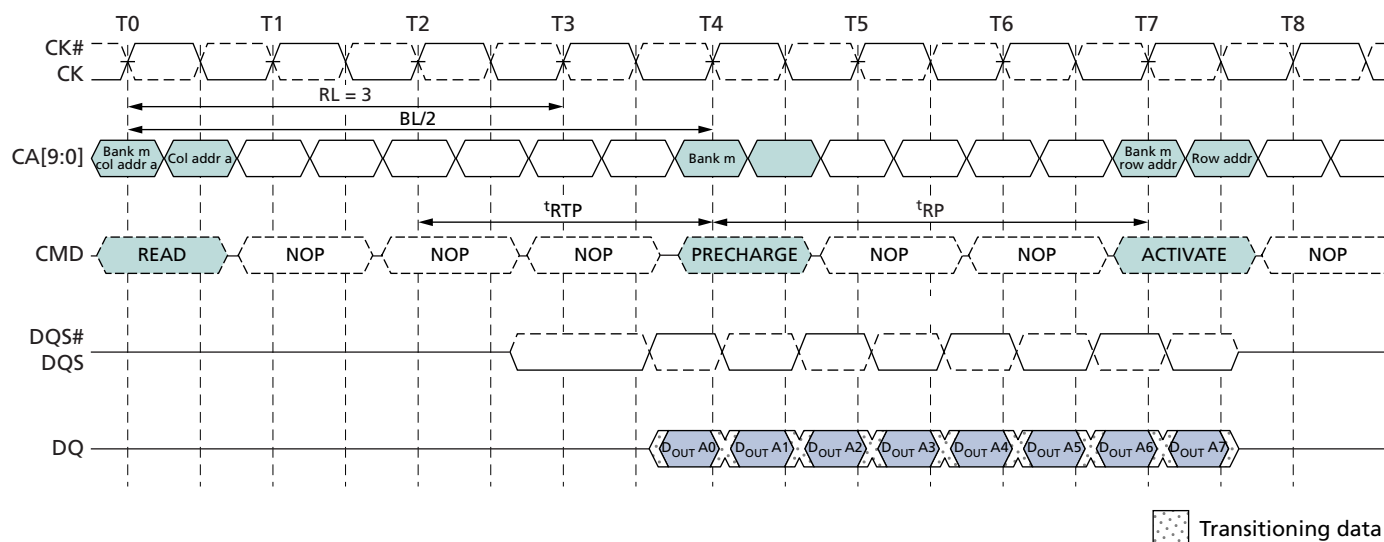
## READ Burst Followed by PRECHARGE

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.

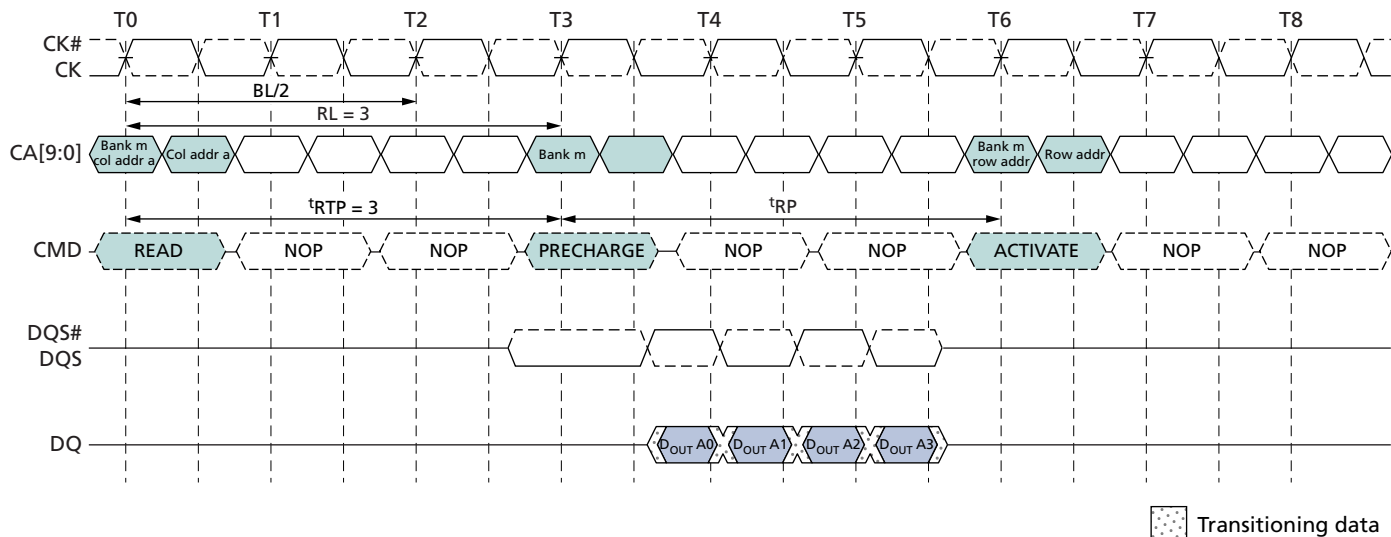
The minimum READ-to-PRECHARGE time ( $t_{RTP}$ ) must also satisfy a minimum analog time from the rising clock edge that initiates the last 4-bit prefetch of a READ command.  $t_{RTP}$  begins BL/2 - 2 clock cycles after the READ command.

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

**Figure 31: READ Burst Followed by PRECHARGE – RL = 3, BL = 8,  $RU(t_{RTP(MIN)}/t_{CK}) = 2$**



**Figure 32: READ Burst Followed by PRECHARGE – RL = 3, BL = 4,  $RU(t_{RTP}(\text{MIN})/t_{CK}) = 3$**



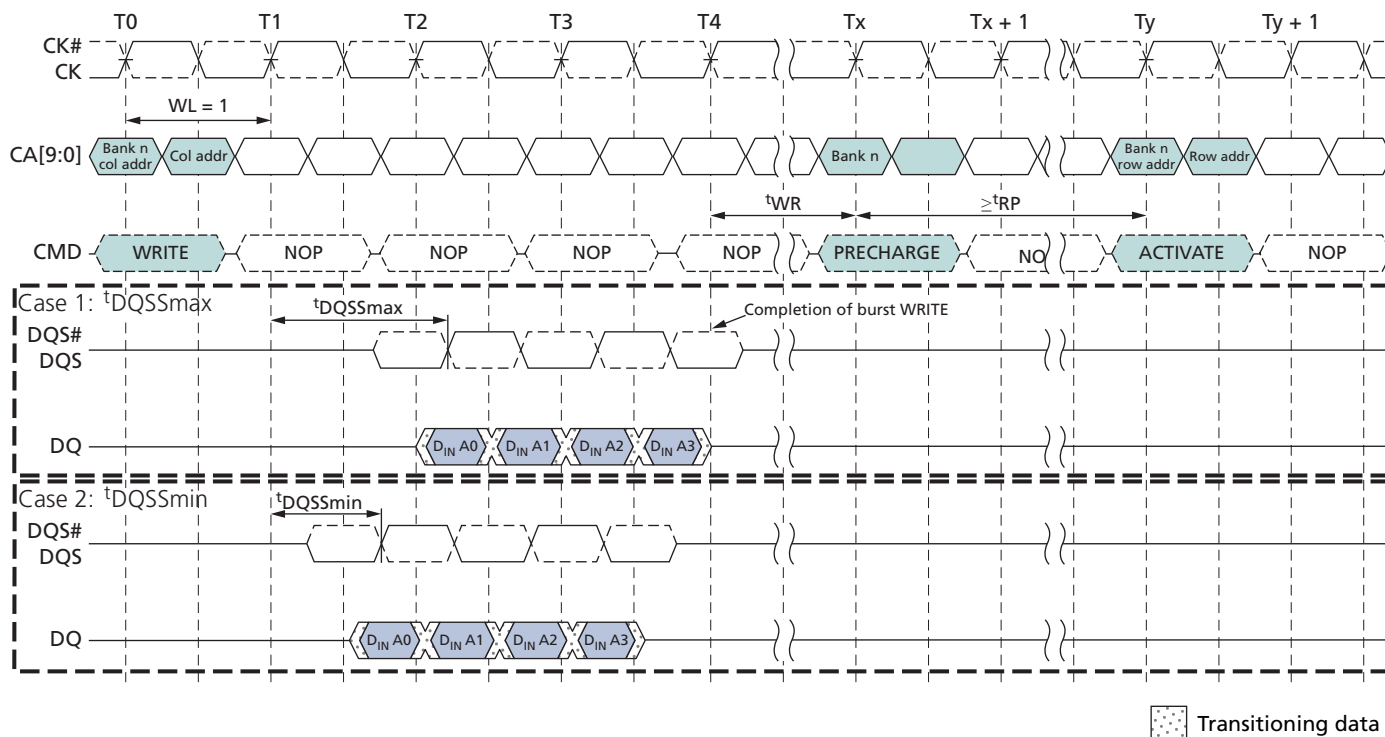
## WRITE Burst Followed by PRECHARGE

For WRITE cycles, a WRITE recovery time ( $t_{WR}$ ) must be provided before a PRECHARGE command can be issued.  $t_{WR}$  delay is referenced from the completion of the burst WRITE. The PRECHARGE command must not be issued prior to the  $t_{WR}$  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  $WL + BL/2 + 1 + RU(t_{WR}/t_{CK})$  clock cycles. For untruncated bursts, BL is the value set in the mode register. For truncated bursts, BL is the effective burst length.

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



## Auto Precharge

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

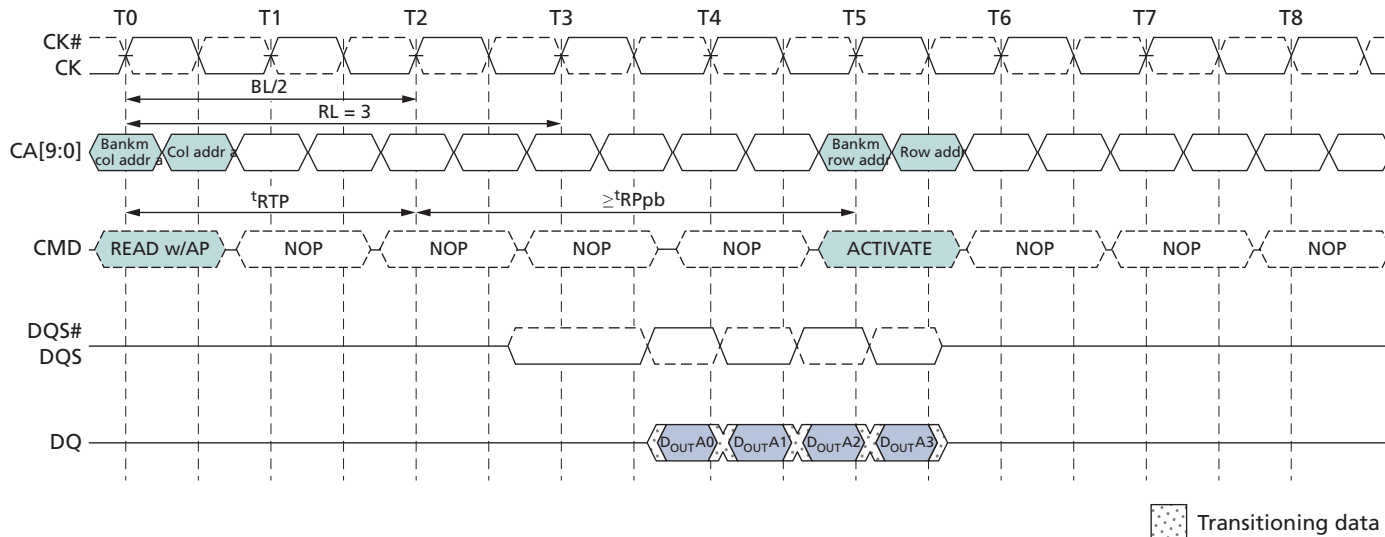
If AP (CA0f) is HIGH when a READ command is issued, the READ with auto precharge function is engaged.

These devices start 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.

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



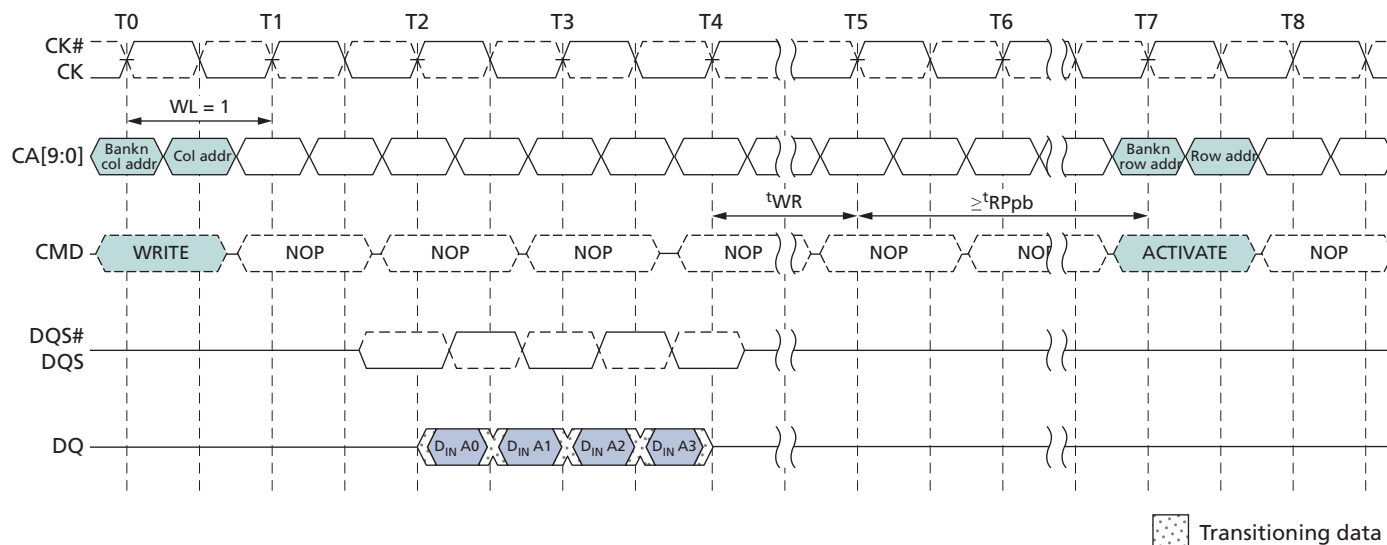
## WRITE Burst with Auto Precharge

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.

**Figure 35: WRITE Burst with Auto Precharge – WL = 1, BL = 4**



**Table 44: PRECHARGE and Auto Precharge Clarification**

| From Command | To Command                           | Minimum Delay Between Commands                                       | Unit | Notes |
|--------------|--------------------------------------|----------------------------------------------------------------------|------|-------|
| READ         | PRECHARGE to same bank as READ       | $BL/2 + \text{MAX}(2, RU(t_{RTP}/t_{CK})) - 2$                       | CLK  | 1     |
|              | PRECHARGE ALL                        | $BL/2 + \text{MAX}(2, RU(t_{RTP}/t_{CK})) - 2$                       | 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  | $BL/2 + \text{MAX}(2, RU(t_{RTP}/t_{CK})) - 2$                       | CLK  | 1, 2  |
|              | PRECHARGE ALL                        | $BL/2 + \text{MAX}(2, RU(t_{RTP}/t_{CK})) - 2$                       | CLK  | 1     |
|              | ACTIVATE to same bank as READ w/AP   | $BL/2 + \text{MAX}(2, RU(t_{RTP}/t_{CK})) - 2 + RU(t_{RPpb}/t_{CK})$ | 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     |

**Table 44: 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:
- 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.
  - Any command issued during the specified minimum delay time is illegal.
  - 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# LOW, CA0 LOW, CA1 LOW, and CA2 HIGH at the rising edge of the clock. Per-bank REFRESH is initiated with CA3 LOW at the rising edge of the clock. All-bank REFRESH is initiated with CA3 HIGH at the rising edge of the clock. 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

- $t_{RRD}$  has been satisfied after the prior ACTIVATE command (if 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 ( $t_{RFCpb}$ ), 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:

- $t_{RFCpb}$  must be satisfied before issuing a REFab command
- $t_{RFCpb}$  must be satisfied before issuing an ACTIVATE command to the same bank
- $t_{RRD}$  must be satisfied before issuing an ACTIVATE command to a different bank
- $t_{RFCpb}$  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:

- $t_{RFCab}$  has been satisfied following the prior REFab command
- $t_{RFCpb}$  has been satisfied following the prior REFpb command
- $t_{RP}$  has been satisfied following the prior PRECHARGE commands

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

- $t_{RFCab}$  latency must be satisfied before issuing an ACTIVATE command
- $t_{RFCab}$  latency must be satisfied before issuing a REFab or REFpb command

**Table 45: REFRESH Command Scheduling Separation Requirements**

| Symbol      | Minimum Delay From | To                                     | Notes |
|-------------|--------------------|----------------------------------------|-------|
| $t_{RFCab}$ | REFab              | REFab                                  |       |
|             |                    | ACTIVATE command to any bank           |       |
|             |                    | REFpb                                  |       |
| $t_{RFCpb}$ | REFpb              | REFab                                  |       |
|             |                    | ACTIVATE command to same bank as REFpb |       |
|             |                    | REFpb                                  |       |

**Table 45: REFRESH Command Scheduling Separation Requirements (Continued)**

| Symbol           | Minimum Delay From | To                                                                   | Notes |
|------------------|--------------------|----------------------------------------------------------------------|-------|
| <sup>t</sup> RRD | REFpb              | ACTIVATE command to a different bank than REFpb                      |       |
|                  | ACTIVATE           | REFpb                                                                | 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.

Mobile LPDDR2 devices provide significant flexibility in scheduling REFRESH commands as long as the required boundary conditions are met (see the <sup>t</sup>SRF Definition figure).

In the most straightforward implementations, a REFRESH command should be scheduled every <sup>t</sup>REFI. 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 multi REFRESH commands at the maximum supported rate (limited by <sup>t</sup>REFBW), 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:  $\text{REFW} - (R/8) \times \text{REFBW} = \text{REFW} - R \times 4 \times \text{RFCab}$ .

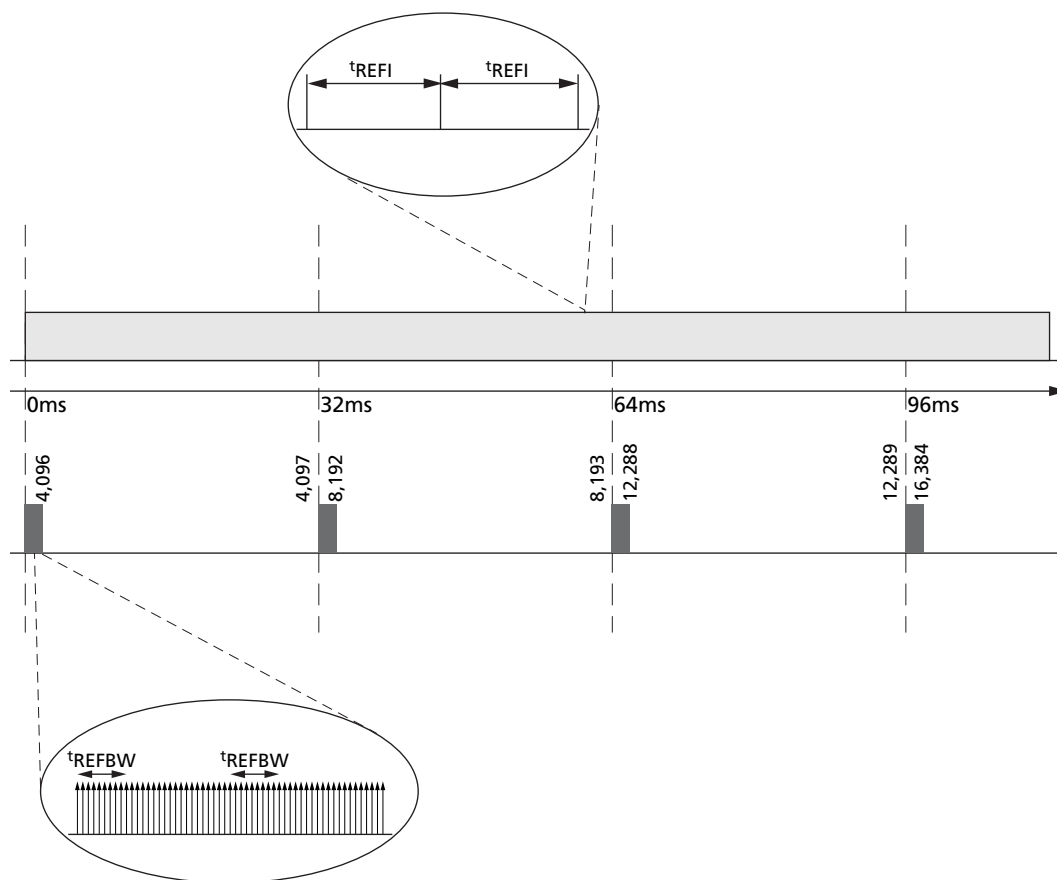
For example, a 1Gb device at  $T_C \leq 85^\circ\text{C}$  can be operated without a refresh for up to 32ms -  $4096 \times 4 \times 130\text{ns} \approx 30\text{ms}$ .

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 <sup>t</sup>REFW intervals will meet the minimum required number of REFRESH commands.

A nonsupported transition is shown in Figure 38 (page 60). In this example, the regular refresh pattern starts after the completion of the pause phase of the burst/pause refresh pattern. For several rolling <sup>t</sup>REFW intervals, the minimum number of REFRESH commands is not satisfied.

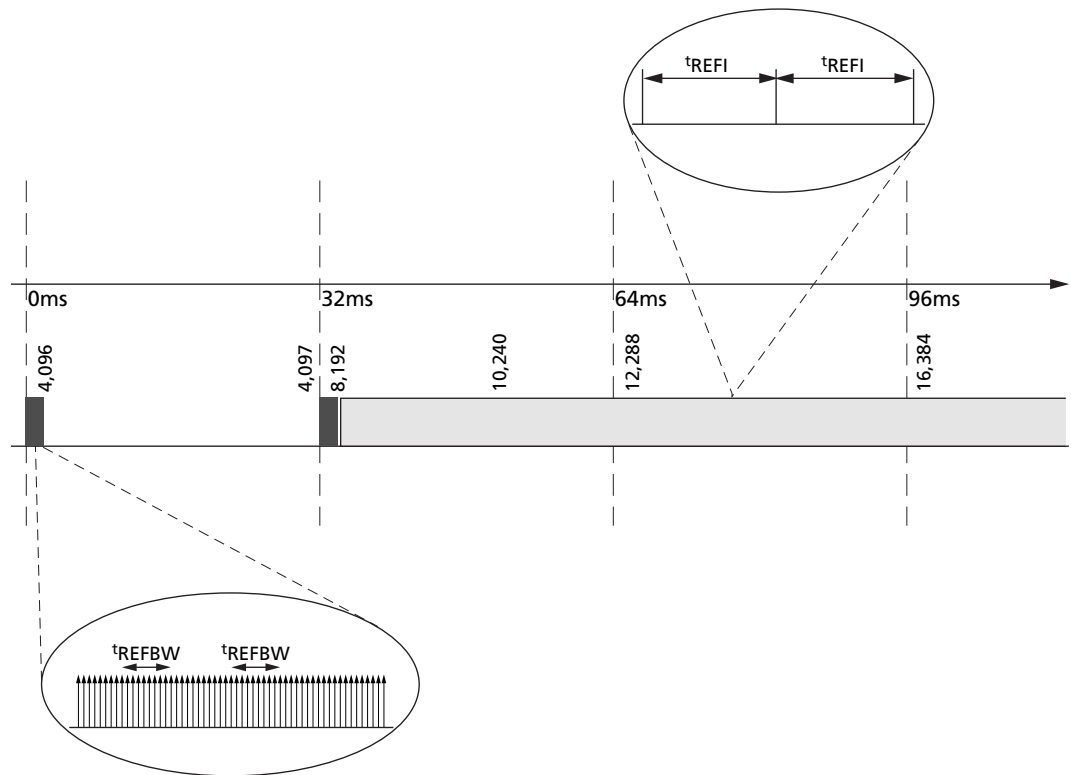
Understanding this pattern transition is extremely important, even when only one pattern is employed. In self refresh mode, a regular distributed refresh pattern must be assumed. Micron recommends entering self refresh mode immediately following the burst phase of a burst/pause refresh pattern; upon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

**Figure 36: Regular Distributed Refresh Pattern**



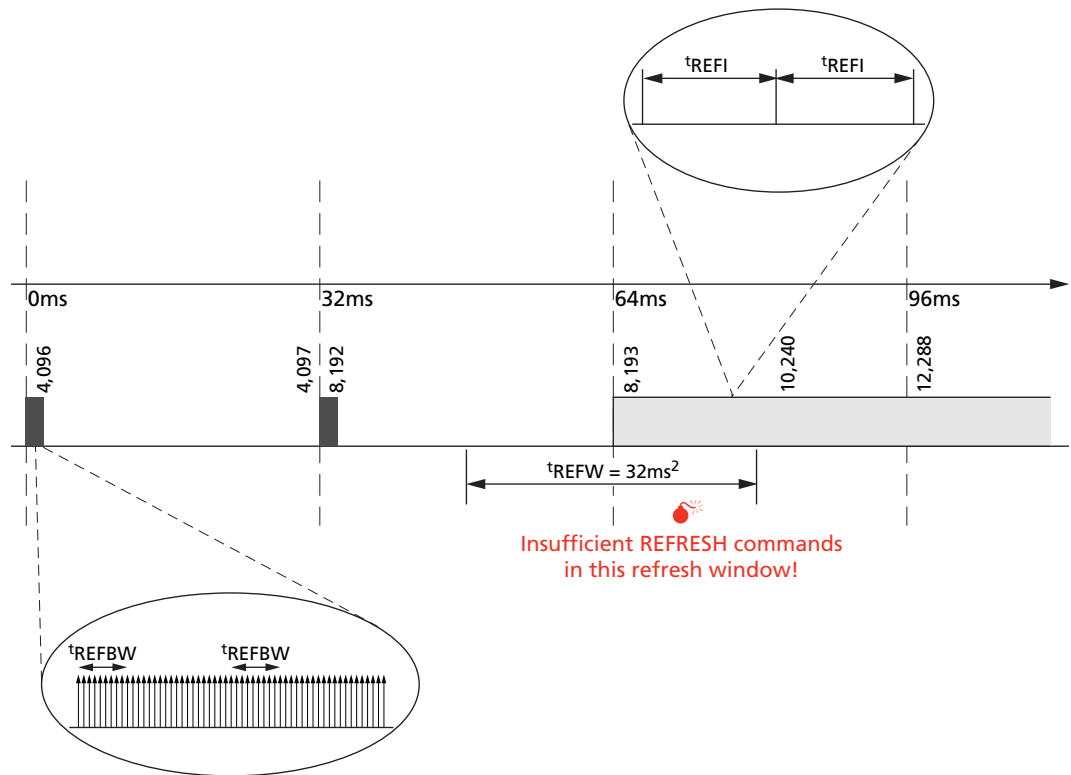
- Notes:
1. Compared to repetitive burst REFRESH with subsequent REFRESH pause.
  2. As an example, in a 1Gb LPDDR2 device at  $T_C \leq 85^\circ\text{C}$ , the distributed refresh pattern has one REFRESH command per  $7.8\mu\text{s}$ ; the burst refresh pattern has one REFRESH command per  $0.52\mu\text{s}$ , followed by  $\approx 30\text{ms}$  without any REFRESH command.
  3. As the nature of a DRAM scaling effect, the maximum burst of 4096 REFRESH commands could affect data retention of the DRAM. Memory controller may limit the maximum burst count to 8 REFRESH commands as similar to LPDDR3 and/or LPDDR4.

**Figure 37: Supported Transition from Repetitive REFRESH Burst**

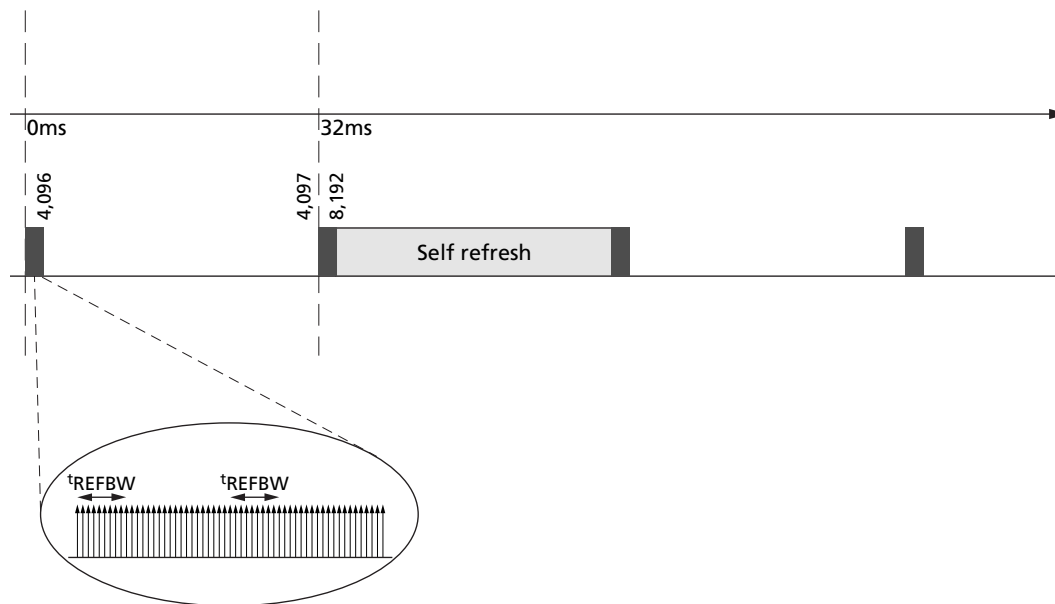


- Notes:
1. Shown with subsequent REFRESH pause to regular distributed refresh pattern.
  2. As an example, in a 1Gb LPDDR2 device at  $T_C \leq 85^\circ\text{C}$ , the distributed refresh pattern has one REFRESH command per  $7.8\mu\text{s}$ ; the burst refresh pattern has one REFRESH command per  $0.52\mu\text{s}$ , followed by  $\approx 30\text{ms}$  without any REFRESH command.
  3. As the nature of a DRAM scaling effect, the maximum burst of 4096 REFRESH commands could affect data retention of the DRAM. Memory controller may limit the maximum burst count to 8 REFRESH commands as similar to LPDDR3 and/or LPDDR4.

