

## 512M x 32 bit LPDDR4 Synchronous DRAM

### Overview

The LPDDR4 SDRAM is organized as 2 channels per device, and individual channel is 8-banks and 16-bits. This product uses a double-data-rate architecture to achieve high-speed operation. The double data rate architecture is essentially a 16n prefetch architecture with an interface designed to transfer two data words per clock cycle at the I/O pins. This product offers fully synchronous operations referenced to both rising and falling edges of the clock. The data paths are internally pipelined and 16n bits prefetched to achieve very high bandwidth. This LPDDR4 device uses a 2 or 4 clocks architecture on the Command/Address (CA) bus to reduce the number of input pins in the system. The 6-bit CA bus contains command, address, and bank information. Each command uses 1, 2 or 4 clock cycle, during which command information is transferred on the positive edge of the clock.

### Features

- JEDEC Standard Compliant
- Fast clock rate: 2133/1866MHz
- Low-voltage Core and I/O Power supplies:
  - $V_{DD1} = 1.8V$  (1.7V~1.95V)
  - $V_{DD2} = 1.1V$  (1.06V~1.17V)
  - $V_{DDQ} = 1.1V$  (1.06V~1.17V)
- Operating temperature range:
  - Automotive Temp (AT):  $T_C = -40\sim 105^{\circ}C$
- Supports JEDEC clock jitter specification
- Configuration:
  - 512 Meg x 32 (2 channels x16 I/O)
- 8 internal banks per each channel
- 16n-bit prefetch architecture
- Single data rate (multiple cycles) CMD/ADR bus
- Bidirectional differential data strobe per byte of data
  - DQS & DQS#
- DMI pin support for write data masking and DBI functionality
- Programmable READ and WRITE latencies
- Programmable and on-the-fly burst lengths
- Directed per-bank refresh for concurrent bank operation and ease of command scheduling
- Selectable output drive strength (DS)
- Dynamic ODT
  - DQ ODT :VSSQ Termination
  - CA ODT :VSS Termination
- On-chip temperature sensor to control self refresh rate
- On-chip temperature sensor whose status can be read from MR4
- Interface: LVSTL
- Internal VREF and VREF Training
- ZQ Calibration
- RoHS compliant
- Package: Pb and Halogen Free
  - 200-ball 10 x 15.0 x 1.0mm FBGA

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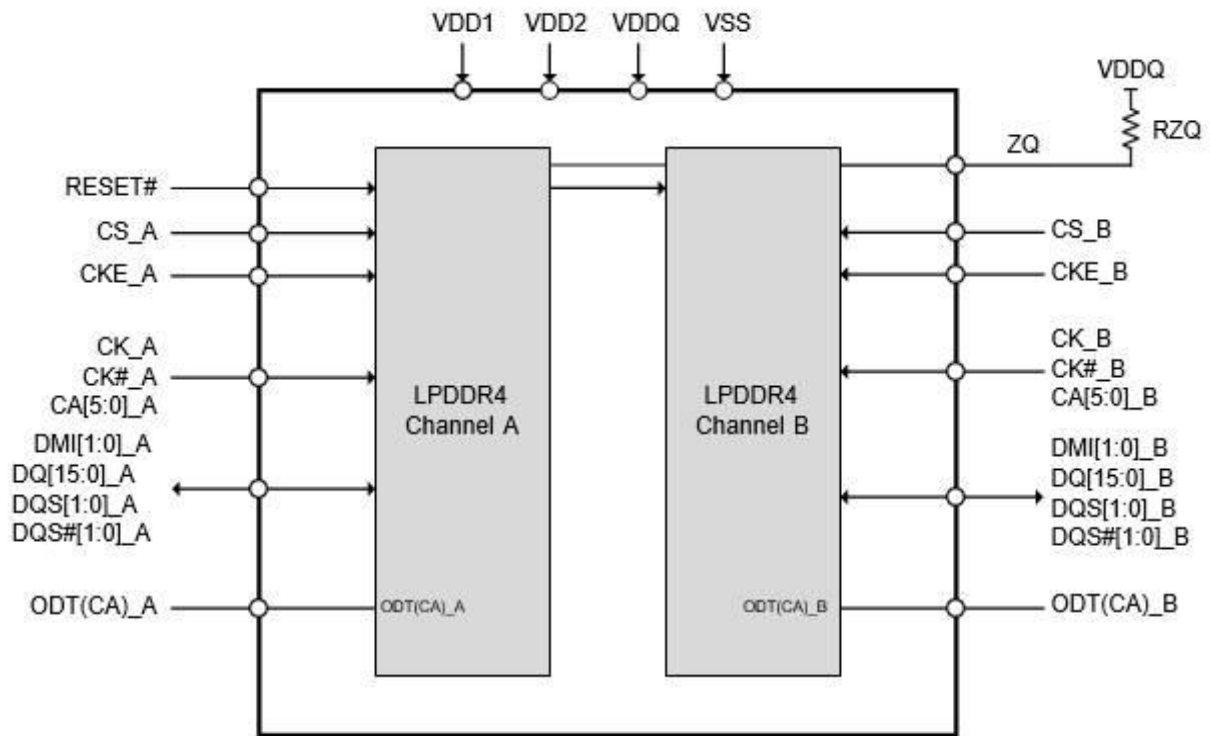
## How to Order

| Function | Density | IO Width | Pkg Type | Pkg Size       | Speed & Latency | Option          | INSIGNIS PART NUMBER: |
|----------|---------|----------|----------|----------------|-----------------|-----------------|-----------------------|
| LPDDR4   | 16Gb    | x32      | FBGA     | 10x15.0 (x1.0) | 3733Mbps/pin    | Automotive Temp | NLQA3PFS-3NAT         |
| LPDDR4   | 16Gb    | x32      | FBGA     | 10x15.0 (x1.0) | 4266Mbps/pin    | Automotive Temp | NLQA3PFS-4NAT         |

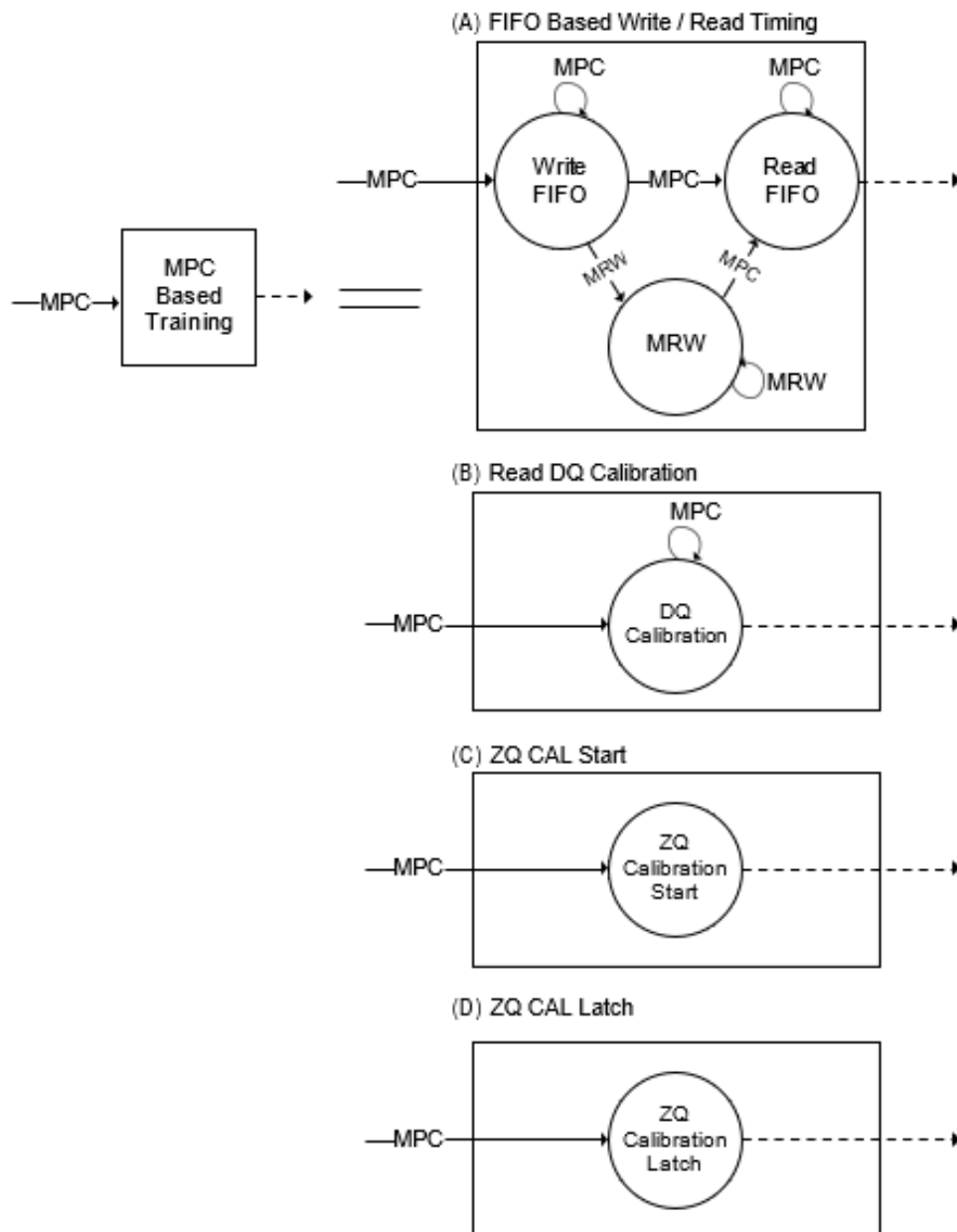
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### Package Block Diagram

### Figure 1. Dual Channel Package Block Diagram (x32)





**Figure 3. LPDDR4: Simplified Bus Interface State Diagram - Sheet 2****NOTES:**

1. From the Self Refresh state the device can enter Power-Down, MRR, MRW, or MPC states. See the Self Refresh section for more information.
2. In IDLE state, all banks are precharged.
3. In the case of a MRW command to enter a training mode, the state machine will not automatically return to the IDLE state at the conclusion of training. See the Mode Register Write (MRW) section for more information.
4. In the case of a MPC command to enter a training mode, the state machine may not automatically return to the IDLE state at the conclusion of training. See the Multi-Purpose Command (MPC) section for more information.
5. This simplified State Diagram is intended to provide an overview of the possible state transitions and the commands to control them. In particular, situations involving more than one bank, the enabling or disabling of on-die termination, and some other events are not captured in full detail.
6. States that have an "automatic return" and can be accessed from more than one prior state (Ex. MRW from either Idle or Active states) will return to the state from when they were initiated (Ex. MRW from Idle will return to Idle).
7. The RESET pin can be asserted from any state, and will cause the SDRAM to go to the Reset State. The diagram shows RESET applied from the Power-On as an example, but the Diagram should not be construed as a restriction on RESET.

Figure 4. Ball Assignment (200-Ball x32 FBGA Top View)

|    | 1    | 2        | 3       | 4     | 5    | ... | 8    | 9      | 10      | 11     | 12   |
|----|------|----------|---------|-------|------|-----|------|--------|---------|--------|------|
| A  | NC   | NC       | VSS     | VDD2  | ZQ   |     | NC   | VDD2   | VSS     | NC     | NC   |
| B  | NC   | DQ0_A    | VDDQ    | DQ7_A | VDDQ |     | VDDQ | DQ15_A | VDDQ    | DQ8_A  | NC   |
| C  | VSS  | DQ1_A    | DMIO_A  | DQ6_A | VSS  |     | VSS  | DQ14_A | DMI1_A  | DQ9_A  | VSS  |
| D  | VDDQ | VSS      | UQ50_A  | VSS   | VDDQ |     | VDDQ | VSS    | UQ51_A  | VSS    | VDDQ |
| E  | VSS  | DQ2_A    | UQ50A_A | DQ5_A | VSS  |     | VSS  | DQ13_A | UQ51A_A | DQ10_A | VSS  |
| F  | VDD1 | DQ3_A    | VDDQ    | DQ4_A | VDD2 |     | VDD2 | DQ12_A | VDDQ    | DQ11_A | VDD1 |
| G  | VSS  | ODT_CA_A | VSS     | VDD1  | VSS  |     | VSS  | VDD1   | VSS     | NC     | VSS  |
| H  | VDD2 | CA0_A    | NC      | CS_A  | VDD2 |     | VDD2 | CA2_A  | CA3_A   | CA4_A  | VDD2 |
| J  | VSS  | CA1_A    | VSS     | CKE_A | NC   |     | CK_A | CK#_A  | VSS     | CA5_A  | VSS  |
| K  | VDD2 | VSS      | VDD2    | VSS   | NC   |     | NC   | VSS    | VDD2    | VSS    | VDD2 |
| L  |      |          |         |       |      |     |      |        |         |        |      |
| M  |      |          |         |       |      |     |      |        |         |        |      |
| N  | VDD2 | VSS      | VDD2    | VSS   | NC   |     | NC   | VSS    | VDD2    | VSS    | VDD2 |
| P  | VSS  | CA1_B    | VSS     | CKE_B | NC   |     | CK_B | CK#_B  | VSS     | CA5_B  | VSS  |
| R  | VDD2 | CA0_B    | NC      | CS_B  | VDD2 |     | VDD2 | CA2_B  | CA3_B   | CA4_B  | VDD2 |
| T  | VSS  | ODT_CA_B | VSS     | VDD1  | VSS  |     | VSS  | VDD1   | VSS     | RESET# | VSS  |
| U  | VDD1 | DQ3_B    | VDDQ    | DQ4_B | VDD2 |     | VDD2 | DQ12_B | VDDQ    | DQ11_B | VDD1 |
| V  | VSS  | DQ2_B    | UQ50B_B | DQ5_B | VSS  |     | VSS  | DQ13_B | UQ51B_B | DQ10_B | VSS  |
| W  | VDDQ | VSS      | DQ50_B  | VSS   | VDDQ |     | VDDQ | VSS    | UQ51_B  | VSS    | VDDQ |
| Y  | VSS  | DQ1_B    | DMIO_B  | DQ6_B | VSS  |     | VSS  | DQ14_B | DMI1_B  | DQ9_B  | VSS  |
| AA | NC   | DQ0_B    | VDDQ    | DQ7_B | VDDQ |     | VDDQ | DQ15_B | VDDQ    | DQ8_B  | NC   |
| AB | NC   | NC       | VSS     | VDD2  | VSS  |     | VSS  | VDD2   | VSS     | NC     | NC   |

NOTE 1 0.8mm pitch (X-axis), 0.65mm pitch (Y-axis), 22 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT\_CA\_[x] balls are wired to ODT\_CA\_[x] pads of Rank 0 DRAM die. ODT\_CA\_[x] pads for other ranks (if present) are disabled in the package.

NOTE 4 Die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 5 Package requires dual channel die or functional equivalent of single channel die-stack.

## Addressing

**Table 1. LPDDR4 SDRAM Addressing**

| Memory Density                       |                  | 512Mx32 (16Gb/Package)            |
|--------------------------------------|------------------|-----------------------------------|
| Organization                         |                  | x32                               |
| Number of Channels                   |                  | 2                                 |
| Number of Ranks                      |                  | 1                                 |
| Density per channel                  |                  | 8Gb                               |
| Configuration                        |                  | 64Mb x 16DQ x 8 banks x 2 channel |
| Number of Banks (per Channel)        |                  | 8                                 |
| Array Pre-Fetch (Bits, per channel)  |                  | 256                               |
| Number of Rows (per channel)         |                  | 65,536                            |
| Number of Columns (fetch boundaries) |                  | 64                                |
| Page Size (Bytes)                    |                  | 2048                              |
| Bank Address                         |                  | BA0-BA2                           |
| x16                                  | Row Addresses    | R0-R15                            |
|                                      | Column Addresses | C0-C9                             |
| Burst Starting Address Boundary      |                  | 64-bit                            |

Note 1. The lower two column addresses (C0 - C1) are assumed to be “zero” and are not transmitted on the CA bus.

Note 2. Row and Column address values on the CA bus that are not used for a particular density be at valid logic levels.

Note 3. For non - binary memory densities, only a quarter of the row address space is invalid. When the MSB address bit is “HIGH”, then the MSB - 1 address bit must be “LOW”.

## Ball Descriptions

Table 2. Ball Details

| Symbol                                                  | Type      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CK_A, CK#_A,<br>CK_B, CK#_B                             | Input     | <b>Clock:</b> CK and CK# are differential clock inputs. All address, command, and control input signals are sampled on the crossing of the positive edge of CK and the negative edge of CK#. AC timings for CA parameters are referenced to CK. Each channel (A & B) has its own clock pair.                                                                                                                                                                                                                                  |
| CKE_A,<br>CKE_B                                         | Input     | <b>Clock Enable:</b> CKE HIGH activates and CKE LOW deactivates the internal clock circuits, input buffers, and output drivers. Power-saving modes are entered and exited via CKE transitions. CKE is part of the command code. Each channel (A & B) has its own CKE signal.                                                                                                                                                                                                                                                  |
| CS_A,<br>CS_B                                           | Input     | <b>Chip Select:</b> CS is part of the command code. Each channel (A & B) has its own CS signal.                                                                                                                                                                                                                                                                                                                                                                                                                               |
| CA[5:0]_A,<br>CA[5:0]_B                                 | Input     | <b>Command/Address Inputs:</b> CA signals provide the Command and Address inputs according to the Command Truth Table. Each channel (A&B) has its own CA signals.                                                                                                                                                                                                                                                                                                                                                             |
| DQ[15:0]_A,<br>DQ[15:0]_B                               | I/O       | <b>Data input/output:</b> Bidirectional data bus.                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| DQS[1:0]_A,<br>DQS#1:0]_A,<br>DQS[1:0]_B,<br>DQS#1:0]_B | I/O       | <b>Data Strobe:</b> DQS and DQS# are bi-directional differential output clock signals used to strobe data during a READ or WRITE. The Data Strobe is generated by the DRAM for a READ and is edge-aligned with Data. The Data Strobe is generated by the Memory Controller for a WRITE and must arrive prior to Data. Each byte of data has a Data Strobe signal pair. Each channel (A & B) has its own DQS strobes.                                                                                                          |
| DMI[1:0]_A,<br>DMI[1:0]_B                               | I/O       | <b>Data Mask Inversion:</b> DMI is a bi-directional signal which is driven HIGH when the data on the data bus is inverted, or driven LOW when the data is in its normal state. Data Inversion can be disabled via a mode register setting. Each byte of data has a DMI signal. Each channel (A & B) has its own DMI signals. This signal is also used along with the DQ signals to provide write data masking information to the DRAM. The DMI pin function - Data Inversion or Data mask - depends on Mode Register setting. |
| ZQ                                                      | Reference | <b>Calibration Reference:</b> Used to calibrate the output drive strength and the termination resistance. There is one ZQ pin per die. The ZQ pin shall be connected to VDDQ through a 240Ω ±1% resistor.                                                                                                                                                                                                                                                                                                                     |
| VDD1,<br>VDD2,<br>VDDQ                                  | Supply    | <b>Power Supplies:</b> Isolated on the die for improved noise immunity.                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| VSS, VSSQ                                               | GND       | <b>Ground Reference:</b> Power supply ground reference.                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| RESET#                                                  | Input     | <b>RESET:</b> When asserted LOW, the RESET# signal resets all channels of the die. There is one RESET# pad per die.                                                                                                                                                                                                                                                                                                                                                                                                           |
| ODT_CA_A,<br>ODT_CA_B                                   | Input     | <b>CA ODT Control:</b> The ODT_CA pin is used in conjunction with the Mode Register to turn on/off the On-Die-Termination for CA pins.                                                                                                                                                                                                                                                                                                                                                                                        |
| NC                                                      | -         | <b>No connect:</b> Not internally connected.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

Note 1. "\_A" and "\_B" indicate DRAM channel "\_A" pads are present in all devices. "\_B" pads are present in dual channel SDRAM devices only.

## Truth Tables

Operation or timing that is not specified is illegal, and after such an event, in order to guarantee proper operation, the device must be reset or power-cycled and then restarted through the specified initialization sequence before normal operation can continue.

CKE signal has to be held high when the commands listed in the command truth table input.

**Table 3. Command Truth Table**

|                                                    | Command Pins | CA Pins |     |     |     |     |     |         |           |
|----------------------------------------------------|--------------|---------|-----|-----|-----|-----|-----|---------|-----------|
| Command                                            | CS           | CA0     | CA1 | CA2 | CA3 | CA4 | CA5 | CK Edge | Notes     |
| Deselect (DES)                                     | L            | X       |     |     |     |     |     | R1      | 1,2       |
| Multi-Purpose Command (MPC)                        | H            | L       | L   | L   | L   | L   | OP6 | R1      | 1,2,9     |
|                                                    | L            | OP0     | OP1 | OP2 | OP3 | OP4 | OP5 | R2      |           |
| Precharge (PRE)<br>(Per Bank, All Bank)            | H            | L       | L   | L   | L   | H   | AB  | R1      | 1~4       |
|                                                    | L            | BA0     | BA1 | BA2 | V   | V   | V   | R2      |           |
| Refresh (REF)<br>(Per Bank, All Bank)              | H            | L       | L   | L   | H   | L   | AB  | R1      | 1~4       |
|                                                    | L            | BA0     | BA1 | BA2 | V   | V   | V   | R2      |           |
| Self Refresh Entry (SRE)                           | H            | L       | L   | L   | H   | H   | L   | R1      | 1,2       |
|                                                    | L            | V       |     |     |     |     |     | R2      |           |
| Write -1 (WR-1)                                    | H            | L       | L   | H   | L   | L   | BL  | R1      | 1~3,6,7,9 |
|                                                    | L            | BA0     | BA1 | BA2 | V   | C9  | AP  | R2      |           |
| Self Refresh Exit (SRX)                            | H            | L       | L   | H   | L   | H   | V   | R1      | 1,2       |
|                                                    | L            | V       |     |     |     |     |     | R2      |           |
| Mask Write -1 (MWR-1)                              | H            | L       | L   | H   | H   | L   | L   | R1      | 1~3,5,6,9 |
|                                                    | L            | BA0     | BA1 | BA2 | V   | C9  | AP  | R2      |           |
| RFU                                                | H            | L       | L   | H   | H   | H   | V   | R1      | 1,2       |
|                                                    | L            | V       |     |     |     |     |     | R2      |           |
| Read -1 (RD-1)                                     | H            | L       | H   | L   | L   | L   | BL  | R1      | 1~3,6,7,9 |
|                                                    | L            | BA0     | BA1 | BA2 | V   | C9  | AP  | R2      |           |
| CAS-2 (Write-2, Mask Write -2, Read-2, MRR-2, MPC) | H            | L       | H   | L   | L   | H   | C8  | R1      | 1,8,9     |
|                                                    | L            | C2      | C3  | C4  | C5  | C6  | C7  | R2      |           |
| RFU                                                | H            | L       | H   | L   | H   | L   | V   | R1      | 1,2       |
|                                                    | L            | V       |     |     |     |     |     | R2      |           |
| RFU                                                | H            | L       | H   | L   | H   | H   | V   | R1      | 1,2       |
|                                                    | L            | V       |     |     |     |     |     | R2      |           |
| Mode Register Write -1 (MRW-1)                     | H            | L       | H   | H   | L   | L   | OP7 | R1      | 1,2,11    |
|                                                    | L            | MA0     | MA1 | MA2 | MA3 | MA4 | MA5 | R2      |           |
| Mode Register Write-2 (MRW-2)                      | H            | L       | H   | H   | L   | H   | OP6 | R1      | 1,2,11    |
|                                                    | L            | OP0     | OP1 | OP2 | OP3 | OP4 | OP5 | R2      |           |
| Mode Register Read-1 (MRR-1)                       | H            | L       | H   | H   | H   | L   | V   | R1      | 1,2,12    |
|                                                    | L            | MA0     | MA1 | MA2 | MA3 | MA4 | MA5 | R2      |           |
| RFU                                                | H            | L       | H   | H   | H   | H   | V   | R1      | 1,2       |
|                                                    | L            | V       |     |     |     |     |     | R2      |           |
| Activate -1 (ACT-1)                                | H            | H       | L   | R12 | R13 | R14 | R15 | R1      | 1~3,10    |
|                                                    | L            | BA0     | BA1 | BA2 | V   | R10 | R11 | R2      |           |
| Activate -2 (ACT-2)                                | H            | H       | H   | R6  | R7  | R8  | R9  | R1      | 1,10      |
|                                                    | L            | R0      | R1  | R2  | R3  | R4  | R5  | R2      |           |

Note 1. All LPDDR4 commands except for Deselect are 2 clock cycle long and defined by states of CS and CA[5:0] at the first rising edge of clock. Deselect command is 1 clock cycle long.

Note 2. "V" means "H" or "L" (a defined logic level). "X" means don't care in which case CA[5:0] can be floated. Note 3.

Bank addresses BA[2:0] determine which bank is to be operated upon.

Note 4. AB "HIGH" during Precharge or Refresh command indicates that command must be applied to all banks and bank address is a don't care.

Note 5. Mask Write-1 command supports only BL 16. For Mask Write-1 command, CA5 must be driven LOW on first rising clock cycle (R1).

Note 6. AP "HIGH" during Write-1, Mask Write-1 or Read-1 commands indicates that an Auto-Precharge will occur to the bank associated with the Write, Mask Write or Read command.

Note 7. If Burst Length on-the-fly is enabled, BL "HIGH" during Write-1 or Read-1 command indicates that Burst Length should be set on-the-fly to BL=32. BL "LOW" during Write-1 or Read-1 command indicates that Burst Length should be set on-the-fly to BL=16. If Burst Length on-the-fly is disabled, then BL must be driven to defined logic level "H" or "L".

- Note 8. For CAS-2 commands (Write-2 or Mask Write-2 or Read-2 or MRR-2 or MPC (Only Write FIFO, Read FIFO & Read DQ Calibration), C[1:0] are not transmitted on the CA[5:0] bus and are assumed to be zero. Note that for CAS-2 Write-2 or CAS-2 Mask Write-2 command, C[3:2] must be driven LOW.
- Note 9. Write-1 or Mask Write-1 or Read-1 or Mode Register Read-1 or MPC (Only Write FIFO, Read FIFO & Read DQ Calibration) command must be immediately followed by CAS-2 command consecutively without any other command in between. Write-1 or Mask Write-1 or Read-1 or Mode Register Read-1 or MPC (Only Write FIFO, Read FIFO & Read DQ Calibration) command must be issued first before issuing CAS-2 command. MPC (Only Start & Stop DQS Oscillator, Start & Latch ZQ Calibration) commands do not require CAS-2 command; they require two additional DES or NOP commands consecutively before issuing any other commands.
- Note 10. Activate-1 command must be immediately followed by Activate-2 command consecutively without any other command in between. Activate-1 command must be issued first before issuing Activate-2 command. Once Activate-1 command is issued, Activate-2 command must be issued before issuing another Activate-1 command.
- Note 11. MRW-1 command must be immediately followed by MRW-2 command consecutively without any other command in between. MRW-1 command must be issued first before issuing MRW-2 command.
- Note 12. MRR-1 command must be immediately followed by CAS-2 command consecutively without any other command in between. MRR-1 command must be issued first before issuing CAS-2 command.

## Power-up, Initialization, and Power-off Procedure

For power-up and reset initialization, in order to prevent DRAM from functioning improperly, default values of the following MR settings are defined as the table below.

**Table 4. MRS defaults settings**

| Item             | MRS          | Default Setting     | Description                     |
|------------------|--------------|---------------------|---------------------------------|
| FSP-OP/WR        | MR13 OP[7:6] | 00 <sub>B</sub>     | FSP-OP/WR[0] are enabled        |
| WLS              | MR2 OP[6]    | 0 <sub>B</sub>      | Write Latency Set 0 is selected |
| WL               | MR2 OP[5:3]  | 000 <sub>B</sub>    | WL = 4                          |
| RL               | MR2 OP[2:0]  | 000 <sub>B</sub>    | RL = 6, nRTP=8                  |
| nWR              | MR1 OP[6:4]  | 000 <sub>B</sub>    | nWR = 6                         |
| DBI-WR/RD        | MR3 OP[7:6]  | 00 <sub>B</sub>     | Write & Read DBI are disabled   |
| CA ODT           | MR11 OP[6:4] | 000 <sub>B</sub>    | CA ODT is disabled              |
| DQ ODT           | MR11 OP[2:0] | 000 <sub>B</sub>    | DQ ODT is disabled              |
| VREF(CA) Setting | MR12 OP[6]   | 1 <sub>B</sub>      | VREF(CA) Range[1] enabled       |
| VREF(CA) Value   | MR12 OP[5:0] | 001101 <sub>B</sub> | Range1 : 27.2% of VDD2          |
| VREF(DQ) Setting | MR14 OP[6]   | 1 <sub>B</sub>      | VREF(DQ) Range[1] enabled       |
| VREF(DQ) Value   | MR14 OP[5:0] | 001101 <sub>B</sub> | Range1 : 27.2% of VDDQ          |

## Voltage Ramp and Device Initialization

The following sequence shall be used to power up the LPDDR4 device. Unless specified otherwise, these steps are mandatory. Note that the power-up sequence of all channels must proceed simultaneously.

1. While applying power (after Ta), RESET# is recommended to be LOW ( $\leq 0.2 \times VDD2$ ) and all other inputs must be between VILmin and VIHmax. The device outputs remain at High-Z while RESET# is held LOW. Power supply voltage ramp requirements are provided in the table below. VDD1 must ramp at the same time or earlier than VDD2. VDD2 must ramp at the same time or earlier than VDDQ.

**Table 5. Voltage Ramp Conditions**

| After         | Applicable Conditions                   |
|---------------|-----------------------------------------|
| Ta is reached | VDD1 must be greater than VDD2          |
|               | VDD2 must be greater than VDDQ - 200 mV |

Note 1. Ta is the point when any power supply first reaches 300 mV.

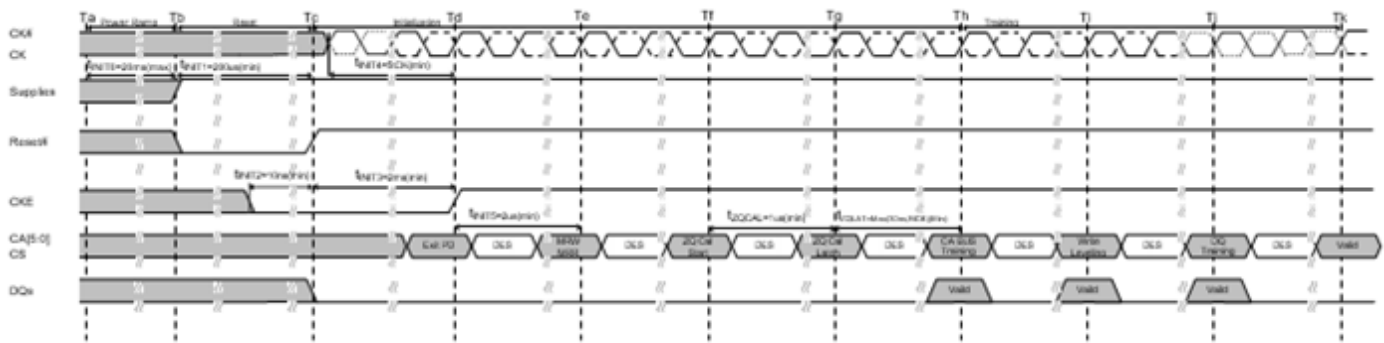
Note 2. Voltage ramp conditions in Table 8 apply between Ta and power-off (controlled or uncontrolled).

Note 3. Tb is the point at which all supply and reference voltages are within their defined ranges.

Note 4. Power ramp duration tINIT0 (Tb-Ta) must not exceed 20ms.

Note 5. The voltage difference between any of VSS and VSSQ pins must not exceed 100 mV.

2. Following the completion of the voltage ramp (Tb), RESET# must be maintained LOW. DQ, DMI, DQS and DQS# voltage levels must be between VSSQ and VDDQ during voltage ramp to avoid latch-up. CKE, CK, CK#, CS and CA input levels must be between VSS and VDD2 during voltage ramp to avoid latch-up.
3. Beginning at Tb, RESET# must remain LOW for at least tINIT1 (Tc), after which RESET# can be deasserted to HIGH (Tc). At least 10ns before RESET# de-assertion, CKE is required to be set LOW. All other input signals are "Don't Care".

**Figure 5. Power Ramp and Initialization Sequence**

Note 1. Training is optional and may be done at the system designer's discretion. The order of training may be different than what is shown here.

4. After RESET# is de-asserted ( $T_c$ ), wait at least  $t_{INIT3}$  before activating CKE. Clock (CK, CK#) is required to be started and stabilized for  $t_{INIT4}$  before CKE goes active ( $T_d$ ). CS is required to be maintained LOW when controller activates CKE.
5. After setting CKE high, wait minimum of  $t_{INIT5}$  to issue any MRR or MRW commands ( $T_e$ ). For both MRR and MRW commands, the clock frequency must be within the range defined for  $t_{CKb}$ . Some AC parameters (for example,  $t_{DQSCk}$ ) could have relaxed timings (such as  $t_{DQSCk_b}$ ) before the system is appropriately configured.
6. After completing all MRW commands to set the Pull-up, Pull-down and Rx termination values, the DRAM controller can issue ZQCAL Start command to the memory ( $T_f$ ). This command is used to calibrate  $V_{OH}$  level and output impedance over process, voltage and temperature. In systems where more than one LPDDR4 DRAM devices share one external ZQ resistor, the controller must not overlap the ZQ calibration sequence of each LPDDR4 device. ZQ calibration sequence is completed after  $t_{ZQCAL}$  ( $T_g$ ) and the ZQCAL Latch command must be issued to update the DQ drivers and DQ+CA ODT to the calibrated values.
7. After  $t_{ZQLAT}$  is satisfied ( $T_h$ ) the command bus (internal  $V_{REF}(CA)$ , CS, and CA) should be trained for high-speed operation by issuing an MRW command (Command Bus Training Mode). This command is used to calibrate the device's internal  $V_{REF}$  and align CS/CA with CK for high-speed operation. The LPDDR4 device will power-up with receivers configured for low-speed operations, and  $V_{REF}(CA)$  set to a default factory setting. Normal device operation at clock speeds higher than  $t_{CKb}$  may not be possible until command bus training has been completed. The command bus training MRW command uses the CA bus as inputs for the calibration data stream, and outputs the results asynchronously on the DQ bus. See command bus training in the MRW section for information on how to enter/exit the training mode.
8. After command bus training, DRAM controller must perform write leveling. Write leveling mode is enabled when MR2 OP[7] is high ( $T_i$ ). See the Write Leveling section for a detailed description of the write leveling entry and exit sequence. In write leveling mode, the DRAM controller adjusts write DQS timing to the point where the device recognizes the start of write DQ data burst with desired write latency.
9. After write leveling, the DQ Bus (internal  $V_{REF}(DQ)$ , DQS, and DQ) should be trained for high-speed operation using the MPC training commands and by issuing MRW commands to adjust  $V_{REF}(DQ)(T_j)$ . The device will power-up with receivers configured for low-speed operations and  $V_{REF}(DQ)$  set to a default factory setting. Normal device operation at clock speeds higher than  $t_{CKb}$  should not be attempted until DQ Bus training has been completed. The MPC Read Calibration command is used together with MPC FIFO Write/Read commands to train DQ bus without disturbing the memory array contents. See DQ Bus Training section for detailed DQ Bus Training sequence.
10. At  $T_k$  the device is ready for normal operation, and is ready to accept any valid command. Any more registers that have not previously been set up for normal operation should be written at this time.

**Table 6. Initialization Timing Parameters**

| Parameter   | Value                 |           | Unit     | Comment                                                  |
|-------------|-----------------------|-----------|----------|----------------------------------------------------------|
|             | Min                   | Max       |          |                                                          |
| $t_{INIT0}$ | -                     | 20        | ms       | Maximum voltage ramp time                                |
| $t_{INIT1}$ | 200                   | -         | us       | Minimum RESET# LOW time after completion of voltage ramp |
| $t_{INIT2}$ | 10                    | -         | ns       | Minimum CKE low time before RESET# high                  |
| $t_{INIT3}$ | 2                     | -         | ms       | Minimum CKE low time after RESET# high                   |
| $t_{INIT4}$ | 5                     | -         | $t_{CK}$ | Minimum stable clock before first CKE high               |
| $t_{INIT5}$ | 2                     | -         | us       | Minimum idle time before first MRW/MRR command           |
| $t_{ZQCAL}$ | 1                     | -         | us       | ZQ calibration time                                      |
| $t_{ZQLAT}$ | Max(30ns, $8t_{CK}$ ) | -         | ns       | ZQCAL latch quiet time                                   |
| $t_{CKb}$   | Note *1,2             | Note *1,2 | ns       | Clock cycle time during boot                             |

**Note:**

1. Min  $t_{CKb}$  guaranteed by DRAM test is 18 ns.
2. The system may boot at a higher frequency than dictated by min  $t_{CKb}$ . The higher boot frequency is system dependent.

**Reset Initialization with Stable Power**

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

1. Assert RESET# below  $0.2 \times V_{DD2}$  anytime when reset is needed. RESET# needs to be maintained for minimum  $t_{PW\_RESET}$ . CKE must be pulled LOW at least 10 ns before de-asserting RESET#.
2. Repeat steps 4 to 10 in Voltage Ramp section.

**Table 7. Reset Timing Parameter**

| Parameter       | Value |     | Unit | Comment                                                            |
|-----------------|-------|-----|------|--------------------------------------------------------------------|
|                 | Min   | Max |      |                                                                    |
| $t_{PW\_RESET}$ | 100   | -   | ns   | Minimum RESET# low Time for Reset Initialization with stable power |

**Power-off Sequence**

The following procedure is required to power off the device.

While powering off, CKE must be held LOW ( $0.2 \times V_{DD2}$ ) and all other inputs must be between  $V_{ILmin}$  and  $V_{IHmax}$ . The device outputs remain at High-Z while CKE is held LOW. DQ, DMI, DQS, and DQS# voltage levels must be between  $V_{SSQ}$  and  $V_{DDQ}$  during voltage ramp to avoid latch-up. RESET#, CK, CK#, CS and CA input levels must be between  $V_{SS}$  and  $V_{DD2}$  during voltage ramp to avoid latch-up.

Tx is the point where any power supply drops below the minimum value specified.

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

**Table 8. Power Supply Conditions**

| After     | Applicable Conditions                             |
|-----------|---------------------------------------------------|
| Tx and Tz | $V_{DD1}$ must be greater than $V_{DD2}$          |
|           | $V_{DD2}$ must be greater than $V_{DDQ} - 200$ mV |

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

**Uncontrolled Power-Off Sequence**

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

At Tx, when the power supply drops below the minimum values specified, 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. During this period, the relative voltage between power supplies is uncontrolled.  $V_{DD1}$  and  $V_{DD2}$  must decrease with a slope lower than 0.5 V/ $\mu$ s between Tx and Tz.

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

**Table 9. Power-Off Timing**

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

## Read and Write Access Operations

After a bank has been activated, a read or write command can be executed. This is accomplished by asserting CKE asynchronously, with CS and CA[5:0] set to the proper state (see Command Truth Table) at a rising edge of CK.

The device provides a fast column access operation. A single Read or Write command will initiate a burst read or write operation, where data is transferred to/from the DRAM on successive clock cycles. Burst interrupts are not allowed, but the optimal burst length may be set on the fly (see Command Truth Table).

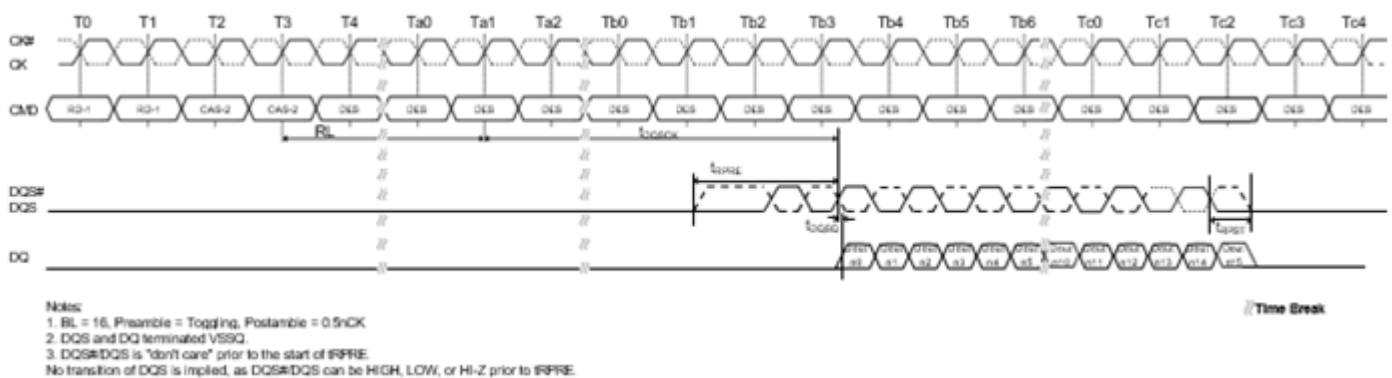
## Read Preamble and Postamble

The DQS strobe for the LPDDR4 device requires a pre-amble prior to the first latching edge (the rising edge of DQS with DATA "valid"), and it requires a post-amble after the last latching edge. The pre-amble and post-amble lengths are set via mode register writes (MRW).

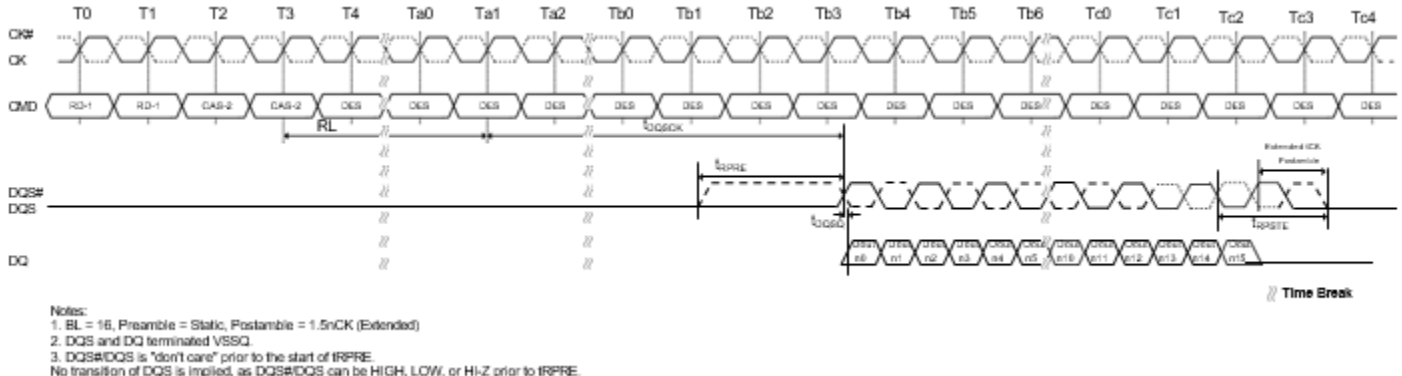
For Read operations the pre-ambles is  $2 \cdot t_{CK}$ , but the pre-ambles is static (no-toggle) or toggling, selectable via mode register.

LPDDR4 will have a DQS Read post-amble of  $0.5 \cdot t_{CK}$  (or extended to  $1.5 \cdot t_{CK}$ ). Standard DQS postamble will be  $0.5 \cdot t_{CK}$  driven by the DRAM for Reads. A mode register setting instructs the DRAM to drive an additional (extended) one cycle DQS Read post-amble. The drawings below show examples of DQS Read post-amble for both standard ( $t_{RPST}$ ) and extended ( $t_{RPSTE}$ ) post-amble operation.

**Figure 6. DQS Read Preamble and Postamble: Toggling Preamble and 0.5nCK Postamble**



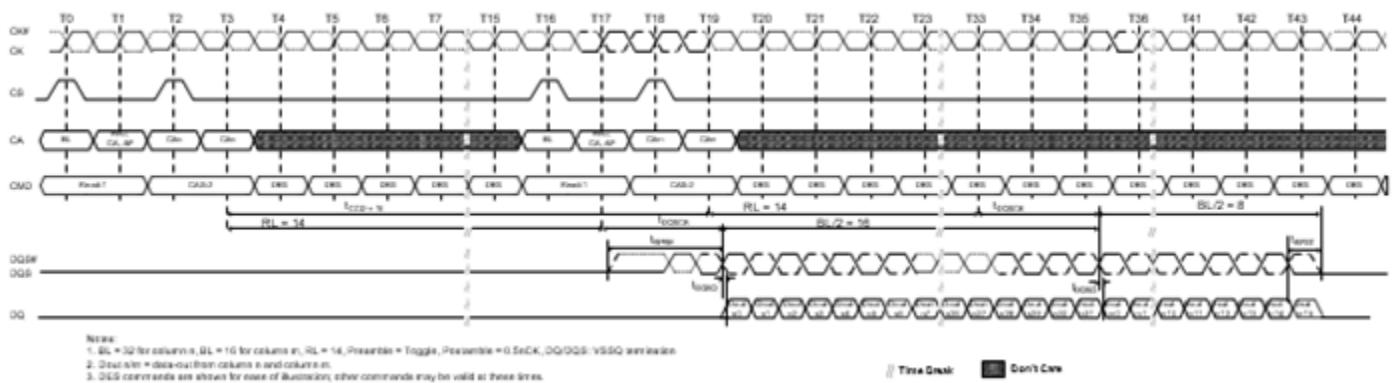
**Figure 7. DQS Read Preamble and Postamble: Static Preamble and 1.5nCK Postamble**



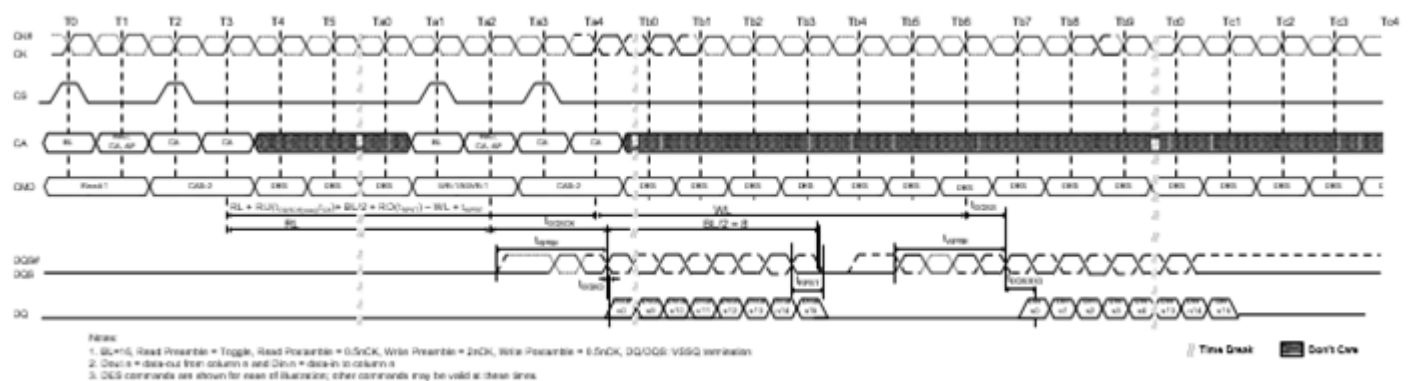
## Burst Read Operation

A burst Read command is initiated with CS, and CA[5:0] asserted to the proper state at the rising edge of CK, as defined by the Command Truth Table. The command address bus inputs determine the starting column address for the burst. The two low-order address bits are not transmitted on the CA bus and are implied to be "0", so that the starting burst address is always a multiple of four (ex. 0x0, 0x4, 0x8, 0xC). The read latency (RL) is defined from the last rising edge of the clock that completes a read command (Ex: the second rising edge of the CAS-2 command) to the rising edge of the clock from which the tDQSQ delay is measured. The first valid data is available  $RL \cdot tCK + tDQSQ + tDQSQ$  after the rising edge of Clock that completes a read command. The data strobe output is driven tRPRE before the first valid rising strobe edge. The first data-bit of the burst is synchronized with the first valid (i.e., post-preamble) rising edge of the data strobe. Each subsequent data out appears on each DQ pin, edge-aligned with the data strobe. At the end of a burst the DQS signals are driven for another half cycle post-amble, or for a 1.5-cycle postamble if the programmable post-amble bit is set in the mode register. The RL is programmed in the mode registers. Pin timings for the data strobe are measured relative to the cross-point of DQS and DQS#.

**Figure 8. Burst Read Timing**



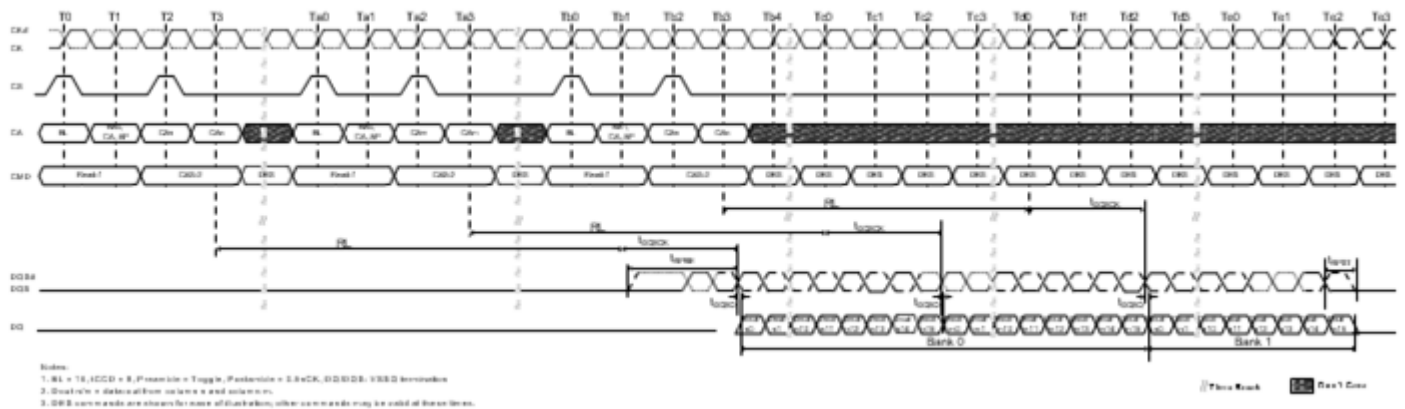
**Figure 9. Burst Read followed by Burst Write or Burst Mask Write**



The minimum time from a Burst Read command to a Write or MASK WRITE command is defined by the read latency (RL) and the burst length (BL).

Minimum Read-to-Write or Mask Write latency is  $RL + RU(tDQSQ(max)/tCK) + BL/2 + RD(tRPST) - WL + tWPRES$ .

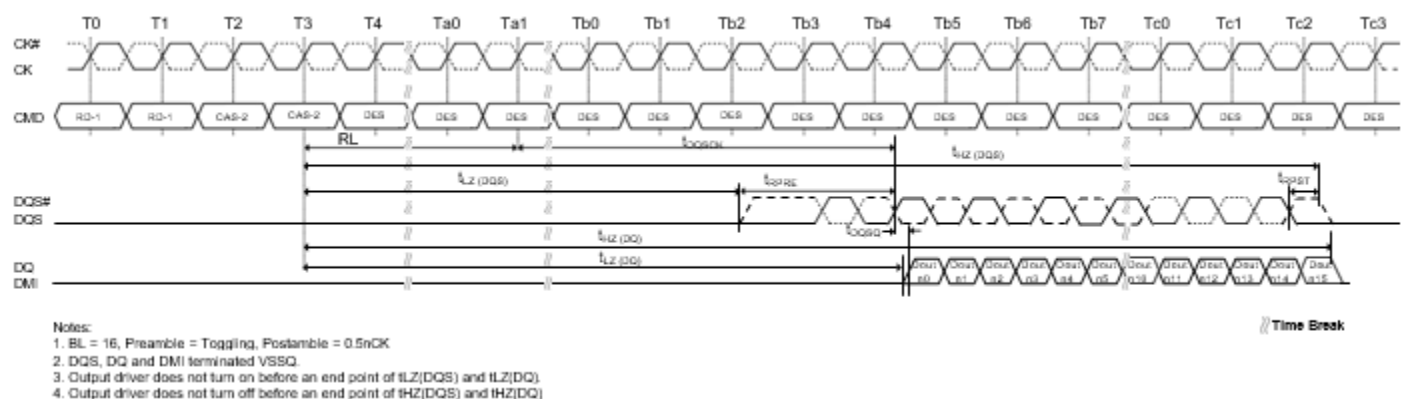
### Figure 10. Seamless Burst Read



The seamless Burst Read operation is supported by placing a Read command at every tCCD(Min) interval for BL16 (or every 2 x tCCD(Min) for BL32).

The seamless Burst Read can access any open bank.