**Figure 38: Nonsupported Transition from Repetitive REFRESH Burst**



- Notes:
1. Shown with subsequent REFRESH pause to regular distributed refresh pattern.
  2. There are only  $\approx 2048$  REFRESH commands in the indicated  $t_{REFW}$  window. This does not provide the required minimum number of REFRESH commands (R).

**Figure 39: Recommended Self Refresh Entry and Exit**


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

## REFRESH Requirements

### 1. Minimum Number of REFRESH Commands

Mobile LPDDR2 requires a minimum number,  $R$ , of REFRESH (REFab) commands within any rolling refresh window ( $t_{REFW} = 32 \text{ ms}$  @  $MR4[2:0] = 011$  or  $T_C \leq 85^\circ\text{C}$ ). 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  $t_{REFBW}$  ( $t_{REFBW} = 4 \times 8 \times t_{RFCab}$ ). This condition does not apply if REFpb commands are used.

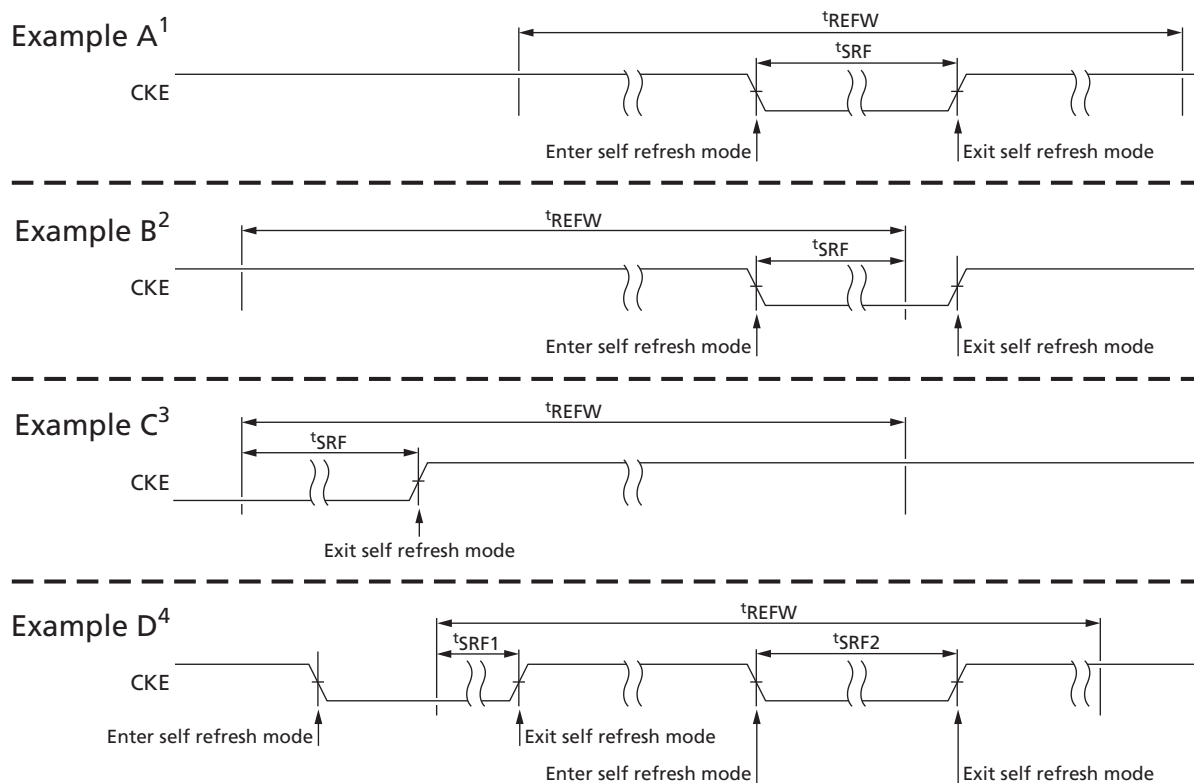
### 3. REFRESH Requirements and Self Refresh

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:

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

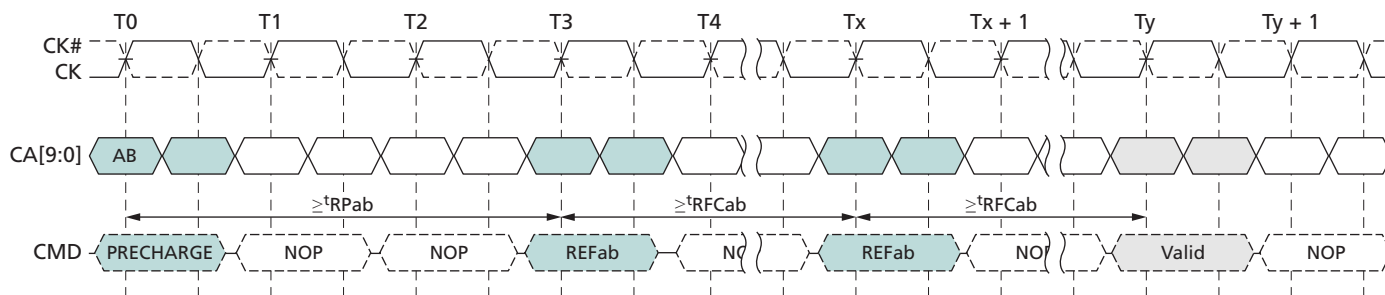
Where  $RU$  represents the round-up function.

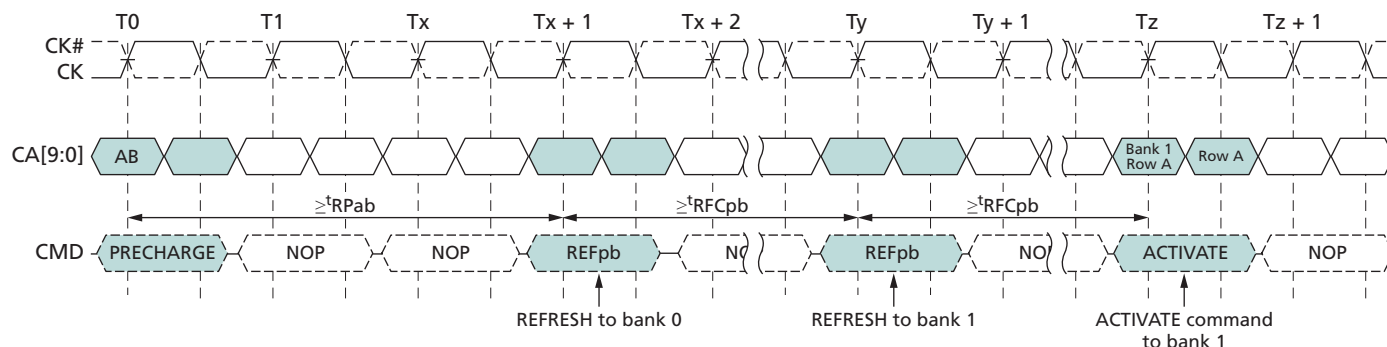
**Figure 40:  $t_{SRF}$  Definition**



- Notes:
1. Time in self refresh mode is fully enclosed in the refresh window ( $t_{REFW}$ ).
  2. At self refresh entry.
  3. At self refresh exit.
  4. Several intervals in self refresh during one  $t_{REFW}$  interval. In this example,  $t_{SRF} = t_{SRF1} + t_{SRF2}$ .

**Figure 41: All-Bank REFRESH Operation**



**Figure 42: 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  $t_{RFCpb}$  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 SELF REFRESH operation. The SELF REFRESH command is executed by taking CKE LOW, CS# LOW, CA0 LOW, CA1 LOW, and CA2 HIGH at the rising edge of the clock.

CKE must be HIGH during the clock cycle preceding a SELF REFRESH command. A NOP command must be driven in the clock cycle following the SELF REFRESH command. After the power-down command is registered, CKE must be held LOW to keep the device in self refresh mode.

Mobile LPDDR2 devices can operate in self refresh mode in both the standard and extended temperature ranges. These devices also manage self refresh power consumption when the operating temperature changes, resulting in the lowest possible power consumption across the operating temperature range. See  $I_{DD6}$  Partial-Array Self Refresh Current Table for details.

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 ( $V_{DD1}$ ,  $V_{DD2}$ ,  $V_{DDQ}$ , and  $V_{DDCA}$ ) 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  $V_{DDCA}$  during self refresh.

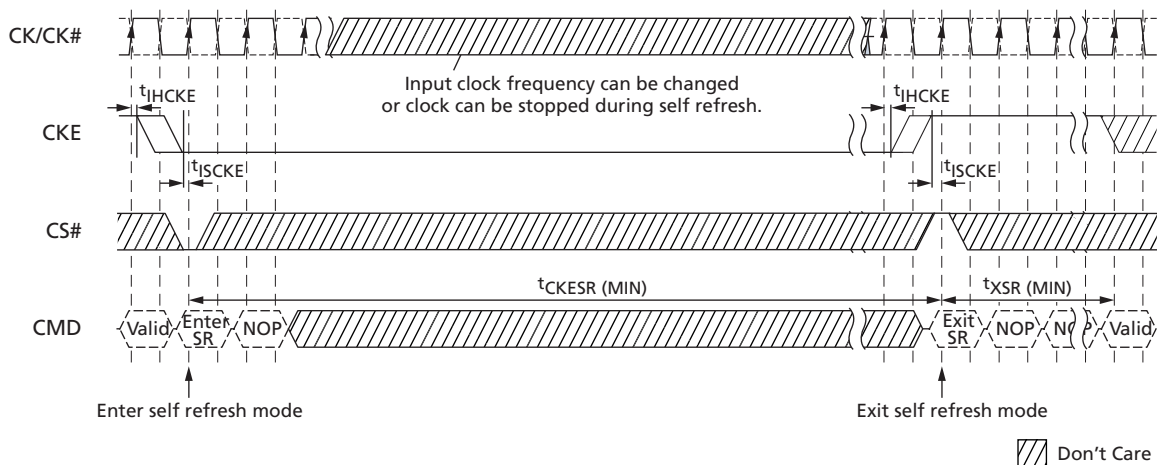
Before exiting self refresh,  $V_{REFDQ}$  and  $V_{REFCA}$  must be within specified limits (see AC and DC Logic Input Measurement Levels for Single-Ended Signals (page 100)). After entering self refresh mode, the device initiates at least one all-bank REFRESH command internally during  $t_{CKESR}$ . 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 43: 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.
  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

Devices in densities of 64Mb–512Mb are comprised of four banks; densities of 1Gb and higher are 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 densities 1Gb and 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 densities 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 46: Bank and Segment Masking Example**

|                         | Segment Mask (MR17) | Bank 0   | Bank 1   | Bank 2   | Bank 3   | Bank 4   | Bank 5   | Bank 6   | Bank 7   |
|-------------------------|---------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| <b>Bank Mask (MR16)</b> |                     | <b>0</b> | <b>1</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>0</b> | <b>1</b> |
| 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        |
| Segment 7               | 1                   | M        | M        | M        | M        | M        | M        | M        | M        |

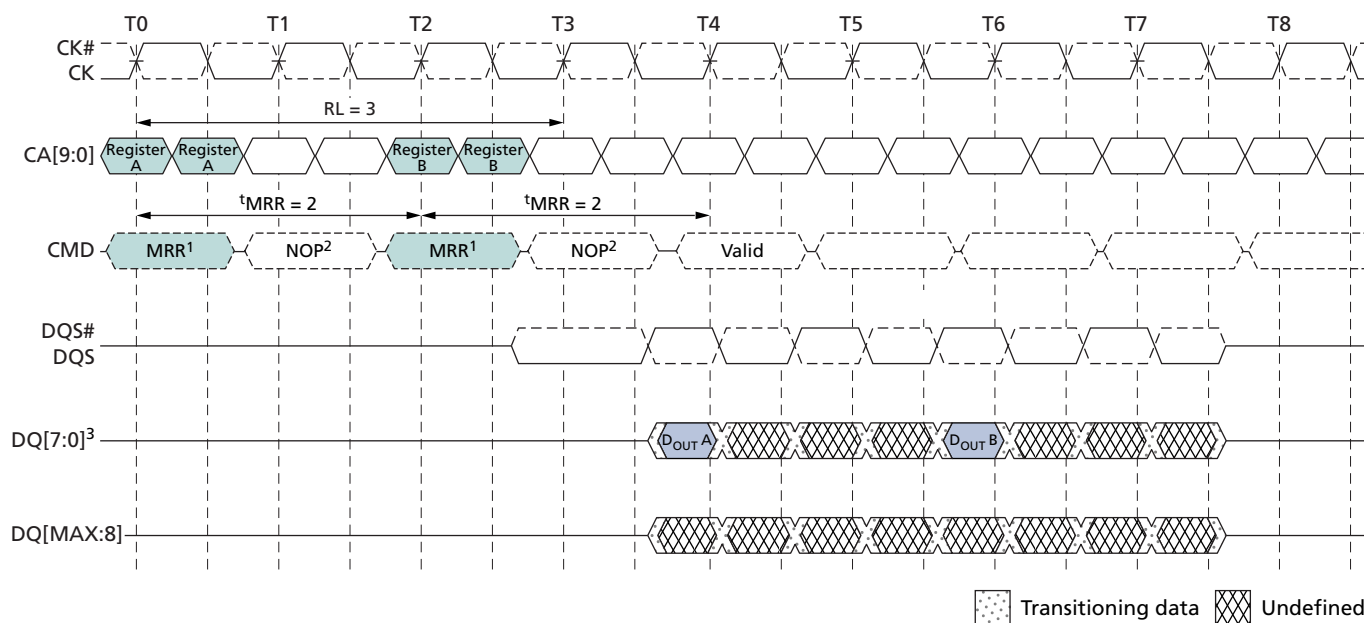
Note: 1. This table provides values for an 8-bank device with REFRESH operations masked to banks 1 and 7, and segments 2 and 7.

## 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# 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  $RL \times ^tCK + ^tDQSCK + ^tDQSQ$  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 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 ( $^tMRR$ ) is two clock cycles.

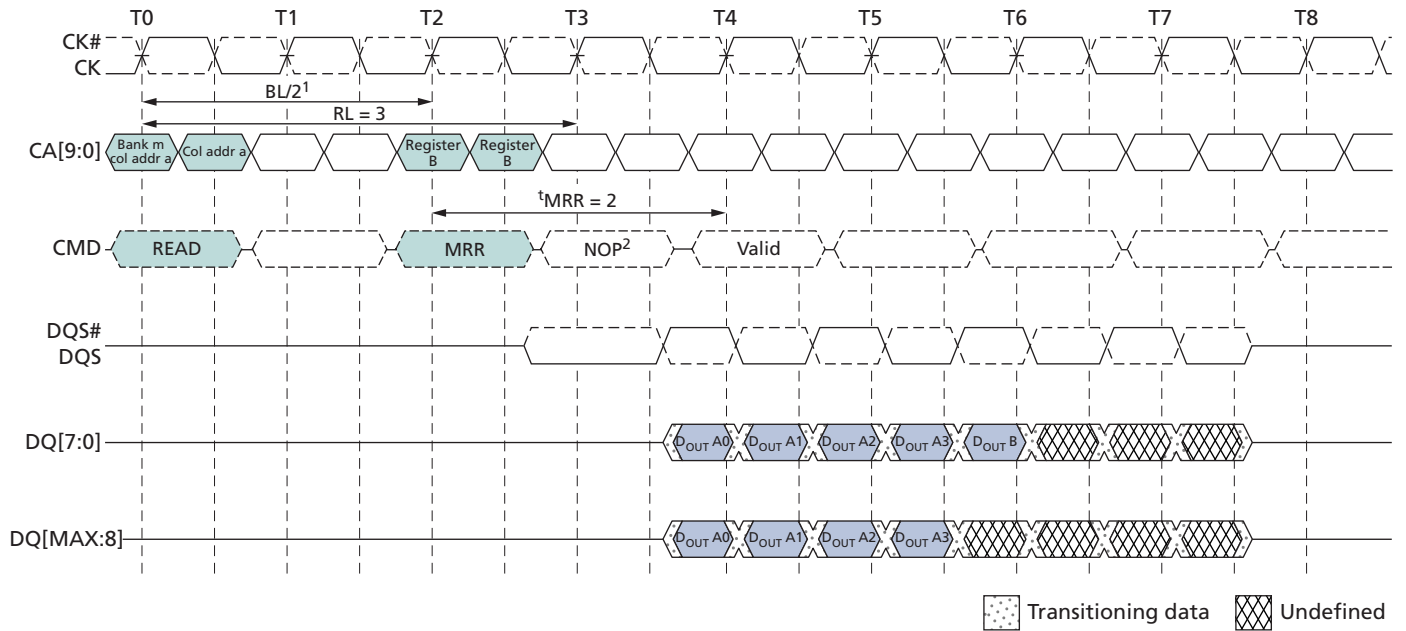
**Figure 44: MRR Timing –  $RL = 3$ ,  $^tMRR = 2$**



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

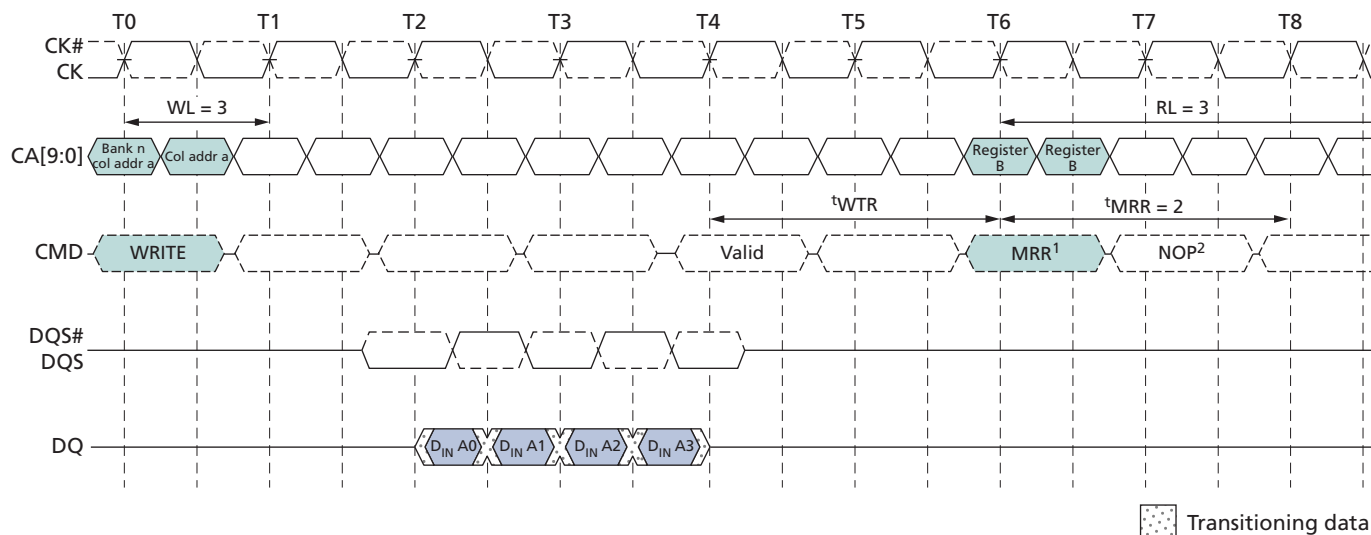
READ bursts and WRITE bursts cannot be truncated by MRR. Following a READ command, the MRR command must not be issued before  $BL/2$  clock cycles have completed. Following a WRITE command, the MRR command must not be issued before  $WL + 1 + BL/2 + RU(^tWTR/^tCK)$  clock cycles have completed. If a 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 45: 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  $t_{MRR}$ .

**Figure 46: 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  $[WL + 1 + BL/2 + RU(tWTR/tCK)]$ .
  2. Only the NOP command is supported during tMRR.

## Temperature Sensor

Mobile LPDDR2 devices feature 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 tTSI.

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<sub>CASE</sub> 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.

**Table 47: 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                                                                    | <sup>t</sup> 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   |

Mobile LPDDR2 devices accommodate 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:

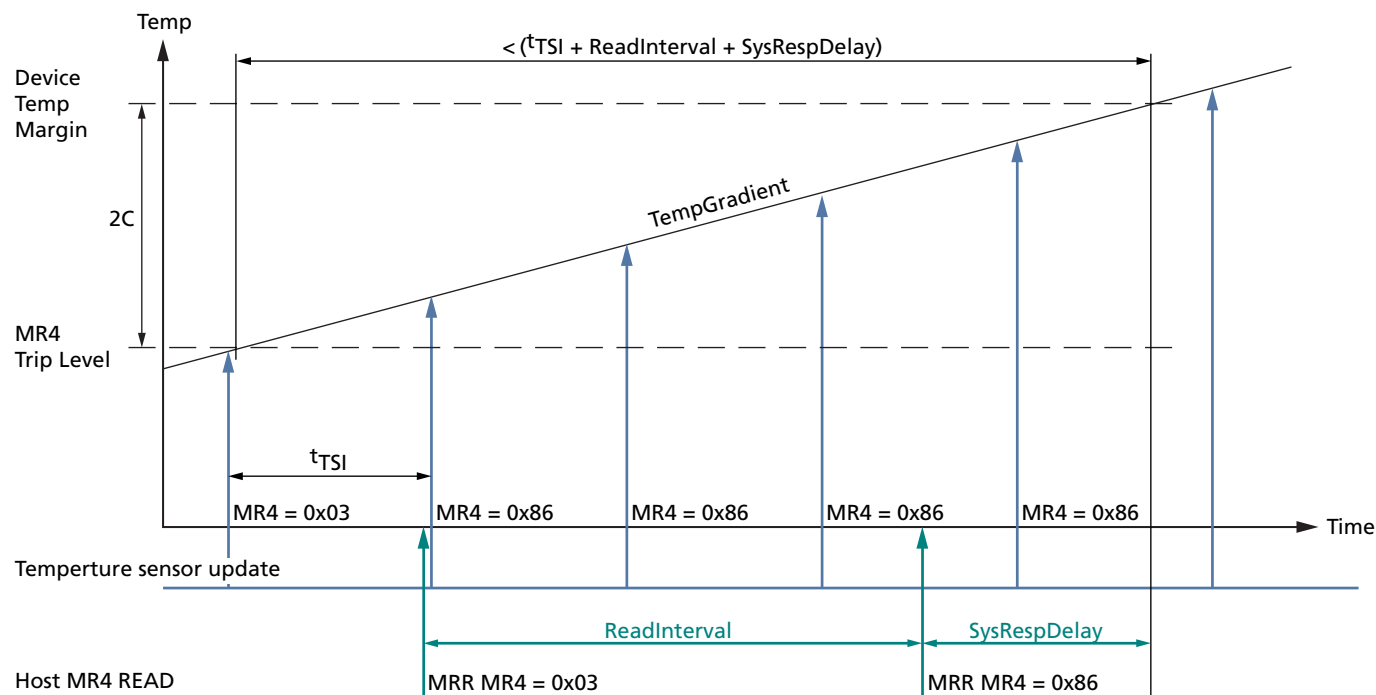
$$\text{TempGradient} \times (\text{ReadInterval} + {}^t\text{TSI} + \text{SysRespDelay}) \leq 2^\circ\text{C}$$

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

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

In this case, ReadInterval must not exceed 167ms.

**Figure 47: Temperature Sensor Timing**

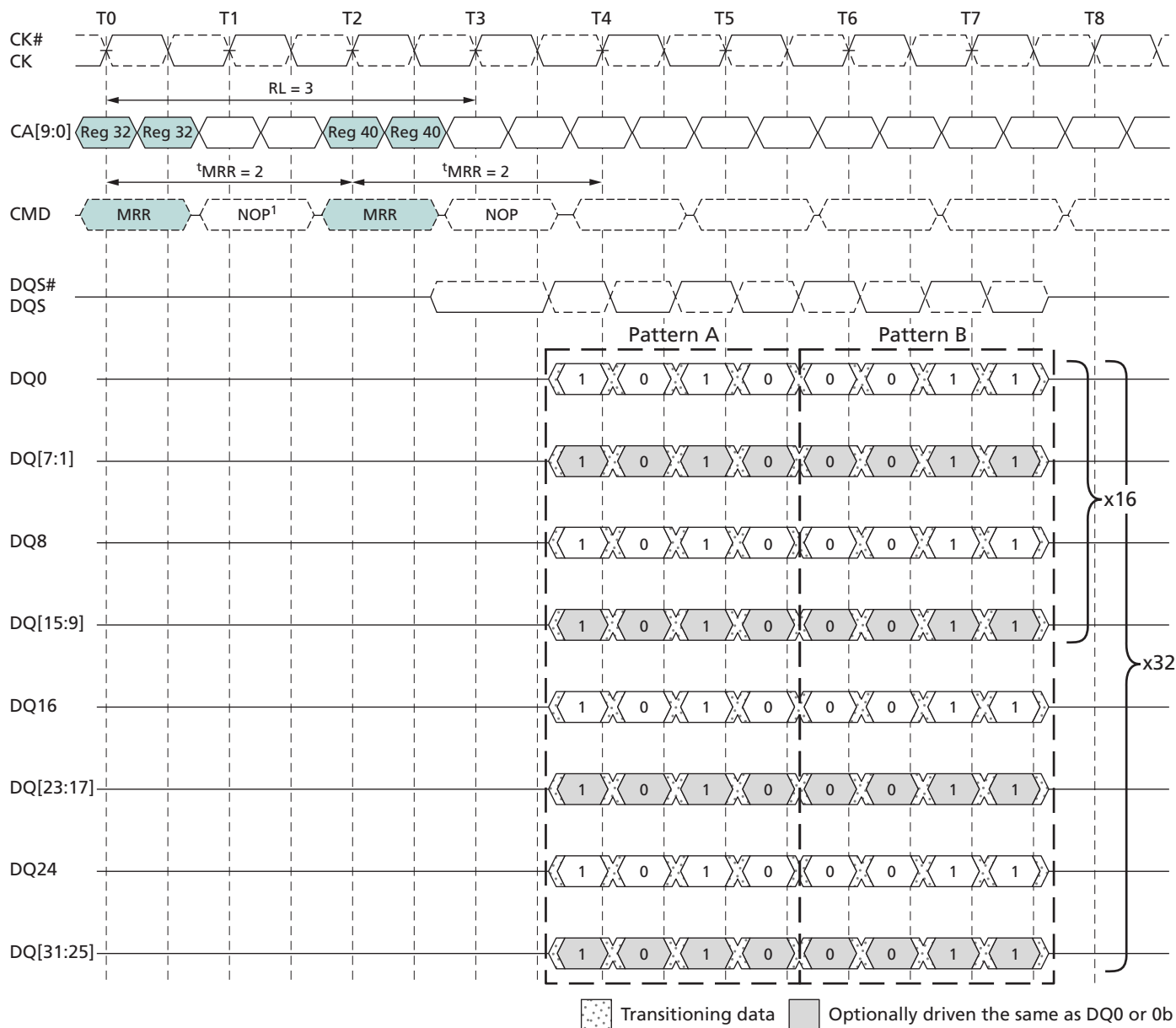


## DQ Calibration

Mobile LPDDR2 devices feature a DQ calibration function that outputs one of two pre-defined system timing calibration patterns. For x16 devices, pattern A (MRR to MRR32), and pattern B (MRR to MRR40), will return the specified pattern on DQ0 and DQ8; x32 devices return the specified pattern on DQ0, DQ8, DQ16, and DQ24.

For x16 devices, DQ[7:1] and DQ[15:9] drive the same information as DQ0 during the MRR burst. For x32 devices, 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.

**Figure 48: MR32 and MR40 DQ Calibration Timing – RL = 3,  $t_{MRR} = 2$**



Note: 1. Only the NOP command is supported during  $t_{MRR}$ .

**Table 48: Data Calibration Pattern Description**

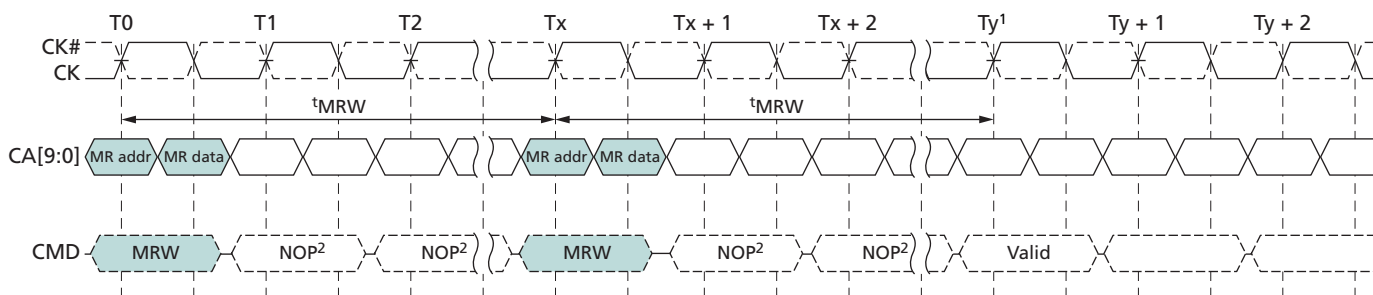
| Pattern   | MR#  | Bit Time 0 | Bit Time 1 | Bit Time 2 | Bit Time 3 | Description                                   |
|-----------|------|------------|------------|------------|------------|-----------------------------------------------|
| Pattern A | MR32 | 1          | 0          | 1          | 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# 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  $t_{MRW}$ . MRWs to read-only registers have no impact on the functionality of the device.

MRW can only be issued 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 49: 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 49: 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) idle   | Bank(s) active |
|                | MRW         | Not allowed                           | Not allowed    |
|                | MRW (RESET) | Not allowed                           | Not allowed    |

## MRW RESET Command

The MRW RESET command brings the device to the device auto initialization (resetting) state in the power-on initialization sequence (see 2. RESET Command under Power-Up (page 21)). 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 Figure 9 (page 23).