### Figure 11. Read Timing



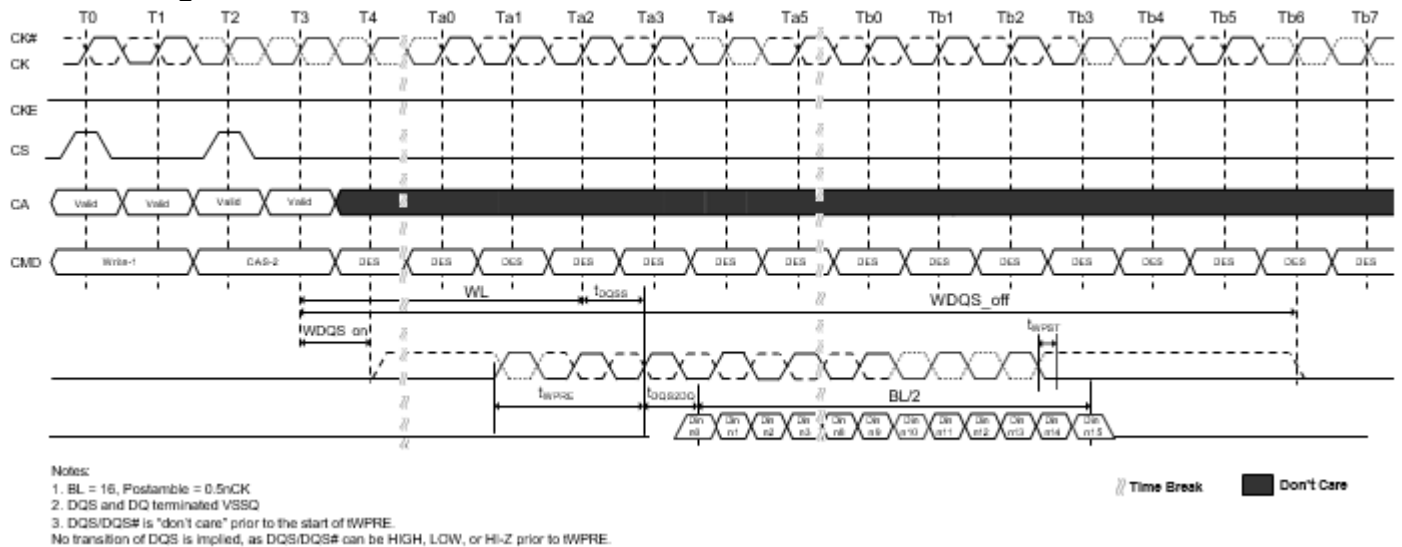
## Write Preamble and Postamble

The DQS strobe for the LPDDR4 requires a pre-amble prior to the first latching edge (the rising edge of DQS with DATA "valid"), and it requires a post-amble after the last latching edge. The pre-amble and post-amble lengths are set via mode register writes (MRW).

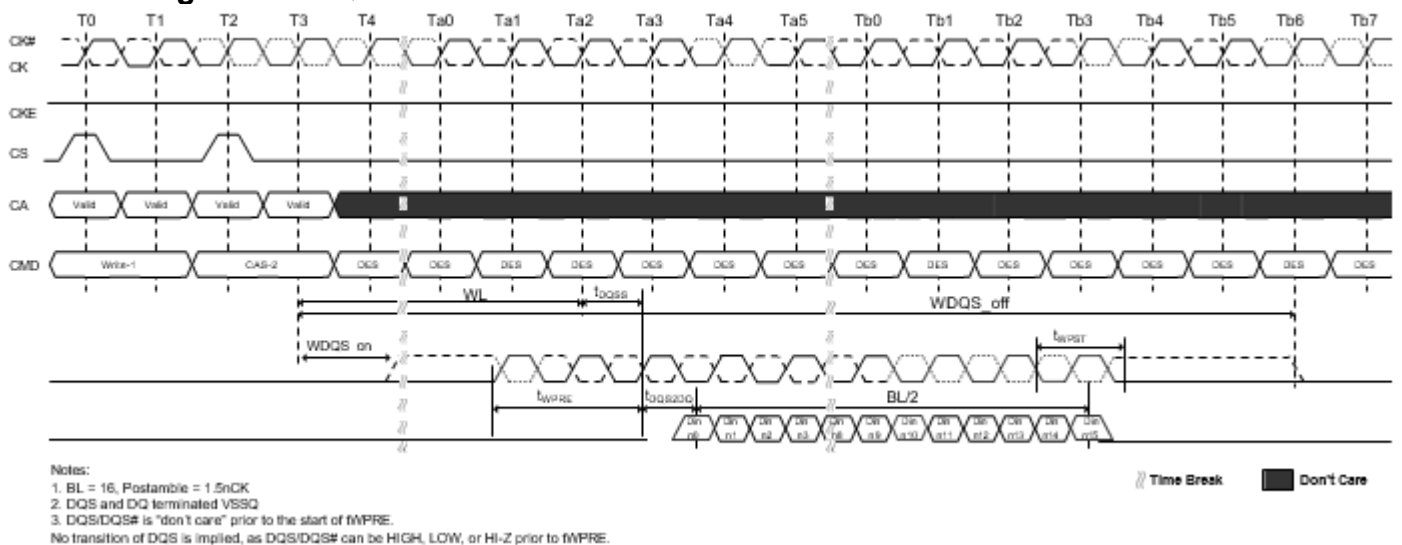
For Write operations, a  $2 \times tCK$  pre-ample is required at all operating frequencies.

LPDDR4 will have a DQS Write post-ample of  $0.5 \times tCK$  or extended to  $1.5 \times tCK$ . Standard DQS post-ample will be  $0.5 \times tCK$  driven by the memory controller for Writes. A mode register setting instructs the DRAM to drive an additional (extended) one cycle DQS Write post-ample. The drawings below show examples of DQS Write post-ample for both standard ( $tWPST$ ) and extended ( $tWPSTE$ ) post-ample operation.

**Figure 12. DQS Write Preamble and Postamble: 0.5nCK Postamble**



**Figure 13. DQS Write Preamble and Postamble: 1.5nCK Postamble**



A burst Write command is initiated with CS, and CA[5:0] asserted to the proper state at the rising edge of CK, as defined by the Command Truth Table. Column addresses C[3:2] should be driven LOW for Burst Write commands, and column addresses C[1:0] are not transmitted on the CA bus (and are assumed to be zero), so that the starting column burst address is always aligned with a 32B boundary. The write latency (WL) is defined from the last rising edge of the clock that completes a write command (Ex: the second rising edge of the CAS-2 command) to the rising edge of the clock from which tDQSS is measured. The first valid “latching” edge of DQS must be driven WL \* tCK + tDQSS after the rising edge of Clock that completes a write command.

The LPDDR4-SDRAM uses an un-matched DQS-DQ path for lower power, so the DQS-strobe must arrive at the SDRAM ball prior to the DQ signal by the amount of  $t_{DQS2DQ}$ . The DQS-strobe output is driven  $t_{WPRES}$  before the first valid rising strobe edge. The  $t_{WPRES}$  pre-amble is required to be  $2 \times t_{CK}$ . The DQS strobe must be trained to arrive at the DQ pad center-aligned with the DQ-data. The DQ-data must be held for  $t_{DIVW}$  (data input valid window) and the DQS must be periodically trained to stay centered in the  $t_{DIVW}$  window to compensate for timing changes due to temperature and voltage variation. Burst data is captured by the SDRAM on successive edges of DQS until the 16 or 32 bit data burst is complete. The DQS-strobe must remain active (toggling) for  $t_{WPST}$  (Write post-amble) after the completion of the burst Write. 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 cross point of DQS and DQS#.

The diagram illustrates the timing of the 68000 microprocessor. The top section shows the clock (CLK) and reset (RST) signals. The middle section shows the data bus (D[31:0]) with instructions being executed. The bottom section shows the timing of the CS#, RAS#, and CAS# signals. The diagram is divided into sections for instruction 1, instruction 2, and instruction 3, with a 'Precharge' period between instructions. The diagram shows the execution of instructions like ADD, MOV, and LDR, with specific clock cycles highlighted for each. The diagram is divided into sections for instruction 1, instruction 2, and instruction 3, with a 'Precharge' period between instructions.

**Notes:**

1.  $60 \times 10^6$  32-bit Precharge = 0.5 CLK, 0.5 CLK, 0.5 CLK, 0.5 CLK
2.  $60 \times 10^6$  32-bit Precharge = 0.5 CLK, 0.5 CLK, 0.5 CLK, 0.5 CLK
3. The minimum number of clock cycles from the start of the instruction to the first precharge is indicated by the number in the box:  $(N+1) \times T + 0.5 \times T + 0.5 \times T + 0.5 \times T$
4. RAS# starts at the rising edge of CLK, after the last precharge edge of CS#.
5. CAS# starts at the rising edge of CLK, after the last precharge edge of CS#.

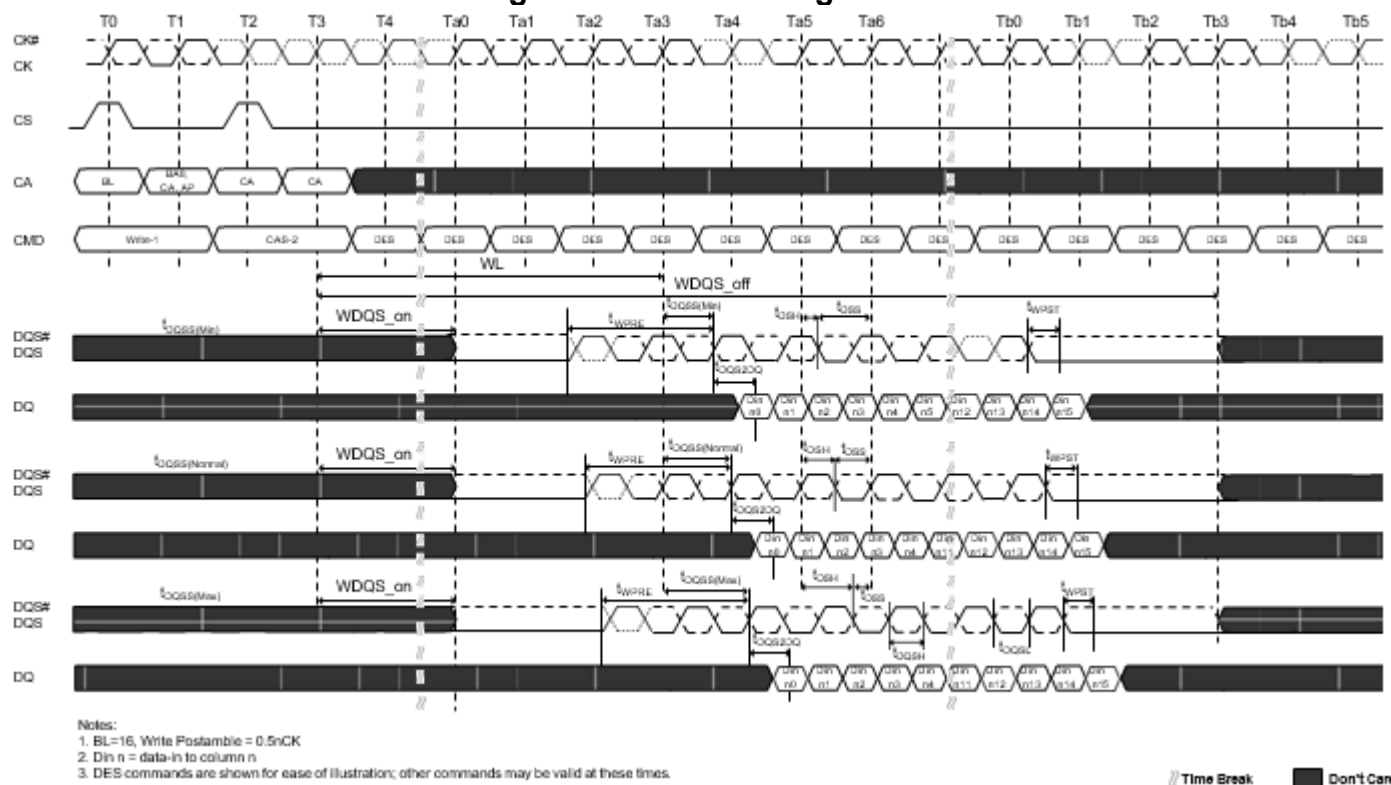
The diagram illustrates the timing of various signals relative to the 68000 clock cycles (T0 to T10). The signals shown are:

- CR:** Control signal, active low, with pulses at T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.
- CA:** Address bus, showing data for T0-T3, T4-T7, T8-T9, and T10.
- Cn:** Chip select signal, active low, with pulses at T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.
- CIO:** Data bus, showing data for T0-T3, T4-T7, T8-T9, and T10.
- CSn:** Chip select signal, active low, with pulses at T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.
- CSn:** Chip select signal, active low, with pulses at T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.
- CSn:** Chip select signal, active low, with pulses at T0, T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10.

Notes:

1.  $20 \times 10$  Write Protection = 0x000, 0x000, 0x000, 0x000
2.  $20 \times 10$  = 0x000 to 0x000
3. The minimum number of clock cycles from the last write command to the last read command for any bank is  $(20 \times 10 + 0x000 + 0x000 + 0x000)$ .
4.  $20 \times 10$  starts at the rising edge of CR after the last falling edge of CSn.
5.  $20 \times 10$  starts at the rising edge of CR after the last falling edge of CSn.

Figure 16. Write Timing



## Write and Masked Write operation DQS controls (WDQS Control)

The device supports write and masked write operations with the following DQS controls. Before and after Write and Masked Write operations are issued, DQS/DQS# is required to have a sufficient voltage gap to make sure the write buffers operating normally without any risk of metastability.

The device is supported by either of two WDQS control modes below.

Mode 1: Read Based Control

Mode 2: WDQS\_on / WDQS\_off definition based control.

Regardless of ODT enable/disable, WDQS related timing described here does not allow any change of existing command timing constraints for all read/write operations. In case of any conflict or ambiguity on the command timing constraints caused by what is specified in 'WDQS Control', the specifications defined in 'MPC', 'Timing Constraints for Training Commands' should have higher priority than WDQS control requirements.

In order to prevent write preamble related failure, it is strongly recommended to support either of the two WDQS controls to the device.

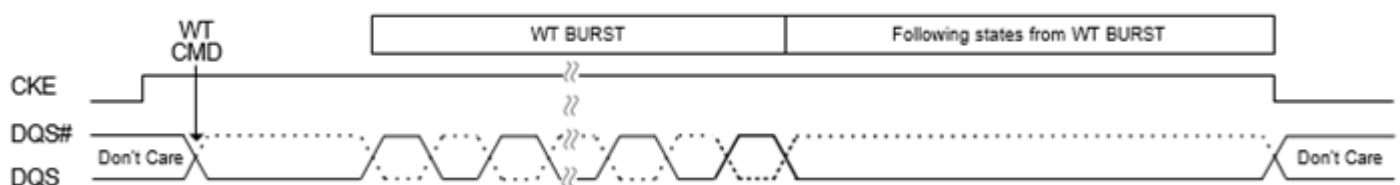
### WDQS Control Mode 1 - Read Based Control

The LPDDR4-SDRAM needs to be guaranteed the differential WDQS, but the differential WDQS can be controlled as described below. WDQS control requirements here can be ignored while differential read DQS is operated or while DQS hands over from Read to Write and vice versa.

1. At the time a write / masked write command is issued, SoC makes the transition from driving DQS# high to driving differential DQS/DQS#, followed by normal differential burst on DQS pins.
2. At the end of postamble of write / masked write burst, SoC resumes driving DQS# high through the subsequent states except for DQS toggling and DQS turn around time of WT-RD and RD-WT as long as CKE is high.

When CKE is low, the state of DQS and DQS# is allowed to be "Don't Care".

**Figure 17. WDQS Control Mode 1 - Read Based Control**



**WDQS Control Mode 2 - WDQS\_on/off**

After write / masked write command is issued, DQS and DQS# required to be differential from WDQS\_on, and DQS and DQS# can be “Don't Care” status from WDQS\_off of write / masked write command. When ODT is enabled, WDQS\_on and WDQS\_off timing is located in the middle of the operations. When host disables ODT, WDQS\_on and WDQS\_off constraints conflict with tRTW. The timing does not conflict when ODT is enabled because WDQS\_on and WDQS\_off timing is covered in ODTLon and ODTLoff. However, regardless of ODT on/off, WDQS\_on/off timing below does not change any command timing constraints for all read and write operations. In order to prevent the conflict, WDQS\_on/off requirement can be ignored when WDQS\_on/off timing is overlapped with read operation period including Read burst period and tRPST or overlapped with turn-around time (RD-WT or WT-RD). In addition, the period during DQS toggling caused by Read and Write can be counted as WDQS\_on/off.

**Parameters**

- WDQS\_on: the max delay from write / masked write command to differential DQS and DQS#.
- WDQS\_off: the min delay for DQS and DQS# differential input after the last write / masked write command.
- WDQS\_Exception: the period where WDQS\_on and WDQS\_off timing is overlapped with read operation or with DQS turn around (RD-WT, WT-RD).
  - WDQS\_Exception @ ODT disable = max (WL - WDQS\_on + tDQSTA - tWPRE - n\*tCK, 0 tCK) where RD to WT command gap = tRTW(min)@ODT disable + n\*tCK
  - WDQS\_Exception @ ODT enable = tDQSTA

**Table 10. WDQS\_on / WDQS\_off Definition**

| WL    |       | nWR | nRTP | WDQS_on (Max) |       | WDQS_off (Min) |       | Lower Clock Frequency Limit (>) | Upper Clock Frequency Limit (≤) |
|-------|-------|-----|------|---------------|-------|----------------|-------|---------------------------------|---------------------------------|
| Set A | Set B |     |      | Set A         | Set B | Set A          | Set B |                                 |                                 |
| 4     | 4     | 6   | 8    | 0             | 0     | 15             | 15    | 50                              | 266                             |
| 6     | 8     | 10  | 8    | 0             | 0     | 18             | 20    | 266                             | 533                             |
| 8     | 12    | 16  | 8    | 0             | 6     | 21             | 25    | 533                             | 800                             |
| 10    | 18    | 20  | 8    | 4             | 12    | 24             | 32    | 800                             | 1066                            |
| 12    | 22    | 24  | 10   | 4             | 14    | 27             | 37    | 1066                            | 1333                            |
| 14    | 26    | 30  | 12   | 6             | 18    | 30             | 42    | 1333                            | 1600                            |
| 16    | 30    | 34  | 14   | 6             | 20    | 33             | 47    | 1600                            | 1866                            |
| 18    | 34    | 40  | 16   | 8             | 24    | 36             | 52    | 1866                            | 2133                            |
| nCK   | nCK   | nCK | nCK  | nCK           | nCK   | nCK            | nCK   | MHz                             | MHz                             |

**Notes:**

1. WDQS\_on/off requirement can be ignored when WDQS\_on/off timing is overlapped with read operation period including read burst period and tRPST or overlapped with turn-around time (RD-WT or WT-RD).
2. DQS toggling period caused by read and write can be counted as WDQS\_on/off.

**Table 11. WDQS\_on / WDQS\_off Allowable Variation Range**

|          | Min   | Max  | Unit     |
|----------|-------|------|----------|
| WDQS_on  | -0.25 | 0.25 | tCK(avg) |
| WDQS_off | -0.25 | 0.25 | tCK(avg) |

**Table 12. DQS turn around parameter**

| Parameter | Description                                         | Max | Unit     | Note |
|-----------|-----------------------------------------------------|-----|----------|------|
| tDQSTA    | Turn-around time RDQS to WDQS for WDQS control case | TBD | tCK(avg) | 1    |

Figure 18. Burst Write Operation

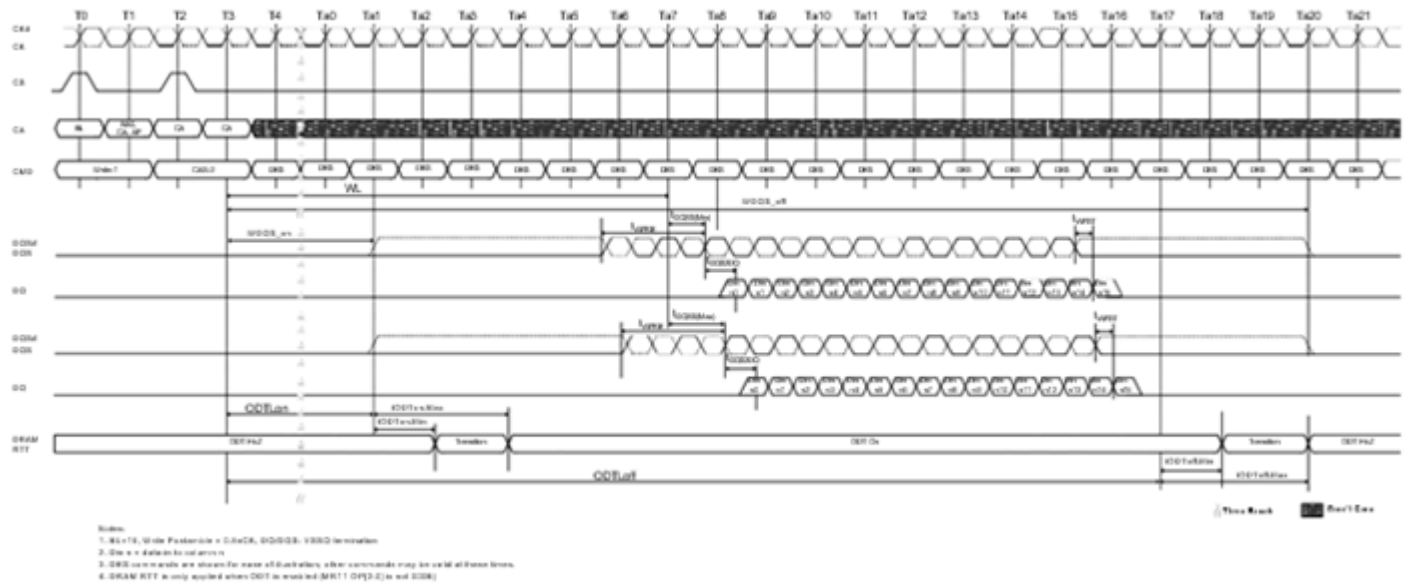


Figure 19. Burst Read followed by Burst Write or Burst Mask Write (ODT Disable)

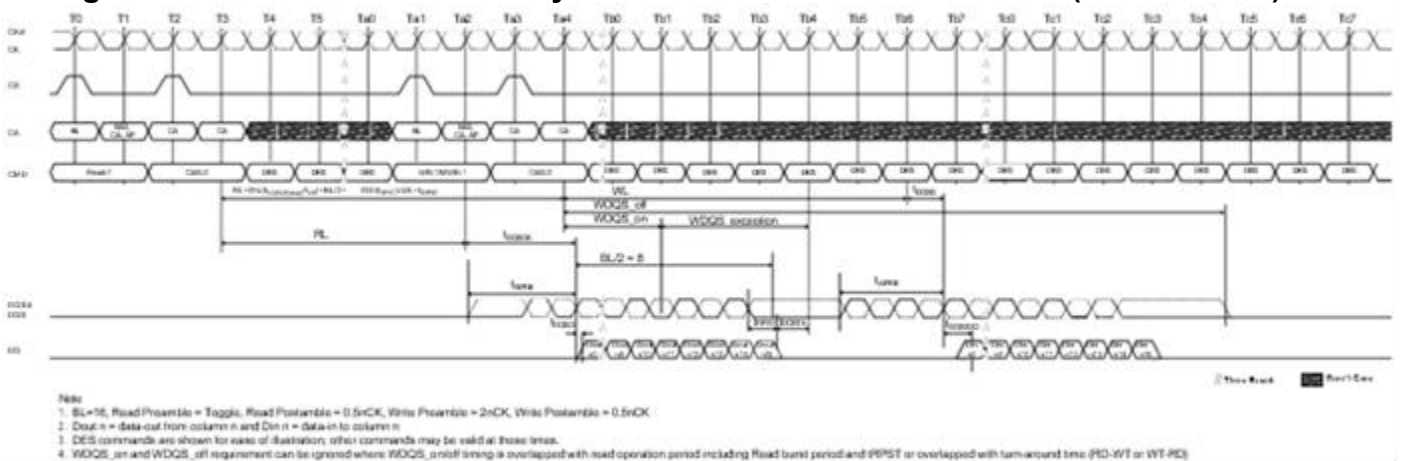
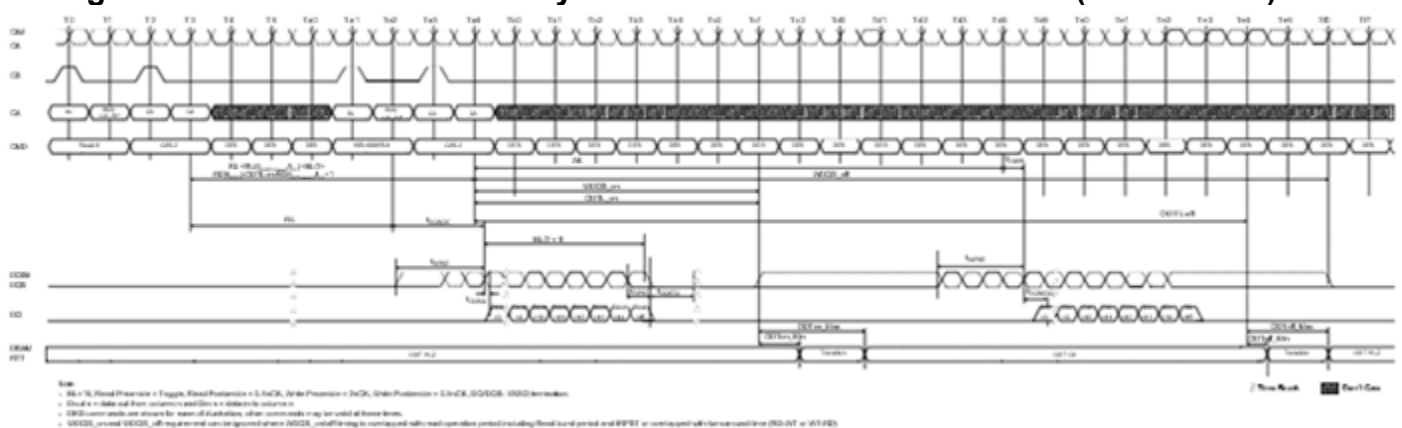


Figure 20. Burst Read followed by Burst Write or Burst Mask Write (ODT Enable)



## Pull Up/Pull Down Driver Characteristics and Calibration

**Table 13. Pull-down Driver Characteristics, with ZQ Calibration**

| RONPD,nom | Resistor | Min | Nom | Max | Unit  |
|-----------|----------|-----|-----|-----|-------|
| 40 Ohm    | RON40PD  | 0.9 | 1   | 1.1 | RZQ/6 |
| 48 Ohm    | RON48PD  | 0.9 | 1   | 1.1 | RZQ/5 |
| 60 Ohm    | RON60PD  | 0.9 | 1   | 1.1 | RZQ/4 |
| 80 Ohm    | RON80PD  | 0.9 | 1   | 1.1 | RZQ/3 |
| 120 Ohm   | RON120PD | 0.9 | 1   | 1.1 | RZQ/2 |
| 240 Ohm   | RON240PD | 0.9 | 1   | 1.1 | RZQ/1 |

**Notes:**

All value are after ZQ Calibration. Without ZQ Calibration RONPD values are  $\pm 30\%$ .

**Table 14. Pull-Up Characteristics, with ZQ Calibration**

| VOHPU,nom | VOH,nom(mV) | Min | Nom | Max | Unit    |
|-----------|-------------|-----|-----|-----|---------|
| VDDQ/2.5  | 440         | 0.9 | 1   | 1.1 | VOH,nom |
| VDDQ/3    | 367         | 0.9 | 1   | 1.1 | VOH,nom |

**Notes:**

1. All values are after ZQ Calibration. Without ZQ Calibration VOH(nom) values are  $\pm 30\%$ .
2. VOH,nom (mV) values are based on a nominal VDDQ = 0.6V.

**Table 15. Valid Calibration Points**

| VOHPU,nom | ODT Value |       |       |       |       |       |
|-----------|-----------|-------|-------|-------|-------|-------|
|           | 240       | 120   | 80    | 60    | 48    | 40    |
| VDDQ/2.5  | VALID     | VALID | VALID | DNU   | DNU   | DNU   |
| VDDQ/3    | VALID     | VALID | VALID | VALID | VALID | VALID |

**Notes:**

1. Once the output is calibrated for a given VOH(nom) calibration point, the ODT value may be changed without recalibration.
2. If the VOH(nom) calibration point is changed, then re-calibration is required.
3. DNU = Do Not Use

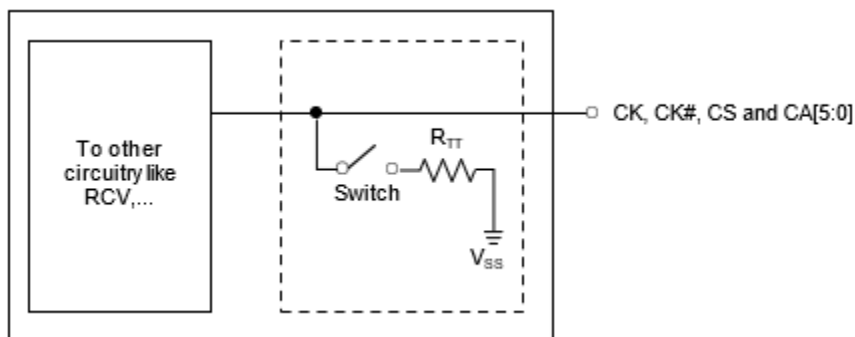
## On Die Termination for Command/Address Bus

ODT (On-Die Termination) is a feature of the LPDDR4 SDRAM that allows the SDRAM to turn on/off termination resistance for CK, CK#, CS and CA[5:0] signals without the ODT control pin.

The ODT feature is designed to improve signal integrity of the memory channel by allowing the DRAM controller to turn on and off termination resistance for any target DRAM devices via Mode Register setting.

A simple functional representation of the DRAM ODT feature is shown below.

**Figure 21. Functional Representation of CA ODT**



## ODT Mode Register and ODT State Table

ODT termination values are set and enabled via MR11. The CA bus (CK, CK#, CS, CA[5:0]) ODT resistance values are set by MR11 OP[6:4]. The default state for the CA is ODT disabled.

ODT is applied on the CA bus to the CK, CK#, CS and CA[5:0] signals. The CA ODT of the device is designed to enable one rank to terminate the entire command bus in a multi-rank system, so only one termination load will be present even if multiple devices are sharing the command signals. For this reason, CA ODT remains on even when the device is in the power-down or Self Refresh power-down states. The die has a bond pad (ODT\_CA) for multi-rank operations. When the ODT\_CA pad is LOW, the die will not terminate the CA bus regardless of the state of the mode register CA ODT bits (MR11 OP[6:4]). If, however, the ODT\_CA bond pad is HIGH, and the mode register CA ODT bits are enabled, the die will terminate the CA bus with the ODT values found in MR11 OP[6:4]. In a multi-rank system, the terminating rank should be trained first, followed by the non-terminating rank(s).

**Table 16. Command Bus ODT State**

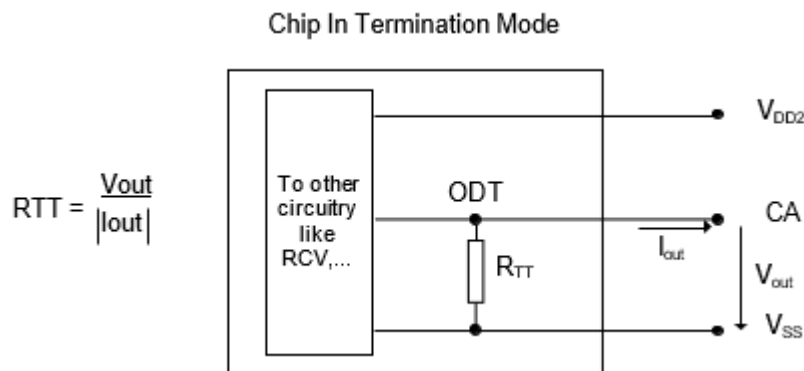
| ODTE-CA<br>MR11[6:4]  | ODT-CA<br>bond pad | ODTD-CA<br>MR22[5] | ODTF-CK<br>MR22[3] | ODTF-CS<br>MR22[4] | ODT State<br>for CA | ODT State<br>for CK/CK# | ODT State<br>for CS |
|-----------------------|--------------------|--------------------|--------------------|--------------------|---------------------|-------------------------|---------------------|
| Disabled <sup>1</sup> | Valid <sup>2</sup> | Valid <sup>3</sup> | Valid <sup>3</sup> | Valid <sup>3</sup> | Off                 | Off                     | Off                 |
| Valid <sup>3</sup>    | 0                  | Valid <sup>3</sup> | 0                  | 0                  | Off                 | Off                     | Off                 |
| Valid <sup>3</sup>    | 0                  | Valid <sup>3</sup> | 0                  | 1                  | Off                 | Off                     | On                  |
| Valid <sup>3</sup>    | 0                  | Valid <sup>3</sup> | 1                  | 0                  | Off                 | On                      | Off                 |
| Valid <sup>3</sup>    | 0                  | Valid <sup>3</sup> | 1                  | 1                  | Off                 | On                      | On                  |
| Valid <sup>3</sup>    | 1                  | 0                  | Valid <sup>3</sup> | Valid <sup>3</sup> | On                  | On                      | On                  |
| Valid <sup>3</sup>    | 1                  | 1                  | Valid <sup>3</sup> | Valid <sup>3</sup> | Off                 | On                      | On                  |

**Notes:**

1. Default Value.
2. "Valid" means "H or L but a defined logic level".
3. "Valid" means "0 or 1".
4. The state of ODT\_CA is not changed when the DRAM enters power-down mode. This maintains termination for alternate ranks in multi-rank systems.

## ODT Mode Register and ODT Characteristics

Figure 22. On Die Termination for CA

**Table 17. ODT DC Electrical Characteristics for Command/Address Bus**

(Assuming RZQ = 240 Ω ±1% over the entire operating temperature range after a proper ZQ calibration up to 3200Mbps)

| (Assuming $V_{DD1} = 1.2V$ , $V_{DD2} = 1.0V$ , $V_{OLdc} = 0.1 \times V_{DD2}$ , $V_{OHdc} = 0.5 \times V_{DD2}$ , $V_{OMdc} = 0.33 \times V_{DD2}$ , $V_{OLdc}$ over the entire operating temperature range and a proper $V_{DD}$ calibration up to 2500ppm) |      |                                  |      |      |                  |       |       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|----------------------------------|------|------|------------------|-------|-------|
| MR11 OP[6:4]                                                                                                                                                                                                                                                   | RTT  | Vout                             | Min. | Nom. | Max.             | Unit  | Note  |
| 001                                                                                                                                                                                                                                                            | 240Ω | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ   | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ   | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.2              | RZQ   | 1,2,3 |
| 010                                                                                                                                                                                                                                                            | 120Ω | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/2 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/2 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.2              | RZQ/2 | 1,2,3 |
| 011                                                                                                                                                                                                                                                            | 80Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/3 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/3 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.2              | RZQ/3 | 1,2,3 |
| 100                                                                                                                                                                                                                                                            | 60Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/4 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/4 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.2              | RZQ/4 | 1,2,3 |
| 101                                                                                                                                                                                                                                                            | 48Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/5 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/5 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.2              | RZQ/5 | 1,2,3 |
| 110                                                                                                                                                                                                                                                            | 40Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/6 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/6 | 1,2,3 |
|                                                                                                                                                                                                                                                                |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.2              | RZQ/6 | 1,2,3 |
| Mismatch CA-CA within clk group                                                                                                                                                                                                                                |      | $0.33 \times V_{DD2}$            | -    | -    | TBD <sup>1</sup> | %     | 1,2,4 |

**Notes:**

1. The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see the section on voltage and temperature sensitivity.
2. Pull-down ODT resistors are recommended to be calibrated at 0.33 x VDDQ. Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at 0.5 x VDDQ and 0.1 x VDDQ.
3. Measurement definition for RTT: TBD.
4. CA to CA mismatch within clock group (CA, CS) variation for a given component including CK and CK# (characterized).

$$CA - CA \text{ mismatch} = \frac{RODT(\text{max}) - RODT(\text{min})}{RODT(\text{avg})}$$

**Table 18. ODT DC Electrical Characteristics for Command/Address Bus**

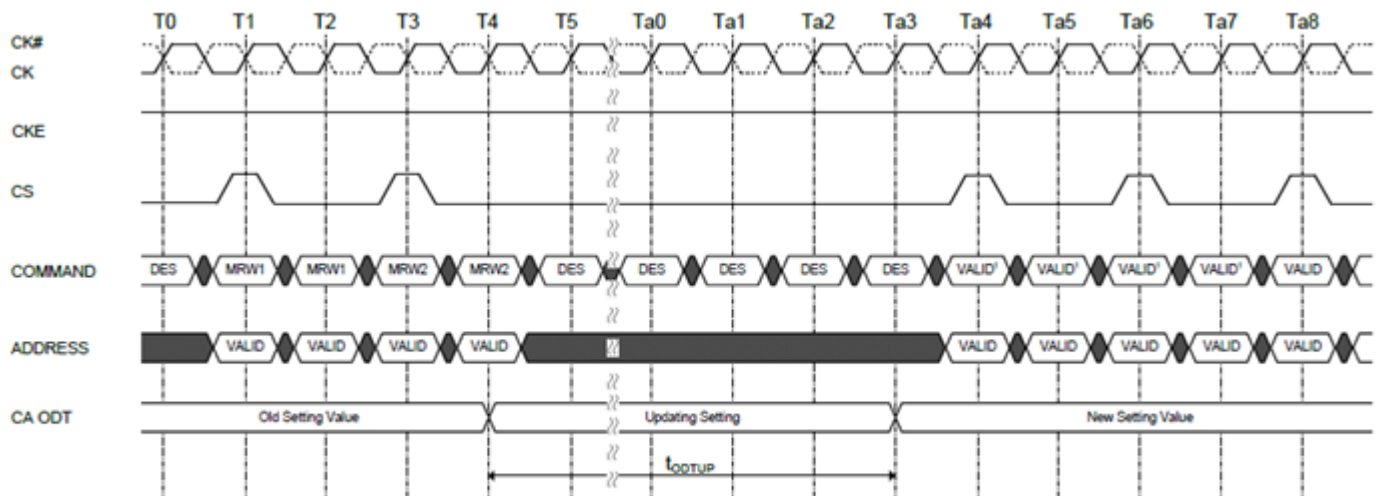
(Assuming RZQ = 240 Ω ±1% over the entire operating temperature range after a proper ZQ calibration for beyond 3200Mbps)

| MR11 OP[6:4]                    | RTT  | Vout                             | Min. | Nom. | Max.             | Unit  | Note  |
|---------------------------------|------|----------------------------------|------|------|------------------|-------|-------|
| 001                             | 240Ω | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ   | 1,2,3 |
|                                 |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ   | 1,2,3 |
|                                 |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.3              | RZQ   | 1,2,3 |
| 010                             | 120Ω | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/2 | 1,2,3 |
|                                 |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/2 | 1,2,3 |
|                                 |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.3              | RZQ/2 | 1,2,3 |
| 011                             | 80Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/3 | 1,2,3 |
|                                 |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/3 | 1,2,3 |
|                                 |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.3              | RZQ/3 | 1,2,3 |
| 100                             | 60Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/4 | 1,2,3 |
|                                 |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/4 | 1,2,3 |
|                                 |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.3              | RZQ/4 | 1,2,3 |
| 101                             | 48Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/5 | 1,2,3 |
|                                 |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/5 | 1,2,3 |
|                                 |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.3              | RZQ/5 | 1,2,3 |
| 110                             | 40Ω  | $V_{OLdc} = 0.1 \times V_{DD2}$  | 0.8  | 1    | 1.1              | RZQ/6 | 1,2,3 |
|                                 |      | $V_{OMdc} = 0.33 \times V_{DD2}$ | 0.9  | 1    | 1.1              | RZQ/6 | 1,2,3 |
|                                 |      | $V_{OHdc} = 0.5 \times V_{DD2}$  | 0.9  | 1    | 1.3              | RZQ/6 | 1,2,3 |
| Mismatch CA-CA within clk group |      | $0.33 \times V_{DD2}$            | -    | -    | TBD <sup>1</sup> | %     | 1,2,4 |

**Notes:**

1. The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see the section on voltage and temperature sensitivity.
2. Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DD2}$ . Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at  $0.5 \times V_{DD2}$  and  $0.1 \times V_{DD2}$ .
3. Measurement definition for RTT: TBD.
4. CA to CA mismatch within clock group (CA, CS) variation for a given component including CK and CK# (characterized).

$$\text{CA - CA mismatch} = \frac{\text{RODT (max)} - \text{RODT (min)}}{\text{RODT (avg)}}$$

**ODT for Command/Address update time****Figure 23. ODT for CA setting update timing in 4 Clock Cycle Command**

Notes:  
1. 4 Clock Cycle Command

Time Break    Don't Care

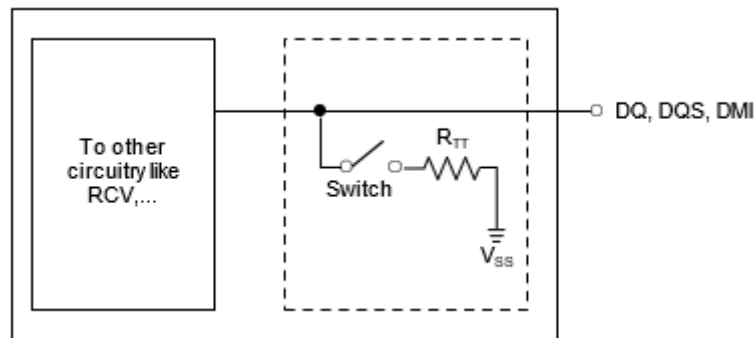
## On-Die Termination (ODT)

ODT (On-Die Termination) is a feature of the LPDDR4 SDRAM that allows the DRAM to turn on/off termination resistance for each DQ, DQS, DQS# and DMI signals without the ODT control pin. The ODT feature is designed to improve signal integrity of the memory channel by allowing the DRAM controller to turn on and off termination resistance for any target DRAM devices during Write or Mask Write operation.

The ODT feature is off and cannot be supported in Power Down and Self Refresh modes.

A simple functional representation of the DRAM ODT feature is shown below.

**Figure 24. Functional representation of ODT**



The switch is enabled by the internal ODT control logic, which uses the Write-1 or Mask Write-1 command and other mode register control information. The value of  $R_{TT}$  is determined by the settings of Mode Register bits.

## ODT Mode Register

The ODT Mode is enabled if MR11 OP[3:0] are non-zero. In this case, the value of  $R_{TT}$  is determined by the settings of those bits. The ODT Mode is disabled if MR11 OP[3] = 0.

## Asynchronous ODT

When ODT Mode is enabled in MR11 OP[3:0], DRAM ODT is always Hi-Z. DRAM ODT feature is automatically turned ON asynchronously based on the Write-1 or Mask Write-1 command that DRAM samples. After the write burst is complete, DRAM ODT featured is automatically turned OFF asynchronously.

Following timing parameters apply when DRAM ODT mode is enabled:

- ODTLon, tODTon,min, tODTon,max
- ODTLoff, tODToff,min, tODToff,max

ODTLon is a synchronous parameter and it is the latency from CAS-2 command to tODTon reference. ODTLon latency is a fixed latency value for each speed bin. Each speed bin has a different ODTLon latency.

Minimum RTT turn-on time (tODTon,min) is the point in time when the device termination circuit leaves high impedance state and ODT resistance begins to turn on.

Maximum RTT turn on time (tODTon,max) is the point in time when the ODT resistance is fully on.

tODTon,min and tODTon,max are measured once ODTLon latency is satisfied from CAS-2 command.

ODTLoff is a synchronous parameter and it is the latency from CAS-2 command to tODToff reference. ODTLoff latency is a fixed latency value for each speed bin. Each speed bin has a different ODTLoff latency.

Minimum RTT turn-off time (tODToff,min) is the point in time when the device termination circuit starts to turn off the ODT resistance.

Maximum ODT turn off time (tODToff,max) is the point in time when the on-die termination has reached high impedance.

tODToff,min and tODToff,max are measured once ODTLoff latency is satisfied from CAS-2 command.

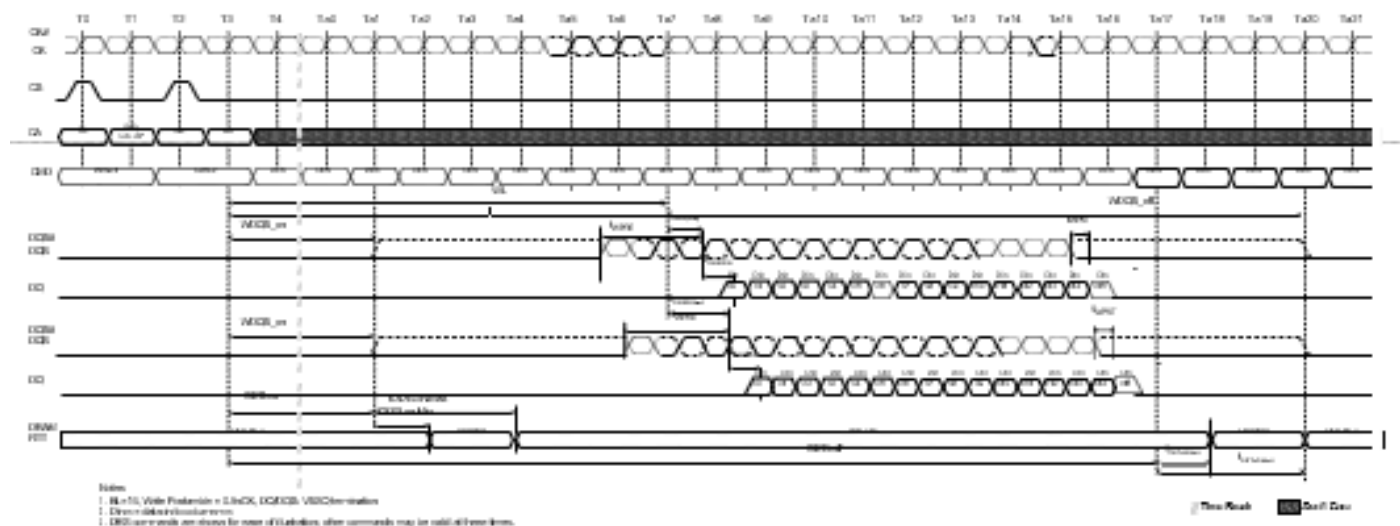
**Table 19. ODTLon and ODTLoff Latency**

| ODTLon Latency <sup>1</sup> |            | ODTLoff Latency <sup>2</sup> |            | Lower Clock Frequency Limit [MHz] (>) | Upper Clock Frequency Limit [MHz] (≤) |
|-----------------------------|------------|------------------------------|------------|---------------------------------------|---------------------------------------|
| tWPRE = 2tCK                |            |                              |            |                                       |                                       |
| WL Set "A"                  | WL Set "B" | WL Set "A"                   | WL Set "B" |                                       |                                       |
| N/A                         | N/A        | N/A                          | N/A        | 50                                    | 266                                   |
| N/A                         | N/A        | N/A                          | N/A        | 266                                   | 533                                   |
| N/A                         | 6          | N/A                          | 22         | 533                                   | 800                                   |
| 4                           | 12         | 20                           | 28         | 800                                   | 1066                                  |
| 4                           | 14         | 22                           | 32         | 1066                                  | 1333                                  |
| 6                           | 18         | 24                           | 36         | 1333                                  | 1600                                  |
| 6                           | 20         | 26                           | 40         | 1600                                  | 1866                                  |
| 8                           | 24         | 28                           | 44         | 1866                                  | 2133                                  |
| nCK                         | nCK        | nCK                          | nCK        | MHz                                   | MHz                                   |

**Notes:**

1. ODTLon is referenced from CAS-2 command.
2. ODTLoff as shown in table assumes BL=16. For BL32, 8 tCK should be added.

### Figure 25. Asynchronous ODTon/ODToff Timing



## ODT during Write Leveling

If ODT is enabled in MR11 OP[3:0], in Write Leveling mode, DRAM always provides the termination on DQS/DQS# signals. DQ termination is always off in Write Leveling mode regardless.

### Table 20. Termination Function in Write Leveling Mode

| ODT Enabled in MR11 | DQS/DQS# termination | DQ termination |
|---------------------|----------------------|----------------|
| Disabled            | OFF                  | OFF            |
| Enabled             | ON                   | OFF            |

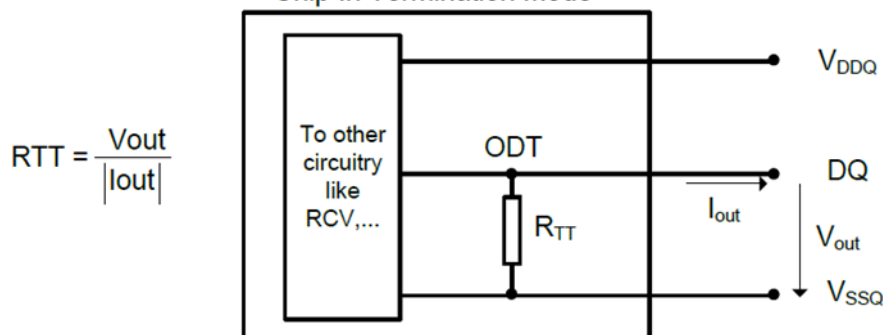
## On Die Termination for DQ, DQS and DMI

On-Die Termination effective resistance  $R_{TT}$  is defined by MR11 OP[2:0].

ODT is applied to the DQ, DMI, DQS and DQS# pins.

A functional representation of the on-die termination is shown below.