## 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: 'ZQINIT, 'ZQRESET, 'ZQCL, and 'ZQCS. 'ZQINIT is used for initialization calibration; 'ZQRESET is used for resetting ZQ to the default output impedance; 'ZQCL is used for long calibration(s); and '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  $\pm 15\%$ . After initialization, the ZQ calibration long (ZQCL) can be used to recalibrate the system to an output impedance accuracy of  $\pm 15\%$ . 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  $\pm 30\%$  across process, voltage, and temperature. This command is used to ensure output impedance accuracy to  $\pm 30\%$  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 'ZQCS for all speed bins, assuming the maximum sensitivities specified in Table 80 and Table 81 are met. 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 ( $T_{\text{driftrate}}$ ) and voltage drift rate ( $V_{\text{driftrate}}$ ) in various applications. To accommodate drift rates and calculate the necessary interval between ZQCS commands, apply the following formula:

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

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

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

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

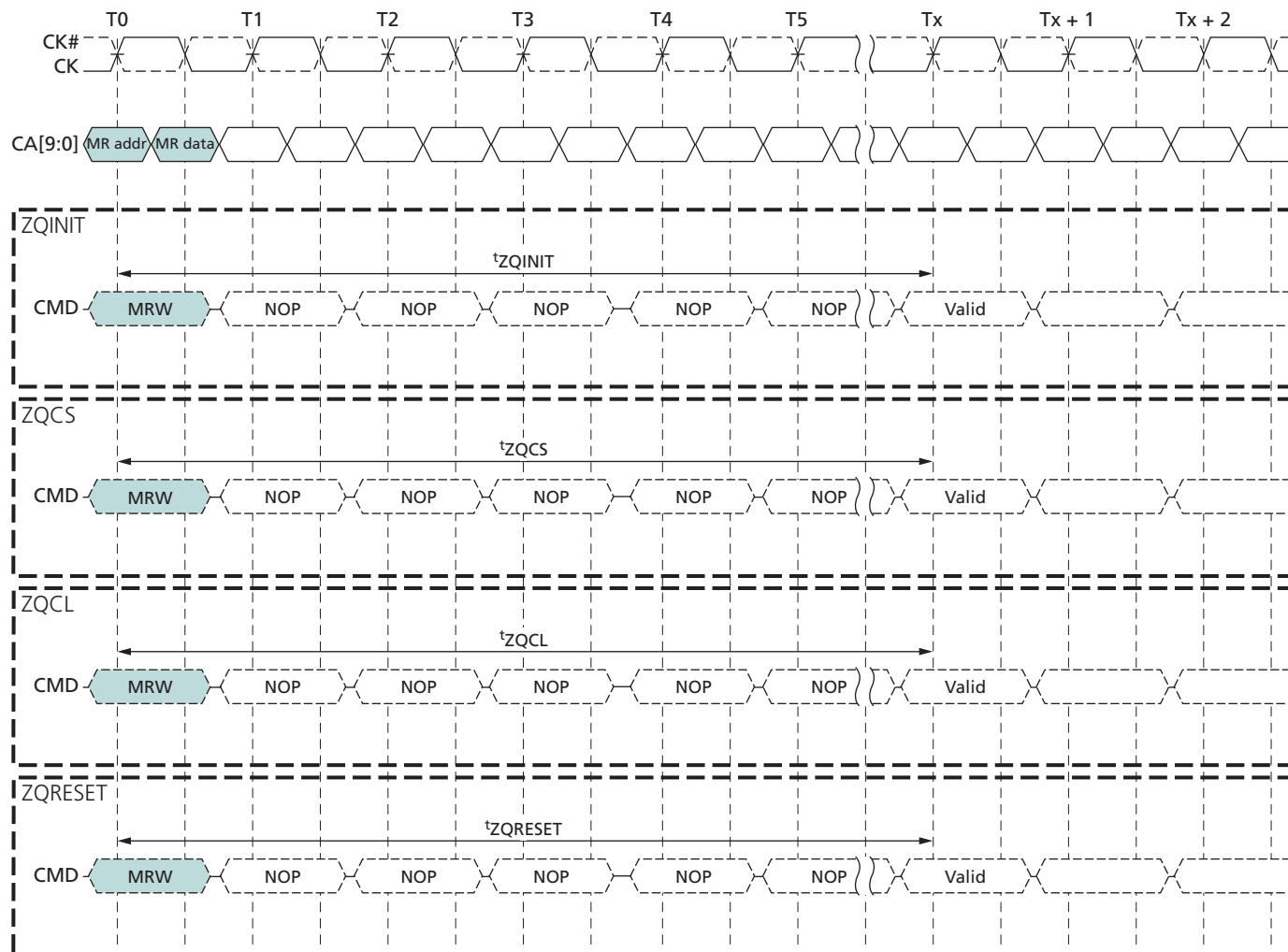
A ZQ calibration command can only be issued when the device is in the idle state with all banks precharged.

No other activities can be performed on the data bus during calibration periods ('ZQINIT, 'ZQCL, or 'ZQCS). The quiet time on the data bus helps to accurately calibrate output impedance. 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 'ZQINIT, 'ZQCS, and '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 50: ZQ Timings**



- Notes:
1. Only the NOP command is supported during ZQ calibrations.
  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 ( $\pm 1\%$  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# 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 operations 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.

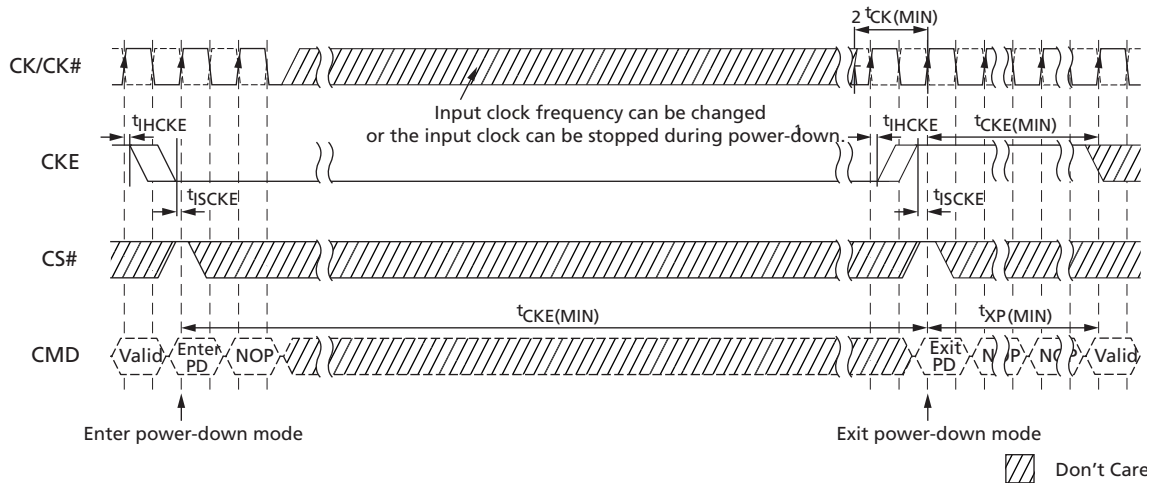
If power-down occurs when all banks are idle, this mode is referred to as idle power-down; if power-down occurs when there is a row active in any bank, this mode is referred to as active power-down.

Entering power-down deactivates the input and output buffers, excluding CK, CK#, 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.

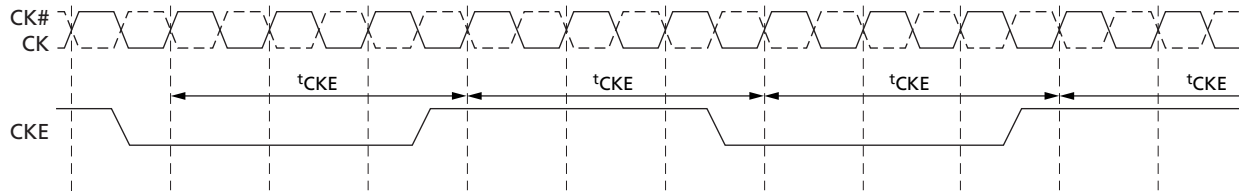
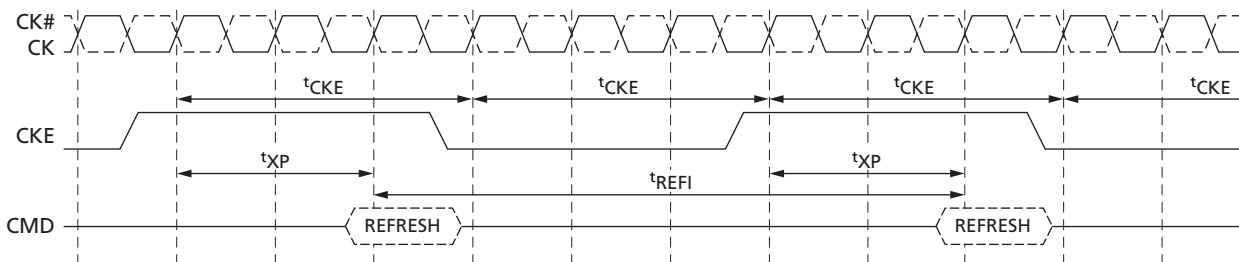
$V_{DDQ}$  can be turned off during power-down. If  $V_{DDQ}$  is turned off,  $V_{REFDQ}$  must also be turned off. Prior to exiting power-down, both  $V_{DDQ}$  and  $V_{REFDQ}$  must be within their respective minimum/maximum operating ranges (see AC and DC Operating Conditions).

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

The power-down state is exited when CKE is registered HIGH. The controller must drive CS# 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.

**Figure 51: Power-Down Entry and Exit Timing**


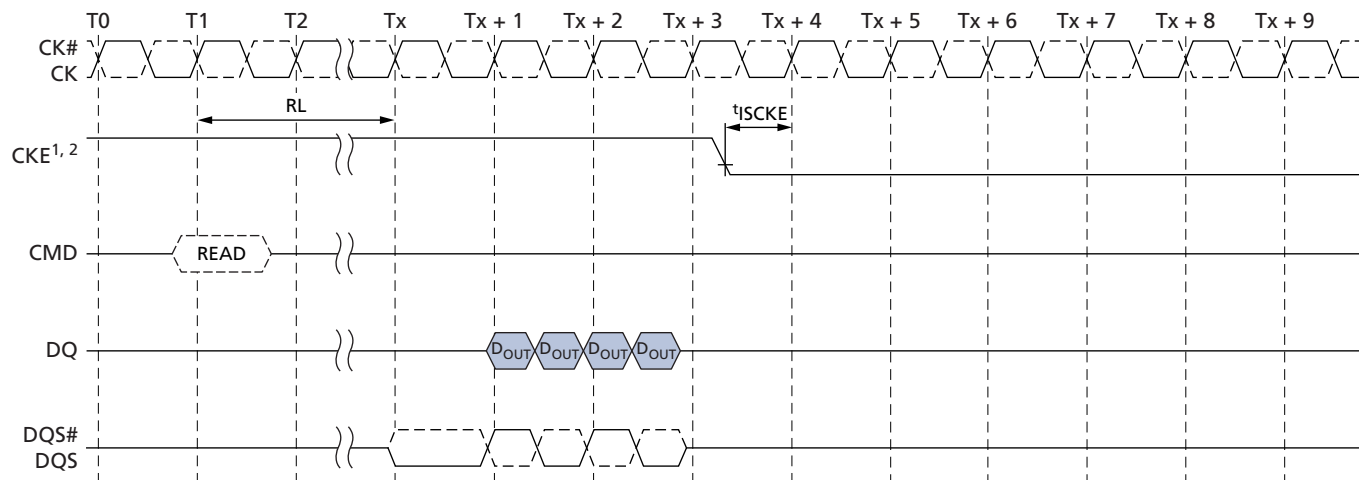
Note: 1. Input clock frequency can be changed or the input clock stopped during power-down, provided that the clock frequency is between the minimum and maximum specified frequencies for the speed grade in use, and that prior to power-down exit, a minimum of two stable clocks complete.

**Figure 52: CKE Intensive Environment**

**Figure 53: REFRESH-to-REFRESH Timing in CKE Intensive Environments**


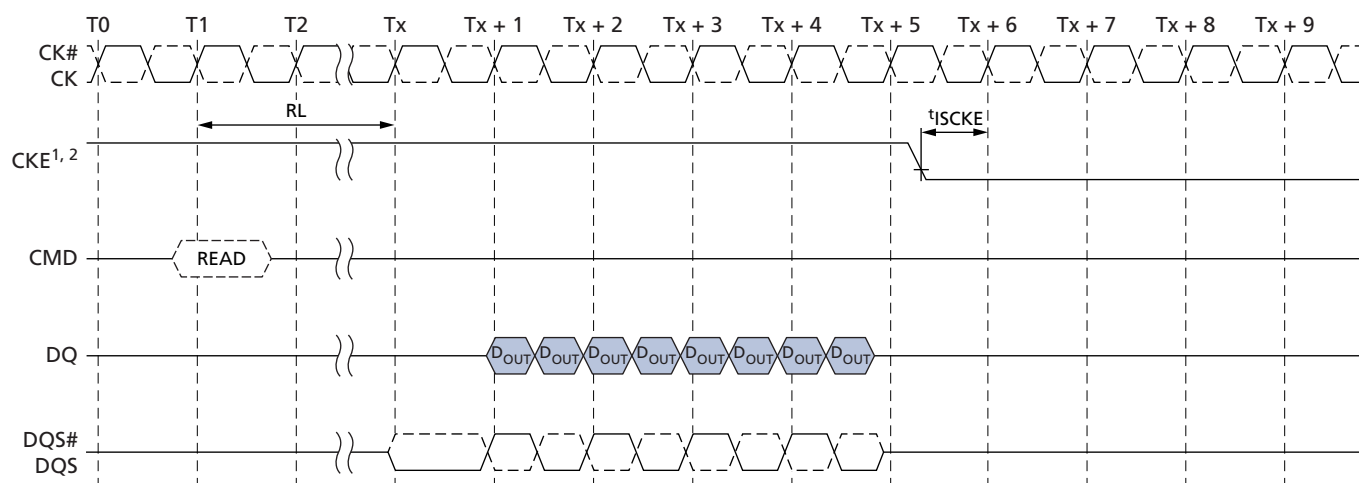
Note: 1. The pattern shown can repeat over an extended period of time. With this pattern, all AC and DC timing and voltage specifications with temperature and voltage drift are ensured.

**Figure 54: READ to Power-Down Entry**

BL = 4



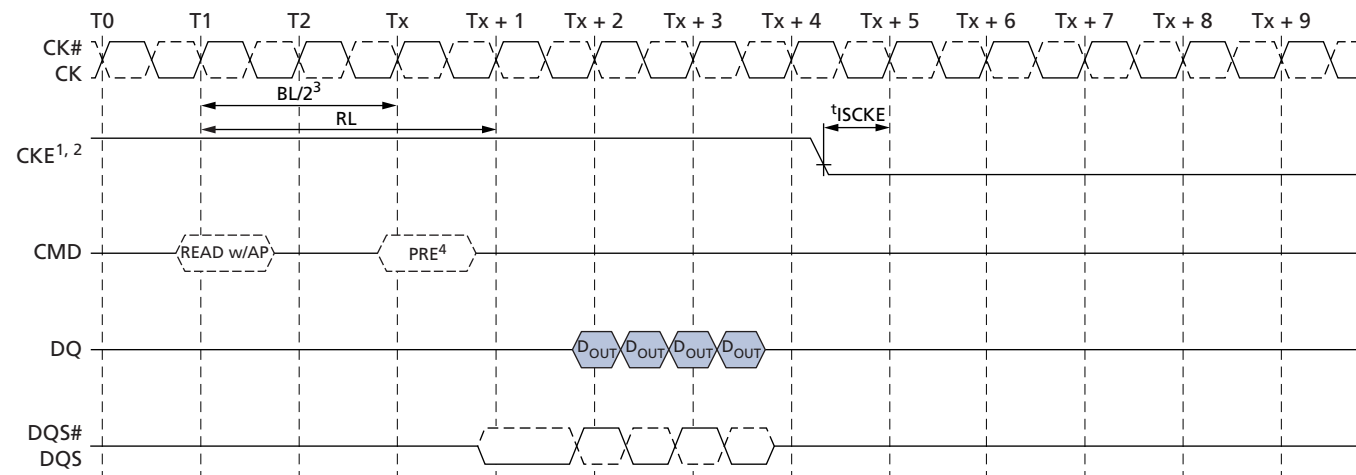
BL = 8



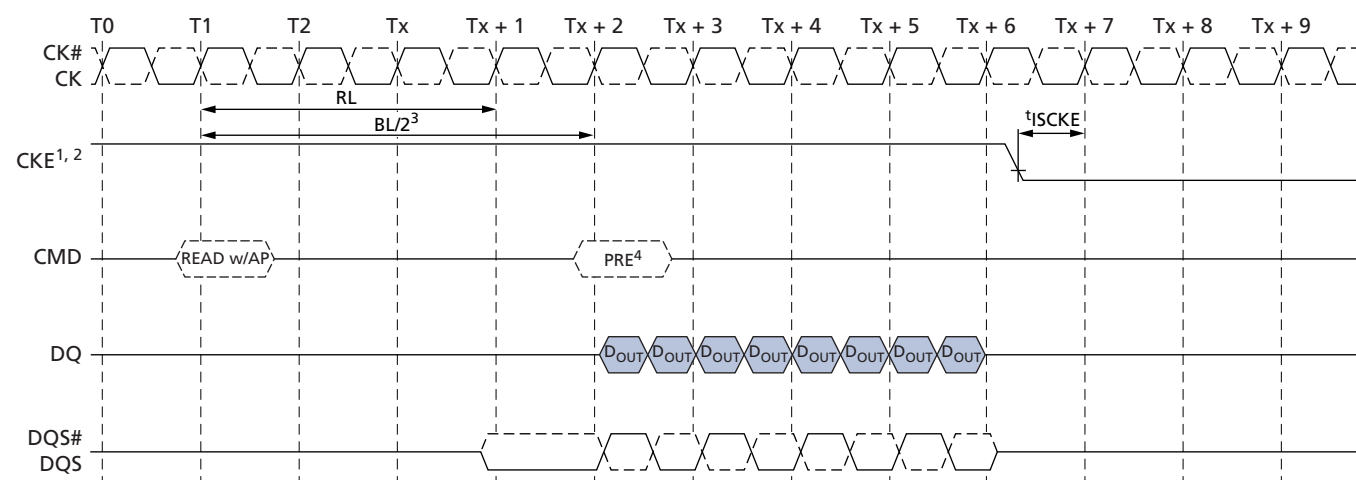
- Notes:
1. CKE must be held HIGH until the end of the burst operation.
  2. CKE can be registered LOW at  $(RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + 1)$  clock cycles after the clock on which the READ command is registered.

**Figure 55: READ with Auto Precharge to Power-Down Entry**

BL = 4



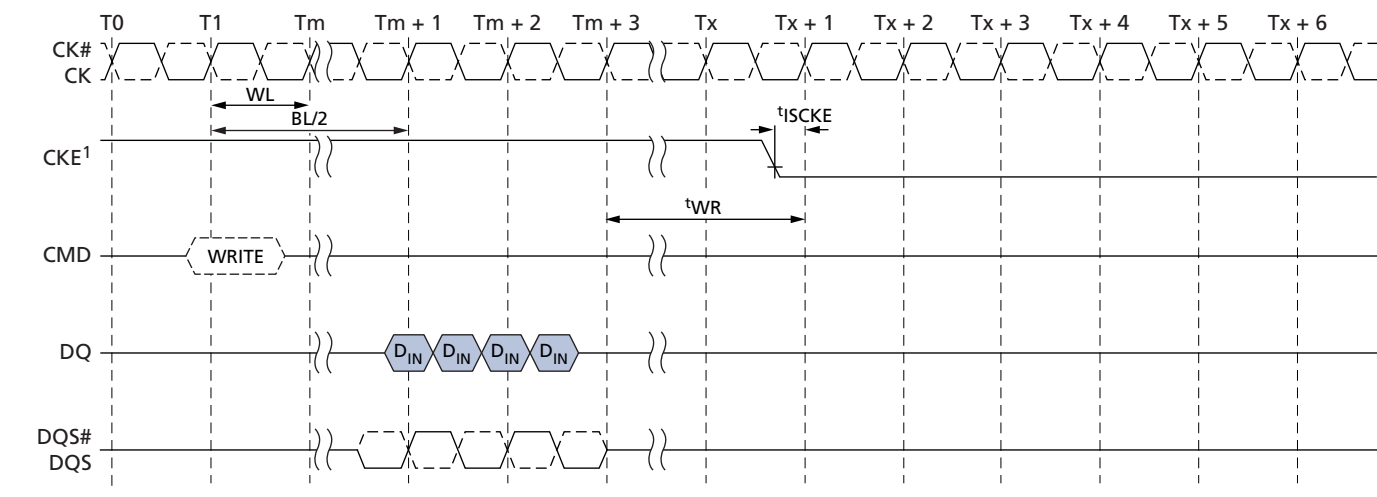
BL = 8



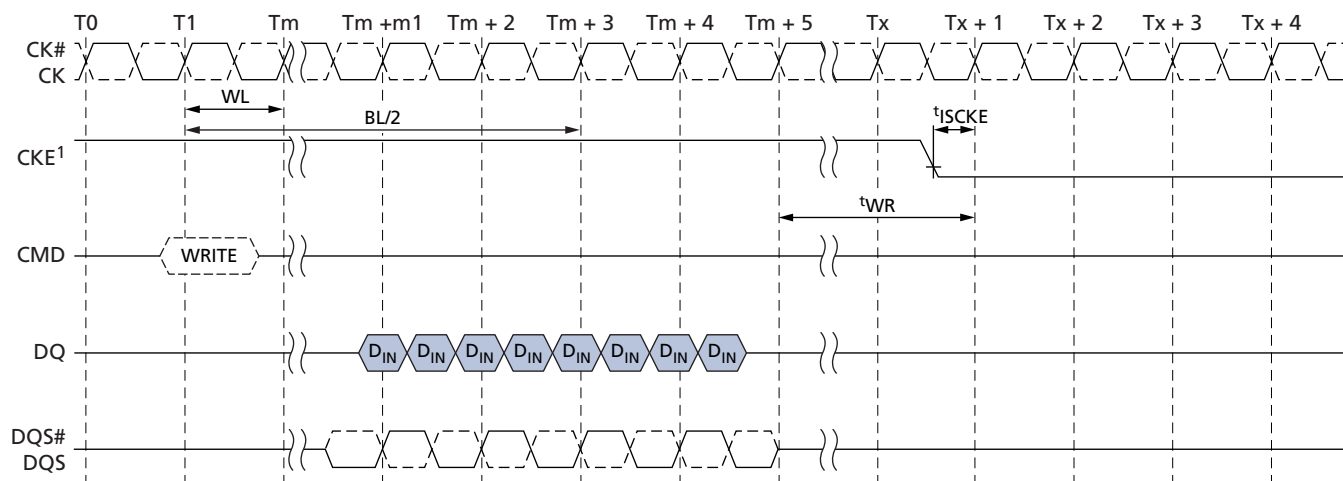
- Notes:
1. CKE must be held HIGH until the end of the burst operation.
  2. CKE can be registered LOW at  $(RL + RU(t_{DQSCK}/t_{CK}) + BL/2 + 1)$  clock cycles after the clock on which the READ command is registered.
  3.  $BL/2$  with  $t_{RTP} = 7.5\text{ns}$  and  $t_{RAS}(\text{MIN})$  is satisfied.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

**Figure 56: WRITE to Power-Down Entry**

BL = 4



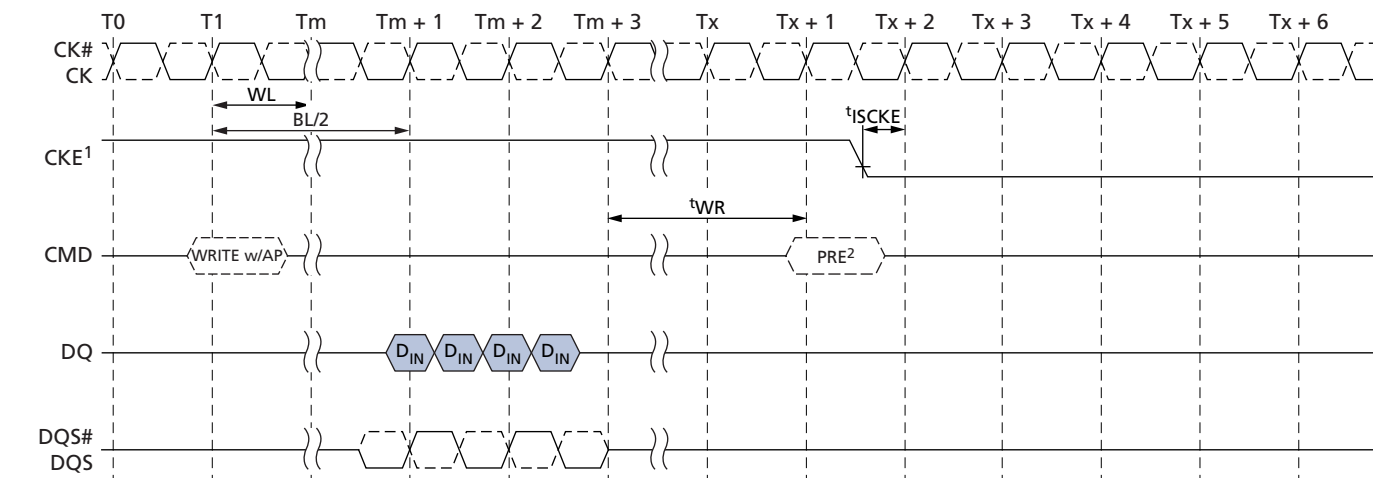
BL = 8



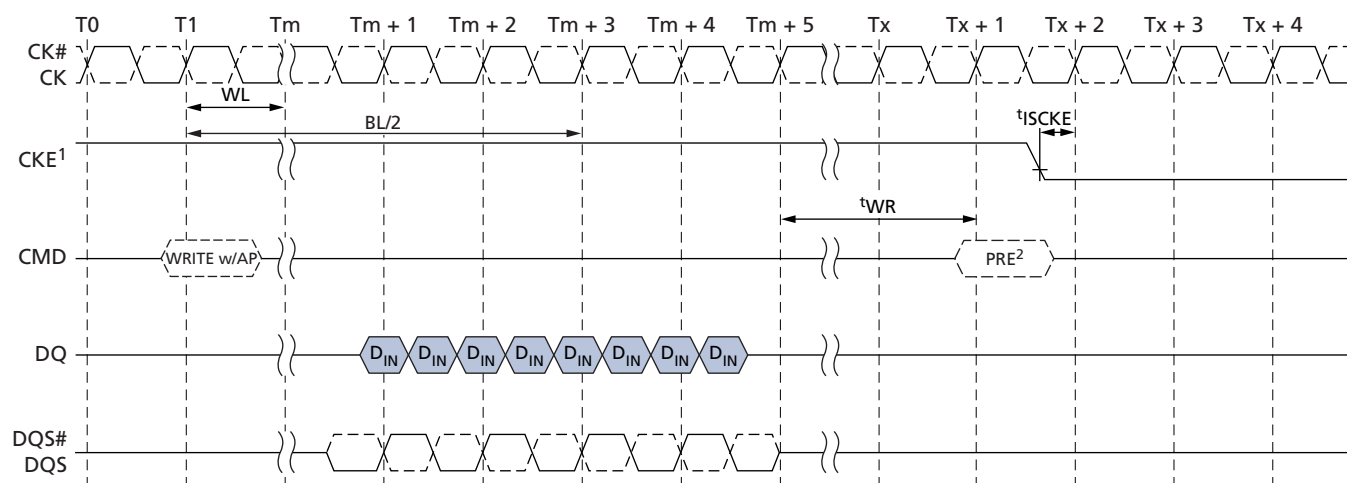
Note: 1. CKE can be registered LOW at  $(WL + 1 + BL/2 + RU(t_{WR}/t_{CK}))$  clock cycles after the clock on which the WRITE command is registered.

**Figure 57: WRITE with Auto Precharge to Power-Down Entry**

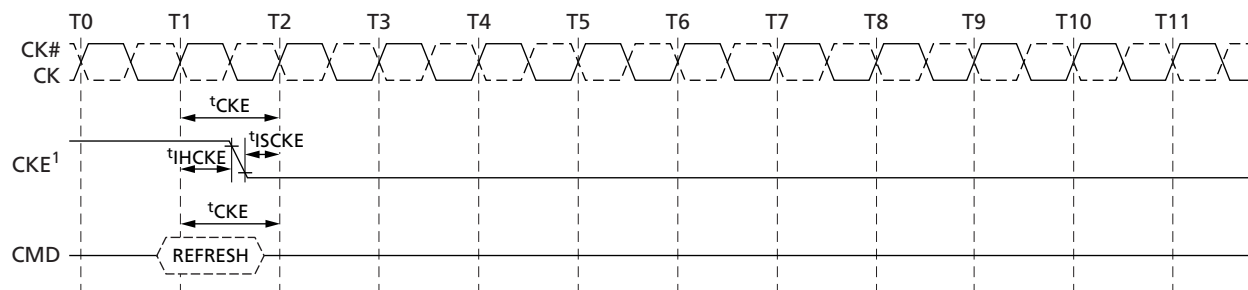
BL = 4



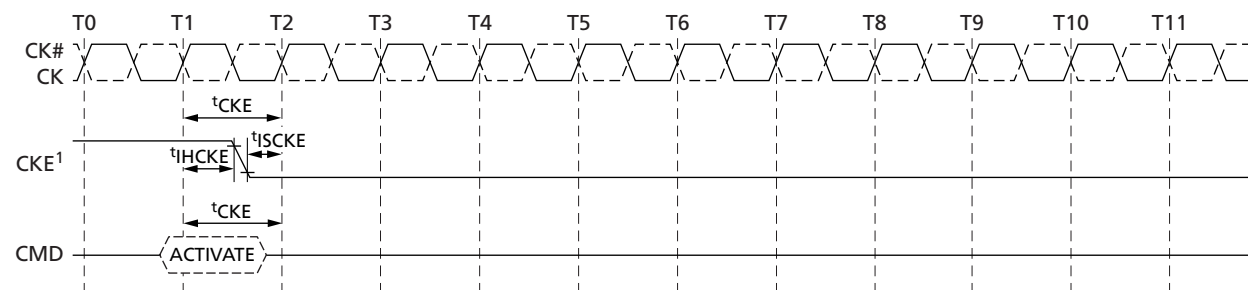
BL = 8



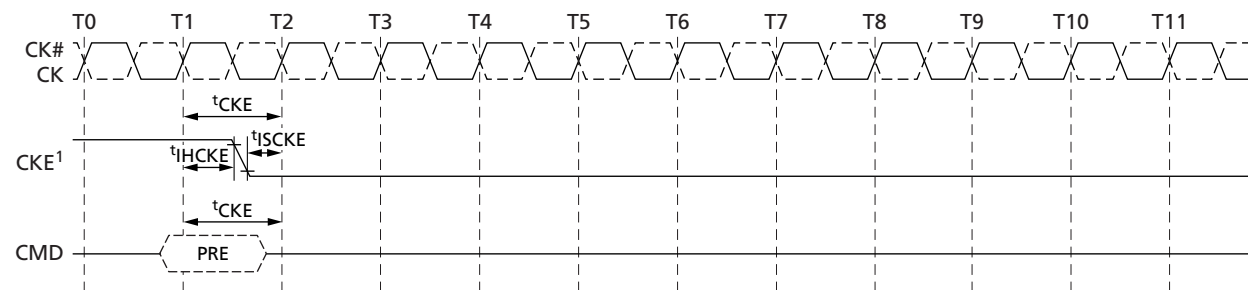
- Notes:
1. CKE can be registered LOW at  $(WL + 1 + BL/2 + RU(t_{WR}/t_{CK} + 1))$  clock cycles after the WRITE command is registered.
  2. Start internal PRECHARGE.