### Figure 26. On Die Termination



**Table 21. ODT DC Electrical Characteristics for DQ, DQS and DMI**

(Assuming RZQ = 240 Ω ±1% over the entire operating temperature range after a proper ZQ calibration up to 3200Mbps)

| MR11 OP[2:0]               | RTT  | Vout                             | Min. | Nom. | Max. | Unit  | Note  |
|----------------------------|------|----------------------------------|------|------|------|-------|-------|
| 001                        | 240Ω | $V_{OLdc} = 0.1 \times V_{DDQ}$  | 0.8  | 1    | 1.1  | RZQ   | 1,2,3 |
|                            |      | $V_{OMdc} = 0.33 \times V_{DDQ}$ | 0.9  | 1    | 1.1  | RZQ   | 1,2,3 |
|                            |      | $V_{OHdc} = 0.5 \times V_{DDQ}$  | 0.9  | 1    | 1.2  | RZQ   | 1,2,3 |
| 010                        | 120Ω | $V_{OLdc} = 0.1 \times V_{DDQ}$  | 0.8  | 1    | 1.1  | RZQ/2 | 1,2,3 |
|                            |      | $V_{OMdc} = 0.33 \times V_{DDQ}$ | 0.9  | 1    | 1.1  | RZQ/2 | 1,2,3 |
|                            |      | $V_{OHdc} = 0.5 \times V_{DDQ}$  | 0.9  | 1    | 1.2  | RZQ/2 | 1,2,3 |
| 011                        | 80Ω  | $V_{OLdc} = 0.1 \times V_{DDQ}$  | 0.8  | 1    | 1.1  | RZQ/3 | 1,2,3 |
|                            |      | $V_{OMdc} = 0.33 \times V_{DDQ}$ | 0.9  | 1    | 1.1  | RZQ/3 | 1,2,3 |
|                            |      | $V_{OHdc} = 0.5 \times V_{DDQ}$  | 0.9  | 1    | 1.2  | RZQ/3 | 1,2,3 |
| 100                        | 60Ω  | $V_{OLdc} = 0.1 \times V_{DDQ}$  | 0.8  | 1    | 1.1  | RZQ/4 | 1,2,3 |
|                            |      | $V_{OMdc} = 0.33 \times V_{DDQ}$ | 0.9  | 1    | 1.1  | RZQ/4 | 1,2,3 |
|                            |      | $V_{OHdc} = 0.5 \times V_{DDQ}$  | 0.9  | 1    | 1.2  | RZQ/4 | 1,2,3 |
| 101                        | 48Ω  | $V_{OLdc} = 0.1 \times V_{DDQ}$  | 0.8  | 1    | 1.1  | RZQ/5 | 1,2,3 |
|                            |      | $V_{OMdc} = 0.33 \times V_{DDQ}$ | 0.9  | 1    | 1.1  | RZQ/5 | 1,2,3 |
|                            |      | $V_{OHdc} = 0.5 \times V_{DDQ}$  | 0.9  | 1    | 1.2  | RZQ/5 | 1,2,3 |
| 110                        | 40Ω  | $V_{OLdc} = 0.1 \times V_{DDQ}$  | 0.8  | 1    | 1.1  | RZQ/6 | 1,2,3 |
|                            |      | $V_{OMdc} = 0.33 \times V_{DDQ}$ | 0.9  | 1    | 1.1  | RZQ/6 | 1,2,3 |
|                            |      | $V_{OHdc} = 0.5 \times V_{DDQ}$  | 0.9  | 1    | 1.2  | RZQ/6 | 1,2,3 |
| Mismatch DQ-DQ within byte |      | $0.33 \times V_{DDQ}$            | -    | -    | 2    | %     | 1,2,4 |

**Notes:**

1. The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see the section on voltage and temperature sensitivity.
2. Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DDQ}$ . Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at  $0.5 \times V_{DDQ}$  and  $0.1 \times V_{DDQ}$ .
3. Measurement definition for RTT: TBD.
4. DQ to DQ mismatch within byte variation for a given component including DQS and DQS# (characterized).

$$\text{DQ - DQ mismatch} = \frac{\text{RODT (max)} - \text{RODT (min)}}{\text{RODT (avg)}}$$

**Table 22. ODT DC Electrical Characteristics for DQ, DQS and DMI**

(Assuming RZQ = 240 Ω ±1% over the entire operating temperature range after a proper ZQ calibration for beyond 3200Mbps)

| MR11 OP[2:0]               | RTT  | Vout                                        | Min. | Nom. | Max. | Unit  | Note  |
|----------------------------|------|---------------------------------------------|------|------|------|-------|-------|
| 001                        | 240Ω | V <sub>OL</sub> dc= 0.1 x V <sub>DDQ</sub>  | 0.8  | 1    | 1.1  | RZQ   | 1,2,3 |
|                            |      | V <sub>OM</sub> dc= 0.33 x V <sub>DDQ</sub> | 0.9  | 1    | 1.1  | RZQ   | 1,2,3 |
|                            |      | V <sub>OH</sub> dc= 0.5 x V <sub>DDQ</sub>  | 0.9  | 1    | 1.3  | RZQ   | 1,2,3 |
| 010                        | 120Ω | V <sub>OL</sub> dc= 0.1 x V <sub>DDQ</sub>  | 0.8  | 1    | 1.1  | RZQ/2 | 1,2,3 |
|                            |      | V <sub>OM</sub> dc= 0.33 x V <sub>DDQ</sub> | 0.9  | 1    | 1.1  | RZQ/2 | 1,2,3 |
|                            |      | V <sub>OH</sub> dc= 0.5 x V <sub>DDQ</sub>  | 0.9  | 1    | 1.3  | RZQ/2 | 1,2,3 |
| 011                        | 80Ω  | V <sub>OL</sub> dc= 0.1 x V <sub>DDQ</sub>  | 0.8  | 1    | 1.1  | RZQ/3 | 1,2,3 |
|                            |      | V <sub>OM</sub> dc= 0.33 x V <sub>DDQ</sub> | 0.9  | 1    | 1.1  | RZQ/3 | 1,2,3 |
|                            |      | V <sub>OH</sub> dc= 0.5 x V <sub>DDQ</sub>  | 0.9  | 1    | 1.3  | RZQ/3 | 1,2,3 |
| 100                        | 60Ω  | V <sub>OL</sub> dc= 0.1 x V <sub>DDQ</sub>  | 0.8  | 1    | 1.1  | RZQ/4 | 1,2,3 |
|                            |      | V <sub>OM</sub> dc= 0.33 x V <sub>DDQ</sub> | 0.9  | 1    | 1.1  | RZQ/4 | 1,2,3 |
|                            |      | V <sub>OH</sub> dc= 0.5 x V <sub>DDQ</sub>  | 0.9  | 1    | 1.3  | RZQ/4 | 1,2,3 |
| 101                        | 48Ω  | V <sub>OL</sub> dc= 0.1 x V <sub>DDQ</sub>  | 0.8  | 1    | 1.1  | RZQ/5 | 1,2,3 |
|                            |      | V <sub>OM</sub> dc= 0.33 x V <sub>DDQ</sub> | 0.9  | 1    | 1.1  | RZQ/5 | 1,2,3 |
|                            |      | V <sub>OH</sub> dc= 0.5 x V <sub>DDQ</sub>  | 0.9  | 1    | 1.3  | RZQ/5 | 1,2,3 |
| 110                        | 40Ω  | V <sub>OL</sub> dc= 0.1 x V <sub>DDQ</sub>  | 0.8  | 1    | 1.1  | RZQ/6 | 1,2,3 |
|                            |      | V <sub>OM</sub> dc= 0.33 x V <sub>DDQ</sub> | 0.9  | 1    | 1.1  | RZQ/6 | 1,2,3 |
|                            |      | V <sub>OH</sub> dc= 0.5 x V <sub>DDQ</sub>  | 0.9  | 1    | 1.3  | RZQ/6 | 1,2,3 |
| Mismatch DQ-DQ within byte |      | 0.33 x V <sub>DDQ</sub>                     | -    | -    | 2    | %     | 1,2,4 |

**Notes:**

1. The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see the section on voltage and temperature sensitivity.
2. Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DDQ}$ . Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at  $0.5 \times V_{DDQ}$  and  $0.1 \times V_{DDQ}$ .
3. Measurement definition for RTT: TBD.
4. DQ to DQ mismatch within byte variation for a given component including DQS and DQS# (characterized).

$$\text{DQ - DQ mismatch} = \frac{\text{RODT (max)} - \text{RODT (min)}}{\text{RODT (avg)}}$$

**Output Driver and Termination Register Temperature and Voltage Sensitivity**

If temperature and/or voltage change after calibration, the tolerance limits are widen according to the tables below.

**Table 23. Output Driver and Termination Register Sensitivity Definition**

| Resistor | Definition Point      | Min                                                        | Max                                                         | Unit | Note  |
|----------|-----------------------|------------------------------------------------------------|-------------------------------------------------------------|------|-------|
| RONPD    | $0.33 \times V_{DDQ}$ | $90 - dRondT \times  \Delta T  - dRondV \times  \Delta V $ | $110 + dRondT \times  \Delta T  + dRondV \times  \Delta V $ | %    | 1,2   |
| VOHPU    | $0.33 \times V_{DDQ}$ | $90 - dVOHdT \times  \Delta T  - dVOHdV \times  \Delta V $ | $110 + dVOHdT \times  \Delta T  + dVOHdV \times  \Delta V $ | %    | 1,2,5 |
| RTT(I/O) | $0.33 \times V_{DDQ}$ | $90 - dRondT \times  \Delta T  - dRondV \times  \Delta V $ | $110 + dRondT \times  \Delta T  + dRondV \times  \Delta V $ | %    | 1,2,3 |
| RTT(In)  | $0.33 \times V_{DD2}$ | $90 - dRondT \times  \Delta T  - dRondV \times  \Delta V $ | $110 + dRondT \times  \Delta T  + dRondV \times  \Delta V $ | %    | 1,2,4 |

**Notes:**

1.  $\Delta T = T - T$  (@ Calibration),  $\Delta V = V - V$  (@ Calibration)
2. dRONdT, dRONdV, dVOHdT, dVOHdV, dRTTdV, and dRTTdT are not subject to production test but are verified by design and characterization.
3. This parameter applies to Input/Output pin such as DQS, DQ and DMI.
4. This parameter applies to input pins such as CK, CA, and CS.
5. Refer to Pull Up/Pull Down Driver Characteristics for VOHPU.

**Table 24. Output Driver and Termination Register Temperature and Voltage Sensitivity**

| Symbol | Parameter                   | Min | Max  | Unit |
|--------|-----------------------------|-----|------|------|
| dRONdT | RON Temperature Sensitivity | 0   | 0.75 | %/°C |
| dRONdV | RON Voltage Sensitivity     | 0   | 0.2  | %/mV |
| dVOHdT | VOH Temperature Sensitivity | 0   | 0.75 | %/°C |
| dVOHdV | VOH Voltage Sensitivity     | 0   | 0.35 | %/mV |
| dRTTdT | RTT Temperature Sensitivity | 0   | 0.75 | %/°C |
| dRTTdV | RTT Voltage Sensitivity     | 0   | 0.2  | %/mV |

## Multi-Purpose Command (MPC)

The device uses the MPC command to issue a NOP and to access various training modes. The MPC command is initiated with CS, and CA[5:0] asserted to the proper state at the rising edge of CK, as defined by the Command Truth Table. The MPC command has seven operands (OP[6:0]) that are decoded to execute specific commands in the device. OP[6] is a special bit that is decoded on the first rising CK edge of the MPC command. When OP[6]=0 then the SDRAM executes a NOP (no operation) command, and when OP[6]=1 then the device further decodes one of several training commands.

When OP[6]=1 and when the training command includes a Read or Write operation, the MPC command must be followed immediately by a CAS-2 command. For training commands that Read or Write the SDRAM, read latency (RL) and write latency (WL) are counted from the second rising CK edge of the CAS-2 command with the same timing relationship as any normal Read or Write command. The operands of the CAS-2 command following a MPC Read/Write command must be driven LOW.

The following MPC commands must be followed by a CAS-2 command:

- Write FIFO
- Read FIFO
- Read DQ Calibration

All other MPC-1 commands do not require a CAS-2 command, including:

- NOP
- Start DQS Interval Oscillator
- Stop DQS Interval Oscillator
- Start ZQ Calibration
- Latch ZQ Calibration

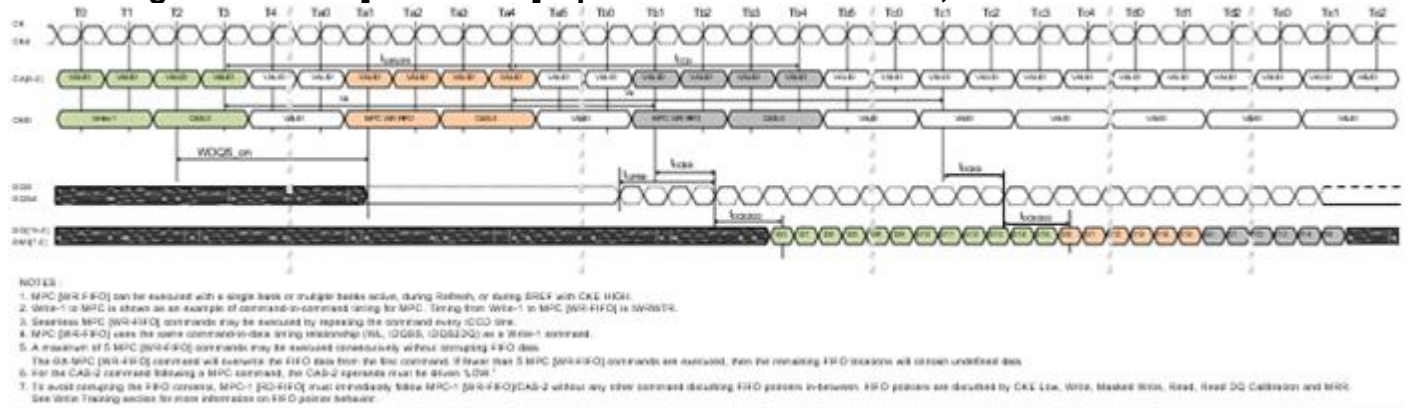
**Table 25. MPC Command Definition**

|                     | Command Pins |         | CA Pins                                                                                                                                                                                                                                                                                                                                         |     |     |     |     |     |     | CK Edge | Note |
|---------------------|--------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|---------|------|
| Command             | CKE          |         | CS                                                                                                                                                                                                                                                                                                                                              | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |         |      |
|                     | CK(n-1)      | CK(n)   |                                                                                                                                                                                                                                                                                                                                                 |     |     |     |     |     |     |         |      |
| MPC<br>(Train, NOP) | H            | H       | H                                                                                                                                                                                                                                                                                                                                               | L   | L   | L   | L   | L   | OP6 | R1      | 1,2  |
|                     |              |         | L                                                                                                                                                                                                                                                                                                                                               | OP0 | OP1 | OP2 | OP3 | OP4 | OP5 | R2      |      |
| Function            |              | Operand | Data                                                                                                                                                                                                                                                                                                                                            |     |     |     |     |     |     | Note    |      |
| Training Modes      |              | OP[6:0] | 0XXXXXXB: NOP<br>1000001B: RD FIFO: RD FIFO supports only BL16 operation<br>1000011B: RD DQ Calibration (MR32/MR40)<br>1000101B: RFU<br>1000111B: WR FIFO: WR FIFO supports only BL16 operation<br>1001001B: RFU<br>1001011B: Start DQS Osc<br>1001101B: Stop DQS Osc<br>1001111B: ZQCal Start<br>1010001B: ZQCal Latch<br>All Others: Reserved |     |     |     |     |     |     | 1,2,3   |      |

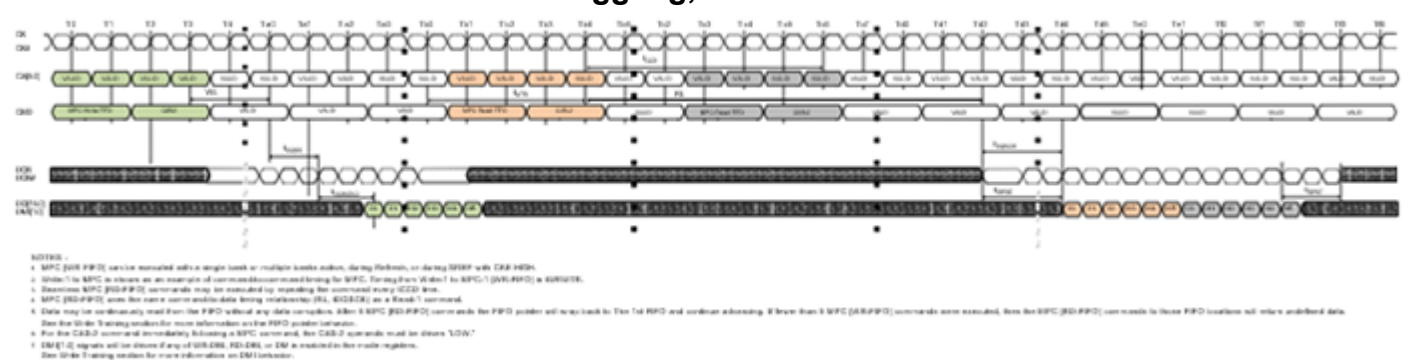
**Notes:**

1. See command truth table for more information.
2. MPC commands for Read or Write training operations must be immediately followed by CAS-2 command consecutively without any other commands in-between. MPC command must be issued first before issuing the CAS-2 command.
3. Write FIFO and Read FIFO commands will only operate as BL16, ignoring the burst length selected by MR1 OP[1:0].

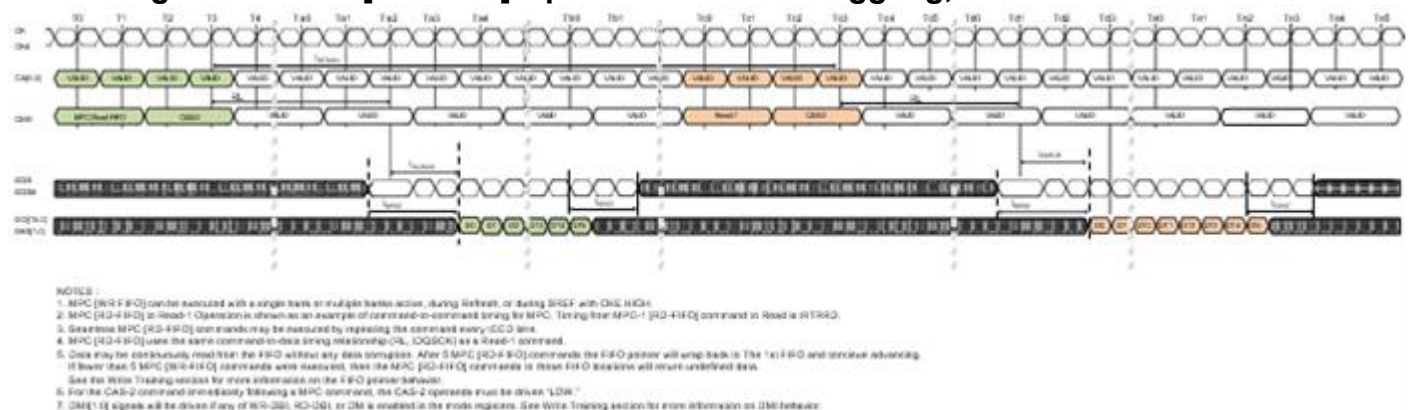
**Figure 27. MPC [Write FIFO] Operation :  $t_{WPRE}=2nCK$ ,  $t_{WPST}=0.5nCK$**



**Figure 28. MPC [RD FIFO] Read Operation:  $t_{WPRE}=2nCK$ ,  $t_{WPST}=0.5nCK$ ,  $t_{RPRE}=toggling$ ,  $t_{RPST}=1.5nCK$**



**Figure 29. MPC [RD FIFO] Operation : tRPRE=toggling, tRPST=1.5nCK**



**Table 26. Timing Constraints for Training Commands**

| Previous Command           | Next Command               | Minimum Delay                            | Unit | Note |
|----------------------------|----------------------------|------------------------------------------|------|------|
| WR/MWR                     | MPC<br>[WR FIFO]           | tWRWTR                                   | nCK  | 1    |
|                            | MPC<br>[RD FIFO]           | Not Allowed                              | -    | 2    |
|                            | MPC<br>[RD DQ Calibration] | WL+RU(tDQSS(max)/tCK) +BL/2+RU(tWTR/tCK) | nCK  |      |
| RD/MRR                     | MPC<br>[WR FIFO]           | tRTRRD                                   | nCK  | 3    |
|                            | MPC<br>[RD FIFO]           | Not Allowed                              | -    | 2    |
|                            | MPC<br>[RD DQ Calibration] | tRTRRD                                   | nCK  | 3    |
| MPC<br>[WR FIFO]           | WR/MWR                     | Not Allowed                              | -    | 2    |
|                            | MPC<br>[WR FIFO]           | tCCD                                     | nCK  |      |
|                            | RD/MRR                     | Not Allowed                              | -    | 2    |
|                            | MPC<br>[RD FIFO]           | WL+RU(tDQSS(max)/tCK) +BL/2+RU(tWTR/tCK) | nCK  |      |
|                            | MPC<br>[RD DQ Calibration] | Not Allowed                              | -    | 2    |
| MPC<br>[RD FIFO]           | WR/MWR                     | tRTRRD                                   | nCK  | 3    |
|                            | MPC<br>[WR FIFO]           | tRTW                                     | -    | 4    |
|                            | RD/MRR                     | tRTRRD                                   | nCK  | 3    |
|                            | MPC<br>[RD FIFO]           | tCCD                                     | nCK  |      |
|                            | MPC<br>[RD DQ Calibration] | tRTRRD                                   | nCK  | 3    |
| MPC<br>[RD DQ Calibration] | WR/MWR                     | tRTRRD                                   | nCK  | 3    |
|                            | MPC<br>[WR FIFO]           | tRTRRD                                   | nCK  | 3    |
|                            | RD/MRR                     | tRTRRD                                   | nCK  | 3    |
|                            | MPC<br>[RD FIFO]           | Not Allowed                              | -    | 2    |
|                            | MPC<br>[RD DQ Calibration] | tCCD                                     | nCK  |      |

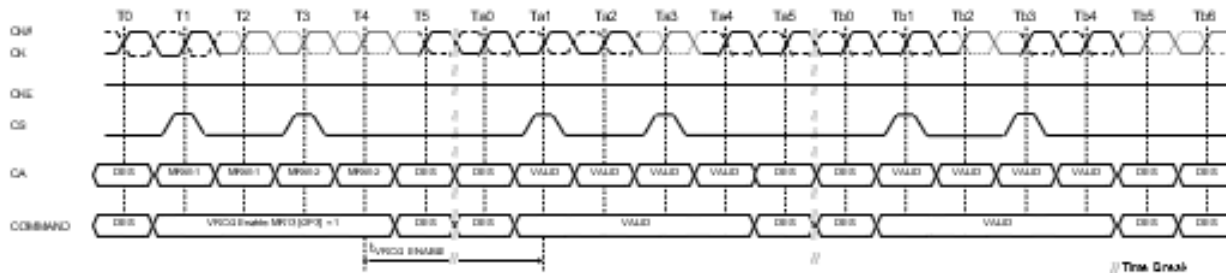
**Notes:**

1.  $tWRWTR = WL + BL/2 + RU(tDQSS(max)/tCK) + \max(RU(7.5ns/tCK), 8nCK)$
2. No commands are allowed between MPC [WR FIFO] and MPC-1 [RD FIFO] except MRW commands related to training parameters.
3.  $tRTRRD = RL + RU(tDQSS(max)/tCK) + BL/2 + RD(tRPST) + \max(RU(7.5ns/tCK), 8nCK)$
4. tRTW:
  - In Case of DQ ODT Disable MR11 OP[2:0] = 000B:  
 $RL + RU(tDQSS(max)/tCK) + BL/2 - WL + tWPRE + RD(tRPST)$
  - In Case of DQ ODT Enable MR11 OP[2:0] ≠ 000B:  
 $RL + RU(tDQSS(max)/tCK) + BL/2 + RD(tRPST) - ODTLon - RD(tODTon, min/tCK) + 1$

## VREF Current Generator (VRCG)

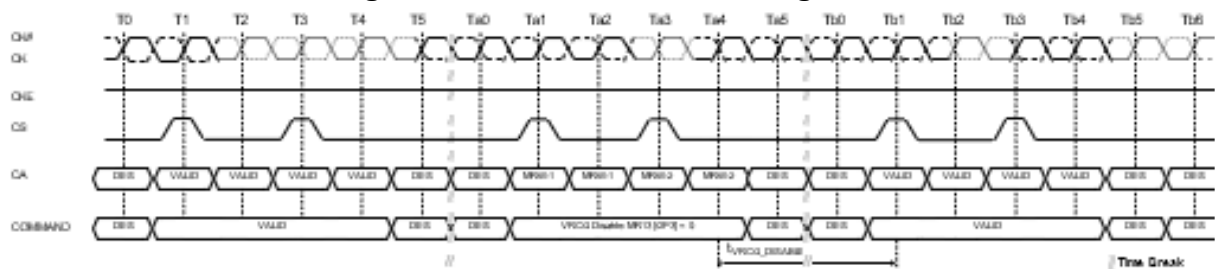
LPDDR4 SDRAM VREF current generators (VRCG) incorporate a high current mode to reduce the settling time of the internal VREF(DQ) and VREF(CA) levels during training and when changing frequency set points during operation. The high current mode is enabled by setting MR13[OP3] = 1. Only Deselect commands may be issued until tVRCG\_ENABLE is satisfied. tVRCG\_ENABLE timing is shown below.

**Figure 30. VRCG Enable timing**



VRCG high current mode is disabled by setting MR13[OP3] = 0. Only Deselect commands may be issued until tVRCG\_DISABLE is satisfied. tVRCG\_DISABLE timing is shown below.

**Figure 31. VRCG Disable timing**



Note that LPDDR4 SDRAM devices support VREF(CA) and VREF(DQ) range and value changes without enabling VRCG high current mode.

**Table 27. VRCG Enable/Disable Timing**

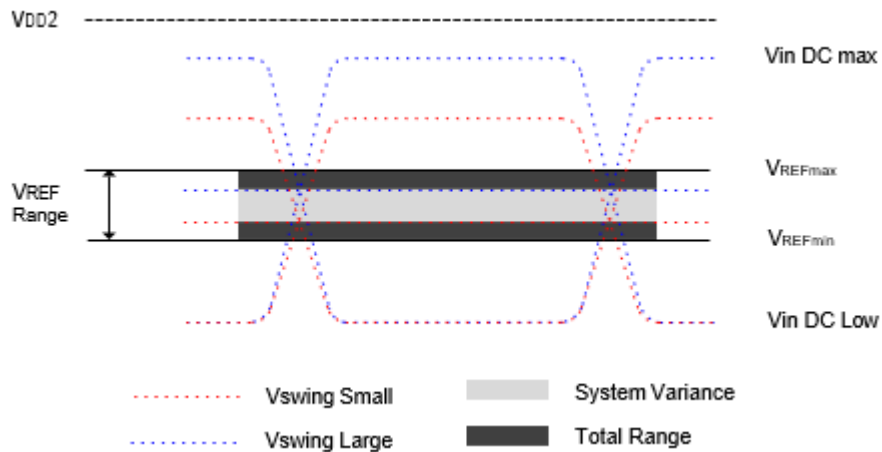
| Symbol        | Parameter                           | Min | Max | Unit |
|---------------|-------------------------------------|-----|-----|------|
| tVRCG_ENABLE  | VREF high current mode enable time  | -   | 200 | ns   |
| tVRCG_DISABLE | VREF high current mode disable time | -   | 100 | ns   |

## CA VREF Training

The DRAM internal CA VREF specification parameters are voltage operating range, step size, VREF set tolerance, VREF step time and VREF valid level.

The voltage operating range specifies the minimum required VREF setting range for LPDDR4 DRAM devices. The minimum range is defined by VREFmax and VREFmin.

**Figure 32. VREF operating range (VREFmin, VREFmax)**

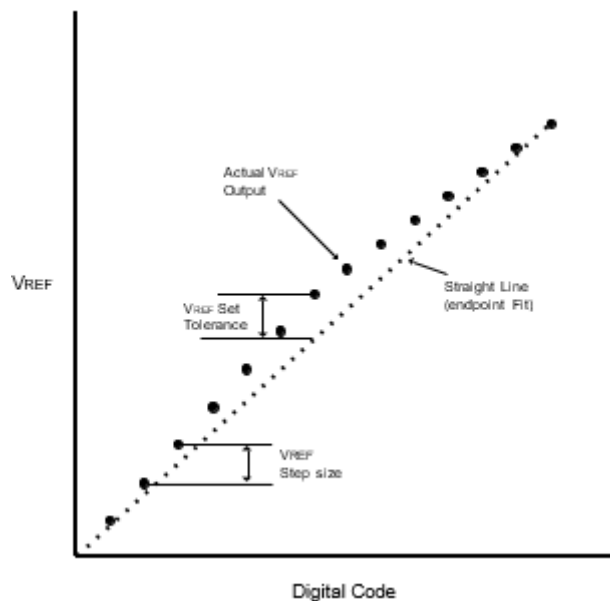


The VREF step size is defined as the step size between adjacent steps. However, for a given design, the device has one value for VREF step size that falls within the range.

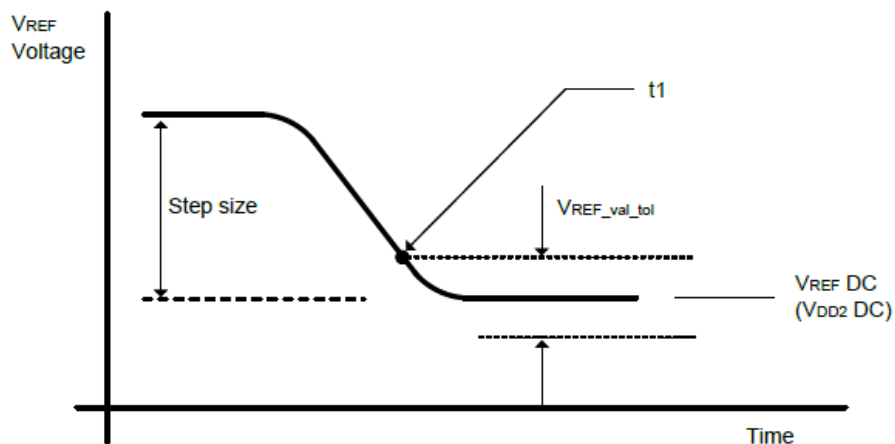
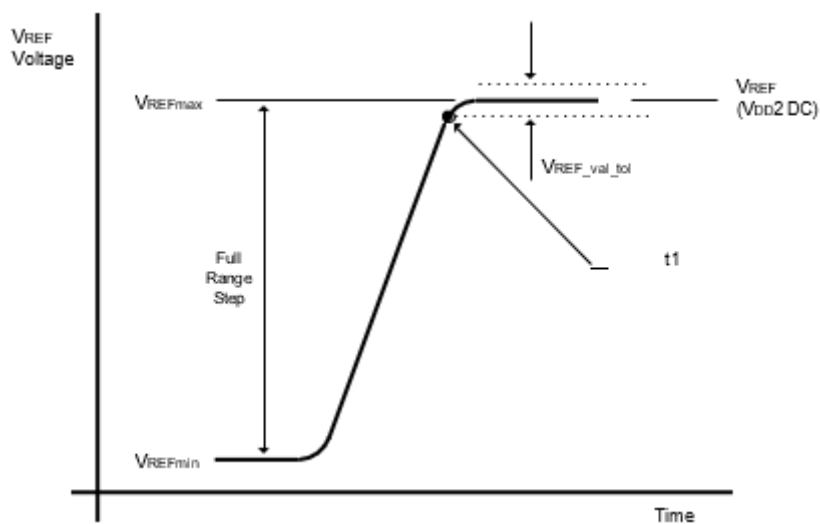
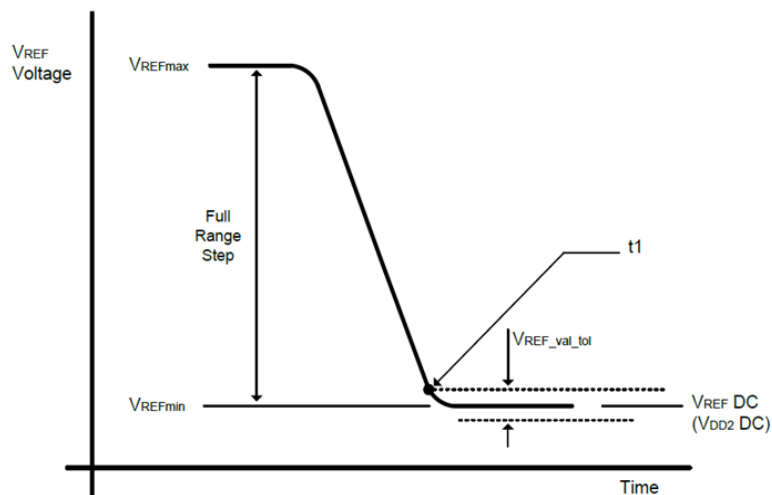
The VREF set tolerance is the variation in the VREF voltage from the ideal setting. This accounts for accumulated error over multiple steps. There are two ranges for VREF set tolerance uncertainty. The range of VREF set tolerance uncertainty is a function of number of steps  $n$ .

The VREF set tolerance is measured with respect to the ideal line which is based on the two endpoints. Where the endpoints are at the min and max VREF values for a specified range.

**Figure 33. Example of VREF set tolerance (max case only shown) and step size**





**Figure 36. VREF step single step size decrement case****Figure 37. VREF full step from VREFmin to VREFmax case****Figure 38. VREF full step from VREFmax to VREFmin case**

The following table contains the CA internal VREF specification that will be characterized at the component level for compliance.

**Table 28. CA Internal VREF Specifications**

| Symbol           | Parameter                       | Min   | Typ  | Max  | Unit | Note  |
|------------------|---------------------------------|-------|------|------|------|-------|
| VREF_max_R0      | VREF Max operating point Range0 | -     | -    | 30%  | VDD2 | 1,11  |
| VREF_min_R0      | VREF Min operating point Range0 | 10%   | -    | -    | VDD2 | 1,11  |
| VREF_max_R1      | VREF Max operating point Range1 | -     | -    | 42%  | VDD2 | 1,11  |
| VREF_min_R1      | VREF Min operating point Range1 | 22%   | -    | -    | VDD2 | 1,11  |
| VREF_step        | VREF Step size                  | 0.3%  | 0.4% | 0.5% | VDD2 | 2     |
| VREF_set_tol     | VREF Set Tolerance              | -1%   | 0%   | 1%   | VDD2 | 3,4,6 |
|                  |                                 | -0.1% | 0%   | 0.1% | VDD2 | 3,5,7 |
| VREF_time_Short  | VREF Step Time                  | -     | -    | 100  | ns   | 8     |
| VREF_time_Middle |                                 | -     | -    | 200  | ns   | 12    |
| VREF_time_Long   |                                 | -     | -    | 250  | ns   | 9     |
| VREF_time_weak   |                                 | -     | -    | 1    | ms   | 13,14 |
| VREF_val_tol     | VREF Valid tolerance            | -0.1% | 0%   | 0.1% | VDD2 | 10    |

**Notes:**

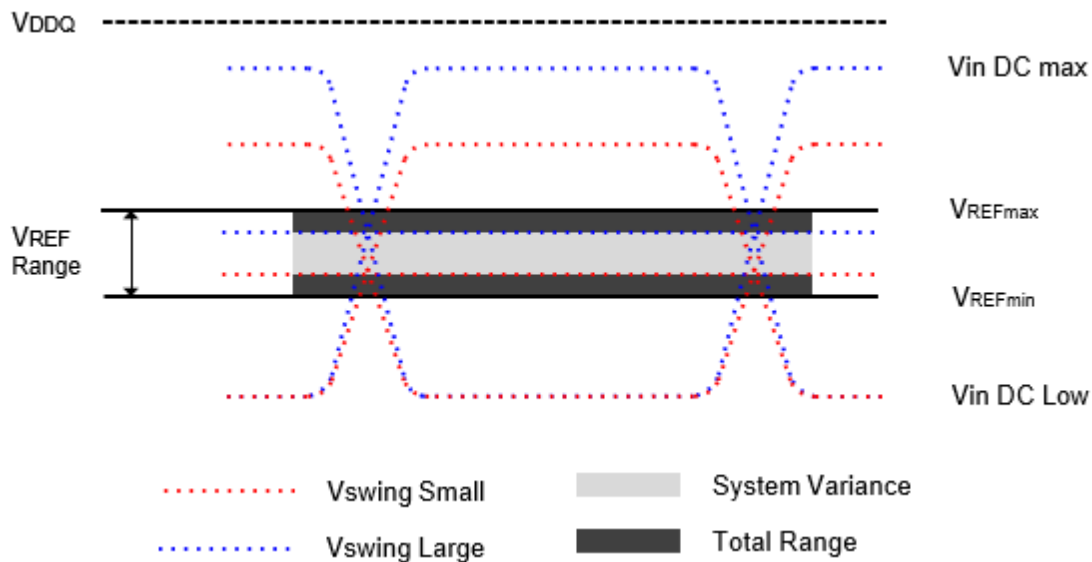
1. VREF DC voltage referenced to VDD2\_DC.
2. VREF stepsize increment/decrement range. VREF at DC level.
3.  $VREF\_new = VREF\_old + n \times VREF\_step$ ; n= number of steps; if increment use "+"; if decrement use "-".
4. The minimum value of VREF setting tolerance =  $VREF\_new - 1.0\% \times VDD2$ . The maximum value of VREF setting tolerance =  $VREF\_new + 1.0\% \times VDD2$ . For  $n > 4$ .
5. The minimum value of VREF setting tolerance =  $VREF\_new - 0.1\% \times VDD2$ . The maximum value of VREF setting tolerance =  $VREF\_new + 0.1\% \times VDD2$ . For  $n \leq 4$ .
6. Measured by recording the min and max values of the VREF output over the range, drawing a straight line between those points and comparing all other VREF output settings to that line.
7. Measured by recording the min and max values of the VREF output across 4 consecutive steps( $n=4$ ), drawing a straight line between those points and comparing all other VREF output settings to that line.
8. Time from MRS command to increment or decrement one step size for VREF.
9. Time from MRS command to increment or decrement VREFmin to VREFmax or VREFmax to VREFmin change across the VREFCA Range in VREF voltage.
10. Only applicable for DRAM component level test/characterization purpose. Not applicable for normal mode of operation. VREF valid is to qualify the step times which will be characterized at the component level.
11. DRAM range 0 or 1 set by MR12 OP[6].
12. Time from MRS command to increment or decrement more than one step size up to a full range of VREF voltage within the same VREFCA range.
13. Applies when VRCG high current mode is not enabled, specified by MR13[OP3] = 0.
14. VREF\_time\_weak covers all VREF(CA) Range and Value change conditions are applied to VREF\_time\_Short/Middle/Long.

## DQ VREF Training

The DRAM internal DQ VREF specification parameters are voltage operating range, step size, VREF set tolerance, VREF step time and VREFvalid level.

The voltage operating range specifies the minimum required VREF setting range for LPDDR4 DRAM devices. The minimum range is defined by VREFmax and VREFmin.

**Figure 39. VREF operating range (VREFmin, VREFmax)**

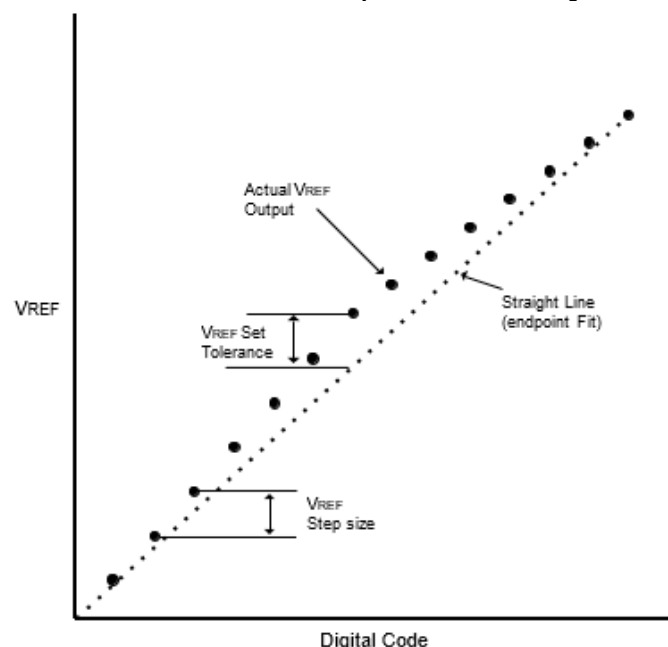


The VREF step size is defined as the step size between adjacent steps. However, for a given design, the device has one value for VREF step size that falls within the range.

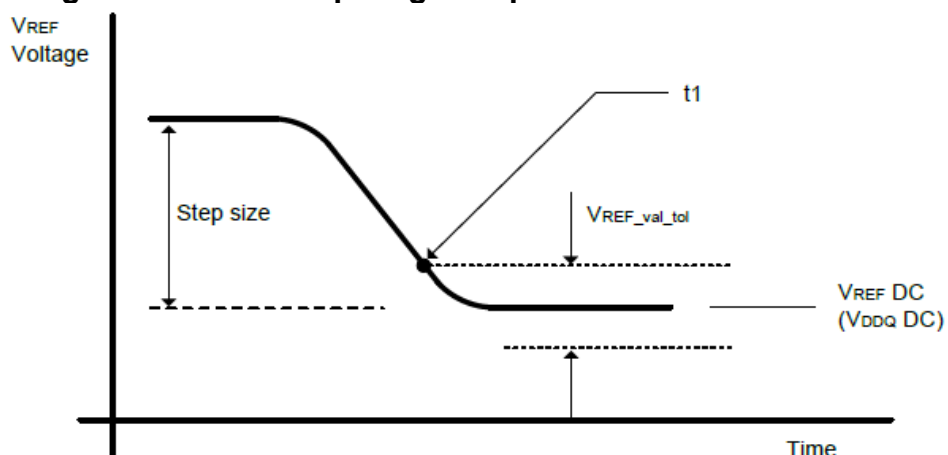
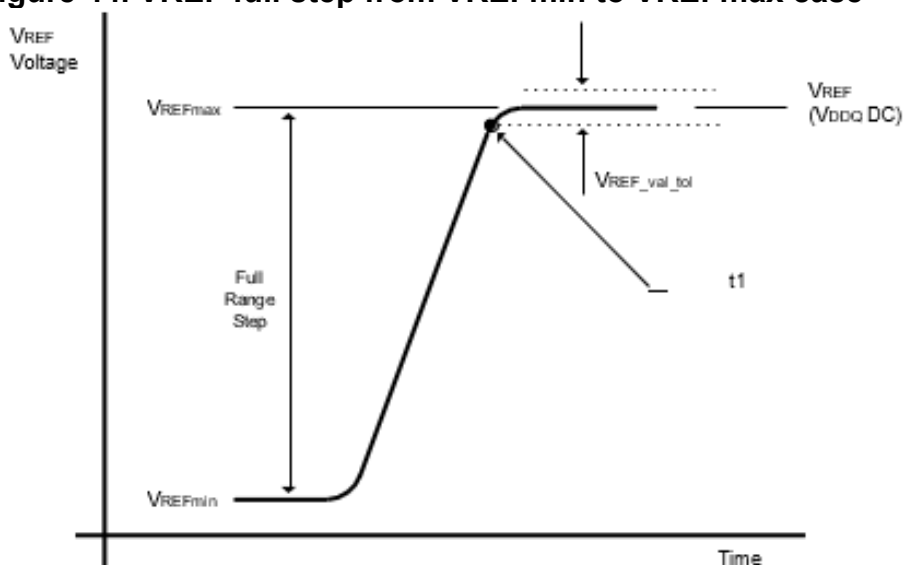
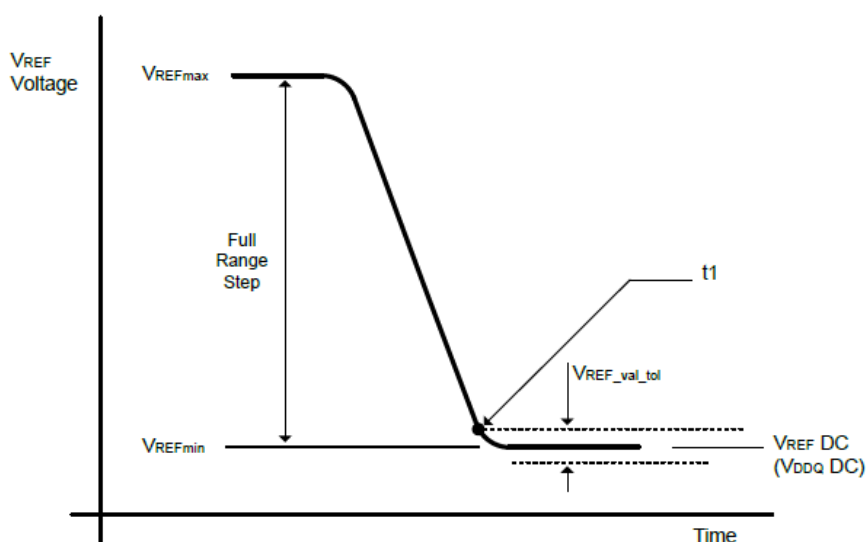
The VREF set tolerance is the variation in the VREF voltage from the ideal setting. This accounts for accumulated error over multiple steps. There are two ranges for VREF set tolerance uncertainty. The range of VREF set tolerance uncertainty is a function of number of steps  $n$ .

The VREF set tolerance is measured with respect to the ideal line which is based on the two endpoints. Where the endpoints are at the min and max VREF values for a specified range.

**Figure 40. Example of VREF set tolerance (max case only shown) and step size**





**Figure 43. VREF step single step size decrement case****Figure 44. VREF full step from VREFmin to VREFmax case****Figure 45. VREF full step from VREFmax to VREFmin case**

The following table contains the DQ internal VREF specification that will be characterized at the component level for compliance.

**Table 29. DQ Internal VREF Specifications**

| Symbol           | Parameter                       | Min   | Typ  | Max  | Unit | Note  |
|------------------|---------------------------------|-------|------|------|------|-------|
| VREF_max_R0      | VREF Max operating point Range0 | -     | -    | 30%  | VDDQ | 1,11  |
| VREF_min_R0      | VREF Min operating point Range0 | 10%   | -    | -    | VDDQ | 1,11  |
| VREF_max_R1      | VREF Max operating point Range1 | -     | -    | 42%  | VDDQ | 1,11  |
| VREF_min_R1      | VREF Min operating point Range1 | 22%   | -    | -    | VDDQ | 1,11  |
| VREF_step        | VREF Step size                  | 0.3%  | 0.4% | 0.5% | VDDQ | 2     |
| VREF_set_tol     | VREF Set Tolerance              | -1%   | 0%   | 1%   | VDDQ | 3,4,6 |
|                  |                                 | -0.1% | 0%   | 0.1% | VDDQ | 3,5,7 |
| VREF_time_Short  | VREF Step Time                  | -     | -    | 100  | ns   | 8     |
| VREF_time_Middle |                                 | -     | -    | 200  | ns   | 12    |
| VREF_time_Long   |                                 | -     | -    | 250  | ns   | 9     |
| VREF_time_weak   |                                 | -     | -    | 1    | ms   | 13,14 |
| VREF_val_tol     | VREF Valid tolerance            | -0.1% | 0%   | 0.1% | VDDQ | 10    |

**Notes:**

1. VREF DC voltage referenced to VDDQ\_DC.
2. VREF stepsize increment/decrement range. VREF at DC level.
3.  $VREF\_new = VREF\_old + n \times VREF\_step$ ; n= number of steps; if increment use "+"; if decrement use "-".
4. The minimum value of VREF setting tolerance =  $VREF\_new - 1.0\% \times VDDQ$ . The maximum value of VREF setting tolerance =  $VREF\_new + 1.0\% \times VDDQ$ . For  $n > 4$ .
5. The minimum value of VREF setting tolerance =  $VREF\_new - 0.1\% \times VDDQ$ . The maximum value of VREF setting tolerance =  $VREF\_new + 0.1\% \times VDDQ$ . For  $n \leq 4$ .
6. Measured by recording the min and max values of the VREF output over the range, drawing a straight line between those points and comparing all other VREF output settings to that line.
7. Measured by recording the min and max values of the VREF output across 4 consecutive steps( $n=4$ ), drawing a straight line between those points and comparing all other VREF output settings to that line.
8. Time from MRS command to increment or decrement one step size for VREF.
9. Time from MRS command to increment or decrement VREFmin to VREFmax or VREFmax to VREFmin change across the VREFDQ Range in VREF voltage.
10. Only applicable for DRAM component level test/characterization purpose. Not applicable for normal mode of operation. VREF valid is to qualify the step times which will be characterized at the component level.
11. DRAM range 0 or 1 set by MR14 OP[6].
12. Time from MRS command to increment or decrement more than one step size up to a full range of VREF voltage within the same VREFDQ range.
13. Applies when VRCG high current mode is not enabled, specified by MR13[OP3] = 0.
14. VREF\_time\_weak covers all VREF(DQ) Range and Value change conditions are applied to VREF\_time\_Short/Middle/Long.

## Mode Register Definition

The table listed below shows the mode registers for LPDDR4 SDRAM. A Mode Register Read command is used to read a mode register. A Mode Register Write command is used to write a mode register.

## Mode Register Assignment and Definition

Table below shows the mode registers. Each register is denoted as “R”, if it can be read but not written, “W” if it can be written but not read, and “R/W” if it can be read and written. Mode Register Read Command shall be used to read a register. Mode Register Write Command shall be used to write a register.

**Table 30. Mode Register Assignments**

| MR# | OP7                                           | OP6            | OP5      | OP4     | OP3       | OP2          | OP1     | OP0      |
|-----|-----------------------------------------------|----------------|----------|---------|-----------|--------------|---------|----------|
| 0   | CATR                                          | RFU            | RFU      | RZQI    |           | RFU          | Latency | Refresh  |
| 1   | RPST                                          | nWR (for AP)   |          |         | RD-PRE    | WR-PRE       | BL      |          |
| 2   | WR Lev                                        | WLS            | WL       |         |           | RL           |         |          |
| 3   | DBI-WR                                        | DBI-RD         | PDDS     |         |           | PPRP         | WR PST  | PU-CAL   |
| 4   | TUF                                           | Thermal Offset |          | PPRE    | SR Abort  | Refresh Rate |         |          |
| 5   | Reserved                                      |                |          |         |           |              |         |          |
| 6   | Reserved                                      |                |          |         |           |              |         |          |
| 7   | Reserved                                      |                |          |         |           |              |         |          |
| 8   | IO Width                                      |                | Density  |         |           |              | Type    |          |
| 9   | Reserved                                      |                |          |         |           |              |         |          |
| 10  | RFU                                           |                |          |         |           |              |         | ZQ-Reset |
| 11  | Reserved                                      | CA ODT         |          |         | Reserved  | DQ ODT       |         |          |
| 12  | RFU                                           | VR-CA          | VREF(CA) |         |           |              |         |          |
| 13  | FSP-OP                                        | FSP-WR         | DMD      | RRO     | VRCG      | VRO          | RPT     | CBT      |
| 14  | RFU                                           | VR(DQ)         | VREF(DQ) |         |           |              |         |          |
| 15  | Lower-Byte Invert Register for DQ Calibration |                |          |         |           |              |         |          |
| 16  | PASR Bank Mask                                |                |          |         |           |              |         |          |
| 17  | PASR Segment Mask                             |                |          |         |           |              |         |          |
| 18  | DQS Oscillator Count - LSB                    |                |          |         |           |              |         |          |
| 19  | DQS Oscillator Count - MSB                    |                |          |         |           |              |         |          |
| 20  | Upper-Byte Invert Register for DQ Calibration |                |          |         |           |              |         |          |
| 21  | RFU                                           |                |          |         |           |              |         |          |
| 22  | RFU                                           |                | ODTD-CA  | ODTE-CS | ODTE-CK   | SOC ODT      |         |          |
| 23  | DQS interval timer run time setting           |                |          |         |           |              |         |          |
| 24  | TRR Mode                                      | TRR Mode BAn   |          |         | Unltd MAC | MAC Value    |         |          |
| 25  | PPR Resource                                  |                |          |         |           |              |         |          |
| 26  | RFU                                           |                |          |         |           |              |         |          |
| 27  | RFU                                           |                |          |         |           |              |         |          |
| 28  | RFU                                           |                |          |         |           |              |         |          |
| 29  | RFU                                           |                |          |         |           |              |         |          |
| 30  | Reserved for testing - SDRAM will ignore      |                |          |         |           |              |         |          |
| 31  | RFU                                           |                |          |         |           |              |         |          |
| 32  | DQ Calibration Pattern "A" (default = 5AH)    |                |          |         |           |              |         |          |
| 33  | RFU                                           |                |          |         |           |              |         |          |
| 34  | RFU                                           |                |          |         |           |              |         |          |
| 35  | RFU                                           |                |          |         |           |              |         |          |
| 36  | RFU                                           |                |          |         |           |              |         |          |
| 37  | RFU                                           |                |          |         |           |              |         |          |
| 38  | RFU                                           |                |          |         |           |              |         |          |
| 39  | Reserved for testing - SDRAM will ignore      |                |          |         |           |              |         |          |
| 40  | DQ Calibration Pattern "B" (default = 3CH)    |                |          |         |           |              |         |          |

**Table 31. MR0 Register Information (MA[5:0] = 00H)**

| OP7                                  | OP6       | OP5     | OP4                                                                                                                                                                                                                                        | OP3 | OP2 | OP1     | OP0     |
|--------------------------------------|-----------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|---------|---------|
| CATR                                 | RFU       | RFU     | RZQI                                                                                                                                                                                                                                       |     | RFU | Latency | Refresh |
| Function                             | Type      | Operand | Data                                                                                                                                                                                                                                       |     |     | Notes   |         |
| Refresh Mode                         | Read-only | OP[0]   | 0B : Both legacy & modified refresh mode supported<br>1B : Only modified refresh mode supported                                                                                                                                            |     |     |         |         |
| Latency Mode                         |           | OP[1]   | 0B : Device supports normal latency<br>1B : Reserved                                                                                                                                                                                       |     |     |         |         |
| RZQI<br>(Built-in Self-Test for RZQ) |           | OP[4:3] | 00B: RZQ Self-Test Not Supported<br>01B: ZQ pin may connect to VSSQ or float<br>10B: ZQ-pin may short to VDDQ<br>11B: ZQ-pin Self-Test Completed, no error condition detected (ZQ-pin may not connect to VSSQ or float, nor short to VDDQ) |     |     | 1~ 4    |         |
| CATR<br>(CA Terminating Rank)        |           | OP[7]   | 0B: CA for this rank is not terminated<br>1B: Vendor specific                                                                                                                                                                              |     |     | 5       |         |

**Notes:**

- RZQI MR value, if supported, will be valid after the following sequence:
  - Completion of MPC ZQCAL Start command to either channel.
  - Completion of MPC ZQCAL Latch command to either channel then tZQLAT is satisfied. RZQI value will be lost after Reset.
- If the ZQ-pin is connected to VSSQ to set default calibration, OP[4:3] shall be set to 01B. If the ZQ-pin is not connected to VSSQ, either OP[4:3] = 01B or OP[4:3] = 10B might indicate a ZQ-pin assembly error. It is recommended that the assembly error is corrected.
- In the case of possible assembly error, the LPDDR4-SDRAM device will default to factory trim settings for RON, and will ignore ZQ Calibration commands. In either case, the device may not function as intended.
- If ZQ Self-Test returns OP[4:3] = 11B, the device has detected a resistor connected to the ZQ-pin. However, this result cannot be used to validate the ZQ resistor value or that the ZQ resistor tolerance meets the specified limits (i.e.,  $240\Omega \pm 1\%$ ).
- CATR functionality is Vendor specific. CATR can either indicate the connection status of the ODTCA pad for the die or whether CA for the rank is terminated.