**Figure 58: 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 59: ACTIVATE Command to Power-Down Entry**


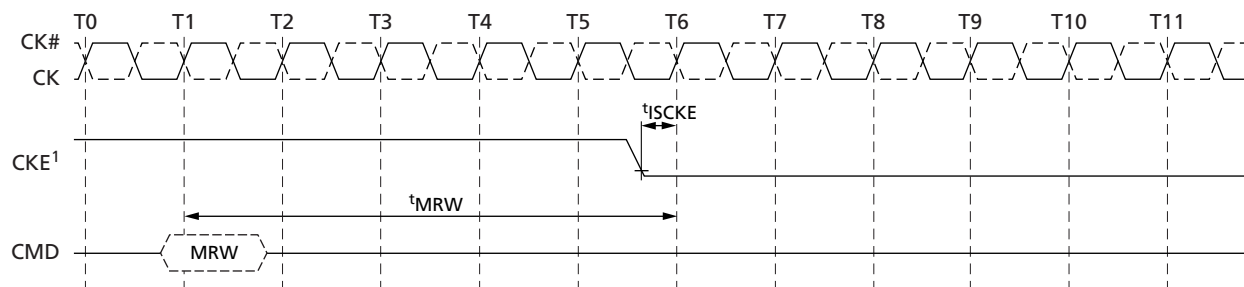
Note: 1. CKE can go LOW at  $t_{IHCKE}$  after the clock on which the ACTIVATE command is registered.

**Figure 60: PRECHARGE Command to Power-Down Entry**


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

Timing diagram for a memory read operation. The diagram shows signals CK#, CK, CKE1, CMD, DQ, DQS#, and DQS over time. CK# and CK are clock signals. CKE1 is the clock enable signal. CMD is the command signal, showing an MRR (Memory Read Command) at T1. DQ is the data bus, showing data output (DOUT) from Tx to Tx+3. DQS# is the data strobe signal, showing a pulse from Tx to Tx+3. The diagram includes timing parameters: RL (Read Latency) from T1 to Tx, and tISKE (Input Setup and Hold Time for K) from Tx+3 to Tx+4.

### Figure 62: MRW Command to Power-Down Entry

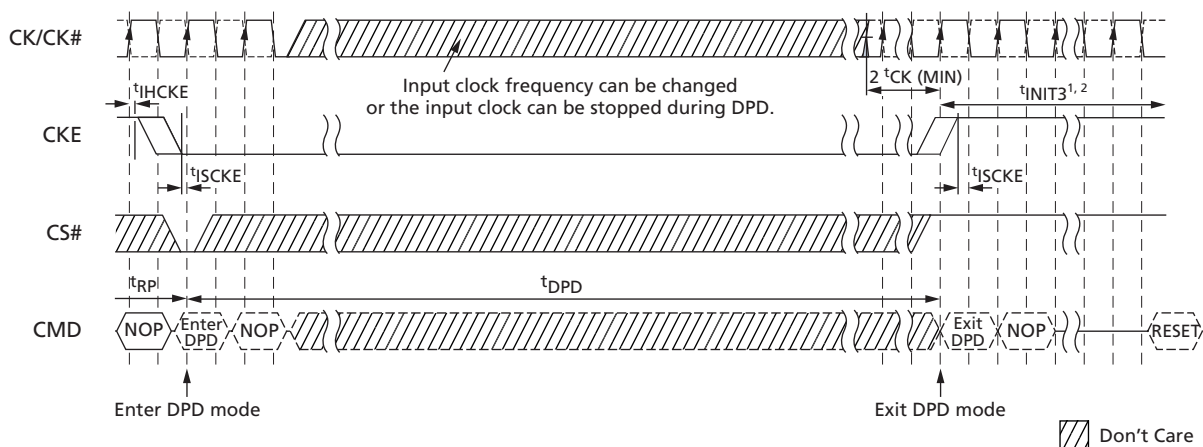


## Deep Power-Down

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  $V_{DDCA}$  during DPD. All power 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,  $t_{\text{ISCKE}}$  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 63: Deep Power-Down Entry and Exit Timing**



- Notes:
1. The initialization sequence can start at any time after  $T_x + 1$ .
  2.  $t_{\text{INIT3}}$  and  $T_x + 1$  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, Mobile LPDDR2 devices support 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,  $t_{\text{RCD}}$  and  $t_{\text{RP}}$ , 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  $t_{\text{CH(ABS)}}$  and  $t_{\text{CL(ABS)}}$  for a minimum of two clock cycles prior to CKE going HIGH

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

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 is held LOW and CK# is held HIGH.

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

During CKE HIGH, LPDDR2 devices support 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,  $t_{RCD}$ ,  $t_{WR}$ ,  $t_{WRA}$ ,  $t_{RP}$ ,  $t_{MRW}$ , and  $t_{MRR}$ , etc., are met
- CS# 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  $2 \times t_{CK} + t_{XP}$ .

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 is held LOW and CK# 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 only be issued 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# HIGH at the clock rising edge N; and CS# LOW with CA0, CA1, CA2 HIGH at the clock rising edge N.

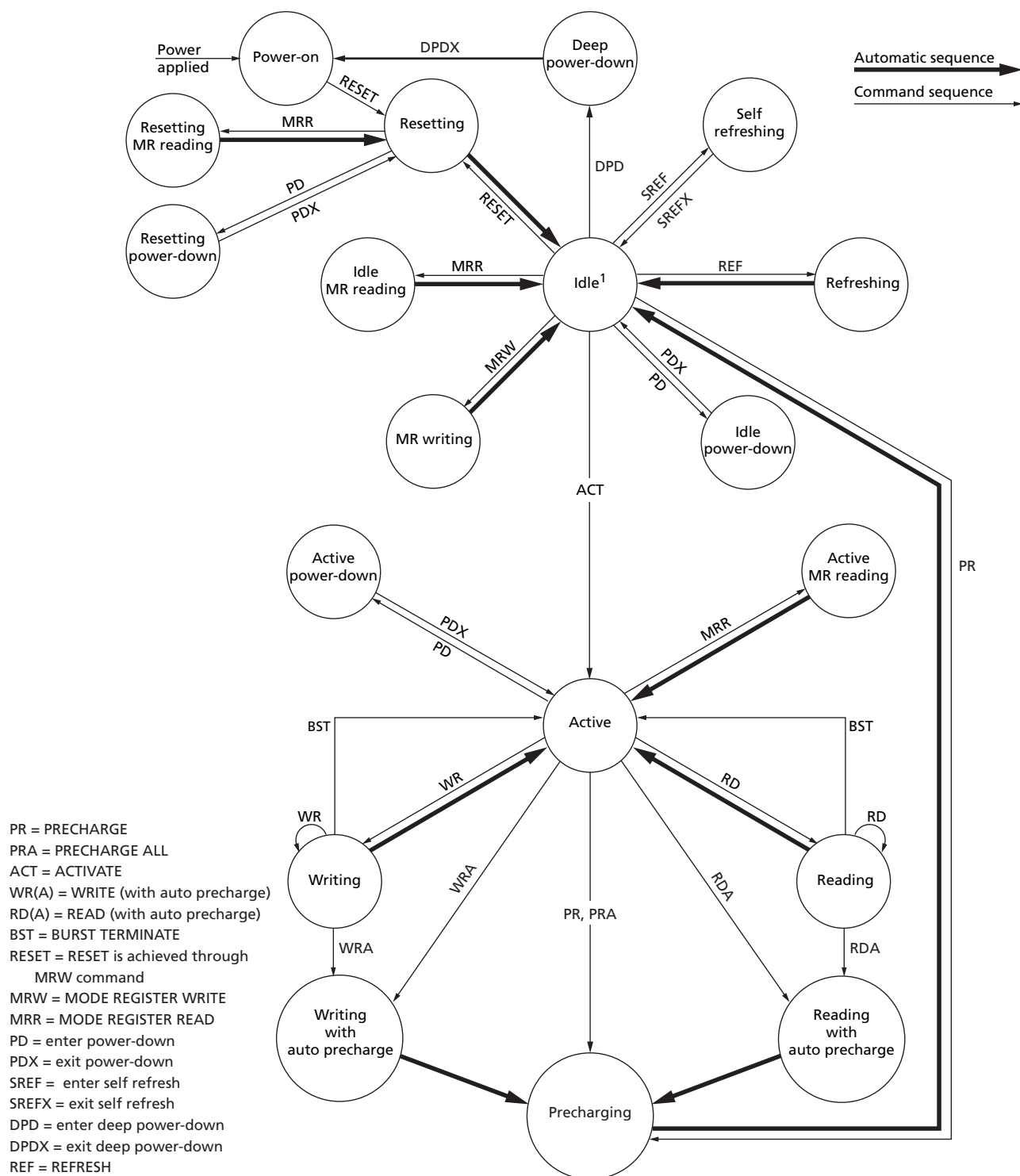
The NOP command will not terminate a previous operation that is still in process, such as a READ burst or WRITE burst cycle.

## Simplified Bus Interface State Diagram

The state diagram (see Figure 64 (page 85)) provides a simplified illustration of the bus interface, supported state transitions, and the commands that control them. For a complete description of device behavior, use the information provided in the state diagram with the truth tables and timing specifications.

The truth tables describe device behavior and applicable restrictions when considering the actual state of all banks.

**Figure 64: Simplified Bus Interface State Diagram**



**Note:** 1. All banks are precharged in the idle state.

## 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.

**Table 50: Command Truth Table**

Notes 1–11 apply to all parameters conditions

| Command                             | Command Pins |       |     | CA Pins |     |     |     |     |     |     |     |     |                                                                                     | CK Edge                                                                               |
|-------------------------------------|--------------|-------|-----|---------|-----|-----|-----|-----|-----|-----|-----|-----|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|                                     | CKE          |       | CS# | CA0     | CA1 | CA2 | CA3 | CA4 | CA5 | CA6 | CA7 | CA8 | CA9                                                                                 |                                                                                       |
|                                     | CK(n-1)      | CK(n) |     |         |     |     |     |     |     |     |     |     |                                                                                     |                                                                                       |
| 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<br>(per bank)               | H            | H     | L   | L       | L   | H   | L   | X   |     |     |     |     |                                                                                     |    |
|                                     | H            | H     | X   | X       |     |     |     |     |     |     |     |     |                                                                                     |   |
| REFRESH<br>(all banks)              | H            | H     | L   | L       | L   | H   | H   | X   |     |     |     |     |                                                                                     |  |
|                                     | H            | H     | X   | X       |     |     |     |     |     |     |     |     |                                                                                     |  |
| Enter self<br>refresh               | H            | L     | L   | L       | L   | H   | X   |     |     |     |     |     |                                                                                     |  |
|                                     | X            | L     | X   | X       |     |     |     |     |     |     |     |     |                                                                                     |  |
| ACTIVATE<br>(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<br>(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,<br>SREF, DPD,<br>(NOP) | L            | L     | L   | H       | H   | H   | X   |     |     |     |     |     |                                                                                     |  |
|                                     | L            | L     | X   | X       |     |     |     |     |     |     |     |     |                                                                                     |  |

**Table 50: Command Truth Table (Continued)**

Notes 1–11 apply to all parameters conditions

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

- Notes:
1. All commands are defined by the current state of CS#, 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. CA<sub>xr</sub> refers to command/address bit "x" on the rising edge of clock.
  8. CA<sub>xf</sub> refers to command/address bit "x" on the falling edge of clock.
  9. CS# and CKE are sampled on the rising edge of the clock.
  10. Per-bank refresh is only supported 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.

**Table 51: CKE Truth Table**

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

| Current State             | CKEn-1 | CKEn | CS# | Command <i>n</i> | Operation <i>n</i>            | 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 |

**Table 51: CKE Truth Table (Continued)**

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

| Current State   | CKEn-1 | CKEn | CS#                              | Command <i>n</i>   | Operation <i>n</i>         | Next State           | Notes  |
|-----------------|--------|------|----------------------------------|--------------------|----------------------------|----------------------|--------|
| 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    |        |
| 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. CKEn = the logic state of CKE at clock rising edge *n*; CKEn-1 was the state of CKE at the previous clock edge.
  4. CS# = the logic state of CS# 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*<sub>XP</sub>) must elapse before any command other than NOP is issued.
  7. The clock must toggle at least twice prior to the *t*<sub>XP</sub> period.
  8. Upon exiting the resetting power-down state, the device will return to the idle state if *t*<sub>INIT5</sub> has expired.
  9. The DPD exit procedure must be followed as described in Deep Power Down.
  10. Self refresh exit time (*t*<sub>XSR</sub>) must elapse before any command other than NOP is issued.
  11. The clock must toggle at least twice prior to the *t*<sub>XSR</sub> time.

**Table 52: 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 |       |

**Table 52: 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      |
|---------------|---------------------|-----------------------------------------|------------------------|------------|
| Idle          | ACTIVATE            | Select and activate row                 | Active                 | 6          |
|               | Refresh (per bank)  | Begin to refresh                        | Refreshing (per bank)  | 7          |
|               | Refresh (all banks) | Begin to refresh                        | Refreshing (all banks) | 8          |
|               | MRW                 | Load value to mode register             | MR writing             | 8          |
|               | MRR                 | Read value from mode register           | Idle, MR reading       |            |
|               | RESET               | Begin device auto initialization        | Resetting              | 8, 9       |
|               | PRECHARGE           | Deactivate row(s) in bank or banks      | Precharging            | 10, 11     |
| 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            | 10         |
| Reading       | READ                | Select column and start new read burst  | Reading                | 12, 13     |
|               | WRITE               | Select column and start write burst     | Writing                | 12, 13, 14 |
|               | BST                 | Read burst terminate                    | Active                 | 15         |
| Writing       | WRITE               | Select column and start new write burst | Writing                | 12, 13     |
|               | READ                | Select column and start read burst      | Reading                | 12, 13, 16 |
|               | BST                 | Write burst terminate                   | Active                 | 15         |
| Power-on      | MRW RESET           | Begin device auto initialization        | Resetting              | 8, 10      |
| Resetting     | MRR                 | Read value from mode register           | Resetting MR reading   |            |

- Notes:
1. Values in this table apply when both  $CKEn-1$  and  $CKEn$  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. The states listed below 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 in the following table.

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 pre-charge 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 pre-charge enabled and ends when  $t_{RP}$  is met. After  $t_{RP}$  is met, the bank is in the idle state.

5. The states listed below 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.

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. There are no restrictions to the number of ACTIVATE commands to a given row in a refresh period provided DRAM timing specifications are not violated. However, specific attempts to bypass Rowhammer circuits may result in data disturb.
7. Bank-specific; requires that the bank is idle and no bursts are in progress.
8. Not bank-specific; requires that all banks are idle and no bursts are in progress.
9. Not bank-specific.
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. If a PRECHARGE command is issued to a bank in the idle state,  $t_{RP}$  still applies.
12. 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.
13. The new READ or WRITE command could be auto precharge enabled or auto precharge disabled.
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. Not bank-specific. The BST command affects the most recent READ/WRITE burst started by the most recent READ/WRITE command, regardless of bank.
16. 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 53: 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     |

**Table 53: 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 <i>n</i>          | Command to Bank <i>m</i> | Operation                                                                   | Next State for Bank <i>m</i>         | Notes      |
|-----------------------------------------|--------------------------|-----------------------------------------------------------------------------|--------------------------------------|------------|
| Row activating, active, or pre-charging | ACTIVATE                 | Select and activate row in bank <i>m</i>                                    | Active                               | 8          |
|                                         | READ                     | Select column and start READ burst from bank <i>m</i>                       | Reading                              | 9          |
|                                         | WRITE                    | Select column and start WRITE burst to bank <i>m</i>                        | 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 <i>m</i> | Active                               | 7          |
| Reading (auto precharge disabled)       | READ                     | Select column and start READ burst from bank <i>m</i>                       | Reading                              | 9          |
|                                         | WRITE                    | Select column and start WRITE burst to bank <i>m</i>                        | Writing                              | 9, 14      |
|                                         | ACTIVATE                 | Select and activate row in bank <i>m</i>                                    | Active                               |            |
|                                         | PRECHARGE                | Deactivate row(s) in bank or banks                                          | Precharging                          | 10         |
| Writing (auto precharge disabled)       | READ                     | Select column and start READ burst from bank <i>m</i>                       | Reading                              | 9, 15      |
|                                         | WRITE                    | Select column and start WRITE burst to bank <i>m</i>                        | Writing                              | 9          |
|                                         | ACTIVATE                 | Select and activate row in bank <i>m</i>                                    | Active                               |            |
|                                         | PRECHARGE                | Deactivate row(s) in bank or banks                                          | Precharging                          | 10         |
| Reading with auto precharge             | READ                     | Select column and start READ burst from bank <i>m</i>                       | Reading                              | 9, 16      |
|                                         | WRITE                    | Select column and start WRITE burst to bank <i>m</i>                        | Writing                              | 9, 14, 16  |
|                                         | ACTIVATE                 | Select and activate row in bank <i>m</i>                                    | Active                               |            |
|                                         | PRECHARGE                | Deactivate row(s) in bank or banks                                          | Precharging                          | 10         |
| Writing with auto precharge             | READ                     | Select column and start READ burst from bank <i>m</i>                       | Reading                              | 9, 15, 16  |
|                                         | WRITE                    | Select column and start WRITE burst to bank <i>m</i>                        | Writing                              | 9, 16      |
|                                         | ACTIVATE                 | Select and activate row in bank <i>m</i>                                    | Active                               |            |
|                                         | PRECHARGE                | Deactivate row(s) in bank or banks                                          | Precharging                          | 10         |
| Power-on                                | MRW 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 <sup>t</sup>XSR or <sup>t</sup>XP has been met; and both CKEn -1 and CKEn 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 only be issued 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. The states listed below 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.

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 54: 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 Specifications

### 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 55: Absolute Maximum DC Ratings**

| Parameter                                                      | Symbol                             | Min  | Max  | Unit | Notes |
|----------------------------------------------------------------|------------------------------------|------|------|------|-------|
| V <sub>DD1</sub> supply voltage relative to V <sub>SS</sub>    | V <sub>DD1</sub>                   | −0.4 | +2.3 | V    | 1     |
| V <sub>DD2</sub> supply voltage relative to V <sub>SS</sub>    | V <sub>DD2</sub> (1.2V)            | −0.4 | +1.6 | V    | 1     |
| V <sub>DDCA</sub> supply voltage relative to V <sub>SSCA</sub> | V <sub>DDCA</sub>                  | −0.4 | +1.6 | V    | 1, 2  |
| V <sub>DDQ</sub> supply voltage relative to V <sub>SSQ</sub>   | V <sub>DDQ</sub>                   | −0.4 | +1.6 | V    | 1, 3  |
| Voltage on any ball relative to V <sub>SS</sub>                | V <sub>IN</sub> , V <sub>OUT</sub> | −0.4 | +1.6 | V    |       |
| Storage temperature                                            | T <sub>STG</sub>                   | −55  | +125 | °C   | 4     |

- Notes:
- See 1. Voltage Ramp under Power-Up.
  - V<sub>REFCA</sub> 0.6 ≤ V<sub>DDCA</sub>; however, V<sub>REFCA</sub> may be ≥ V<sub>DDCA</sub> provided that V<sub>REFCA</sub> ≤ 300mV.
  - V<sub>REFDQ</sub> 0.6 ≤ V<sub>DDQ</sub>; however, V<sub>REFDQ</sub> may be ≥ V<sub>DDQ</sub> provided that V<sub>REFDQ</sub> ≤ 300mV.
  - Storage temperature is the case surface temperature on the center/top side of the device. For measurement conditions, refer to the JE5D51-2 standard.

### Input/Output Capacitance

**Table 56: Input/Output Capacitance**

Note 1 applies to all parameters and conditions

| Parameter                                          | Symbol            | LPDDR2 1066-466 |       | LPDDR2 400-200 |       | Unit | Notes       |
|----------------------------------------------------|-------------------|-----------------|-------|----------------|-------|------|-------------|
|                                                    |                   | MIN             | MAX   | MIN            | MAX   |      |             |
| Input capacitance, CK and CK#                      | C <sub>CK</sub>   | 1.0             | 2.0   | 1.0            | 2.0   | pF   | 2, 3        |
| Input capacitance delta, CK and CK#                | C <sub>DCK</sub>  | 0               | 0.20  | 0              | 0.25  | pF   | 2, 3, 4     |
| Input capacitance, all other input-only pins       | C <sub>I</sub>    | 1.0             | 2.0   | 1.0            | 2.0   | pF   | 2, 3, 5     |
| Input capacitance delta, all other input-only pins | C <sub>DI</sub>   | −0.40           | +0.40 | −0.50          | +0.50 | pF   | 2, 3, 6     |
| Input/output capacitance, DQ, DM, DQS, DQS#        | C <sub>IO</sub>   | 1.25            | 2.5   | 1.25           | 2.5   | pF   | 2, 3, 7, 8  |
| Input/output capacitance delta, DQS, DQS#          | C <sub>DDQS</sub> | 0               | 0.25  | 0              | 0.30  | pF   | 2, 3, 8, 9  |
| Input/output capacitance delta, DQ, DM             | C <sub>DIO</sub>  | −0.5            | +0.5  | −0.6           | +0.6  | pF   | 2, 3, 8, 10 |

**Table 56: Input/Output Capacitance (Continued)**

Note 1 applies to all parameters and conditions

| Parameter                   | Symbol          | LPDDR2 1066-466 |     | LPDDR2 400-200 |     | Unit | Notes    |
|-----------------------------|-----------------|-----------------|-----|----------------|-----|------|----------|
|                             |                 | MIN             | MAX | MIN            | MAX |      |          |
| Input/output capacitance ZQ | C <sub>ZQ</sub> | 0               | 2.5 | 0              | 2.5 | pF   | 2, 3, 11 |

- Notes:
1. T<sub>C</sub> –40°C to +105°C; V<sub>DDQ</sub> = 1.14–1.3V; V<sub>DDCA</sub> = 1.14–1.3V; V<sub>DD1</sub> = 1.7–1.95V; V<sub>DD2</sub> = 1.14–1.3V.
  2. This parameter applies to die devices only (does not include package capacitance).
  3. This parameter is not subject to production testing. It is verified by design and characterization. The capacitance is measured according to JEP147 (procedure for measuring input capacitance using a vector network analyzer), with V<sub>DD1</sub>, V<sub>DD2</sub>, V<sub>DDQ</sub>, V<sub>SS</sub>, V<sub>SSCA</sub>, and V<sub>SSQ</sub> applied; all other pins are left floating.
  4. Absolute value of C<sub>CK</sub> - C<sub>CK#</sub>.
  5. C<sub>I</sub> applies to CS#, CKE, and CA[9:0].
  6. C<sub>DI</sub> = C<sub>I</sub> - 0.5 × (C<sub>CK</sub> + C<sub>CK#</sub>).
  7. DM loading matches DQ and DQS.
  8. MR3 I/O configuration drive strength OP[3:0] = 0001b (34.3 ohm typical).
  9. Absolute value of C<sub>DQS</sub> and C<sub>DQS#</sub>.
  10. C<sub>DIO</sub> = C<sub>IO</sub> - 0.5 × (C<sub>DQS</sub> + C<sub>DQS#</sub>) in byte-lane.
  11. Maximum external load capacitance on ZQ pin: 5pF.

## Electrical Specifications – I<sub>DD</sub> Specifications and Conditions

The following definitions and conditions are used in the I<sub>DD</sub> measurement tables unless stated otherwise:

- LOW: V<sub>IN</sub> ≤ V<sub>IL(DC)max</sub>
- HIGH: V<sub>IN</sub> ≥ V<sub>IH(DC)min</sub>
- STABLE: Inputs are stable at a HIGH or LOW level
- SWITCHING: See the following three tables

**Table 57: Switching for CA Input Signals**

Notes 1–3 apply to all parameters and conditions

|       | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising |
|-------|--------------------------|---------------------------|--------------------------|---------------------------|--------------------------|---------------------------|--------------------------|---------------------------|
| Cycle | N                        |                           | N + 1                    |                           | N + 2                    |                           | N + 3                    |                           |
| CS#   | 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                         |

**Table 57: Switching for CA Input Signals (Continued)**

Notes 1–3 apply to all parameters and conditions

|     | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising | CK Rising/<br>CK#Falling | CK Falling/<br>CK# Rising |
|-----|--------------------------|---------------------------|--------------------------|---------------------------|--------------------------|---------------------------|--------------------------|---------------------------|
| 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<sub>DD</sub> measurement for I<sub>DD</sub> values that require switching on the CA bus.

**Table 58: Switching for I<sub>DD4R</sub>**

| Clock   | CKE | CS# | 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     | LHLHLHL | L      |
| Rising  | H   | L   | N + 2              | Read_Rising  | HLH     | LHLHLHL | H      |
| Falling | H   | L   | N + 2              | Read_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. The noted pattern (N, N + 1...) is used continuously during I<sub>DD</sub> measurement for I<sub>DD4R</sub>.

**Table 59: Switching for I<sub>DD4W</sub>**

| Clock   | CKE | CS# | Clock Cycle Number | Command       | CA[2:0] | CA[9:3] | All DQ |
|---------|-----|-----|--------------------|---------------|---------|---------|--------|
| Rising  | H   | L   | N                  | Write_Rising  | LLH     | 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     | LHLHLHL | L      |
| Rising  | H   | L   | N + 2              | Write_Rising  | LLH     | LHLHLHL | 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<sub>DD</sub> measurement for I<sub>DD4W</sub>.

**Table 60: I<sub>DD</sub> Specification Parameters and Operating Conditions**

Notes 1–3 apply to all parameters and conditions

| Parameter/Condition                                                                                                                                                                                                                              | Symbol                | Power Supply                         | Notes |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------------------------|-------|
| <b>Operating one bank active-precharge current (SDRAM):</b> <sup>t</sup> CK = <sup>t</sup> CKmin; <sup>t</sup> RC = <sup>t</sup> RCmin; CKE is HIGH; CS# is HIGH between valid commands; CA bus inputs are switching; Data bus inputs are stable | I <sub>DD01</sub>     | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD02</sub>     | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD0in</sub>    | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Idle power-down standby current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CKE is LOW; CS# is HIGH; All banks are idle; CA bus inputs are switching; Data bus inputs are stable                                                               | I <sub>DD2P1</sub>    | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2P2</sub>    | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2P,in</sub>  | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Idle power-down standby current with clock stop:</b> CK = LOW, CK# = HIGH; CKE is LOW; CS# is HIGH; All banks are idle; CA bus inputs are stable; Data bus inputs are stable                                                                  | I <sub>DD2PS1</sub>   | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2PS2</sub>   | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2PS,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Idle non-power-down standby current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CKE is HIGH; CS# is HIGH; All banks are idle; CA bus inputs are switching; Data bus inputs are stable                                                          | I <sub>DD2N1</sub>    | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2N2</sub>    | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2N,in</sub>  | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Idle non-power-down standby current with clock stopped:</b> CK = LOW; CK# = HIGH; CKE is HIGH; CS# is HIGH; All banks are idle; CA bus inputs are stable; Data bus inputs are stable                                                          | I <sub>DD2NS1</sub>   | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2NS2</sub>   | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD2NS,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Active power-down standby current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CKE is LOW; CS# is HIGH; One bank is active; CA bus inputs are switching; Data bus inputs are stable                                                             | I <sub>DD3P1</sub>    | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3P2</sub>    | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3P,in</sub>  | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Active power-down standby current with clock stop:</b> CK = LOW, CK# = HIGH; CKE is LOW; CS# is HIGH; One bank is active; CA bus inputs are stable; Data bus inputs are stable                                                                | I <sub>DD3PS1</sub>   | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3PS2</sub>   | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3PS,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Active non-power-down standby current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CKE is HIGH; CS# is HIGH; One bank is active; CA bus inputs are switching; Data bus inputs are stable                                                        | I <sub>DD3N1</sub>    | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3N2</sub>    | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3N,in</sub>  | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Active non-power-down standby current with clock stopped:</b> CK = LOW, CK# = HIGH; CKE is HIGH; CS# is HIGH; One bank is active; CA bus inputs are stable; Data bus inputs are stable                                                        | I <sub>DD3NS1</sub>   | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3NS2</sub>   | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD3NS,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>Operating burst READ current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CS# 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 <sub>DD4R1</sub>    | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD4R2</sub>    | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD4R,in</sub>  | V <sub>DDCA</sub>                    |       |
|                                                                                                                                                                                                                                                  | I <sub>DD4RQ</sub>    | V <sub>DDQ</sub>                     | 5     |
| <b>Operating burst WRITE current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CS# 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 <sub>DD4W1</sub>    | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD4W2</sub>    | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD4W,in</sub>  | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |
| <b>All-bank REFRESH burst current:</b> <sup>t</sup> CK = <sup>t</sup> CKmin; CKE is HIGH between valid commands; <sup>t</sup> RC = <sup>t</sup> RFCabmin; Burst refresh; CA bus inputs are switching; Data bus inputs are stable                 | I <sub>DD51</sub>     | V <sub>DD1</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD52</sub>     | V <sub>DD2</sub>                     |       |
|                                                                                                                                                                                                                                                  | I <sub>DD5IN</sub>    | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4     |

**Table 60: I<sub>DD</sub> Specification Parameters and Operating Conditions (Continued)**

Notes 1–3 apply to all parameters and conditions

| Parameter/Condition                                                                                                                                                                 | Symbol                | Power Supply                         | Notes   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------------------------|---------|
| <b>All-bank REFRESH average current:</b> $t_{CK} = t_{CKmin}$ ; CKE is HIGH between valid commands; $t_{RC} = t_{REFI}$ ; CA bus inputs are switching; Data bus inputs are stable   | I <sub>DD5AB1</sub>   | V <sub>DD1</sub>                     |         |
|                                                                                                                                                                                     | I <sub>DD5AB2</sub>   | V <sub>DD2</sub>                     |         |
|                                                                                                                                                                                     | I <sub>DD5AB,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4       |
| <b>Per-bank REFRESH average current:</b> $t_{CK} = t_{CKmin}$ ; CKE is HIGH between valid commands; $t_{RC} = t_{REFI}/8$ ; CA bus inputs are switching; Data bus inputs are stable | I <sub>DD5PB1</sub>   | V <sub>DD1</sub>                     | 6       |
|                                                                                                                                                                                     | I <sub>DD5PB2</sub>   | V <sub>DD2</sub>                     | 6       |
|                                                                                                                                                                                     | I <sub>DD5PB,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4, 6    |
| <b>Self refresh current (–40°C to +85°C):</b> CK = LOW, CK# = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable; Maximum 1x self refresh rate                  | I <sub>DD61</sub>     | V <sub>DD1</sub>                     | 7       |
|                                                                                                                                                                                     | I <sub>DD62</sub>     | V <sub>DD2</sub>                     | 7       |
|                                                                                                                                                                                     | I <sub>DD6IN</sub>    | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4, 7    |
| <b>Self refresh current (+85°C to +105°C):</b> CK = LOW, CK# = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable                                               | I <sub>DD6ET1</sub>   | V <sub>DD1</sub>                     | 7, 8    |
|                                                                                                                                                                                     | I <sub>DD6ET2</sub>   | V <sub>DD2</sub>                     | 7, 8    |
|                                                                                                                                                                                     | I <sub>DD6ET,in</sub> | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4, 7, 8 |
| Self refresh current (+105°C to +125°C): Not available.                                                                                                                             |                       |                                      | 9       |
| <b>Deep power-down current:</b> CK = LOW, CK# = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable                                                              | I <sub>DD81</sub>     | V <sub>DD1</sub>                     | 8       |
|                                                                                                                                                                                     | I <sub>DD82</sub>     | V <sub>DD2</sub>                     | 8       |
|                                                                                                                                                                                     | I <sub>DD8IN</sub>    | V <sub>DDCA</sub> , V <sub>DDQ</sub> | 4, 8    |

- Notes:
1. I<sub>DD</sub> values are the maximum of the distribution of the arithmetic mean.
  2. I<sub>DD</sub> current specifications are tested after the device is properly initialized.
  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<sub>DDQ</sub> and V<sub>DDCA</sub>.
  5. Guaranteed by design with output reference load and R<sub>ON</sub> = 40 ohm.
  6. Per-bank REFRESH is only applicable for LPDDR2-S4 device densities 1Gb or higher.
  7. This is the general definition that applies to full-array self refresh.
  8. I<sub>DD6ET</sub> and I<sub>DD8</sub> are typical values, are sampled only, and are not tested.
  9. When TC > 105°C, self-refresh mode is not available.

## AC and DC Operating Conditions

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

**Table 61: Recommended DC Operating Conditions**

| Symbol                        | LPDDR2-S4B |      |      | Power Supply       | Unit |
|-------------------------------|------------|------|------|--------------------|------|
|                               | Min        | Typ  | Max  |                    |      |
| V <sub>DD1</sub> <sup>1</sup> | 1.70       | 1.80 | 1.95 | Core power 1       | V    |
| V <sub>DD2</sub>              | 1.14       | 1.20 | 1.30 | Core power 2       | V    |
| V <sub>DDCA</sub>             | 1.14       | 1.20 | 1.30 | Input buffer power | V    |

**Table 61: Recommended DC Operating Conditions (Continued)**

| Symbol    | LPDDR2-S4B |      |      | Power Supply     | Unit |
|-----------|------------|------|------|------------------|------|
|           | Min        | Typ  | Max  |                  |      |
| $V_{DDQ}$ | 1.14       | 1.20 | 1.30 | I/O buffer power | V    |

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

**Table 62: Input Leakage Current**

| Parameter/Condition                                                                                                                                 | Symbol     | Min | Max | Unit    | Notes |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----|-----|---------|-------|
| <b>Input leakage current:</b> For CA, CKE, CS#, CK, CK#;<br>Any input $0V \leq V_{IN} \leq V_{DDCA}$ ; (All other pins not under test = 0V)         | $I_L$      | -2  | 2   | $\mu A$ | 1     |
| <b><math>V_{REF}</math> supply leakage current:</b> $V_{REFDQ} = V_{DDQ}/2$ , or<br>$V_{REFCA} = V_{DDCA}/2$ ; (All other pins not under test = 0V) | $I_{VREF}$ | -1  | 1   | $\mu A$ | 2     |

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

**Table 63: Operating Temperature Range**

| Parameter/Condition  | Symbol       | Min | Max  | Unit        |
|----------------------|--------------|-----|------|-------------|
| IT temperature range | $T_{CASE}^1$ | -40 | +85  | $^{\circ}C$ |
| AT temperature range |              | -40 | +105 | $^{\circ}C$ |
| UT temperature range |              | -40 | +125 | $^{\circ}C$ |

- Notes:
- 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.
  - Some applications require operation in the maximum case temperature range, between  $85^{\circ}C$  and  $105^{\circ}C$ . For some LPDDR2 devices, derating may be necessary to operate in this range (see the MR4 Device Temperature (MA[7:0] = 04h) table).
  - 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  $85^{\circ}C$  when the temperature sensor indicates a temperature of less than  $85^{\circ}C$ .
  - UT option use based on automotive usage model. Please contact Micron sales representative if you have questions.

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

**Table 64: Single-Ended AC and DC Input Levels for CA and CS# 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                     | $V_{REF} + 0.130$         | $V_{DDCA}$             | $V_{REF} + 0.200$        | $V_{DDCA}$             | V    | 1     |
| $V_{ILCA(DC)}$  | DC input logic LOW                      | $V_{SSCA}$                | $V_{REF} - 0.130$      | $V_{SSCA}$               | $V_{REF} - 0.200$      | V    | 1     |
| $V_{REFCA(DC)}$ | Reference voltage for CA and CS# inputs | $0.49 \times V_{DDCA}$    | $0.51 \times V_{DDCA}$ | $0.49 \times V_{DDCA}$   | $0.51 \times V_{DDCA}$ | V    | 3, 4  |

- Notes:
1. For CA and CS# 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  $\pm 1\% V_{DDCA}$  from  $V_{REFCA(DC)}$  (for reference, approximately  $\pm 12mV$ ).
  4. For reference, approximately  $V_{DDCA}/2 \pm 12mV$ .

**Table 65: Single-Ended AC and DC Input Levels for CKE**

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

- Note:
1. See Overshoot and Undershoot Definition.

**Table 66: Single-Ended AC and DC Input Levels for DQ and DM**

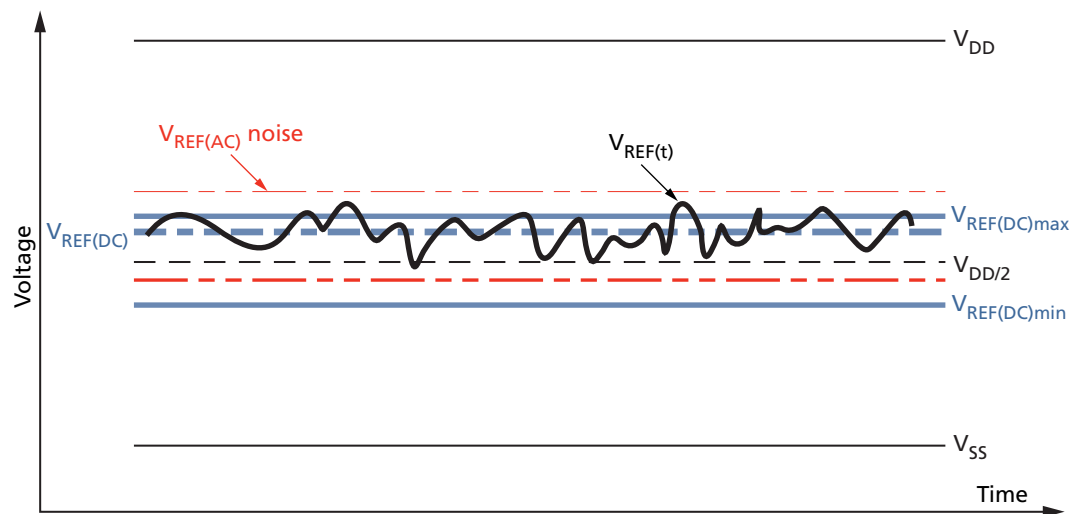
| Symbol          | Parameter                              | LPDDR2-1066 to LPDDR2-466 |                       | LPDDR2-400 to LPDDR2-200 |                       | Unit | Notes |
|-----------------|----------------------------------------|---------------------------|-----------------------|--------------------------|-----------------------|------|-------|
|                 |                                        | 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                     | $V_{SSQ}$                 | $V_{REF} - 0.130$     | $V_{SSQ}$                | $V_{REF} - 0.200$     | V    | 1     |
| $V_{REFDQ(DC)}$ | Reference voltage for DQ and DM inputs | $0.49 \times V_{DDQ}$     | $0.51 \times V_{DDQ}$ | $0.49 \times V_{DDQ}$    | $0.51 \times V_{DDQ}$ | 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  $\pm 1\% V_{DDQ}$  from  $V_{REFDQ(DC)}$  (for reference, approximately  $\pm 12mV$ ).
  4. For reference, approximately.  $V_{DDQ}/2 \pm 12mV$ .

## **$V_{REF}$ 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  $V_{DDCA}$  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  $V_{DDCA}$ , also over a very long period of time (for example, 1 second). This average must meet the MIN/MAX requirements in Table 64 (page 100). Additionally,  $V_{REF}(t)$  can temporarily deviate from  $V_{REF(DC)}$  by no more than  $\pm 1\% V_{DD}$ .  $V_{REF}(t)$  cannot track noise on  $V_{DDQ}$  or  $V_{DDCA}$  if doing so would force  $V_{REF}$  outside these specifications.

**Figure 65:  $V_{REF}$  DC Tolerance and  $V_{REF}$  AC Noise Limits**



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:

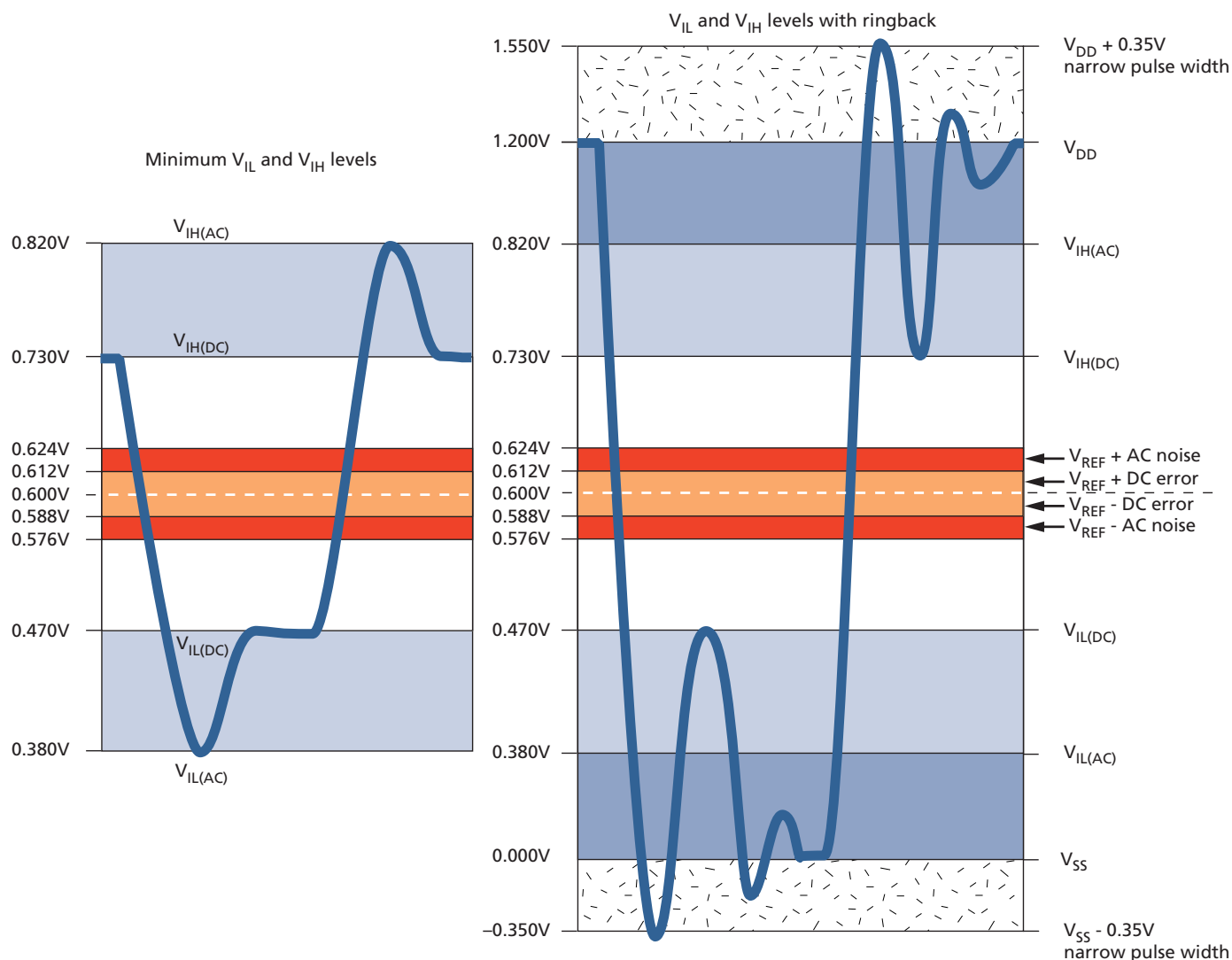
- $V_{REF}$  is maintained between  $0.44 \times V_{DDQ}$  (or  $V_{DDCA}$ ) and  $0.56 \times V_{DDQ}$  (or  $V_{DDCA}$ ), and
- the controller achieves the required single-ended AC and DC input levels from instantaneous  $V_{REF}$  (see Table 64 (page 100)).

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 ( $\pm 1\% V_{DD}$ ) are included in LPDDR2 timings and their associated deratings.

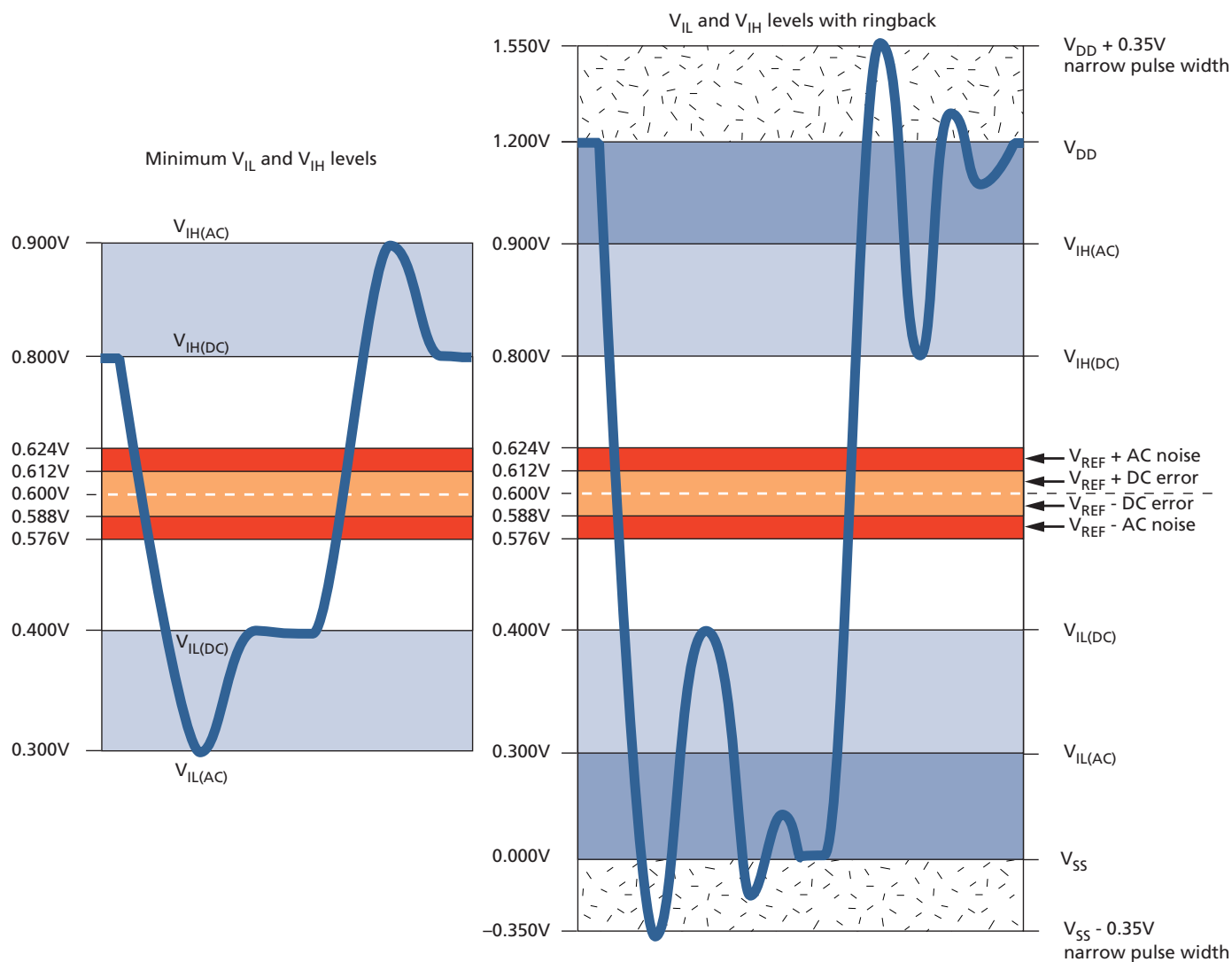
### Input Signal

**Figure 66: LPDDR2-466 to LPDDR2-1066 Input Signal**



- Notes:
1. Numbers reflect typical values.
  2. For CA[9:0], CK, CK#, and CS#  $V_{DD}$  stands for  $V_{DDCA}$ . For DQ, DM, DQS, and DQS#,  $V_{DD}$  stands for  $V_{DDQ}$ .
  3. For CA[9:0], CK, CK#, and CS#  $V_{SS}$  stands for  $V_{SSCA}$ . For DQ, DM, DQS, and DQS#,  $V_{SS}$  stands for  $V_{SSQ}$ .

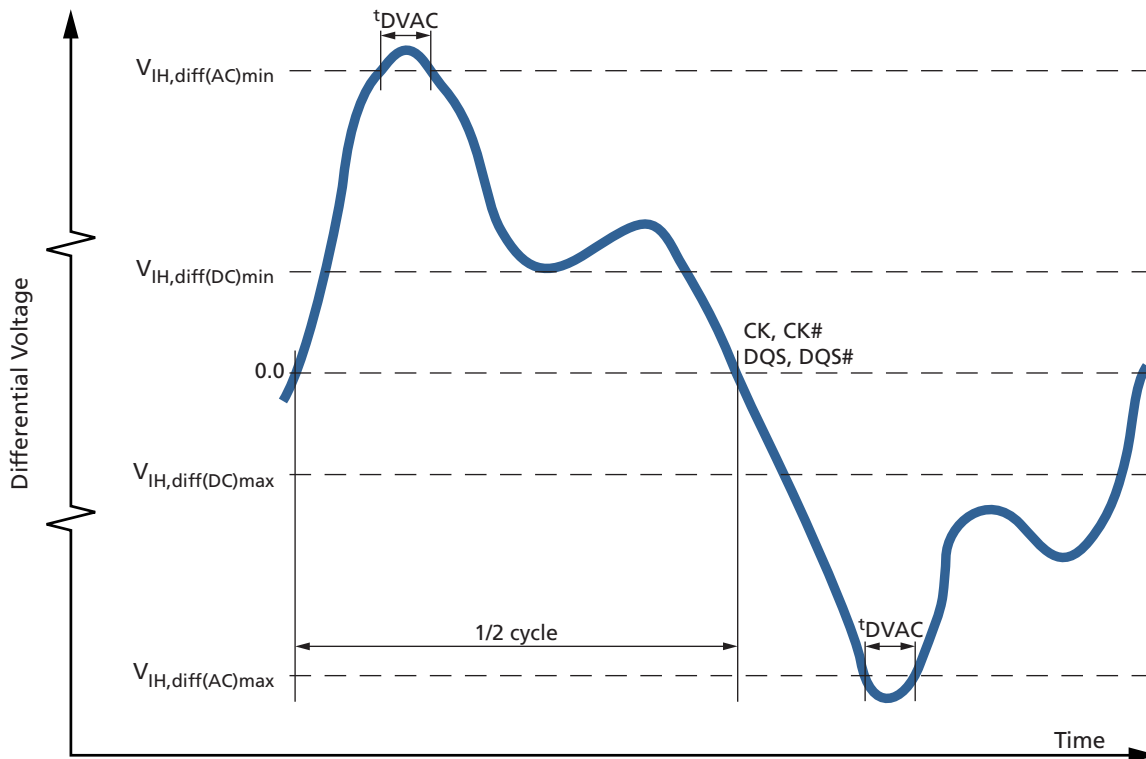
**Figure 67: LPDDR2-200 to LPDDR2-400 Input Signal**



- Notes:
1. Numbers reflect typical values.
  2. For CA[9:0], CK, CK#, and CS#  $V_{DD}$  stands for  $V_{DDCA}$ . For DQ, DM, DQS, and DQS#,  $V_{DD}$  stands for  $V_{DDQ}$ .
  3. For CA[9:0], CK, CK#, and CS#  $V_{SS}$  stands for  $V_{SSCA}$ . For DQ, DM, DQS, and DQS#,  $V_{SS}$  stands for  $V_{SSQ}$ .

## AC and DC Logic Input Measurement Levels for Differential Signals

**Figure 68: Differential AC Swing Time and  $t_{DVAC}$**



**Table 67: Differential AC and DC Input Levels**

For CK and CK#,  $V_{REF} = V_{REFCA(DC)}$ ; For DQS and DQS#  $V_{REF} = V_{REFDQ(DC)}$

| 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                            | $2 \times (V_{REF} - V_{IL(AC)})$ | Note 1                            | $2 \times (V_{REF} - V_{IL(AC)})$ | 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                            | $2 \times (V_{REF} - V_{IL(DC)})$ | Note 1                            | $2 \times (V_{REF} - V_{IL(DC)})$ | V    | 3     |

Notes: 1. These values are not defined, however the single-ended signals CK, CK#, DQS, and DQS# 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 Definition).

- For CK and CK#, use  $V_{IH}/V_{IL(AC)}$  of CA and  $V_{REFCA}$ ; for DQS and DQS#, 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.
- Used to define a differential signal slew rate.

**Table 68: CK/CK# and DQS/DQS# 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                                                  |

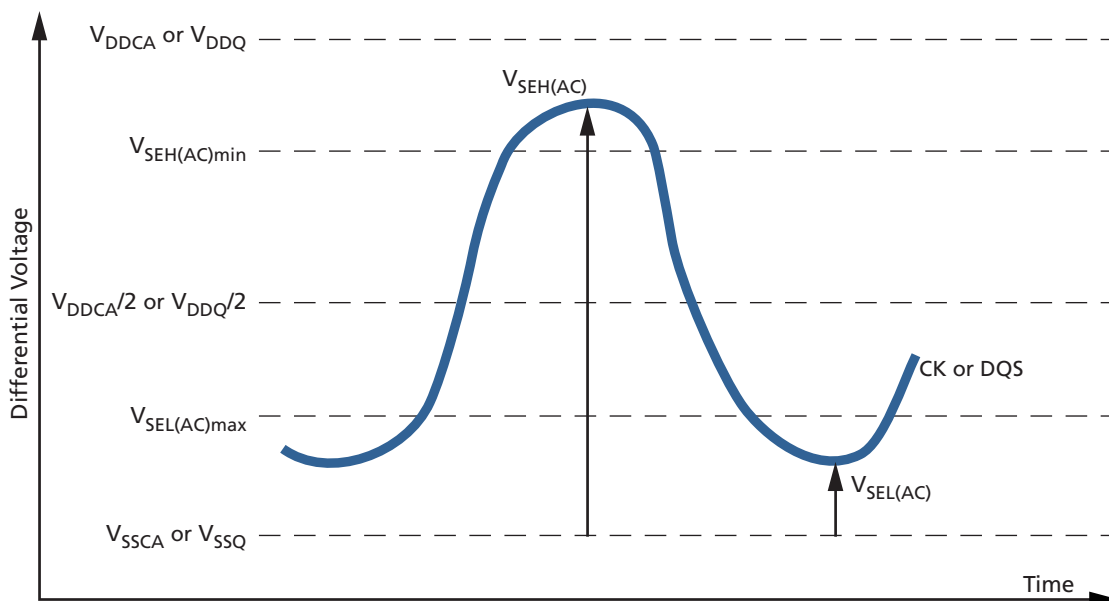
### Single-Ended Requirements for Differential Signals

Each individual component of a differential signal (CK, CK#, DQS, and DQS#) must also comply with certain requirements for single-ended signals.

CK and CK# must meet  $V_{SEH(AC)min}/V_{SEL(AC)max}$  in every half cycle. DQS, DQS# 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.

**Figure 69: Single-Ended Requirements for Differential Signals**



Note that 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  $V_{DDCA}/2$  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# Inputs" for CK/CK# single-ended requirements, and "Single-Ended AC and DC Input Levels for DQ and DM" for DQ and DQM single-ended requirements).

**Table 69: Single-Ended Levels for CK, CK#, DQS, DQS#**

| 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, CK# | $(V_{DDCA}/2) + 0.220$    | Note 1                 | $(V_{DDCA}/2) + 0.300$   | 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, CK#  | Note 1                    | $(V_{DDCA}/2) - 0.220$ | Note 1                   | $(V_{DDCA}/2) - 0.300$ | V    | 2, 3  |

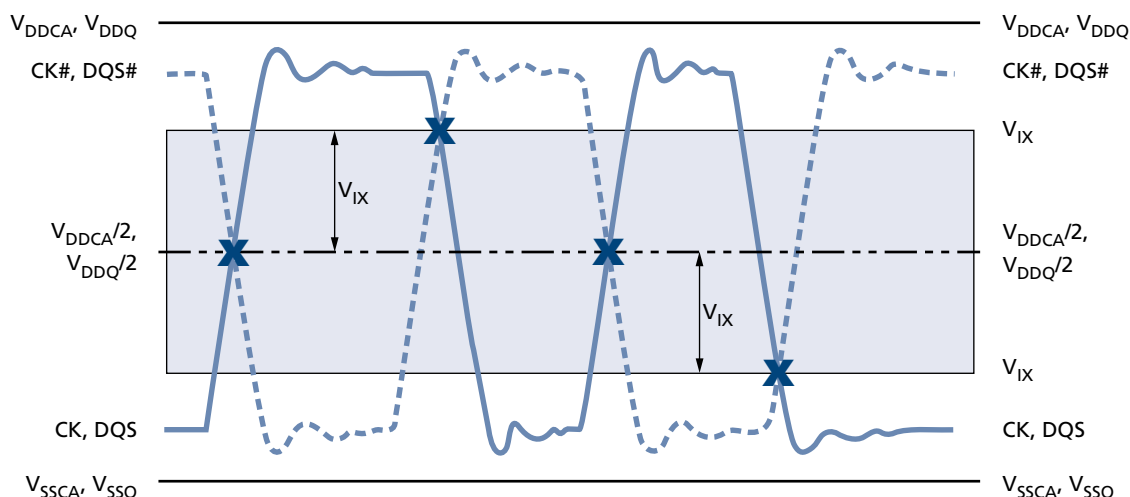
Notes: 1. These values are not defined, however, the single-ended signals CK, CK#, DQS0, DQS#0, DQS1, DQS#1, DQS2, DQS#2, DQS3, DQS#3 must be within the respective limits  $(V_{IH(DC)max}/V_{IL(DC)min})$  for single-ended signals, and must comply with the specified limitations for overshoot and undershoot (See Overshoot and Undershoot Definition).

- For CK and CK#, use  $V_{SEH}/V_{SEL(AC)}$  of CA; for strobes (DQS[3:0] and DQS#[3:0]), use  $V_{IH}/V_{IL(AC)}$  of DQ.
- $V_{IH(AC)}$  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, CK#, DQS, and DQS#) must meet the specifications in Table 69 (page 106). The differential input crosspoint voltage ( $V_{IX}$ ) is measured from the actual crosspoint of the true signal and its complement to the midlevel between  $V_{DD}$  and  $V_{SS}$ .