**Table 32. MR1 Register Information (MA[5:0] = 01H)**

| OP7                                                 | OP6          | OP5     | OP4                                                                                                                                                   | OP3    | OP2    | OP1   | OP0 |
|-----------------------------------------------------|--------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------|--------|-------|-----|
| RPST                                                | nWR (for AP) |         |                                                                                                                                                       | RD-PRE | WR-PRE | BL    |     |
| Function                                            | Type         | Operand | Data                                                                                                                                                  |        |        | Notes |     |
| BL<br>(Burst Length)                                | Write-only   | OP[1:0] | 00B: BL=16 Sequential (default)<br>01B: BL=32 Sequential<br>10B: BL=16 or 32 Sequential (on-the-fly)<br>All Others: Reserved                          |        |        | 1     |     |
| WR-PRE<br>(WR Pre-amble Length)                     |              | OP[2]   | 0B: Reserved<br>1B: WR Pre-amble = 2 x tCK                                                                                                            |        |        | 5,6   |     |
| RD-PRE<br>(RD Pre-amble Type)                       |              | OP[3]   | 0B: RD Pre-amble = Static (default)<br>1B: RD Pre-amble = Toggle                                                                                      |        |        | 3,5,6 |     |
| nWR<br>(Write-Recovery for Auto-Precharge commands) |              | OP[6:4] | 000B: nWR = 6 (default)<br>001B: nWR = 10<br>010B: nWR = 16<br>011B: nWR = 20<br>100B: nWR = 24<br>101B: nWR = 30<br>110B: nWR = 34<br>111B: nWR = 40 |        |        | 2,5,6 |     |
| RPST<br>(RD Post-Ambale Length)                     |              | OP[7]   | 0B: RD Post-ambale = 0.5 x tCK (default)<br>1B: RD Post-ambale = 1.5 x tCK                                                                            |        |        | 4,5,6 |     |

**Notes:**

- Burst length on-the-fly can be set to either BL=16 or BL=32 by setting the "BL" bit in the command operands. See the Command Truth Table.
- The programmed value of nWR is the number of clock cycles the LPDDR4-SDRAM device uses to determine the starting point of an internal Precharge operation after a Write burst with AP (auto-precharge) enabled. See Read and Write Latencies.
- For Read operations this bit must be set to select between a "toggling" pre-ambale and a "Non-toggling" Pre-ambale.
- OP[7] provides an optional READ post-ambale with an additional rising and falling edge of DQS. The optional postamble cycle is provided for the benefit of certain memory controllers.
- There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
- There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.
- Supporting the two physical registers for Burst Length: MR1 OP[1:0] as optional feature. Applications requiring support of both vendor options shall assure that both FSP-OP[0] and FSP-OP[1] are set to the same code.

**Table 33. Burst Sequence for Read**

| Burst Length | Burst Type | C4 | C3 | C2 | C1 | C0 | Burst Cycle Number and Burst Address Sequence |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|--------------|------------|----|----|----|----|----|-----------------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|              |            |    |    |    |    |    | 1                                             | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| 16           | SEQ        | V  | 0  | 0  | 0  | 0  | 0                                             | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|              |            | V  | 0  | 1  | 0  | 0  | 4                                             | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  | 0  | 1  | 2  | 3  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|              |            | V  | 1  | 0  | 0  | 0  | 8                                             | 9  | A  | B  | C  | D  | E  | F  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|              |            | V  | 1  | 1  | 0  | 0  | C                                             | D  | E  | F  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 32           | SEQ        | 0  | 0  | 0  | 0  | 0  | 0                                             | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F |
|              |            | 0  | 0  | 1  | 0  | 0  | 4                                             | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  | 0  | 1  | 2  | 3  | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 |
|              |            | 0  | 1  | 0  | 0  | 0  | 8                                             | 9  | A  | B  | C  | D  | E  | F  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|              |            | 0  | 1  | 1  | 0  | 0  | C                                             | D  | E  | F  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B |
|              |            | 1  | 0  | 0  | 0  | 0  | 10                                            | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  |
|              |            | 1  | 0  | 1  | 0  | 0  | 14                                            | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  | C  | D  | E  | F  | 0  | 1  | 2  | 3  |
|              |            | 1  | 1  | 0  | 0  | 0  | 18                                            | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 8  | 9  | A  | B  | C  | D  | E  | F  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|              |            | 1  | 1  | 1  | 0  | 0  | 1C                                            | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | C  | D  | E  | F  | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | A  | B  |

**Notes:**

1. C0-C1 are assumed to be '0', and are not transmitted on the command bus.
2. The starting burst address is on 64-bit (4n) boundaries.

**Table 34. Burst Sequence for Write**

| Burst Length | Burst Type | C4 | C3 | C2 | C1 | C0 | Burst Cycle Number and Burst Address Sequence |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|--------------|------------|----|----|----|----|----|-----------------------------------------------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|              |            |    |    |    |    |    | 1                                             | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| 16           | SEQ        | V  | 0  | 0  | 0  | 0  | 0                                             | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9  | A  | B  | C  | D  | E  | F  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 32           | SEQ        | 0  | 0  | 0  | 0  | 0  | 0                                             | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9  | A  | B  | C  | D  | E  | F  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F |

**Notes:**

1. C0-C1 are assumed to be '0', and are not transmitted on the command bus.
2. The starting address is on 256-bit (16n) boundaries for Burst length 16.
3. The starting address is on 512-bit (32n) boundaries for Burst length 32.
4. C2-C3 shall be set to '0' for all Write operations.

**Table 35. MR2 Register Information (MA[5:0] = 02H)**

| OP7                        | OP6        | OP5     | OP4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | OP3 | OP2 | OP1   | OP0 |
|----------------------------|------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-------|-----|
| WR Lev                     | WLS        | WL      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |     | RL  |       |     |
| Function                   | Type       | Operand | Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |     |     | Notes |     |
| RL<br>(Read latency)       | Write-only | OP[2:0] | <b>RL &amp; nRTP for DBI-RD Disabled (MR3 OP[6]=0B)</b><br>000B: RL=6, nRTP = 8 (Default)<br>001B: RL=10, nRTP = 8<br>010B: RL=14, nRTP = 8<br>011B: RL=20, nRTP = 8<br>100B: RL=24, nRTP = 10<br>101B: RL=28, nRTP = 12<br>110B: RL=32, nRTP = 14<br>111B: RL=36, nRTP = 16<br><b>RL &amp; nRTP for DBI-RD Enabled (MR3 OP[6]=1B)</b><br>000B: RL=6, nRTP = 8<br>001B: RL=12, nRTP = 8<br>010B: RL=16, nRTP = 8<br>011B: RL=22, nRTP = 8<br>100B: RL=28, nRTP = 10<br>101B: RL=32, nRTP = 12<br>110B: RL=36, nRTP = 14<br>111B: RL=40, nRTP = 16 |     |     | 1,3,4 |     |
| WL<br>(Write latency)      |            | OP[5:3] | <b>WL Set "A" (MR2 OP[6]=0B)</b><br>000B: WL=4 (Default)<br>001B: WL=6<br>010B: WL=8<br>011B: WL=10<br>100B: WL=12<br>101B: WL=14<br>110B: WL=16<br>111B: WL=18<br><b>WL Set "B" (MR2 OP[6]=1B)</b><br>000B: WL=4<br>001B: WL=8<br>010B: WL=12<br>011B: WL=18<br>100B: WL=22<br>101B: WL=26<br>110B: WL=30<br>111B: WL=34                                                                                                                                                                                                                         |     |     | 1,3,4 |     |
| WLS<br>(Write Latency Set) |            | OP[6]   | 0B: WL Set "A" (default)<br>1B: WL Set "B"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |     |     | 1,3,4 |     |
| WR Lev<br>(Write Leveling) |            | OP[7]   | 0B: Disabled (default)<br>1B: Enabled                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |     |     | 2     |     |

**Notes:**

1. See Read and Write Latencies table for detail.
2. After a MRW to set the Write Leveling Enable bit (OP[7]=1B), the device remains in the MRW state until another MRW command clears the bit (OP[7]=0B). No other commands are allowed until the Write Leveling Enable bit is cleared.
3. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
4. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

**Table 36. Read and Write Latencies**

| Read Latency |       | Write Latency |       | nWR | nRTP | Lower Clock Frequency Limit [MHz]( > ) | Upper Clock Frequency Limit [MHz]( ≤ ) | Notes       |
|--------------|-------|---------------|-------|-----|------|----------------------------------------|----------------------------------------|-------------|
| No DBI       | w/DBI | Set A         | Set B |     |      |                                        |                                        |             |
| 6            | 6     | 4             | 4     | 6   | 8    | 50                                     | 266                                    | 1,2,3,4,5,6 |
| 10           | 12    | 6             | 8     | 10  | 8    | 266                                    | 533                                    |             |
| 14           | 16    | 8             | 12    | 16  | 8    | 533                                    | 800                                    |             |
| 20           | 22    | 10            | 18    | 20  | 8    | 800                                    | 1066                                   |             |
| 24           | 28    | 12            | 22    | 24  | 10   | 1066                                   | 1333                                   |             |
| 28           | 32    | 14            | 26    | 30  | 12   | 1333                                   | 1600                                   |             |
| 32           | 36    | 16            | 30    | 34  | 14   | 1600                                   | 1866                                   |             |
| 36           | 40    | 18            | 34    | 40  | 16   | 1866                                   | 2133                                   |             |

**Notes:**

1. The device should not be operated at a frequency above the Upper Frequency Limit, or below the Lower Frequency Limit, shown for each RL, WL, nRTP, or nWR value.
2. DBI for Read operations is enabled in MR3 OP[6]. When MR3 OP[6]=0, then the "No DBI" column should be used for Read Latency. When MR3 OP[6]=1, then the "w/DBI" column should be used for Read Latency.
3. Write Latency Set "A" and Set "B" is determined by MR2 OP[6]. When MR2 OP[6]=0, then Write Latency Set "A" should be used. When MR2 OP[6]=1, then Write Latency Set "B" should be used.
4. The programmed value of nWR is the number of clock cycles the device uses to determine the starting point of an internal Precharge operation after a Write burst with AP (Auto Pre-charge). It is determined by RU(tWR/tCK).
5. The programmed value of nRTP is the number of clock cycles the device uses to determine the starting point of an internal Precharge operation after a Read burst with AP (Auto Pre-charge). It is determined by RU(tRTP/tCK).
6. nRTP shown in this table is valid for BL16 only. For BL32, the SDRAM will add 8 clocks to the nRTP value before starting a precharge.

**Table 37. MR3 Register Information (MA[5:0] = 03H)**

| OP7                                   | OP6    | OP5        | OP4     | OP3                                                                                                                             | OP2  | OP1    | OP0    |
|---------------------------------------|--------|------------|---------|---------------------------------------------------------------------------------------------------------------------------------|------|--------|--------|
| DBI-WR                                | DBI-RD | PDDS       |         |                                                                                                                                 | PPRP | WR PST | PU-CAL |
| Function                              |        | Type       | Operand | Data                                                                                                                            |      | Notes  |        |
| PU-Cal<br>(Pull-up Calibration Point) |        | Write-only | OP[0]   | 0B: VDDQ/2.5<br>1B: VDDQ/3 (default)                                                                                            |      | 1,4    |        |
| WR PST<br>(WR Post-Amble Length)      |        |            | OP[1]   | 0B: WR Post-amble = 0.5 x tCK (default)<br>1B: WR Post-amble = 1.5 x tCK                                                        |      | 2,3,5  |        |
| Post Package Repair<br>Protection     |        |            | OP[2]   | 0B: PPR protection disabled (default)<br>1B: PPR protection enabled                                                             |      | 6      |        |
| PDDS<br>(Pull-Down Drive Strength)    |        |            | OP[5:3] | 000B: RFU<br>001B: RZQ/1<br>010B: RZQ/2<br>011B: RZQ/3<br>100B: RZQ/4<br>101B: RZQ/5<br>110B: RZQ/6 (default)<br>111B: Reserved |      | 1,2,3  |        |
| DBI-RD<br>(DBI-Read Enable)           |        |            | OP[6]   | 0B: Disabled (default)<br>1B: Enabled                                                                                           |      | 2,3    |        |
| DBI-WR<br>(DBI-Write Enable)          |        |            | OP[7]   | 0B: Disabled (default)<br>1B: Enabled                                                                                           |      | 2,3    |        |

**Notes:**

1. All values are "typical". The actual value after calibration will be within the specified tolerance for a given voltage and temperature. Re-calibration may be required as voltage and temperature vary.
2. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
3. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.
4. For dual channel devices, PU-CAL setting is required as the same value for both Ch.A and Ch.B before issuing ZQ Cal start command.
5. 1.5 x tCK apply > 1.6GHz clock.
6. If MR3 OP[2] is set to 1b then PPR protection mode is enabled. The PPR Protection bit is a sticky bit and can only be set to 0b by a power on reset. MR4 OP[4] controls entry to PPR Mode. If PPR protection is enabled then DRAM will not allow writing of 1 to MR4 OP[4].

**Table 38. MR4 Register Information (MA[5:0] = 04H)**

| OP7                                          | OP6            | OP5     | OP4                                                                                                                                                                                                                                 | OP3      | OP2          | OP1 | OP0      |
|----------------------------------------------|----------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------|-----|----------|
| TUF                                          | Thermal Offset |         | PPRE                                                                                                                                                                                                                                | SR Abort | Refresh Rate |     |          |
| Function                                     | Type           | Operand | Data                                                                                                                                                                                                                                |          |              |     | Notes    |
| Refresh Rate                                 | Read           | OP[2:0] | 000B: 8x refresh<br>001B: 8x refresh<br>010B: 4x refresh<br>011B: 1x refresh (default)<br>100B: 1x refresh<br>101B: 1x refresh, no de-rating<br>110B: 1x refresh, with de-rating<br>111B: High temperature operating limit exceeded |          |              |     | 1-4, 7-9 |
| SR Abort (Self Refresh Abort)                | Write          | OP[3]   | 0B: Disable (default)<br>1B: Enable                                                                                                                                                                                                 |          |              |     | 9, 10    |
| PPRE<br>(Post-package repair entry/exit)     | Write          | OP[4]   | 0B: Exit PPR mode (default)<br>1B: Enter PPR mode                                                                                                                                                                                   |          |              |     | 5, 9     |
| Thermal Offset<br>(Vender Specific Function) | Write          | OP[6:5] | 00B: No offset, 0~5°C gradient (default)<br>01B: 5°C offset, 5~10°C gradient<br>10B: 10°C offset, 10~15°C gradient<br>11B: Reserved                                                                                                 |          |              |     |          |
| TUF<br>(Temperature Update Flag)             | Read           | OP[7]   | 0B: No change in OP[2:0] since last MR4 read (default)<br>1B: Change in OP[2:0] since last MR4 read                                                                                                                                 |          |              |     | 6-8      |

**Notes:**

1. The refresh rate for each MR4-OP[2:0] setting applies to tREFI, tREFIpb, and tREFW. OP[2:0]=011B corresponds to a device temperature of 85 °C. Other values require either a longer (4x, 8x) refresh interval at lower temperatures, or a shorter (1x) refresh interval at higher temperatures. If OP[2]=1B, the device temperature is greater than 85 °C.
2. At higher temperatures (>85 °C), AC timing derating may be required. If derating is required the LPDDR4-SDRAM will set OP[2:0]=110B.
3. DRAM vendors may or may not report all of the possible settings over the operating temperature range of the device. Each vendor guarantees that their device will work at any temperature within the range using the refresh interval requested by their device.
4. The device may not operate properly when OP[2:0]=000B or 111B.
5. Post-package repair can be entered or exited by writing to OP[4].
6. When OP[7]=1, the refresh rate reported in OP[2:0] has changed since the last MR4 read. A mode register read from MR4 will reset OP[7] to '0'.
7. OP[7] = 0 at power-up. OP[2:0] bits are valid after initialization sequence(Te).
8. See the section on "temperature Sensor" for information on the recommended frequency of reading MR4.
9. OP[6:3] bits that can be written in this register. All other bits will be ignored by the DRAM during a MRW to this register.
10. Self Refresh abort feature is available for higher density devices starting with 12Gb device.

**MR5~7 (Reserved) (MA[5:0] = 05H-07H)****Table 39. MR8 Register Information (MA[5:0] = 08H)**

| OP7      | OP6       | OP5     | OP4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | OP3 | OP2 | OP1  | OP0   |
|----------|-----------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|------|-------|
| IO Width |           | Density |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |     |     | Type |       |
| Function | Type      | Operand | Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |     |     |      | Notes |
| Type     | Read-only | OP[1:0] | 00B: S16 SDRAM (16n pre-fetch)<br>All Others: Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                     |     |     |      |       |
| Density  |           | OP[5:2] | 0000B: 4Gb dual channel die / 2Gb single channel die<br>0001B: 6Gb dual channel die / 3Gb single channel die<br>0010B: 8Gb dual channel die / 4Gb single channel die<br>0011B: 12Gb dual channel die / 6Gb single channel die<br>0100B: 16Gb dual channel die / 8Gb single channel die<br>0101B: 24Gb dual channel die / 12Gb single channel die<br>0110B: 32Gb dual channel die / 16Gb single channel die<br>1100B: 2Gb dual channel die / 1Gb single channel die<br>All Others: Reserved |     |     |      |       |
| IO Width |           | OP[7:6] | 00B: x16 (per channel)<br>All Others: Reserved                                                                                                                                                                                                                                                                                                                                                                                                                                             |     |     |      |       |

**MR9 (Reserved) (MA[5:0] = 09H)**

**Table 40. MR10 Register Information (MA[5:0] = 0AH)**

| OP7      | OP6 | OP5        | OP4     | OP3                                            | OP2 | OP1 | OP0      |
|----------|-----|------------|---------|------------------------------------------------|-----|-----|----------|
| RFU      |     |            |         |                                                |     |     | ZQ-Reset |
| Function |     | Type       | Operand | Data                                           |     |     | Notes    |
| ZQ-Reset |     | Write-only | OP[0]   | 0B: Normal Operation (Default)<br>1B: ZQ Reset |     |     | 1, 2     |

**Notes:**

1. See ZQCal Timing Parameters for calibration latency and timing.
2. If the ZQ-pin is connected to VDDQ through RZQ, either the ZQ calibration function or default calibration (via ZQ-Reset) is supported. If the ZQ-pin is connected to VSS, the device operates with default calibration, and ZQ calibration commands are ignored. In both cases, the ZQ connection shall not change after power is applied to the device.

**Table 41. MR11 Register Information (MA[5:0] = 0BH)**

| OP7                                            | OP6    | OP5        | OP4     | OP3                                                                                                                            | OP2    | OP1 | OP0   |
|------------------------------------------------|--------|------------|---------|--------------------------------------------------------------------------------------------------------------------------------|--------|-----|-------|
| Reserved                                       | CA ODT |            |         | Reserved                                                                                                                       | DQ ODT |     |       |
| Function                                       |        | Type       | Operand | Data                                                                                                                           |        |     | Notes |
| DQ ODT<br>(DQ Bus Receiver On-Die-Termination) |        | Write-only | OP[2:0] | 000B: Disable (Default)<br>001B: RZQ/1<br>010B: RZQ/2<br>011B: RZQ/3<br>100B: RZQ/4<br>101B: RZQ/5<br>110B: RZQ/6<br>111B: RFU |        |     | 1,2,3 |
| CA ODT<br>(CA Bus Receiver On-Die-Termination) |        |            | OP[6:4] | 000B: Disable (Default)<br>001B: RZQ/1<br>010B: RZQ/2<br>011B: RZQ/3<br>100B: RZQ/4<br>101B: RZQ/5<br>110B: RZQ/6<br>111B: RFU |        |     | 1,2,3 |

**Notes:**

1. All values are "typical". The actual value after calibration will be within the specified tolerance for a given voltage and temperature. Re-calibration may be required as voltage and temperature vary.
2. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
3. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

**Table 42. MR12 Register Information (MA[5:0] = 0CH)**

| OP7                            | OP6   | OP5          | OP4     | OP3                                                                      | OP2 | OP1           | OP0 |
|--------------------------------|-------|--------------|---------|--------------------------------------------------------------------------|-----|---------------|-----|
| RFU                            | VR-CA | VREF(CA)     |         |                                                                          |     |               |     |
| Function                       |       | Type         | Operand | Data                                                                     |     | Notes         |     |
| VREF(CA)<br>(VREF(CA) Setting) |       | Read / Write | OP[5:0] | 000000B - 110010B: See table below<br>All Others: Reserved               |     | 1,2,3,<br>5,6 |     |
| VR-CA<br>(VREF(CA) Range)      |       |              | OP[6]   | 0B: VREF(CA) Range[0] enabled<br>1B: VREF(CA) Range[1] enabled (default) |     | 1,2,4,<br>5,6 |     |

**Notes:**

1. This register controls the VREF(CA) levels. Refer to VREF Settings for Range[0] and Range[1] for actual voltage of VREF(CA).
2. A read to this register places the contents of OP[7:0] on DQ[7:0]. Any RFU bits and unused DQ's shall be set to '0'. See the section on MRR Operation.
3. A write to OP[5:0] sets the internal VREF(CA) level for FSP[0] when MR13 OP[6]=0B, or sets FSP[1] when MR13 OP[6]=1B. The time required for VREF(CA) to reach the set level depends on the step size from the current level to the new level. See the section on VREF(CA) training for more information.
4. A write to OP[6] switches the LPDDR4-SDRAM between two internal VREF(CA) ranges. The range (Range[0] or Range[1]) must be selected when setting the VREF(CA) register. The value, once set, will be retained until overwritten, or until the next power-on or RESET event.
5. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
6. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

**Table 43. VREF Settings for Range[0] and Range[1]**

| Function                     | Operand | Range[0] Values (% of VDD2) |                      | Range[1] Values (% of VDD2) |                      | Notes |
|------------------------------|---------|-----------------------------|----------------------|-----------------------------|----------------------|-------|
| VREF<br>Settings for<br>MR12 | OP[5:0] | 000000B: 10.0%              | 011010B: 20.4%       | 000000B: 22.0%              | 011010B: 32.4%       | 1,2,3 |
|                              |         | 000001B: 10.4%              | 011011B: 20.8%       | 000001B: 22.4%              | 011011B: 32.8%       |       |
|                              |         | 000010B: 10.8%              | 011100B: 21.2%       | 000010B: 22.8%              | 011100B: 33.2%       |       |
|                              |         | 000011B: 11.2%              | 011101B: 21.6%       | 000011B: 23.2%              | 011101B: 33.6%       |       |
|                              |         | 000100B: 11.6%              | 011110B: 22.0%       | 000100B: 23.6%              | 011110B: 34.0%       |       |
|                              |         | 000101B: 12.0%              | 011111B: 22.4%       | 000101B: 24.0%              | 011111B: 34.4%       |       |
|                              |         | 000110B: 12.4%              | 100000B: 22.8%       | 000110B: 24.4%              | 100000B: 34.8%       |       |
|                              |         | 000111B: 12.8%              | 100001B: 23.2%       | 000111B: 24.8%              | 100001B: 35.2%       |       |
|                              |         | 001000B: 13.2%              | 100010B: 23.6%       | 001000B: 25.2%              | 100010B: 35.6%       |       |
|                              |         | 001001B: 13.6%              | 100011B: 24.0%       | 001001B: 25.6%              | 100011B: 36.0%       |       |
|                              |         | 001010B: 14.0%              | 100100B: 24.4%       | 001010B: 26.0%              | 100100B: 36.4%       |       |
|                              |         | 001011B: 14.4%              | 100101B: 24.8%       | 001011B: 26.4%              | 100101B: 36.8%       |       |
|                              |         | 001100B: 14.8%              | 100110B: 25.2%       | 001100B: 26.8%              | 100110B: 37.2%       |       |
|                              |         | 001101B: 15.2%              | 100111B: 25.6%       | 001101B: 27.2% (Default)    | 100111B: 37.6%       |       |
|                              |         | 001110B: 15.6%              | 101000B: 26.0%       | 001110B: 27.6%              | 101000B: 38.0%       |       |
|                              |         | 001111B: 16.0%              | 101001B: 26.4%       | 001111B: 28.0%              | 101001B: 38.4%       |       |
|                              |         | 010000B: 16.4%              | 101010B: 26.8%       | 010000B: 28.4%              | 101010B: 38.8%       |       |
|                              |         | 010001B: 16.8%              | 101011B: 27.2%       | 010001B: 28.8%              | 101011B: 39.2%       |       |
|                              |         | 010010B: 17.2%              | 101100B: 27.6%       | 010010B: 29.2%              | 101100B: 39.6%       |       |
|                              |         | 010011B: 17.6%              | 101101B: 28.0%       | 010011B: 29.6%              | 101101B: 40.0%       |       |
|                              |         | 010100B: 18.0%              | 101110B: 28.4%       | 010100B: 30.0%              | 101110B: 40.4%       |       |
|                              |         | 010101B: 18.4%              | 101111B: 28.8%       | 010101B: 30.4%              | 101111B: 40.8%       |       |
|                              |         | 010110B: 18.8%              | 110000B: 29.2%       | 010110B: 30.8%              | 110000B: 41.2%       |       |
|                              |         | 010111B: 19.2%              | 110001B: 29.6%       | 010111B: 31.2%              | 110001B: 41.6%       |       |
|                              |         | 011000B: 19.6%              | 110010B: 30.0%       | 011000B: 31.6%              | 110010B: 42.0%       |       |
|                              |         | 011001B: 20.0%              | All Others: Reserved | 011001B: 32.0%              | All Others: Reserved |       |

**Notes:**

1. These values may be used for MR12 OP[5:0] to set the VREF(CA) levels in the LPDDR4-SDRAM.
2. The range may be selected in the MR12 register by setting OP[6] appropriately.
3. The MR12 registers represents either FSP[0] or FSP[1]. Two frequency-set-points each for CA and DQ are provided to allow for faster switching between terminated and un-terminated operation, or between different high frequency setting which may use different terminations values.