**Figure 70:  $V_{IX}$  Definition**



**Table 70: Crosspoint Voltage for Differential Input Signals (CK, CK#, DQS, DQS#)**

| Symbol         | Parameter                                                                      | LPDDR2-1066 to LPDDR2-200 |     | Unit | Notes |
|----------------|--------------------------------------------------------------------------------|---------------------------|-----|------|-------|
|                |                                                                                | Min                       | Max |      |       |
| $V_{IXCA(AC)}$ | Differential input crosspoint voltage relative to $V_{DDCA}/2$ for CK and CK#  | -120                      | 120 | mV   | 1, 2  |
| $V_{IXDQ(AC)}$ | Differential input crosspoint voltage relative to $V_{DDQ}/2$ for DQS and DQS# | -120                      | 120 | mV   | 1, 2  |

- Notes:
- The typical value of  $V_{IX(AC)}$  is expected to be about  $0.5 \times V_{DD}$  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.
  - For CK and CK#,  $V_{REF} = V_{REFCA(DC)}$ . For DQS and DQS#,  $V_{REF} = V_{REFDQ(DC)}$ .

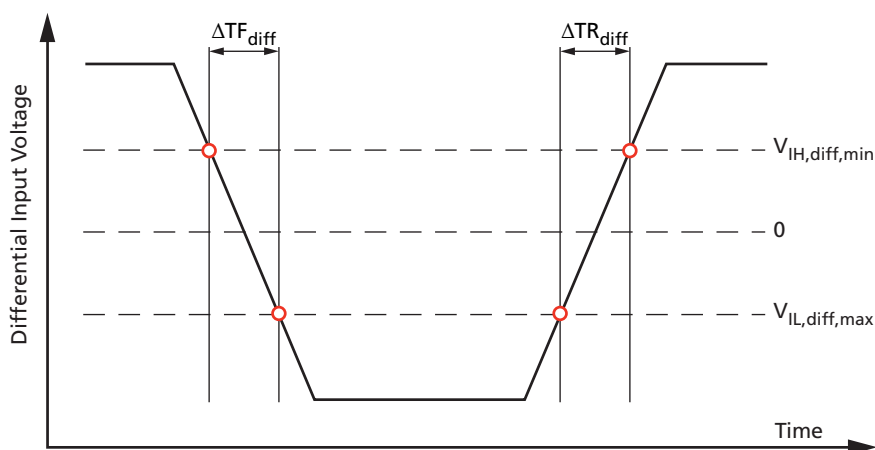
### Input Slew Rate

**Table 71: Differential Input Slew Rate Definition**

| Description                                                         | Measured <sup>1</sup> |                   | Defined by                                               |
|---------------------------------------------------------------------|-----------------------|-------------------|----------------------------------------------------------|
|                                                                     | From                  | To                |                                                          |
| Differential input slew rate for rising edge (CK/CK# and DQS/DQS#)  | $V_{IL,diff,max}$     | $V_{IH,diff,min}$ | $[V_{IH,diff,min} - V_{IL,diff,max}] / \Delta TR_{diff}$ |
| Differential input slew rate for falling edge (CK/CK# and DQS/DQS#) | $V_{IH,diff,min}$     | $V_{IL,diff,max}$ | $[V_{IH,diff,min} - V_{IL,diff,max}] / \Delta TF_{diff}$ |

Note: 1. The differential signals (CK/CK# and DQS/DQS#) must be linear between these thresholds.

**Figure 71: Differential Input Slew Rate Definition for CK, CK#, DQS, and DQS#**



## Output Characteristics and Operating Conditions

**Table 72: 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)                                             | $0.9 \times V_{DDQ}$ | V    | 1     |
| $V_{OL(DC)}$ | DC output LOW measurement level (for I-V curve linearity)                                              | $0.1 \times V_{DDQ}$ | V    | 2     |
| $I_{OZ}$     | Output leakage current (DQ, DM, DQS, DQS#); DQ, DQS, DQS# are disabled; $0V \leq V_{OUT} \leq V_{DDQ}$ | MIN                  | -5   | μA    |
|              |                                                                                                        | MAX                  | +5   | μA    |
| 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 73: Differential AC and DC Output Levels**

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

## Single-Ended Output Slew Rate

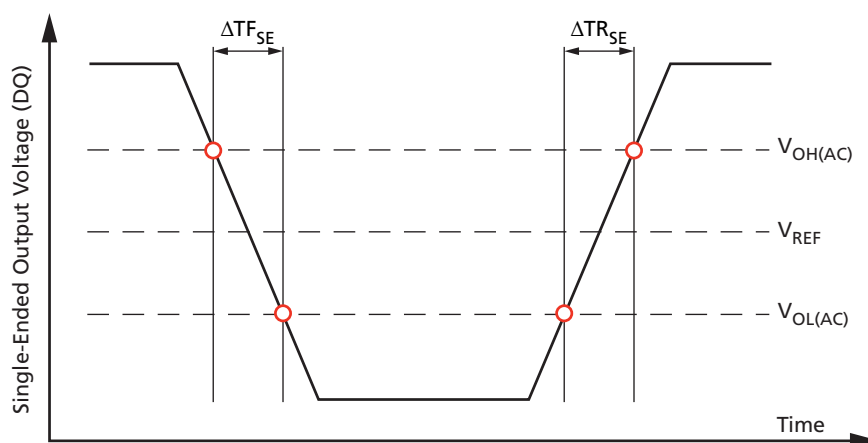
With the reference load for timing measurements, the output slew rate for falling and rising edges is defined and measured between  $V_{OL(AC)}$  and  $V_{OH(AC)}$  for single-ended signals.

**Table 74: 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.

**Figure 72: Single-Ended Output Slew Rate Definition**



**Table 75: 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 = $40\Omega \pm 30\%$ ) | $SRQ_{SE}$ | 1.5   | 3.5 | V/ns |
| Single-ended output slew rate (output impedance = $60\Omega \pm 30\%$ ) | $SRQ_{SE}$ | 1.0   | 2.5 | V/ns |

**Table 75: Single-Ended Output Slew Rate (Continued)**

Notes 1–5 apply to all parameters conditions

| Parameter                                              | Symbol | Value |     | Unit |
|--------------------------------------------------------|--------|-------|-----|------|
|                                                        |        | Min   | Max |      |
| 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

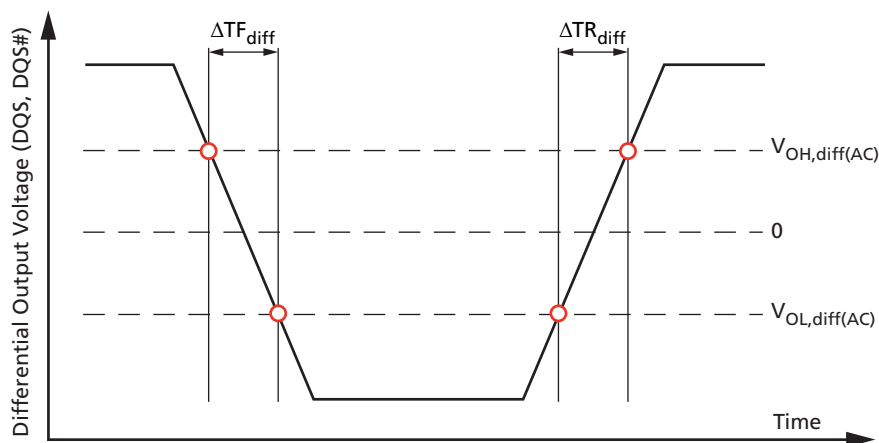
With the reference load for timing measurements, the output slew rate for falling and rising edges is defined and measured between  $V_{OL,diff(AC)}$  and  $V_{OH,diff(AC)}$  for differential signals.

**Table 76: Differential Output Slew Rate Definition**

| Description                                    | Measured          |                   | Defined by                                                |
|------------------------------------------------|-------------------|-------------------|-----------------------------------------------------------|
|                                                | From              | To                |                                                           |
| Differential output slew rate for rising edge  | $V_{OL,diff(AC)}$ | $V_{OH,diff(AC)}$ | $[V_{OH,diff(AC)} - V_{OL,diff(AC)}] / \Delta T_{R,diff}$ |
| Differential output slew rate for falling edge | $V_{OH,diff(AC)}$ | $V_{OL,diff(AC)}$ | $[V_{OH,diff(AC)} - V_{OL,diff(AC)}] / \Delta T_{F,diff}$ |

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

**Figure 73: Differential Output Slew Rate Definition**



**Table 77: Differential Output Slew Rate**

| Parameter                                                   | Symbol              | Value |     | Unit |
|-------------------------------------------------------------|---------------------|-------|-----|------|
|                                                             |                     | Min   | Max |      |
| Differential output slew rate (output impedance = 40Ω ±30%) | SRQ <sub>diff</sub> | 3.0   | 7.0 | V/ns |
| Differential output slew rate (output impedance = 60Ω ±30%) | SRQ <sub>diff</sub> | 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<sub>OL(AC)</sub> and V<sub>OH(AC)</sub>.
  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.

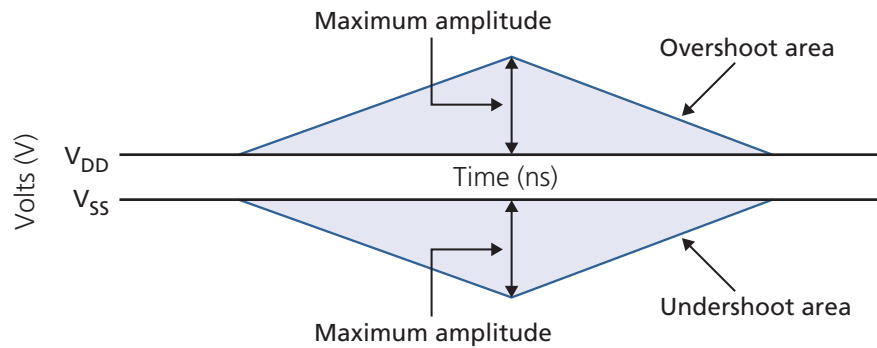
**Table 78: AC Overshoot/Undershoot Specification**

Applies for CA[9:0], CS#, CKE, CK, CK#, DQ, DQS, DQS#, DM

| Parameter                                           | 1066 | 933  | 800  | 667  | 533  | 400  | 333  | Unit |
|-----------------------------------------------------|------|------|------|------|------|------|------|------|
| Maximum peak amplitude provided for overshoot area  | 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 | V    |
| Maximum area above V <sub>DD</sub> <sup>1</sup>     | 0.15 | 0.17 | 0.20 | 0.24 | 0.30 | 0.40 | 0.48 | V/ns |
| Maximum area below V <sub>SS</sub> <sup>2</sup>     | 0.15 | 0.17 | 0.20 | 0.24 | 0.30 | 0.40 | 0.48 | V/ns |

- Notes:
1. V<sub>DD</sub> stands for V<sub>DDCA</sub> for CA[9:0], CK, CK#, CS#, and CKE. V<sub>DD</sub> stands for V<sub>DDQ</sub> for DQ, DM, DQS, and DQS#.
  2. V<sub>SS</sub> stands for V<sub>SSCA</sub> for CA[9:0], CK, CK#, CS#, and CKE. V<sub>SS</sub> stands for V<sub>SSQ</sub> for DQ, DM, DQS, and DQS#.

**Figure 74: Overshoot and Undershoot Definition**

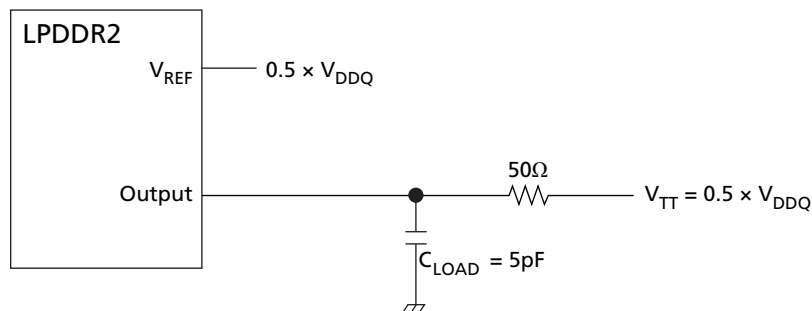


- Notes:
1.  $V_{DD}$  stands for  $V_{DDCA}$  for CA[9:0], CK, CK#, CS#, and CKE.  $V_{DD}$  stands for  $V_{DDQ}$  for DQ, DM, DQS, and DQS#.
  2.  $V_{SS}$  stands for  $V_{SSCA}$  for CA[9:0], CK, CK#, CS#, and CKE.  $V_{SS}$  stands for  $V_{SSQ}$  for DQ, DM, DQS, and DQS#.

## 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.

**Figure 75: 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

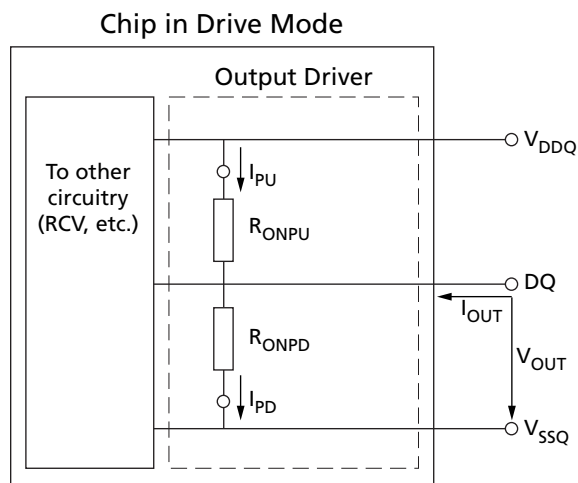
Output driver impedance is selected by a mode register during initialization. To achieve tighter tolerances, ZQ calibration is required. Output specifications refer to the default output drive unless specifically stated otherwise. The output driver impedance  $R_{ON}$  is defined by the value of the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

**Figure 76: 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 79: 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 |
|----------------------------------------|---------------|----------------------|--------|------|--------|------------|-------|
| 34.3 $\Omega$                          | $R_{ON34PD}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/7$ |       |
|                                        | $R_{ON34PU}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/7$ |       |
| 40.0 $\Omega$                          | $R_{ON40PD}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/6$ |       |
|                                        | $R_{ON40PU}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/6$ |       |
| 48.0 $\Omega$                          | $R_{ON48PD}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/5$ |       |
|                                        | $R_{ON48PU}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/5$ |       |
| 60.0 $\Omega$                          | $R_{ON60PD}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/4$ |       |
|                                        | $R_{ON60PU}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/4$ |       |
| 80.0 $\Omega$                          | $R_{ON80PD}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/3$ |       |
|                                        | $R_{ON80PU}$  | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/3$ |       |
| 120.0 $\Omega$                         | $R_{ON120PD}$ | $0.5 \times V_{DDQ}$ | 0.85   | 1.00 | 1.15   | $R_{ZQ}/2$ |       |
|                                        | $R_{ON120PU}$ | $0.5 \times V_{DDQ}$ | 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.  $R_{ZQ} = 240\Omega$ .
  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  $0.5 \times V_{DDQ}$ .
  5. Measurement definition for mismatch between pull-up and pull-down,  $MM_{PUPD}$ :

Measure  $R_{ONPU}$  and  $R_{ONPD}$ , both at  $0.5 \times V_{DDQ}$ :

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

For example, with  $MM_{PUPD} (MAX) = 15\%$  and  $R_{ONPD} = 0.85$ ,  $R_{ONPU}$  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 80: Output Driver Sensitivity Definition**

| Resistor   | $V_{OUT}$            | Min                                                                | Max                                                                 | Unit |
|------------|----------------------|--------------------------------------------------------------------|---------------------------------------------------------------------|------|
| $R_{ONPD}$ | $0.5 \times V_{DDQ}$ | $85 - (dR_{ONdT} \cdot  \Delta T ) - (dR_{ONdV} \cdot  \Delta V )$ | $115 + (dR_{ONdT} \cdot  \Delta T ) - (dR_{ONdV} \cdot  \Delta V )$ | %    |
| $R_{ONPU}$ |                      |                                                                    |                                                                     |      |

Notes: 1.  $\Delta T = T - T$  (at calibration).  $\Delta V = V - V$  (at calibration).

2.  $dR_{ONdT}$  and  $dR_{ONdV}$  are not subject to production testing; they are verified by design and characterization.

**Table 81: 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 82: Output Driver DC Electrical Characteristics Without ZQ Calibration**

| $R_{ON,nom}$ | Resistor     | $V_{OUT}$            | Min  | Typ  | Max  | Unit       |
|--------------|--------------|----------------------|------|------|------|------------|
| 34.3Ω        | $R_{ON34PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/7$ |
|              | $R_{ON34PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/7$ |
| 40.0Ω        | $R_{ON40PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/6$ |
|              | $R_{ON40PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/6$ |
| 48.0Ω        | $R_{ON48PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/5$ |
|              | $R_{ON48PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/5$ |
| 60.0Ω        | $R_{ON60PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/4$ |
|              | $R_{ON60PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/4$ |
| 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 | $R_{ZQ}/3$ |

**Table 82: Output Driver DC Electrical Characteristics Without ZQ Calibration (Continued)**

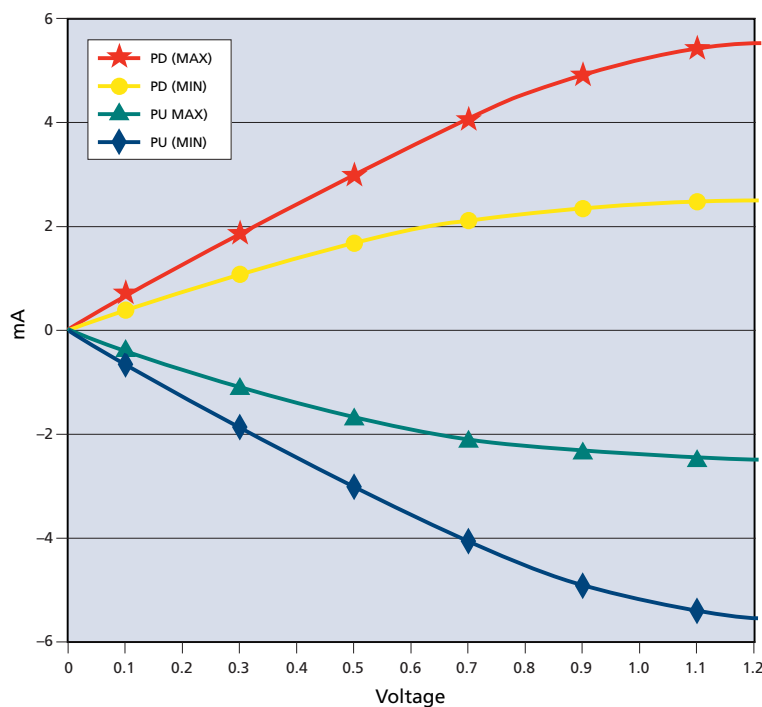
| $R_{ON_{nom}}$ | Resistor      | $V_{OUT}$            | Min  | Typ  | Max  | Unit       |
|----------------|---------------|----------------------|------|------|------|------------|
| 120.0 $\Omega$ | $R_{ON120PD}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/2$ |
|                | $R_{ON120PU}$ | $0.5 \times V_{DDQ}$ | 0.70 | 1.00 | 1.30 | $R_{ZQ}/2$ |

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

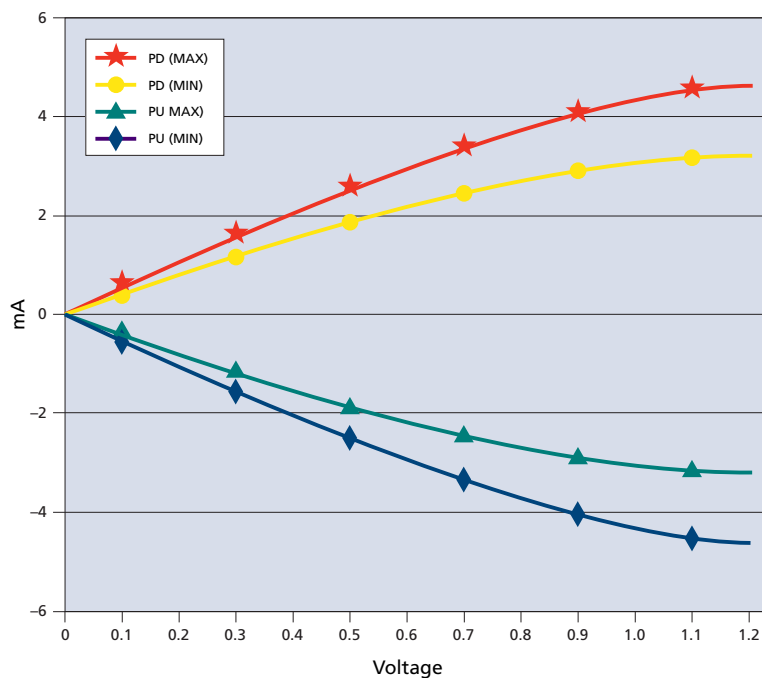
**Table 83: I-V Curves**

| Voltage (V) | $R_{ON} = 240\Omega (R_{ZQ})$  |          |                  |          |                                |          |                  |          |
|-------------|--------------------------------|----------|------------------|----------|--------------------------------|----------|------------------|----------|
|             | 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 |          |
|             | Min (mA)                       | Max (mA) | Min (mA)         | Max (mA) | Min (mA)                       | Max (mA) | Min (mA)         | Max (mA) |
|             | 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    |
| 1.20        | 2.50                           | 5.55     | 3.23             | 4.65     | -2.50                          | -5.55    | -3.23            | -4.65    |

**Figure 77: Output Impedance = 240 Ohms, I-V Curves After ZQRESET**



**Figure 78: Output Impedance = 240 Ohms, I-V Curves After Calibration**



## 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 84: 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 $\pm 1\%$ within a 100-clock-cycle window, provided that all jitter and timing specifications are met. | $t_{CK(avg)} = \left( \sum_{j=1}^N t_{CKj} \right) / N$<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.                                                                                                                                                                                                                                                                                                                                                                                                                                                   | $t_{CH(avg)} = \left( \sum_{j=1}^N t_{CHj} \right) / (N \times t_{CK(avg)})$<br>Where $N = 200$                |       |
| $t_{CL(avg)}$              | The average LOW pulse width, as calculated across any 200 consecutive LOW pulses.                                                                                                                                                                                                                                                                                                                                                                                                                                                     | $t_{CL(avg)} = \left( \sum_{j=1}^N t_{CLj} \right) / (N \times t_{CK(avg)})$<br>Where $N = 200$                |       |
| $t_{JIT(per)}$             | The single-period jitter defined as the largest deviation of any signal $t_{CK}$ from $t_{CK(avg)}$ .                                                                                                                                                                                                                                                                                                                                                                                                                                 | $t_{JIT(per)} = \min/\max \text{ of } \left\{ t_{CKi} - t_{CK(avg)} \right\}$<br>Where $i = 1 \text{ to } 200$ | 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.                                                                                                                                                                                                                                                                                                                                                                                                       | $t_{JIT(cc)} = \max \text{ of } \left\{ t_{CK_{i+1}} - t_{CK_i} \right\}$                                      | 1     |
| $t_{ERR(nper)}$            | The cumulative error across $n$ multiple consecutive cycles from $t_{CK(avg)}$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                      | $t_{ERR(nper)} = \left( \sum_{j=i}^{i+n-1} t_{CKj} \right) - (n \times t_{CK(avg)})$                           | 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     |

**Table 84: Definitions and Calculations (Continued)**

| Symbol              | Description                                                                                | Calculation                                                                                                                                                                                                                                                              | Notes |
|---------------------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| $t_{ERR(nper),max}$ | 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. | $t_{JIT(duty),min} =$<br>$MIN((t_{CH(abs),min} - t_{CH(avg),min}),$<br>$(t_{CL(abs),min} - t_{CL(avg),min})) \times t_{CK(avg)}$<br><br>$t_{JIT(duty),max} =$<br>$MAX((t_{CH(abs),max} - t_{CH(avg),max}),$<br>$(t_{CL(abs),max} - t_{CL(avg),max})) \times t_{CK(avg)}$ |       |

- 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 85:  $t_{CK(abs)}$ ,  $t_{CH(abs)}$ , and  $t_{CL(abs)}$  Definitions**

| Parameter                       | Symbol        | Minimum                                                 | Unit            |
|---------------------------------|---------------|---------------------------------------------------------|-----------------|
| Absolute clock period           | $t_{CK(abs)}$ | $t_{CK(avg),min} + t_{JIT(per),min}$                    | ps <sup>1</sup> |
| 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

LPDDR2 devices 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.

### 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  $n_{PARAM} = RU[t_{PARAM}/t_{CK(avg)}]$ . 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 ( $t_{nPARAM}$ ), when  $t_{CK(avg)}$  and  $t_{ERR}(t_{nPARAM},act)$  exceed  $t_{ERR}(t_{nPARAM},allowed)$ , cycle time derating may be required for core timing parameters.

$$CycleTimeDerating = \max \left\{ \left[ \frac{t_{PARAM} + t_{ERR}(t_{nPARAM},act) - t_{ERR}(t_{nPARAM},allowed)}{t_{nPARAM}} - t_{CK(avg)} \right], 0 \right\}$$

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 ( $t_{nPARAM}$ ), clock cycle derating should be specified with  $t_{JIT(per)}$ .

For a given number of clocks ( $t_{nPARAM}$ ), when  $t_{CK(avg)}$  plus  $t_{ERR}(t_{nPARAM},act)$  exceed the supported cumulative  $t_{ERR}(t_{nPARAM},allowed)$ , 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).

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

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, or CA[9:0]) transition edge to its respective clock signal (CK/CK#) 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:

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

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 =  $\min [(t_{QSH}(abs)_{min} \times t_{CK}(avg)_{min} - t_{DQSQmax} - t_{QHSmax}), (t_{QSL}(abs)_{min} \times t_{CK}(avg)_{min} - t_{DQSQmax} - t_{QHSmax})]$ . 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 ( $DQS_n$ ,  $DQS_n\#$ :  $n = 0, 1, 2, 3$ ) 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 ( $DQS_x$ ,  $DQS_x\#$ ) to its clock signal crossing ( $CK/CK\#$ ). 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 ( $CK/CK\#$ ) to the first latching data strobe signal crossing ( $DQS_x$ ,  $DQS_x\#$ ). 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  $t_{JIT}(per)_{allowed}$ .

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

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

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:

$$t_{DQSS}(min, derated) = 0.75 - (t_{JIT}(per)_{act, min} - t_{JIT}(per)_{allowed, min}) / t_{CK}(avg) = 0.75 - (-172 + 100) / 2500 = 0.7788 \text{ } t_{CK}(avg), \text{ and}$$

$$t_{DQSS}(max, derated) = 1.25 - (t_{JIT}(per)_{act, max} - t_{JIT}(per)_{allowed, max}) / t_{CK}(avg) =$$

$$1.25 - (193 - 100)/2500 = 1.2128 \text{ }^t\text{CK}(\text{avg}).$$

## Refresh Requirements

**Table 86: 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: $T_{\text{CASE}} \leq 85^{\circ}$                                                                           |       | $^t\text{REFW}$   | 32                              | 32    | 32    | 32    | 32    | 32     | 32     | 32     | ms            |
| Refresh window:<br>$85^{\circ}\text{C} < T_{\text{CASE}} \leq 105^{\circ}\text{C}$                                          |       | $^t\text{REFW}$   | 8                               | 8     | 8     | 8     | 8     | 8      | 8      | 8      | ms            |
| Refresh window:<br>$105^{\circ}\text{C} < T_{\text{CASE}} \leq 125^{\circ}\text{C}$                                         |       | $^t\text{REFW}$   | 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) $T_{\text{CASE}} \leq 85^{\circ}\text{C}$                        | REFab | $^t\text{REFI}$   | 15.6                            | 15.6  | 7.8   | 7.8   | 7.8   | 3.9    | 3.9    | 3.9    | $\mu\text{s}$ |
|                                                                                                                             | REFpb | $^t\text{REFIpb}$ | (REFpb not supported below 1Gb) |       |       |       | 0.975 | 0.4875 | 0.4875 | 0.4875 | $\mu\text{s}$ |
| Average time between REFRESH commands (for reference only) $85^{\circ}\text{C} < T_{\text{CASE}} \leq 105^{\circ}\text{C}$  | REFab | $^t\text{REFI}$   | 3.9                             | 3.9   | 1.95  | 1.95  | 1.95  | 0.977  | 0.977  | 0.977  | $\mu\text{s}$ |
|                                                                                                                             | REFpb | $^t\text{REFIpb}$ | (REFpb not supported below 1Gb) |       |       |       | 0.244 | 0.122  | 0.122  | 0.122  | $\mu\text{s}$ |
| Average time between REFRESH commands (for reference only) $105^{\circ}\text{C} < T_{\text{CASE}} \leq 125^{\circ}\text{C}$ | REFab | $^t\text{REFI}$   | 3.9                             | 3.9   | 1.95  | 1.95  | 1.95  | 0.977  | 0.977  | 0.977  | $\mu\text{s}$ |
|                                                                                                                             | REFpb | $^t\text{REFIpb}$ | (REFpb not supported below 1Gb) |       |       |       | 0.244 | 0.122  | 0.122  | 0.122  | $\mu\text{s}$ |
| Refresh cycle time                                                                                                          |       | $^t\text{RFCab}$  | 90                              | 90    | 90    | 90    | 130   | 130    | 130    | 210    | ns            |
| Per-bank REFRESH cycle time                                                                                                 |       | $^t\text{RFCpb}$  | na                              |       |       |       | 60    | 60     | 60     | 90     | ns            |
| Burst REFRESH window = $4 \times 8 \times ^t\text{RFCab}$                                                                   |       | $^t\text{REFBW}$  | 2.88                            | 2.88  | 2.88  | 2.88  | 4.16  | 4.16   | 4.16   | 6.72   | $\mu\text{s}$ |

## AC Timing

**Table 87: 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/<br>Max | $t_{CK}$<br>Min | Data Rate                                                                                                           |      |      |      |      |      |      | Unit              | Notes |
|-----------------------------------------------------------------------------------------|------------------------------|-------------|-----------------|---------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|-------------------|-------|
|                                                                                         |                              |             |                 | 1066                                                                                                                | 933  | 800  | 667  | 533  | 400  | 333  |                   |       |
| Maximum frequency                                                                       |                              | –           | –               | 533                                                                                                                 | 466  | 400  | 333  | 266  | 200  | 166  | MHz               |       |
| <b>Clock Timing</b>                                                                     |                              |             |                 |                                                                                                                     |      |      |      |      |      |      |                   |       |
| 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 | $t_{CK}$<br>(avg) |       |
|                                                                                         |                              | MAX         | –               | 0.55                                                                                                                | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |                   |       |
| Average LOW pulse width                                                                 | $t_{CL}(avg)$                | MIN         | –               | 0.45                                                                                                                | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | $t_{CK}$<br>(avg) |       |
|                                                                                         |                              | MAX         | –               | 0.55                                                                                                                | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |                   |       |
| Absolute clock period                                                                   | $t_{CK}(abs)$                | MIN         | –               | $t_{CK}(avg)_{min} \pm t_{JIT(per)}_{min}$                                                                          |      |      |      |      |      |      | ps                |       |
| Absolute clock HIGH pulse width                                                         | $t_{CH}(abs)$                | MIN         | –               | 0.43                                                                                                                | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | $t_{CK}$<br>(avg) |       |
|                                                                                         |                              | MAX         | –               | 0.57                                                                                                                | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 |                   |       |
| Absolute clock LOW pulse width                                                          | $t_{CL}(abs)$                | MIN         | –               | 0.43                                                                                                                | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | 0.43 | $t_{CK}$<br>(avg) |       |
|                                                                                         |                              | MAX         | –               | 0.57                                                                                                                | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57 |                   |       |
| Clock period jitter<br>(with supported jitter)                                          | $t_{JIT(per)}$ ,<br>allowed  | MIN         | –               | –90                                                                                                                 | –95  | –100 | –110 | –120 | –140 | –150 | ps                |       |
|                                                                                         |                              | MAX         | –               | 90                                                                                                                  | 95   | 100  | 110  | 120  | 140  | 150  |                   |       |
| Maximum clock jitter between<br>two consecutive clock cycles<br>(with supported jitter) | $t_{JIT(cc)}$ ,<br>allowed   | MAX         | –               | 180                                                                                                                 | 190  | 200  | 220  | 240  | 280  | 300  | ps                |       |
| Duty cycle jitter<br>(with supported jitter)                                            | $t_{JIT(duty)}$ ,<br>allowed | MIN         | –               | MIN ( $(t_{CH}(abs)_{min} - t_{CH}(avg)_{min})$ ,<br>$(t_{CL}(abs)_{min} - t_{CL}(avg)_{min}) \times t_{CK}(avg)$ ) |      |      |      |      |      |      | ps                |       |
|                                                                                         |                              | MAX         | –               | MAX ( $(t_{CH}(abs)_{max} - t_{CH}(avg)_{max})$ ,<br>$(t_{CL}(abs)_{max} - t_{CL}(avg)_{max}) \times t_{CK}(avg)$ ) |      |      |      |      |      |      |                   |       |
| Cumulative errors across 2 cycles                                                       | $t_{ERR(2per)}$ ,<br>allowed | MIN         | –               | –132                                                                                                                | –140 | –147 | –162 | –177 | –206 | –221 | ps                |       |
|                                                                                         |                              | MAX         | –               | 132                                                                                                                 | 140  | 147  | 162  | 177  | 206  | 221  |                   |       |
| Cumulative errors across 3 cycles                                                       | $t_{ERR(3per)}$ ,<br>allowed | MIN         | –               | –157                                                                                                                | –166 | –175 | –192 | –210 | –245 | –262 | ps                |       |
|                                                                                         |                              | MAX         | –               | 157                                                                                                                 | 166  | 175  | 192  | 210  | 245  | 262  |                   |       |
| Cumulative errors across 4 cycles                                                       | $t_{ERR(4per)}$ ,<br>allowed | MIN         | –               | –175                                                                                                                | –185 | –194 | –214 | –233 | –272 | –291 | ps                |       |
|                                                                                         |                              | MAX         | –               | 175                                                                                                                 | 185  | 194  | 214  | 233  | 272  | 291  |                   |       |
| Cumulative errors across 5 cycles                                                       | $t_{ERR(5per)}$ ,<br>allowed | MIN         | –               | –188                                                                                                                | –199 | –209 | –230 | –251 | –293 | –314 | ps                |       |
|                                                                                         |                              | MAX         | –               | 188                                                                                                                 | 199  | 209  | 230  | 251  | 293  | 314  |                   |       |
| Cumulative errors across 6 cycles                                                       | $t_{ERR(6per)}$ ,<br>allowed | MIN         | –               | –200                                                                                                                | –211 | –222 | –244 | –266 | –311 | –333 | ps                |       |
|                                                                                         |                              | MAX         | –               | 200                                                                                                                 | 211  | 222  | 244  | 266  | 311  | 333  |                   |       |
| Cumulative errors across 7 cycles                                                       | $t_{ERR(7per)}$ ,<br>allowed | MIN         | –               | –209                                                                                                                | –221 | –232 | –256 | –279 | –325 | –348 | ps                |       |
|                                                                                         |                              | MAX         | –               | 209                                                                                                                 | 221  | 232  | 256  | 279  | 325  | 348  |                   |       |

**Table 87: 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/<br>Max | <sup>t</sup> CK<br>Min                                                                                      | Data Rate                                 |      |      |      |      |      |      | Unit                  | Notes |
|------------------------------------------------------------------|---------------------------------------------|-------------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------|------|------|------|------|------|------|-----------------------|-------|
|                                                                  |                                             |             |                                                                                                             | 1066                                      | 933  | 800  | 667  | 533  | 400  | 333  |                       |       |
| Cumulative errors across 8 cycles                                | <sup>t</sup> ERR(8per),<br>allowed          | MIN         | –                                                                                                           | –217                                      | –229 | –241 | –266 | –290 | –338 | –362 | ps                    |       |
|                                                                  |                                             | MAX         | –                                                                                                           | 217                                       | 229  | 241  | 266  | 290  | 338  | 362  |                       |       |
| Cumulative errors across 9 cycles                                | <sup>t</sup> ERR(9per),<br>allowed          | MIN         | –                                                                                                           | –224                                      | –237 | –249 | –274 | –299 | –349 | –374 | ps                    |       |
|                                                                  |                                             | MAX         | –                                                                                                           | 224                                       | 237  | 249  | 274  | 299  | 349  | 374  |                       |       |
| Cumulative errors across 10 cycles                               | <sup>t</sup> ERR(10per),<br>allowed         | MIN         | –                                                                                                           | –231                                      | –244 | –257 | –282 | –308 | –359 | –385 | ps                    |       |
|                                                                  |                                             | MAX         | –                                                                                                           | 231                                       | 244  | 257  | 282  | 308  | 359  | 385  |                       |       |
| Cumulative errors across 11 cycles                               | <sup>t</sup> ERR(11per),<br>allowed         | MIN         | –                                                                                                           | –237                                      | –250 | –263 | –289 | –316 | –368 | –395 | ps                    |       |
|                                                                  |                                             | MAX         | –                                                                                                           | 237                                       | 250  | 263  | 289  | 316  | 368  | 395  |                       |       |
| Cumulative errors across 12 cycles                               | <sup>t</sup> ERR(12per),<br>allowed         | MIN         | –                                                                                                           | –242                                      | –256 | –269 | –296 | –323 | –377 | –403 | ps                    |       |
|                                                                  |                                             | MAX         | –                                                                                                           | 242                                       | 256  | 269  | 296  | 323  | 377  | 403  |                       |       |
| Cumulative errors across <i>n</i> = 13, 14, 15..., 49, 50 cycles | <sup>t</sup> ERR( <i>n</i> per),<br>allowed | MIN         | <sup>t</sup> ERR( <i>n</i> per),allowed,min = (1 + 0.68ln( <i>n</i> )) × <sup>t</sup> JIT(per),allowed,min  |                                           |      |      |      |      |      |      | ps                    |       |
|                                                                  |                                             | MAX         | <sup>t</sup> ERR( <i>n</i> per), allowed,max = (1 + 0.68ln( <i>n</i> )) × <sup>t</sup> JIT(per),allowed,max |                                           |      |      |      |      |      |      |                       |       |
| ZQ Calibration Parameters                                        |                                             |             |                                                                                                             |                                           |      |      |      |      |      |      |                       |       |
| Initialization calibration time                                  | <sup>t</sup> ZQINIT                         | MIN         | –                                                                                                           | 1                                         | 1    | 1    | 1    | 1    | 1    | 1    | μs                    |       |
| Long calibration time                                            | <sup>t</sup> ZQCL                           | MIN         | 6                                                                                                           | 360                                       | 360  | 360  | 360  | 360  | 360  | 360  | ns                    |       |
| Short calibration time                                           | <sup>t</sup> ZQCS                           | MIN         | 6                                                                                                           | 90                                        | 90   | 90   | 90   | 90   | 90   | 90   | ns                    |       |
| Calibration RESET time                                           | <sup>t</sup> ZQRESET                        | MIN         | 3                                                                                                           | 50                                        | 50   | 50   | 50   | 50   | 50   | 50   | ns                    |       |
| READ Parameters <sup>3</sup>                                     |                                             |             |                                                                                                             |                                           |      |      |      |      |      |      |                       |       |
| DQS output access time from CK/CK#                               | <sup>t</sup> DQSCK                          | MIN         | –                                                                                                           | 2500                                      | 2500 | 2500 | 2500 | 2500 | 2500 | 2500 | ps                    |       |
|                                                                  |                                             | MAX         | –                                                                                                           | 5500                                      | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 |                       |       |
| DQSCK delta short                                                | <sup>t</sup> DQSCKDS                        | MAX         | –                                                                                                           | 330                                       | 380  | 450  | 540  | 670  | 900  | 1080 | ps                    | 4     |
| DQSCK delta medium                                               | <sup>t</sup> DQSCKDM                        | MAX         | –                                                                                                           | 680                                       | 780  | 900  | 1050 | 1350 | 1800 | 1900 | ps                    | 5     |
| DQSCK delta long                                                 | <sup>t</sup> DQSCKDL                        | MAX         | –                                                                                                           | 920                                       | 1050 | 1200 | 1400 | 1800 | 2400 | –    | ps                    | 6     |
| DQS-DQ skew                                                      | <sup>t</sup> DQSQ                           | MAX         | –                                                                                                           | 200                                       | 220  | 240  | 280  | 340  | 400  | 500  | ps                    |       |
| Data-hold skew factor                                            | <sup>t</sup> QHS                            | MAX         | –                                                                                                           | 230                                       | 260  | 280  | 340  | 400  | 480  | 600  | ps                    |       |
| DQS output HIGH pulse width                                      | <sup>t</sup> QSH                            | MIN         | –                                                                                                           | <sup>t</sup> CH(abs) - 0.05               |      |      |      |      |      |      | <sup>t</sup> CK (avg) |       |
| DQS output LOW pulse width                                       | <sup>t</sup> QSL                            | MIN         | –                                                                                                           | <sup>t</sup> CL(abs) - 0.05               |      |      |      |      |      |      | <sup>t</sup> CK (avg) |       |
| Data half period                                                 | <sup>t</sup> QHP                            | MIN         | –                                                                                                           | MIN ( <sup>t</sup> QSH, <sup>t</sup> QSL) |      |      |      |      |      |      | <sup>t</sup> CK (avg) |       |
| DQ/DQS output hold time from DQS                                 | <sup>t</sup> QH                             | MIN         | –                                                                                                           | <sup>t</sup> QHP - <sup>t</sup> QHS       |      |      |      |      |      |      | ps                    |       |

**Table 87: 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/<br>Max | tCK<br>Min | Data Rate                        |      |      |      |      |      |      | Unit         | Notes |
|-----------------------------------------------------|----------|-------------|------------|----------------------------------|------|------|------|------|------|------|--------------|-------|
|                                                     |          |             |            | 1066                             | 933  | 800  | 667  | 533  | 400  | 333  |              |       |
| READ preamble                                       | tRPRE    | MIN         | –          | 0.9                              | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | 0.9  | tCK<br>(avg) | 7     |
| READ postamble                                      | tRPST    | MIN         | –          | tCL(abs) - 0.05                  |      |      |      |      |      |      | tCK<br>(avg) | 8     |
| DQS Low-Z from clock                                | tLZ(DQS) | MIN         | –          | tDQSCK (MIN) - 300               |      |      |      |      |      |      | ps           |       |
| DQ Low-Z from clock                                 | tLZ(DQ)  | MIN         | –          | tDQSCK(MIN) - (1.4 × tQHS(MAX))  |      |      |      |      |      |      | ps           |       |
| DQS High-Z from clock                               | tHZ(DQS) | MAX         | –          | tDQSCK (MAX) - 100               |      |      |      |      |      |      | ps           |       |
| DQ High-Z from clock                                | tHZ(DQ)  | MAX         | –          | tDQSCK(MAX) + (1.4 × tDQSQ(MAX)) |      |      |      |      |      |      | ps           |       |
| WRITE Parameters <sup>3</sup>                       |          |             |            |                                  |      |      |      |      |      |      |              |       |
| DQ and DM input hold time (V <sub>REF</sub> based)  | tDH      | MIN         | –          | 210                              | 235  | 270  | 350  | 430  | 480  | 600  | ps           |       |
| DQ and DM input setup time (V <sub>REF</sub> based) | tDS      | MIN         | –          | 210                              | 235  | 270  | 350  | 430  | 480  | 600  | ps           |       |
| DQ and DM input pulse width                         | tDIPW    | MIN         | –          | 0.35                             | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | tCK<br>(avg) |       |
| Write command to first DQS latching transition      | tDQSS    | MIN         | –          | 0.75                             | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | tCK<br>(avg) |       |
|                                                     |          | MAX         | –          | 1.25                             | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | tCK<br>(avg) |       |
| DQS input high-level width                          | tDQSH    | MIN         | –          | 0.4                              | 0.4  | 0.4  | 0.4  | 0.4  | 0.4  | 0.4  | tCK<br>(avg) |       |
| DQS input low-level width                           | tDQSL    | MIN         | –          | 0.4                              | 0.4  | 0.4  | 0.4  | 0.4  | 0.4  | 0.4  | tCK<br>(avg) |       |
| DQS falling edge to CK setup time                   | tDSS     | MIN         | –          | 0.2                              | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | tCK<br>(avg) |       |
| DQS falling edge hold time from CK                  | tDSH     | MIN         | –          | 0.2                              | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | tCK<br>(avg) |       |
| Write postamble                                     | tWPST    | MIN         | –          | 0.4                              | 0.4  | 0.4  | 0.4  | 0.4  | 0.4  | 0.4  | tCK<br>(avg) |       |
| Write preamble                                      | tWPRE    | MIN         | –          | 0.35                             | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | tCK<br>(avg) |       |
| CKE Input Parameters                                |          |             |            |                                  |      |      |      |      |      |      |              |       |
| CKE minimum pulse width (HIGH and LOW pulse width)  | tCKE     | MIN         | 3          | 3                                | 3    | 3    | 3    | 3    | 3    | 3    | tCK<br>(avg) |       |
| CKE input setup time                                | tISCKE   | MIN         | –          | 0.25                             | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | tCK<br>(avg) | 9     |
| CKE input hold time                                 | tIHCKE   | MIN         | –          | 0.25                             | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | tCK<br>(avg) | 10    |

**Table 87: 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/<br>Max | <sup>t</sup> CK<br>Min | Data Rate                                                                                                                         |      |      |      |      |      |      | Unit                     | Notes |
|-----------------------------------------------------------------------------------|---------------------|-------------|------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------|------|------|------|------|------|--------------------------|-------|
|                                                                                   |                     |             |                        | 1066                                                                                                                              | 933  | 800  | 667  | 533  | 400  | 333  |                          |       |
| Command Address Input Parameters <sup>3</sup>                                     |                     |             |                        |                                                                                                                                   |      |      |      |      |      |      |                          |       |
| Address and control input setup time                                              | <sup>t</sup> IS     | MIN         | –                      | 220                                                                                                                               | 250  | 290  | 370  | 460  | 600  | 740  | ps                       | 11    |
| Address and control input hold time                                               | <sup>t</sup> IH     | MIN         | –                      | 220                                                                                                                               | 250  | 290  | 370  | 460  | 600  | 740  | ps                       | 11    |
| Address and control input pulse width                                             | <sup>t</sup> IPW    | MIN         | –                      | 0.40                                                                                                                              | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | <sup>t</sup> CK<br>(avg) |       |
| Boot Parameters (10 MHz–55 MHz) <sup>12, 13, 14</sup>                             |                     |             |                        |                                                                                                                                   |      |      |      |      |      |      |                          |       |
| Clock cycle time                                                                  | <sup>t</sup> CKb    | MAX         | –                      | 100                                                                                                                               | 100  | 100  | 100  | 100  | 100  | 100  | ns                       |       |
|                                                                                   |                     | MIN         | –                      | 18                                                                                                                                | 18   | 18   | 18   | 18   | 18   | 18   |                          |       |
| CKE input setup time                                                              | <sup>t</sup> ISCKEb | MIN         | –                      | 2.5                                                                                                                               | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | ns                       |       |
| CKE input hold time                                                               | <sup>t</sup> IHCKEb | MIN         | –                      | 2.5                                                                                                                               | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | ns                       |       |
| Address and control input setup time                                              | <sup>t</sup> ISb    | MIN         | –                      | 1150                                                                                                                              | 1150 | 1150 | 1150 | 1150 | 1150 | 1150 | ps                       |       |
| Address and control input hold time                                               | <sup>t</sup> IHb    | MIN         | –                      | 1150                                                                                                                              | 1150 | 1150 | 1150 | 1150 | 1150 | 1150 | ps                       |       |
| DQS output data access time from CK/CK#                                           | <sup>t</sup> DQSCKb | 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                                              | <sup>t</sup> DQSQb  | MAX         | –                      | 1.2                                                                                                                               | 1.2  | 1.2  | 1.2  | 1.2  | 1.2  | 1.2  | ns                       |       |
| Data hold skew factor                                                             | <sup>t</sup> QHSb   | MAX         | –                      | 1.2                                                                                                                               | 1.2  | 1.2  | 1.2  | 1.2  | 1.2  | 1.2  | ns                       |       |
| Mode Register Parameters                                                          |                     |             |                        |                                                                                                                                   |      |      |      |      |      |      |                          |       |
| MODE REGISTER WRITE command period                                                | <sup>t</sup> MRW    | MIN         | 5                      | 5                                                                                                                                 | 5    | 5    | 5    | 5    | 5    | 5    | <sup>t</sup> CK<br>(avg) |       |
| MODE REGISTER READ command period                                                 | <sup>t</sup> MRR    | MIN         | 2                      | 2                                                                                                                                 | 2    | 2    | 2    | 2    | 2    | 2    | <sup>t</sup> CK<br>(avg) |       |
| Core Parameters <sup>15</sup>                                                     |                     |             |                        |                                                                                                                                   |      |      |      |      |      |      |                          |       |
| READ latency                                                                      | RL                  | MIN         | 3                      | 8                                                                                                                                 | 7    | 6    | 5    | 4    | 3    | 3    | <sup>t</sup> CK<br>(avg) |       |
| WRITE latency                                                                     | WL                  | MIN         | 1                      | 4                                                                                                                                 | 4    | 3    | 2    | 2    | 1    | 1    | <sup>t</sup> CK<br>(avg) |       |
| ACTIVATE-to-ACTIVATE command period                                               | <sup>t</sup> RC     | MIN         | –                      | <sup>t</sup> RAS + <sup>t</sup> RPab (with all-bank precharge),<br><sup>t</sup> RAS + <sup>t</sup> RPpb (with per-bank precharge) |      |      |      |      |      |      | ns                       | 17    |
| CKE minimum pulse width during SELF REFRESH (low pulse width during SELF REFRESH) | <sup>t</sup> CKESR  | MIN         | 3                      | 15                                                                                                                                | 15   | 15   | 15   | 15   | 15   | 15   | ns                       |       |
| SELF REFRESH exit to next valid command delay                                     | <sup>t</sup> XSR    | MIN         | 2                      | <sup>t</sup> RFCab + 10                                                                                                           |      |      |      |      |      |      | ns                       |       |

**Table 87: AC Timing (Continued)**

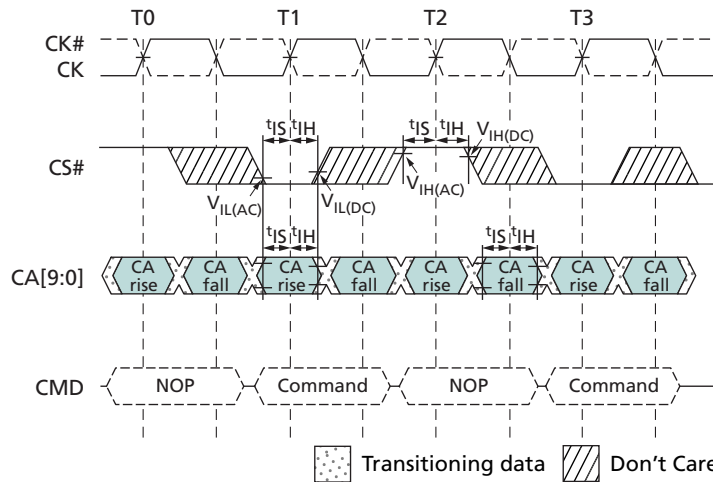
Notes 1–2 apply to all parameters and conditions. AC timing parameters must satisfy the  $t_{CK}$  minimum conditions (in multiples of  $t_{CK}$ ) as well as the timing specifications when values for both are indicated.

| Parameter                                    | Symbol                   | Min/<br>Max | $t_{CK}$<br>Min | Data Rate         |      |      |      |      |      |      | Unit              | Notes |
|----------------------------------------------|--------------------------|-------------|-----------------|-------------------|------|------|------|------|------|------|-------------------|-------|
|                                              |                          |             |                 | 1066              | 933  | 800  | 667  | 533  | 400  | 333  |                   |       |
| Exit power-down to next valid command delay  | $t_{XP}$                 | MIN         | 2               | 7.5               | 7.5  | 7.5  | 7.5  | 7.5  | 7.5  | 7.5  | ns                |       |
| CAS-to-CAS delay                             | $t_{CCD}$                | MIN         | 2               | 2                 | 2    | 2    | 2    | 2    | 2    | 2    | $t_{CK}$<br>(avg) |       |
| Internal READ to PRECHARGE command delay     | $t_{RTP}$                | MIN         | 2               | 7.5               | 7.5  | 7.5  | 7.5  | 7.5  | 7.5  | 7.5  | ns                |       |
| RAS-to-CAS delay                             | $t_{RCD}$                | MIN         | 3               | 18                | 18   | 18   | 18   | 18   | 18   | 18   | ns                |       |
| Row precharge time (single bank)             | $t_{RPpb}$               | MIN         | 3               | 18                | 18   | 18   | 18   | 18   | 18   | 18   | ns                |       |
| Row precharge time (all banks)               | $t_{RPab}$<br>4-bank     | MIN         | 3               | 18                | 18   | 18   | 18   | 18   | 18   | 18   | ns                |       |
| Row precharge time (all banks)               | $t_{RPab}$<br>8-bank     | MIN         | 3               | 21                | 21   | 21   | 21   | 21   | 21   | 21   | ns                |       |
| Row active time                              | $t_{RAS}$                | MIN         | 3               | 42                | 42   | 42   | 42   | 42   | 42   | 42   | ns                | 17    |
|                                              |                          | MAX         | –               | 70                | 70   | 70   | 70   | 70   | 70   | 70   | $\mu s$           |       |
| WRITE recovery time                          | $t_{WR}$                 | MIN         | 3               | 15                | 15   | 15   | 15   | 15   | 15   | 15   | ns                |       |
| Internal WRITE-to-READ command delay         | $t_{WTR}$                | MIN         | 2               | 7.5               | 7.5  | 7.5  | 7.5  | 7.5  | 10   | 10   | ns                |       |
| Active bank <i>a</i> to active bank <i>b</i> | $t_{RRD}$                | MIN         | 2               | 10                | 10   | 10   | 10   | 10   | 10   | 10   | ns                |       |
| Four-bank activate window                    | $t_{FAW}$                | MIN         | 8               | 50                | 50   | 50   | 50   | 50   | 50   | 60   | ns                |       |
| Minimum deep power-down time                 | $t_{DPD}$                | MIN         | –               | 500               | 500  | 500  | 500  | 500  | 500  | 500  | $\mu s$           |       |
| <b>Temperature Derating<sup>16</sup></b>     |                          |             |                 |                   |      |      |      |      |      |      |                   |       |
| $t_{DQSCK}$ derating                         | $t_{DQSCK}$<br>(derated) | MAX         | –               | 5620              | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | ps                |       |
| Core timing temperature derating             | $t_{RCD}$<br>(derated)   | MIN         | –               | $t_{RCD} + 1.875$ |      |      |      |      |      |      | ns                |       |
|                                              | $t_{RC}$<br>(derated)    | MIN         | –               | $t_{RC} + 1.875$  |      |      |      |      |      |      | ns                |       |
|                                              | $t_{RAS}$<br>(derated)   | MIN         | –               | $t_{RAS} + 1.875$ |      |      |      |      |      |      | ns                |       |
|                                              | $t_{RP}$<br>(derated)    | MIN         | –               | $t_{RP} + 1.875$  |      |      |      |      |      |      | ns                |       |
|                                              | $t_{RRD}$<br>(derated)   | MIN         | –               | $t_{RRD} + 1.875$ |      |      |      |      |      |      | ns                |       |

- Notes:
1. Frequency values are for reference only. Clock cycle time ( $t_{CK}$ ) 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  $V_{REF}$ .



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 and/or reduction in data retention ability.

**Figure 79: Command Input Setup and Hold Timing**


- Notes:
1. The setup and hold timing shown applies to all commands.
  2. Setup and hold conditions also apply to the CKE pin. For timing diagrams related to the CKE pin, see Power-Down.

## CA and CS# Setup, Hold, and Derating

For all input signals (CA and CS#), the total required setup time ( $t_{IS}$ ) and hold time ( $t_{IH}$ ) is calculated by adding the data sheet  $t_{IS}$  (base) and  $t_{IH}$  (base) values to the  $\Delta t_{IS}$  and  $\Delta t_{IH}$  derating values, respectively. Example:  $t_{IS}$  (total setup time) =  $t_{IS}(\text{base}) + \Delta t_{IS}$ . (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 the Typical Slew Rate and  $V_{AC} - t_{IS}$  for CA and CS# Relative to Clock figure). 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 the Tangent Line -  $t_{IS}$  for CA and CS# Relative to Clock figure).

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 the Typical Slew Rate –  $t_{IH}$  for CA and CS# Relative to Clock figure). 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 the Tangent Line –  $t_{IH}$  for CA and CS# Relative to Clock figure).

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

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 the AC220 table, the derating values are obtained using linear interpolation. Slew rate values are not typically subject to production testing. They are verified by design and characterization.

**Table 88: CA and CS# 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 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)} \pm 220mV$ |
| $t_{IH}$ (base) | 90        | 120 | 160 | 240 | 330 | 390 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)} \pm 130mV$ |

Note: 1. AC/DC referenced for 1 V/ns CA and CS# slew rate, and 2 V/ns differential CK/CK# slew rate.

**Table 89: CA and CS# Setup and Hold Base Values (<400 MHz, 1 V/ns Slew Rate)**

| Parameter       | Data Rate |     |     |     | Reference                                   |
|-----------------|-----------|-----|-----|-----|---------------------------------------------|
|                 | 400       | 333 | 255 | 200 |                                             |
| $t_{IS}$ (base) | 300       | 440 | 600 | 850 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)} \pm 300mV$ |
| $t_{IH}$ (base) | 400       | 540 | 700 | 950 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)} \pm 200mV$ |

Note: 1. AC/DC referenced for 1 V/ns CA and CS# slew rate, and 2 V/ns differential CK/CK# slew rate.

**Table 90: Derating Values for AC/DC-Based  $t_{IS}/t_{IH}$  (AC220)**
 $\Delta t_{IS}$ ,  $\Delta t_{IH}$  derating in ps

|                        |     | CK, CK# 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# 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 91: Derating Values for AC/DC-Based  $t_{IS}/t_{IH}$  (AC300)**
 $\Delta t_{IS}$ ,  $\Delta t_{IH}$  derating in ps

|                        |     | CK, CK# 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# 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.

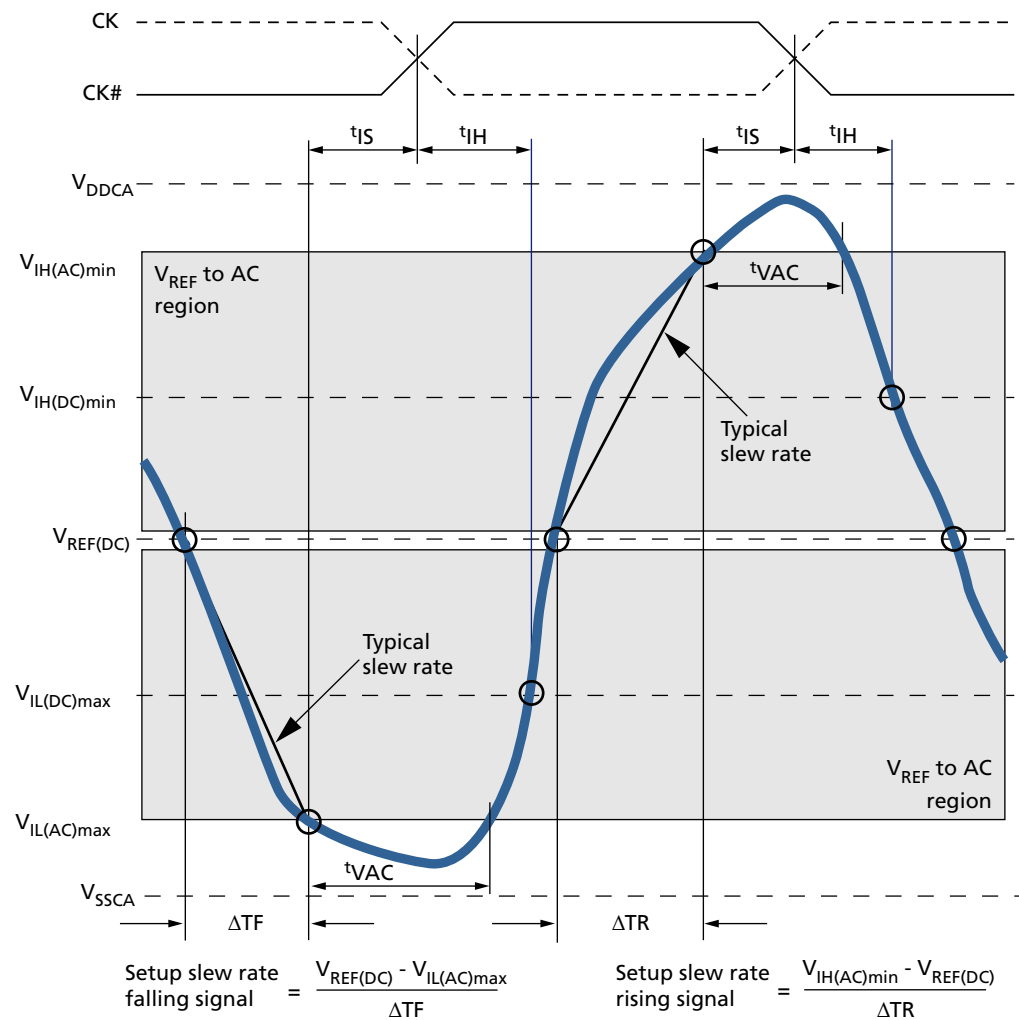
**Table 92: Required Time for Valid Transition –  $t_{VAC} > V_{IH(AC)}$  and  $< V_{IL(AC)}$** 

| 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                     | –   |
| 1.5              | 50                      | –   | 167                     | –   |
| 1.0              | 38                      | –   | 163                     | –   |

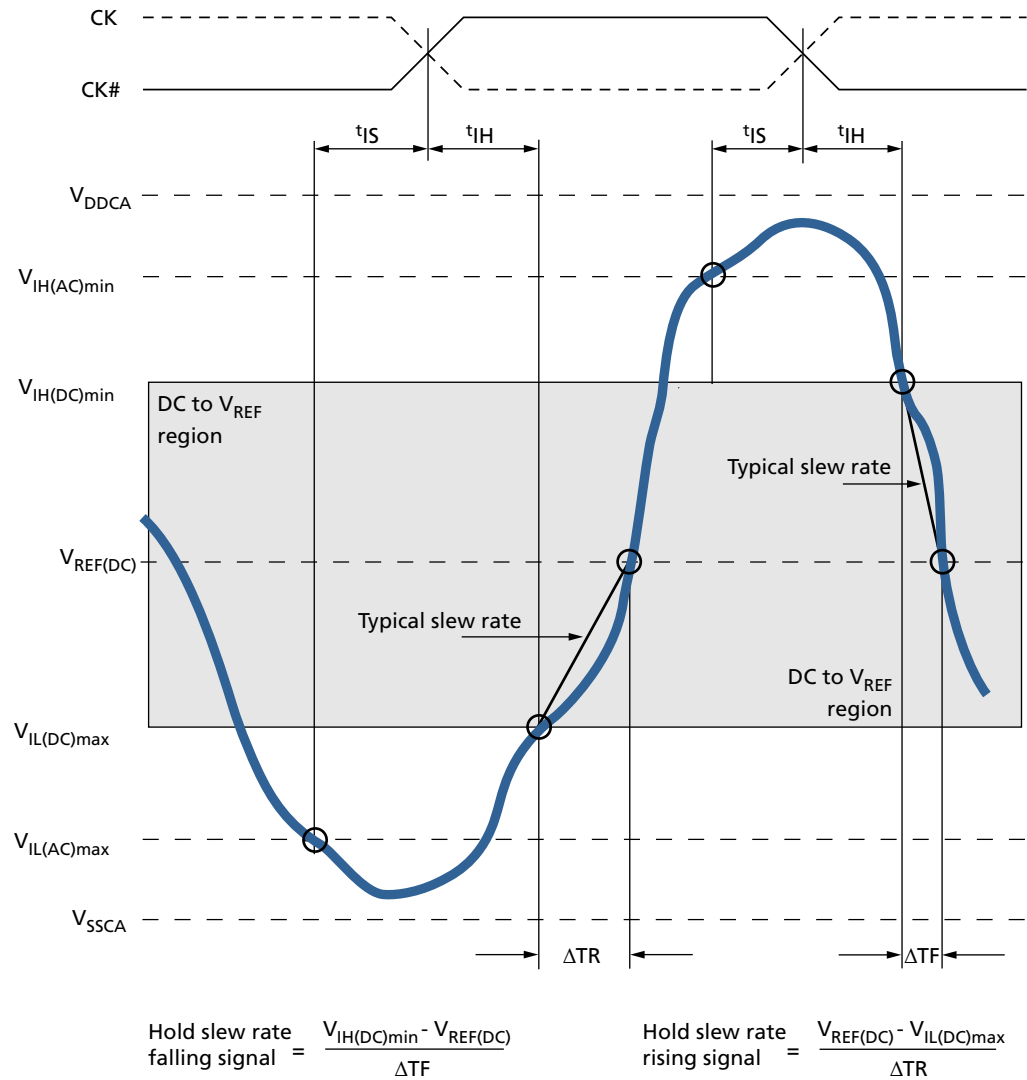
**Table 92: Required Time for Valid Transition –  $t_{VAC} > V_{IH(AC)}$  and  $< V_{IL(AC)}$  (Continued)**

| Slew Rate<br>(V/ns) | $t_{VAC}$ at 300mV (ps) |     | $t_{VAC}$ at 220mV (ps) |     |
|---------------------|-------------------------|-----|-------------------------|-----|
|                     | Min                     | Max | Min                     | Max |
| 0.9                 | 34                      | –   | 162                     | –   |
| 0.8                 | 29                      | –   | 161                     | –   |
| 0.7                 | 22                      | –   | 159                     | –   |
| 0.6                 | 13                      | –   | 155                     | –   |
| 0.5                 | 0                       | –   | 150                     | –   |
| <0.5                | 0                       | –   | 150                     | –   |

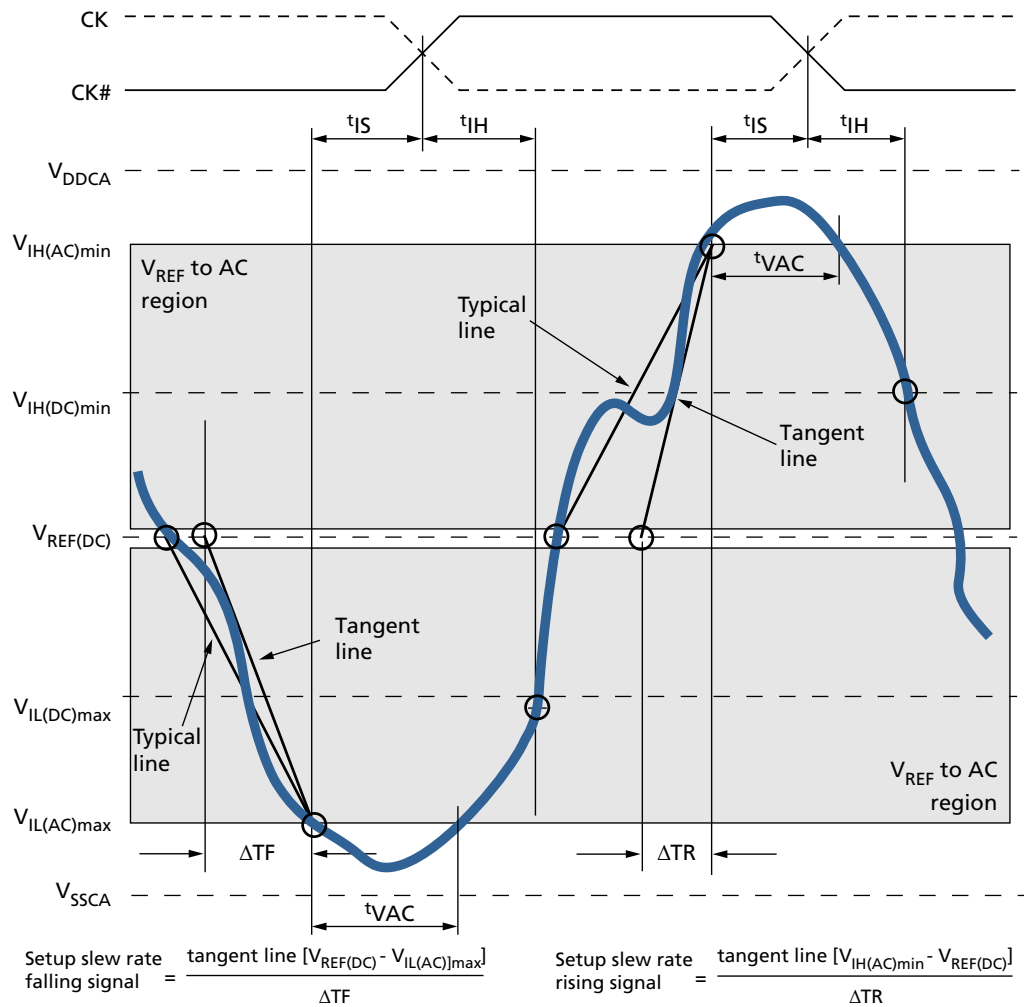
**Figure 80: Typical Slew Rate and  $t_{VAC}$  –  $t_{IS}$  for CA and CS# Relative to Clock**



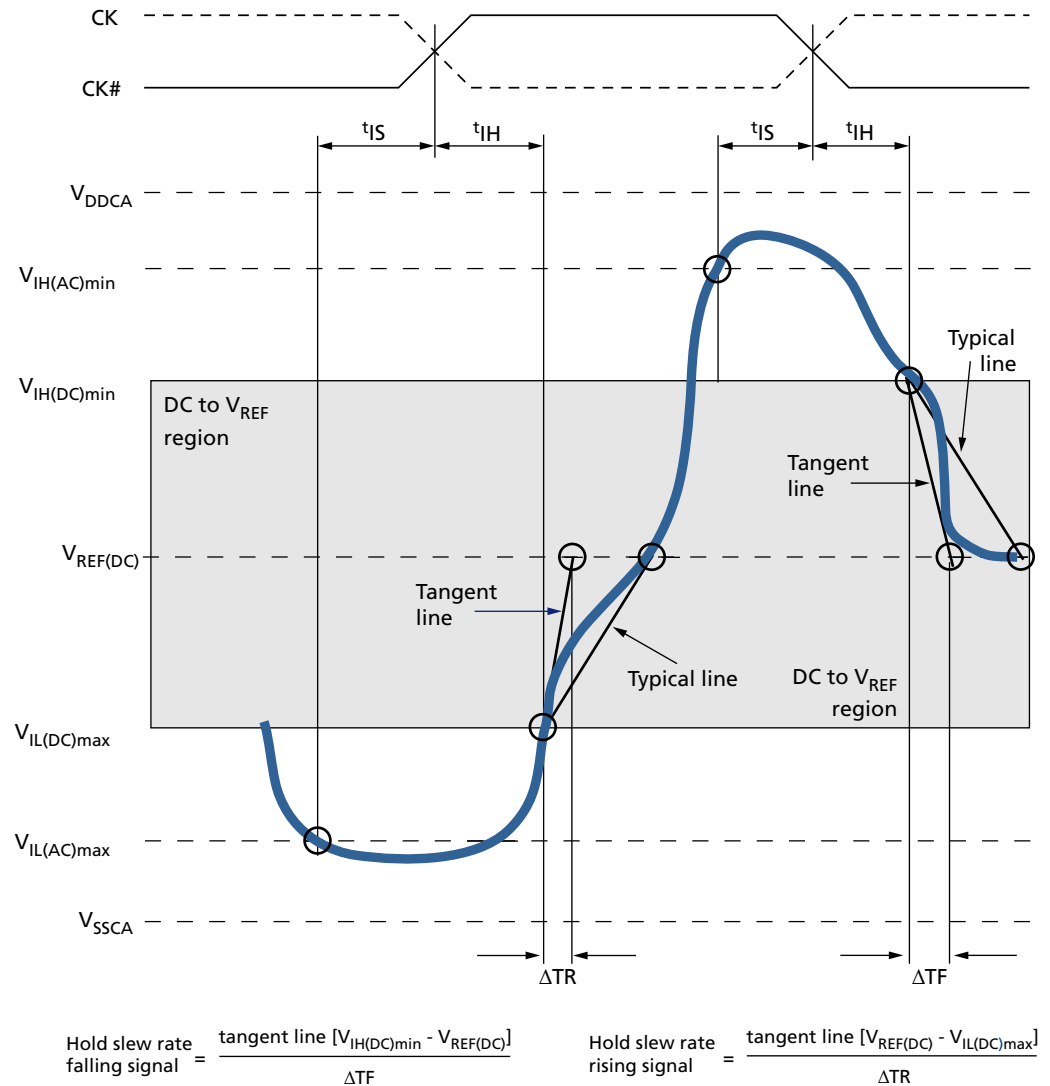
**Figure 81: Typical Slew Rate –  $t_{IH}$  for CA and CS# Relative to Clock**



**Figure 82: Tangent Line –  $t_{IS}$  for CA and CS# Relative to Clock**



**Figure 83: Tangent Line –  $t_{IH}$  for CA and CS# Relative to Clock**



## Data Setup, Hold, and Slew Rate Derating

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

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# Relative to Clock (CA and CS# 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# Relative to Clock" in CA and CS# 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, use the typical slew rate 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. Slew rate values are not typically subject to production testing. They are verified by design and characterization.

**Table 93: Data Setup and Hold Base Values (>400 MHz, 1 V/ns Slew Rate)**

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

**Table 93: 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 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)} \pm 130mV$ |

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

**Table 94: Data Setup and Hold Base Values (<400 MHz, 1 V/ns Slew Rate)**

| Parameter       | Data Rate |     |     |     | Reference                                   |
|-----------------|-----------|-----|-----|-----|---------------------------------------------|
|                 | 400       | 333 | 255 | 200 |                                             |
| $t_{DS}$ (base) | 180       | 300 | 450 | 700 | $V_{IH}/V_{IL(AC)} = V_{REF(DC)} \pm 300mV$ |
| $t_{DH}$ (base) | 280       | 400 | 550 | 800 | $V_{IH}/V_{IL(DC)} = V_{REF(DC)} \pm 200mV$ |

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

**Table 95: Derating Values for AC/DC-Based  $t_{DS}/t_{DH}$  (AC220)**

$\Delta t_{DS}$ ,  $\Delta t_{DH}$  derating in ps

|                                |     | DQS, DQS# 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<br>slew<br>rate<br>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 96: Derating Values for AC/DC-Based  $t_{DS}/t_{DH}$  (AC300)**
 $\Delta t_{DS}$ ,  $\Delta t_{DH}$  derating in ps

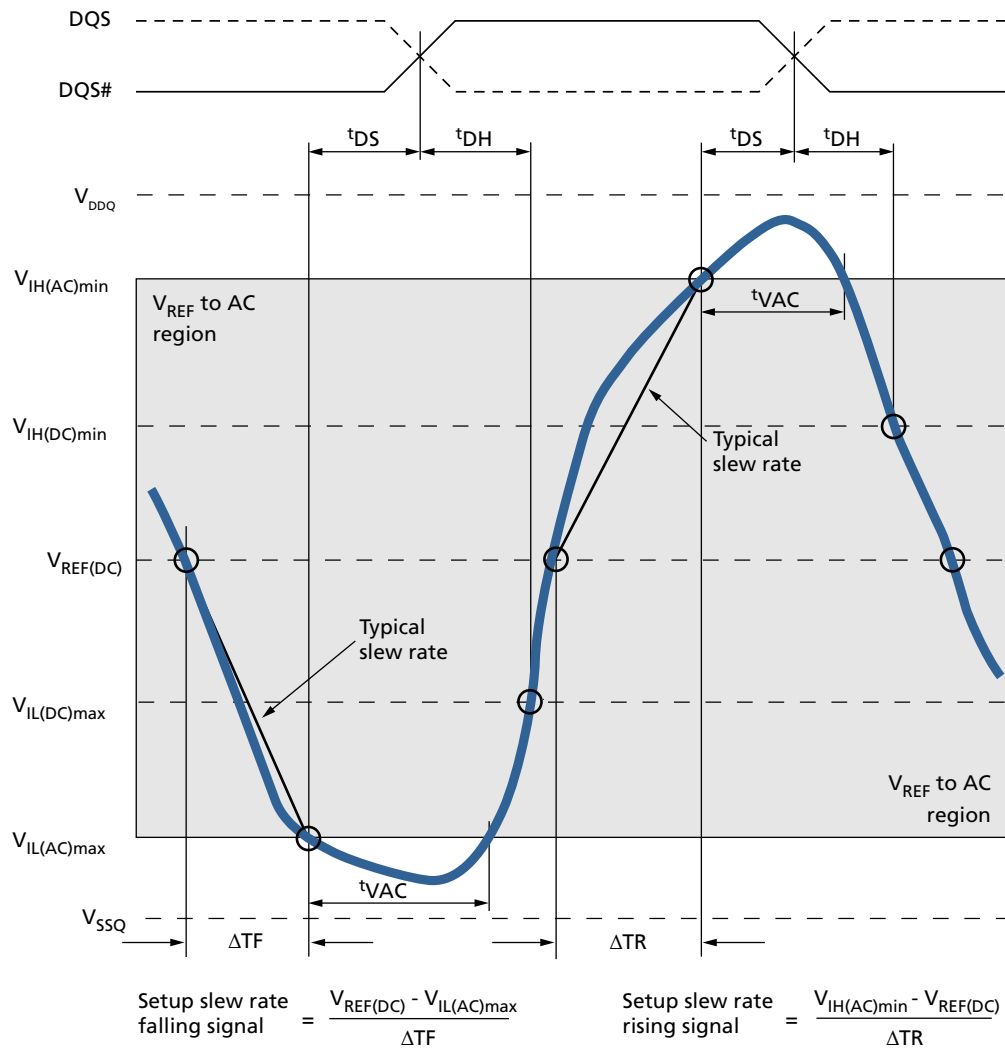
|                             |     | DQS, DQS# Differential Slew Rate |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
|-----------------------------|-----|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                             |     | 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<br>slew<br>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 |                                  |                 |                 |                 |                 |                 |                 |                 |                 |                 | 4               | -35             | -40             | -11             | -8              |                 |

Note: 1. Shaded cells are not supported.

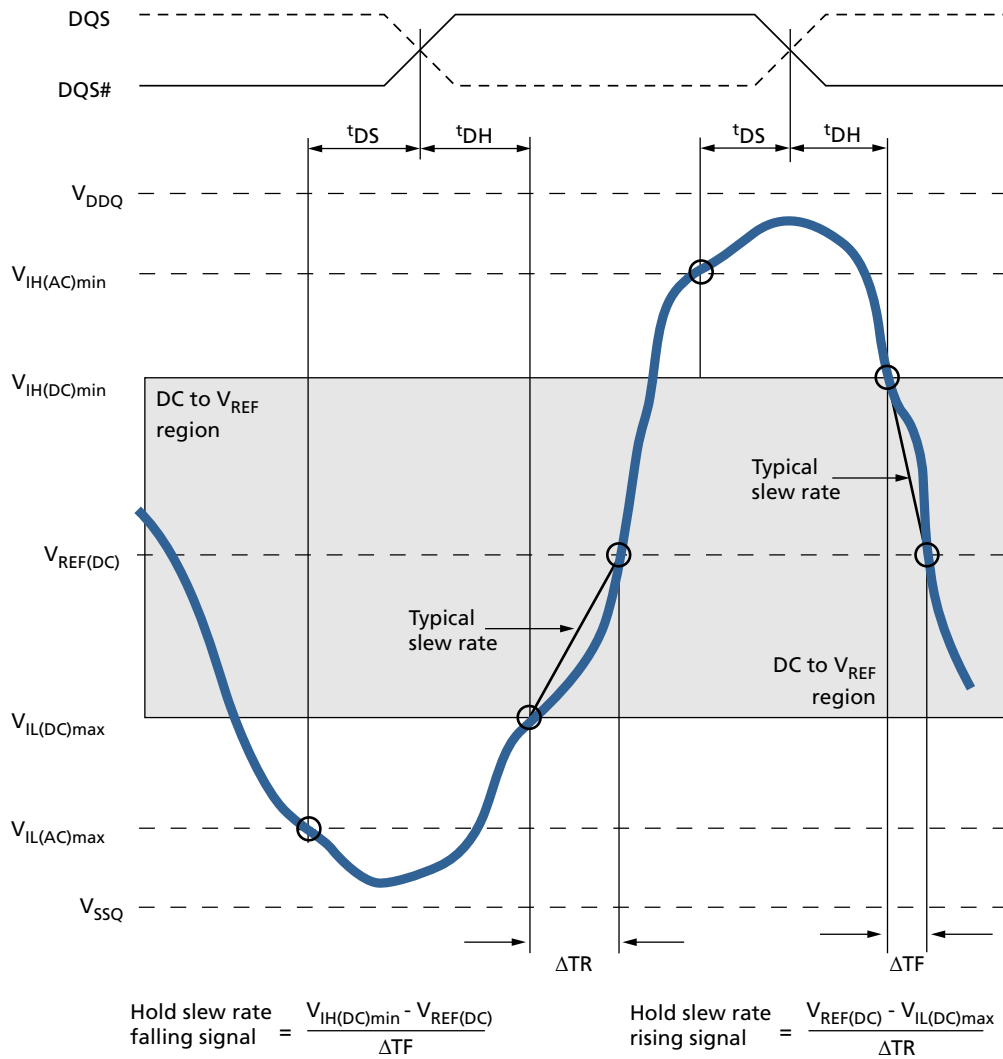
**Table 97: Required Time for Valid Transition –  $t_{VAC} > V_{IH(AC)}$  or  $< V_{IL(AC)}$** 

| 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                     | –   |

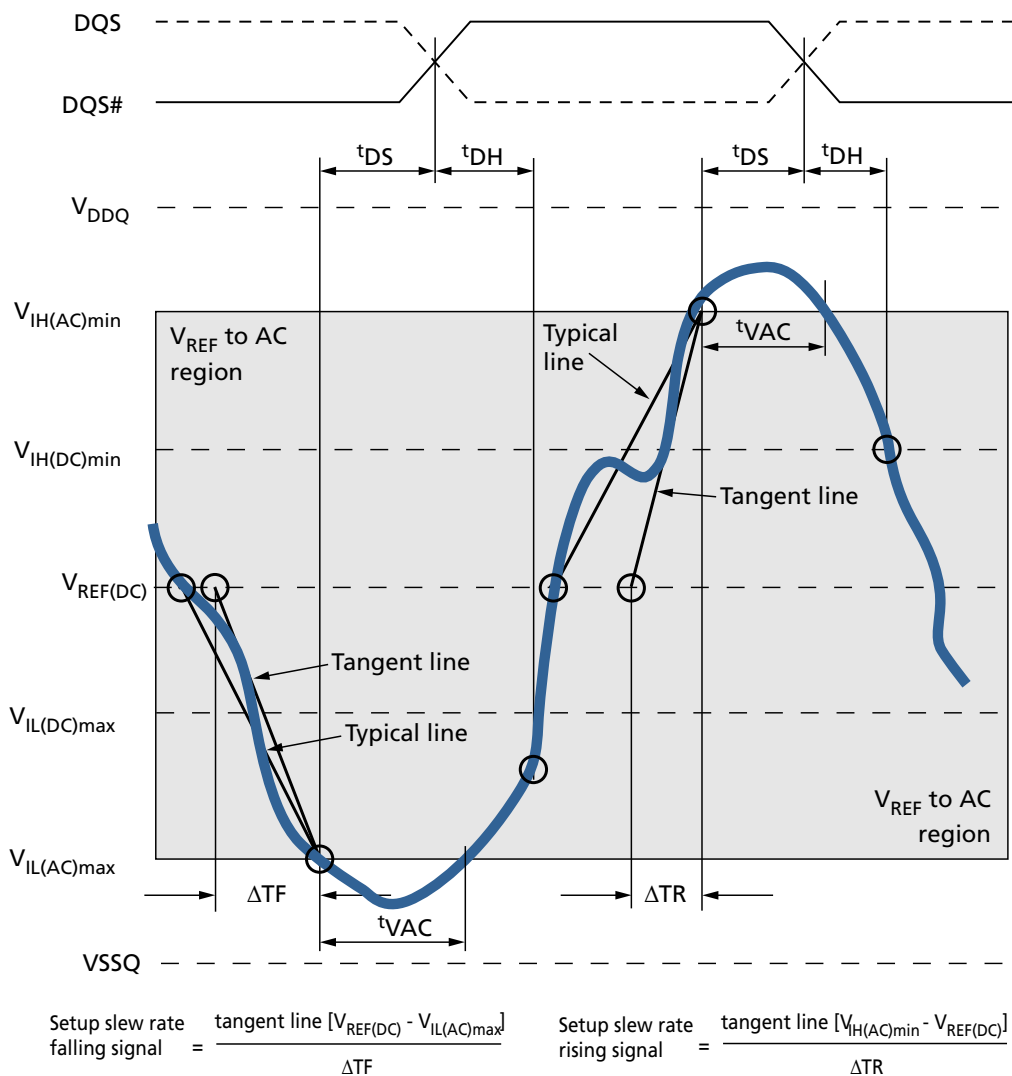
**Figure 84: Typical Slew Rate and  $t_{VAC} - t_{DS}$  for DQ Relative to Strobe**



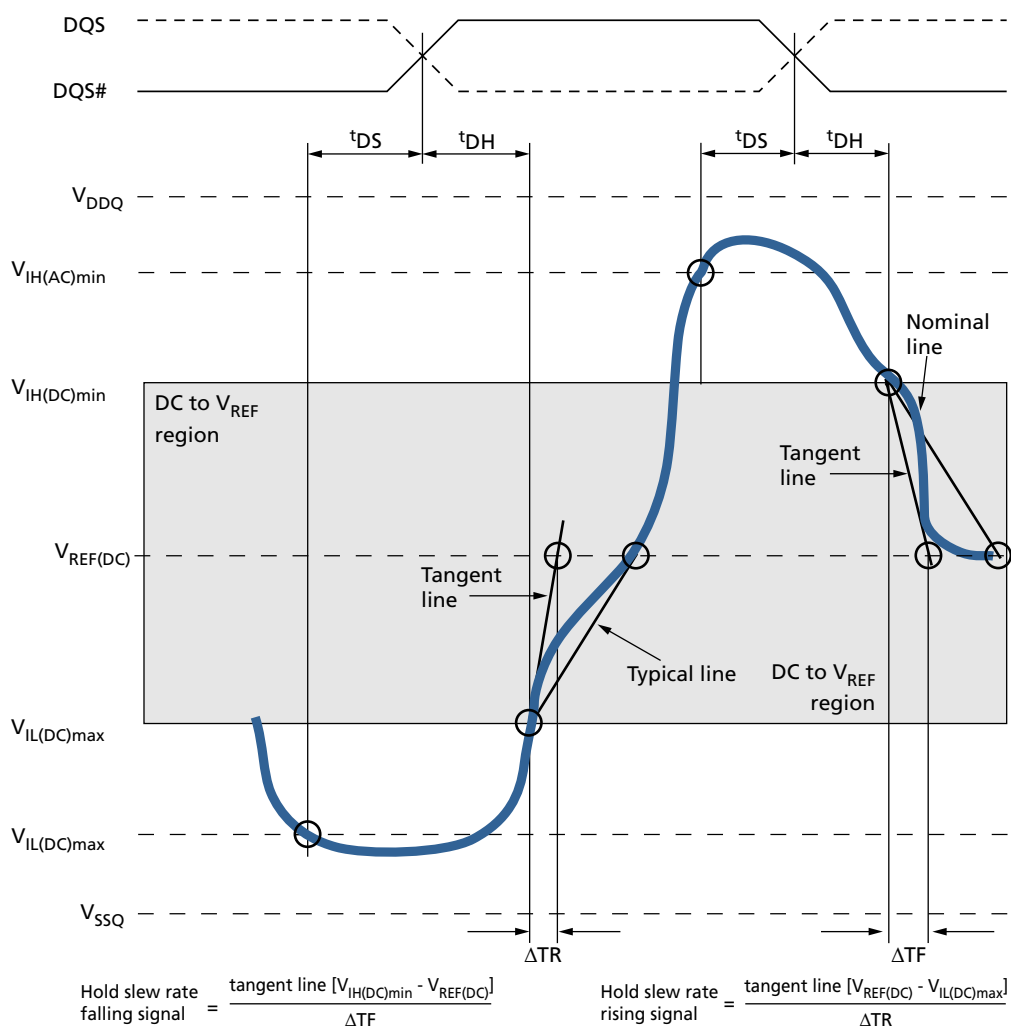
**Figure 85: Typical Slew Rate –  $t_{DH}$  for DQ Relative to Strobe**



**Figure 86: Tangent Line –  $t_{DS}$  for DQ with Respect to Strobe**



**Figure 87: Tangent Line –  $t_{DH}$  for DQ with Respect to Strobe**



## Revision History

### Rev. D – 06/2020

- Updated legal status to Production
- Updated I<sub>DD</sub> tables
- Updated table note for ACTIVATE: Table note of Current State Bank n to Command to Bank n Truth Table in Truth Tables section

### Rev. C – 02/2020

- Corrected package code HE: Standoff from 0.226 ±0.05mm to 0.266 ±0.05mm

### Rev. B – 11/2019

- Advance data sheet with full contents of LPDDR2
- Updated Package Dimensions: Changed package height from 0.9 ±0.1mm to 0.89 ±0.11mm
- Added the note to Regular Distributed Refresh Pattern figure: Recommended max refresh burst size 8 times as similar to LPDDR3 and/or LPDDR4

### Rev. A – 06/2019

- Initial release
- Used u98m\_lpddr2\_auto\_at\_ut.pdf - Rev. I 05/18 as basis; PDF: 09005aef86530ccb

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This data sheet contains minimum and maximum limits specified over the power supply and temperature range set forth herein. Although considered final, these specifications are subject to change, as further product development and data characterization sometimes occur.