**Table 44. MR13 Register Information (MA[5:0] = 0DH)**

| OP7                                            | OP6    | OP5        | OP4     | OP3                                                                                      | OP2 | OP1   | OP0 |
|------------------------------------------------|--------|------------|---------|------------------------------------------------------------------------------------------|-----|-------|-----|
| FSP-OP                                         | FSP-WR | DMD        | RRO     | VRCG                                                                                     | VRO | RPT   | CBT |
| Function                                       |        | Type       | Operand | Data                                                                                     |     | Notes |     |
| CBT<br>(Command Bus Training)                  |        | Write-only | OP[0]   | 0B: Normal Operation (default)<br>1B: Command Bus Training Mode Enabled                  |     | 1     |     |
| RPT<br>(Read Preamble Training)                |        |            | OP[1]   | 0B: Disable (default)<br>1B: Enable                                                      |     |       |     |
| VRO<br>(VREF Output)                           |        |            | OP[2]   | 0B: Normal operation (default)<br>1B: Output the VREF(CA) and VREF(DQ) values on DQ bits |     | 2     |     |
| VRCG<br>(VREF Current Generator)               |        |            | OP[3]   | 0B: Normal Operation (default)<br>1B: VREF Fast Response (high current) mode             |     | 3     |     |
| RRO<br>Refresh rate option                     |        |            | OP[4]   | 0B: Disable codes 001 and 010 in MR4 OP[2:0]<br>1B: Enable all codes in MR4 OP[2:0]      |     | 4, 5  |     |
| DMD<br>(Data Mask Disable)                     |        |            | OP[5]   | 0B: Data Mask Operation Enabled (default)<br>1B: Data Mask Operation Disabled            |     | 6     |     |
| FSP-WR<br>(Frequency Set Point Write/Read)     |        |            | OP[6]   | 0B: Frequency-Set-Point[0] (default)<br>1B: Frequency-Set-Point [1]                      |     | 7     |     |
| FSP-OP<br>(Frequency Set Point Operation Mode) |        |            | OP[7]   | 0B: Frequency-Set-Point[0] (default)<br>1B: Frequency-Set-Point [1]                      |     | 8     |     |

**Notes:**

1. A write to set OP[0]=1 causes the LPDDR4-SDRAM to enter the Command Bus Training mode. When OP[0]=1 and CKE goes LOW, commands are ignored and the contents of CA[5:0] are mapped to the DQ bus. CKE must be brought HIGH before doing a MRW to clear this bit (OP[0]=0) and return to normal operation. See the Command Bus Training section for more information.
2. When set, the LPDDR4-SDRAM will output the VREF(CA) and VREF(DQ) voltages on DQ pins. Only the “active” frequency-set-point, as defined by MR13 OP[7], will be output on the DQ pins. This function allows an external test system to measure the internal VREF levels. The DQ pins used for VREF output are vendor specific.
3. When OP[3]=1, the VREF circuit uses a high-current mode to improve VREF settling time.
4. MR13 OP4 RRO bit is valid only when MR0 OP0 = 1. For LPDDR4 devices with MR0 OP0 = 0, MR4 OP[2:0] bits are not dependent on MR13 OP4.
5. When OP[4] = 0, only 001b and 010b in MR4 OP[2:0] are disabled. LPDDR4 devices must report 011b instead of 001b or 010b in this case. Controller should follow the refresh mode reported by MR4 OP[2:0], regardless of RRO setting. TCSR function does not depend on RRO setting.
6. When enabled (OP[5]=0B) data masking is enabled for the device. When disabled (OP[5]=1B), masked write command is illegal. See LPDDR4 Data Mask (DM) and Data Bus Inversion (DBI<sub>dc</sub>) Function.
7. FSP-WR determines which frequency-set-point registers are accessed with MRW commands for the following functions such as VREF(CA) Setting, VREF(CA) Range, VREF(DQ) Setting, VREF(DQ) Range. For more information, refer to Frequency Set Point section.
8. FSP-OP determines which frequency-set-point register values are currently used to specify device operation for the following functions such as VREF(CA) Setting, VREF(CA) Range, VREF(DQ) Setting, VREF(DQ) Range. For more information, refer to Frequency Set Point section.

**Table 45. MR14 Register Information (MA[5:0] = 0EH)**

| OP7                            | OP6    | OP5          | OP4     | OP3                                                                      | OP2 | OP1           | OP0 |
|--------------------------------|--------|--------------|---------|--------------------------------------------------------------------------|-----|---------------|-----|
| RFU                            | VR(DQ) | VREF(DQ)     |         |                                                                          |     |               |     |
| Function                       |        | Type         | Operand | Data                                                                     |     | Notes         |     |
| VREF(DQ)<br>(VREF(DQ) Setting) |        | Read / Write | OP[5:0] | 000000B - 110010B: See table below<br>All Others: Reserved               |     | 1,2,3,<br>5,6 |     |
| VR(DQ)<br>(VREF(DQ) Range)     |        |              | OP[6]   | 0B: VREF(DQ) Range[0] enabled<br>1B: VREF(DQ) Range[1] enabled (default) |     | 1,2,4,<br>5,6 |     |

**Notes:**

1. This register controls the VREF(DQ) levels for Frequency-Set-Point[1:0]. Values from either VR(DQ)[0] or VR(dq)[1] may be selected by setting OP[6] appropriately.
2. A read (MRR) to this register places the contents of OP[7:0] on DQ[7:0]. Any RFU bits and unused DQ's shall be set to '0'. See the MRR Operation section.
3. A write to OP[5:0] sets the internal VREF(DQ) level for FSP[0] when MR13 OP[6]=0B, or sets FSP[1] when MR13 OP[6]=1B. The time required for VREF(DQ) to reach the set level depends on the step size from the current level to the new level. See the VREF(DQ) training section.
4. A write to OP[6] switches the LPDDR4-SDRAM between two internal VREF(DQ) ranges. The range (Range[0] or Range[1]) must be selected when setting the VREF(DQ) register. The value, once set, will be retained until overwritten, or until the next power-on or RESET event.
5. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address or read from with an MRR command to this address.
6. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device and may be changed without affecting device operation.

**Table 46. VREF Settings for Range[0] and Range[1]**

| Function                     | Operand | Range[0] Values (% of VDDQ) |                      | Range[1] Values (% of VDDQ) |                      | Notes |
|------------------------------|---------|-----------------------------|----------------------|-----------------------------|----------------------|-------|
| VREF<br>Settings for<br>MR14 | OP[5:0] | 000000B: 10.0%              | 011010B: 20.4%       | 000000B: 22.0%              | 011010B: 32.4%       | 1,2,3 |
|                              |         | 000001B: 10.4%              | 011011B: 20.8%       | 000001B: 22.4%              | 011011B: 32.8%       |       |
|                              |         | 000010B: 10.8%              | 011100B: 21.2%       | 000010B: 22.8%              | 011100B: 33.2%       |       |
|                              |         | 000011B: 11.2%              | 011101B: 21.6%       | 000011B: 23.2%              | 011101B: 33.6%       |       |
|                              |         | 000100B: 11.6%              | 011110B: 22.0%       | 000100B: 23.6%              | 011110B: 34.0%       |       |
|                              |         | 000101B: 12.0%              | 011111B: 22.4%       | 000101B: 24.0%              | 011111B: 34.4%       |       |
|                              |         | 000110B: 12.4%              | 100000B: 22.8%       | 000110B: 24.4%              | 100000B: 34.8%       |       |
|                              |         | 000111B: 12.8%              | 100001B: 23.2%       | 000111B: 24.8%              | 100001B: 35.2%       |       |
|                              |         | 001000B: 13.2%              | 100010B: 23.6%       | 001000B: 25.2%              | 100010B: 35.6%       |       |
|                              |         | 001001B: 13.6%              | 100011B: 24.0%       | 001001B: 25.6%              | 100011B: 36.0%       |       |
|                              |         | 001010B: 14.0%              | 100100B: 24.4%       | 001010B: 26.0%              | 100100B: 36.4%       |       |
|                              |         | 001011B: 14.4%              | 100101B: 24.8%       | 001011B: 26.4%              | 100101B: 36.8%       |       |
|                              |         | 001100B: 14.8%              | 100110B: 25.2%       | 001100B: 26.8%              | 100110B: 37.2%       |       |
|                              |         | 001101B: 15.2%              | 100111B: 25.6%       | 001101B: 27.2% (Default)    | 100111B: 37.6%       |       |
|                              |         | 001110B: 15.6%              | 101000B: 26.0%       | 001110B: 27.6%              | 101000B: 38.0%       |       |
|                              |         | 001111B: 16.0%              | 101001B: 26.4%       | 001111B: 28.0%              | 101001B: 38.4%       |       |
|                              |         | 010000B: 16.4%              | 101010B: 26.8%       | 010000B: 28.4%              | 101010B: 38.8%       |       |
|                              |         | 010001B: 16.8%              | 101011B: 27.2%       | 010001B: 28.8%              | 101011B: 39.2%       |       |
|                              |         | 010010B: 17.2%              | 101100B: 27.6%       | 010010B: 29.2%              | 101100B: 39.6%       |       |
|                              |         | 010011B: 17.6%              | 101101B: 28.0%       | 010011B: 29.6%              | 101101B: 40.0%       |       |
|                              |         | 010100B: 18.0%              | 101110B: 28.4%       | 010100B: 30.0%              | 101110B: 40.4%       |       |
|                              |         | 010101B: 18.4%              | 101111B: 28.8%       | 010101B: 30.4%              | 101111B: 40.8%       |       |
|                              |         | 010110B: 18.8%              | 110000B: 29.2%       | 010110B: 30.8%              | 110000B: 41.2%       |       |
|                              |         | 010111B: 19.2%              | 110001B: 29.6%       | 010111B: 31.2%              | 110001B: 41.6%       |       |
|                              |         | 011000B: 19.6%              | 110010B: 30.0%       | 011000B: 31.6%              | 110010B: 42.0%       |       |
|                              |         | 011001B: 20.0%              | All Others: Reserved | 011001B: 32.0%              | All Others: Reserved |       |

**Notes:**

1. These values may be used for MR14 OP[5:0] to set the VREF(DQ) levels in the LPDDR4-SDRAM.
2. The range may be selected in the MR14 register by setting OP[6] appropriately.
3. The MR14 registers represents either FSP[0] or FSP[1]. Two frequency-set-points each for CA and DQ are provided to allow for faster switching between terminated and un-terminated operation, or between different high frequency setting which may use different terminations values.

**Table 47. MR15 Register Information (MA[5:0] = 0FH)**

| OP7                                           | OP6 | OP5        | OP4     | OP3                                                                                                                                                                                                                                                             | OP2 | OP1 | OP0   |
|-----------------------------------------------|-----|------------|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-------|
| Lower-Byte Invert Register for DQ Calibration |     |            |         |                                                                                                                                                                                                                                                                 |     |     |       |
| Function                                      |     | Type       | Operand | Data                                                                                                                                                                                                                                                            |     |     | Notes |
| Lower-Byte Invert for DQ Calibration          |     | Write-only | OP[7:0] | The following values may be written for any operand OP[7:0], and will be applied to the corresponding DQ locations DQ[7:0] within a byte lane:<br>0B: Do not invert<br>1B: Invert the DQ Calibration patterns in MR32 and MR40<br>Default value for OP[7:0]=55H |     |     | 1,2,3 |

**Notes:**

1. This register will invert the DQ Calibration pattern found in MR32 and MR40 for any single DQ, or any combination of DQ's. Example: If MR15 OP[7:0]=00010101B, then the DQ Calibration patterns transmitted on DQ[7,6,5,3,1] will not be inverted, but the DQ Calibration patterns transmitted on DQ[4,2,0] will be inverted.
2. DMI[0] is not inverted, and always transmits the "true" data contained in MR32/MR40.
3. No Data Bus Inversion (DBI) function is enacted during DQ Read Calibration, even if DBI is enabled in MR3-OP[6].

**Table 48. MR15 Invert Register Pin Mapping**

| PIN  | DQ0 | DQ1 | DQ2 | DQ3 | DMI0      | DQ4 | DQ5 | DQ6 | DQ7 |
|------|-----|-----|-----|-----|-----------|-----|-----|-----|-----|
| MR15 | OP0 | OP1 | OP2 | OP3 | NO-Invert | OP4 | OP5 | OP6 | OP7 |

**Table 49. MR16 Register Information (MA[5:0] = 10H)**

| OP7            | OP6 | OP5        | OP4     | OP3                                                                                 | OP2          | OP1 | OP0   |
|----------------|-----|------------|---------|-------------------------------------------------------------------------------------|--------------|-----|-------|
| PASR Bank Mask |     |            |         |                                                                                     |              |     |       |
| Function       |     | Type       | Operand | Data                                                                                |              |     | Notes |
| Bank[7:0] Mask |     | Write-only | OP[7:0] | 0B: Bank Refresh enabled (default) : Unmasked<br>1B: Bank Refresh disabled : Masked |              |     | 1     |
| OP[n]          |     | Bank Mask  |         |                                                                                     | 8-Bank SDRAM |     |       |
| 0              |     | xxxxxx1    |         |                                                                                     | Bank 0       |     |       |
| 1              |     | xxxxxx1x   |         |                                                                                     | Bank 1       |     |       |
| 2              |     | xxxxx1xx   |         |                                                                                     | Bank 2       |     |       |
| 3              |     | xxx1xxx    |         |                                                                                     | Bank 3       |     |       |
| 4              |     | xx1xxxx    |         |                                                                                     | Bank 4       |     |       |
| 5              |     | x1xxxxx    |         |                                                                                     | Bank 5       |     |       |
| 6              |     | 1xxxxxx    |         |                                                                                     | Bank 6       |     |       |
| 7              |     | 1xxxxxx    |         |                                                                                     | Bank 7       |     |       |

**Notes:**

1. When a mask bit is asserted (OP[n]=1), refresh to that bank is disabled.
2. PASR bank-masking is on a per-channel basis. The two channels on the die may have different bank masking in dual channel devices.

**Table 50. MR17 Register Information (MA[5:0] = 11H)**

| OP7               | OP6   | OP5          | OP4     | OP3                                                                   | OP2 | OP1 | OP0 |
|-------------------|-------|--------------|---------|-----------------------------------------------------------------------|-----|-----|-----|
| PASR Segment Mask |       |              |         |                                                                       |     |     |     |
| Function          |       | Type         | Operand | Data                                                                  |     |     |     |
| PASR Segment Mask |       | Write-only   | OP[7:0] | 0B: Segment Refresh enabled (default)<br>1B: Segment Refresh disabled |     |     |     |
| Segment           | OP[n] | Segment Mask |         | 8Gb per channel                                                       |     |     |     |
|                   |       |              |         | R15:R13                                                               |     |     |     |
| 0                 | 0     | xxxxxx1      |         | 000B                                                                  |     |     |     |
| 1                 | 1     | xxxxxx1x     |         | 001B                                                                  |     |     |     |
| 2                 | 2     | xxxxx1xx     |         | 010B                                                                  |     |     |     |
| 3                 | 3     | xxx1xxx      |         | 011B                                                                  |     |     |     |
| 4                 | 4     | xx1xxxx      |         | 100B                                                                  |     |     |     |
| 5                 | 5     | x1xxxxx      |         | 101B                                                                  |     |     |     |
| 6                 | 6     | 1xxxxxx      |         | 110B                                                                  |     |     |     |
| 7                 | 7     | 1xxxxxx      |         | 111B                                                                  |     |     |     |

**Notes:**

1. This table indicates the range of row addresses in each masked segment. "X" is don't care for a particular segment.
2. PASR segment-masking is on a per-channel basis. The two channels on the die may have different segment masking in dual channel devices.

**Table 51. MR18 Register Information (MA[5:0] = 12H)**

| OP7                                         | OP6 | OP5       | OP4     | OP3                                   | OP2 | OP1 | OP0   |
|---------------------------------------------|-----|-----------|---------|---------------------------------------|-----|-----|-------|
| DQS Oscillator Count - LSB                  |     |           |         |                                       |     |     |       |
| Function                                    |     | Type      | Operand | Data                                  |     |     | Notes |
| DQS Oscillator (WR Training DQS Oscillator) |     | Read-only | OP[7:0] | 0 - 255 LSB DRAM DQS Oscillator Count |     |     | 1~3   |

**Notes:**

1. MR18 reports the LSB bits of the DRAM DQS Oscillator count. The DRAM DQS Oscillator count value is used to train DQS to the DQ data valid window. The value reported by the DRAM in this mode register can be used by the memory controller to periodically adjust the phase of DQS relative to DQ.
2. Both MR18 and MR19 must be read (MRR) and combined to get the value of the DQS Oscillator count.
3. A new MPC [Start DQS Oscillator] should be issued to reset the contents of MR18/MR19.

**Table 52. MR19 Register Information (MA[5:0] = 13H)**

| OP7                                         | OP6       | OP5     | OP4                                   | OP3 | OP2 | OP1 | OP0   |
|---------------------------------------------|-----------|---------|---------------------------------------|-----|-----|-----|-------|
| DQS Oscillator Count - MSB                  |           |         |                                       |     |     |     |       |
| Function                                    | Type      | Operand | Data                                  |     |     |     | Notes |
| DQS Oscillator (WR Training DQS Oscillator) | Read-only | OP[7:0] | 0 - 255 MSB DRAM DQS Oscillator Count |     |     |     | 1~3   |

**Notes:**

- MR19 reports the MSB bits of the DRAM DQS Oscillator count. The DRAM DQS Oscillator count value is used to train DQS to the DQ data valid window. The value reported by the DRAM in this mode register can be used by the memory controller to periodically adjust the phase of DQS relative to DQ.
- Both MR18 and MR19 must be read (MRR) and combined to get the value of the DQS Oscillator count.
- A new MPC [Start DQS Oscillator] should be issued to reset the contents of MR18/MR19.

**Table 53. MR20 Register Information (MA[5:0] = 14H)**

| OP7                                           | OP6        | OP5     | OP4                                                                                                                                                                                                                                                                | OP3 | OP2 | OP1 | OP0   |
|-----------------------------------------------|------------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-------|
| Upper-Byte Invert Register for DQ Calibration |            |         |                                                                                                                                                                                                                                                                    |     |     |     |       |
| Function                                      | Type       | Operand | Data                                                                                                                                                                                                                                                               |     |     |     | Notes |
| Upper-Byte Invert for DQ Calibration          | Write-only | OP[7:0] | The following values may be written for any operand OP[7:0], and will be applied to the corresponding DQ locations DQ[15:8] within a byte lane:<br>0B: Do not invert<br>1B: Invert the DQ Calibration patterns in MR32 and MR40<br>Default value for OP[7:0] = 55H |     |     |     | 1,2   |

**Notes:**

- This register will invert the DQ Calibration pattern found in MR32 and MR40 for any single DQ, or any combination of DQ's. Example: If MR20 OP[7:0]=00010101B, then the DQ Calibration patterns transmitted on DQ[15,14,13,11,9] will not be inverted, but the DQ Calibration patterns transmitted on DQ[12,10,8] will be inverted.
- DMI[1] is not inverted, and always transmits the "true" data contained in MR32/MR40.
- No Data Bus Inversion (DBI) function is enacted during DQ Read Calibration, even if DBI is enabled in MR3- OP[6].

**Table 54. MR20 Invert Register Pin Mapping**

| PIN  | DQ8 | DQ9 | DQ10 | DQ11 | DMI1      | DQ12 | DQ13 | DQ14 | DQ15 |
|------|-----|-----|------|------|-----------|------|------|------|------|
| MR20 | OP0 | OP1 | OP2  | OP3  | NO-Invert | OP4  | OP5  | OP6  | OP7  |

**MR21 (Reserved) (MA[5:0] = 15H)**

**Table 55. MR22 Register Information (MA[5:0] = 16H)**

| OP7                                                   | OP6        | OP5     | OP4                                                                                                                            | OP3     | OP2     | OP1       | OP0 |
|-------------------------------------------------------|------------|---------|--------------------------------------------------------------------------------------------------------------------------------|---------|---------|-----------|-----|
| RFU                                                   |            | ODTD-CA | ODTE-CS                                                                                                                        | ODTE-CK | SOC ODT |           |     |
| Function                                              | Type       | Operand | Data                                                                                                                           |         |         | Notes     |     |
| SoC ODT<br>(Controller ODT Value for VOH calibration) | Write-only | OP[2:0] | 000B: Disable (Default)<br>001B: RZQ/1<br>010B: RZQ/2<br>011B: RZQ/3<br>100B: RZQ/4<br>101B: RZQ/5<br>110B: RZQ/6<br>111B: RFU |         |         | 1,2,3     |     |
| ODTE-CK<br>(CK ODT enabled for non-terminating rank)  |            | OP[3]   | 0B: ODT-CK Over-ride Disabled (Default) 1B: ODT-CK Over-ride Enabled                                                           |         |         | 2,3,4,6,8 |     |
| ODTE-CS<br>(CS ODT enable for non-terminating rank)   |            | OP[4]   | 0B: ODT-CS Over-ride Disabled (Default) 1B: ODT-CS Over-ride Enabled                                                           |         |         | 2,3,5,6,8 |     |
| ODTD-CA<br>(CA ODT termination disable)               |            | OP[5]   | 0B: ODT-CA Obeys ODT_CA bond pad (default)<br>1B: ODT-CA Disabled                                                              |         |         | 2,3,6,7,8 |     |

**Notes:**

- All values are "typical".
- There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
- There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.
- When OP[3]=1, then the CK signals will be terminated to the value set by MR11-OP[6:4] regardless of the state of the ODT\_CA bond pad. This overrides the ODT\_CA bond pad for configurations where CA is shared by two or more DRAMs but CK is not, allowing CK to terminate on all DRAMs.
- When OP[4]=1, then the CS signal will be terminated to the value set by MR11-OP[6:4] regardless of the state of the ODT\_CA bond pad. This overrides the ODT\_CA bond pad for configurations where CA is shared by two or more DRAMs but CS is not, allowing CS to terminate on all DRAMs.
- For system configurations where the CK, CS, and CA signals are shared between packages, the package design should provide for the ODT\_CA ball to be bonded on the system board outside of the memory package. This provides the necessary control of the ODT function for all die with shared Command Bus signals.
- When OP[5]=0, CA[5:0] will terminate when the ODT\_CA bond pad is HIGH and MR11-OP[6:4] is VALID, and disables termination when ODT\_CA is LOW or MR11-OP[6:4] is disabled. When OP[5]=1, termination for CA[5:0] is disabled, regardless of the state of the ODT\_CA bond pad or MR11-OP[6:4].
- To ensure proper operation in a multi-rank configuration, when CA, CK or CS ODT is enabled via MR11 OP[6:4] and also via MR22 or CA-ODT pad setting, the rank providing ODT will continue to terminate the command bus in all DRAM states including Active Self Refresh, Self Refresh Power-down, Active Power-down and Precharge Power-down.

**Table 56. MR23 Register Information (MA[5:0] = 17H)**

| OP7                                 | OP6        | OP5     | OP4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | OP3 | OP2 | OP1   | OP0 |
|-------------------------------------|------------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-------|-----|
| DQS interval timer run time setting |            |         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |     |     |       |     |
| Function                            | Type       | Operand | Data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |     |     | Notes |     |
| DQS interval timer run time         | Write-only | OP[7:0] | 00000000B: DQS interval timer stop via MPC Command (Default)<br>00000001B: DQS timer stops automatically at 16th clocks after timer start<br>00000010B: DQS timer stops automatically at 32nd clocks after timer start<br>00000011B: DQS timer stops automatically at 48th clocks after timer start<br>00000100B: DQS timer stops automatically at 64th clocks after timer start<br>----- Thru -----<br>00111111B: DQS timer stops automatically at (63X16) th clocks after timer start<br>01XXXXXXB: DQS timer stops automatically at 2048th clocks after timer start<br>10XXXXXXB: DQS timer stops automatically at 4096th clocks after timer start<br>11XXXXXXB: DQS timer stops automatically at 8192nd clocks after timer start |     |     | 1,2   |     |

**Notes:**

- MPC command with OP[6:0]=1001101B (Stop DQS Interval Oscillator) stops DQS interval timer in case of MR23 OP[7:0] = 00000000B.
- MPC command with OP[6:0]=1001101B (Stop DQS Interval Oscillator) is illegal with non-zero values in MR23 OP[7:0].

**Table 57. MR24 Register Information (MA[5:0] = 18H)**

| OP7           | OP6          | OP5        | OP4     | OP3                                                                                                                                                                              | OP2       | OP1   | OP0 |
|---------------|--------------|------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-------|-----|
| TRR Mode      | TRR Mode BAn |            |         | Unltd MAC                                                                                                                                                                        | MAC Value |       |     |
| Function      |              | Type       | Operand | Data                                                                                                                                                                             |           | Notes |     |
| MAC Value     |              | Read-only  | OP[2:0] | 000B: Unknown when bit OP3=0 (Note 1)<br>Unlimited when bit OP3=1 (Note 2)<br>001B: 700K<br>010B: 600K<br>011B: 500K<br>100B: 400K<br>101B: 300K<br>110B: 200K<br>111B: Reserved |           |       |     |
| Unlimited MAC |              |            | OP[3]   | 0B: OP[2:0] define MAC value<br>1B: Unlimited MAC value (Note 2, Note 3)                                                                                                         |           |       |     |
| TRR Mode BAn  |              | Write-only | OP[6:4] | 000B: Bank 0<br>001B: Bank 1<br>010B: Bank 2<br>011B: Bank 3<br>100B: Bank 4<br>101B: Bank 5<br>110B: Bank 6<br>111B: Bank 7                                                     |           |       |     |
| TRR Mode      |              |            | OP[7]   | 0B: Disabled (default)<br>1B: Enabled                                                                                                                                            |           |       |     |

**Notes:**

1. Unknown means that the device is not tested for tMAC and pass/fail values are unknown.
2. There is no restriction to number of activates.
3. MR24 OP [2:0] is set to zero.

**Table 58. MR25 Register Information (MA[5:0] = 19H)**

Mode Register 25 contains one bit of readout per bank indicating that at least one resource is available for Post Package Repair programming.

| OP7          | OP6   | OP5       | OP4     | OP3                                                                | OP2   | OP1   | OP0   |
|--------------|-------|-----------|---------|--------------------------------------------------------------------|-------|-------|-------|
| Bank7        | Bank6 | Bank5     | Bank4   | Bank3                                                              | Bank2 | Bank1 | Bank0 |
| Function     |       | Type      | Operand | Data                                                               |       |       |       |
| PPR Resource |       | Read-only | OP[2:0] | 0B: PPR Resource is not available<br>1B: PPR Resource is available |       |       |       |

**MR26~29 (Reserved) (MA[5:0] = 1AH-1DH)****Table 59. MR30 Register Information (MA[5:0] = 1EH)**

| OP7               | OP6 | OP5        | OP4     | OP3        | OP2 | OP1   | OP0 |
|-------------------|-----|------------|---------|------------|-----|-------|-----|
| Valid 0 or 1      |     |            |         |            |     |       |     |
| Function          |     | Type       | Operand | Data       |     | Notes |     |
| SDRAM will ignore |     | Write-only | OP[7:0] | Don't care |     | 1     |     |

**Notes:**

1. This register is reserved for testing purposes. The logical data values written to OP[7:0] shall have no effect on SDRAM operation, however timings need to be observed as for any other MR access command.

**MR31 (Reserved) (MA[5:0] = 1FH)**

**Table 60. MR32 Register Information (MA[5:0] = 20H)**

| OP7                                          | OP6   | OP5     | OP4                                                                                                                                                                                                                                                                                                                                                                                                  | OP3 | OP2 | OP1 | OP0 |
|----------------------------------------------|-------|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-----|
| DQ Calibration Pattern "A" (default = 5AH)   |       |         |                                                                                                                                                                                                                                                                                                                                                                                                      |     |     |     |     |
| Function                                     | Type  | Operand | Data                                                                                                                                                                                                                                                                                                                                                                                                 |     |     |     |     |
| Return DQ Calibration Pattern<br>MR32 + MR40 | Write | OP[7:0] | XB: An MPC command with OP[6:0]= 1000011B causes the device to return the DQ Calibration Pattern contained in this register and (followed by) the contents of MR40. A default pattern "5AH" is loaded at power-up or RESET, or the pattern may be overwritten with a MRW to this register. The contents of MR15 and MR20 will invert the data pattern for a given DQ (See MR15 for more information) |     |     |     |     |

**MR33~38 (Reserved) (MA[5:0] = 21H-26H)****Table 61. MR39 Register Information (MA[5:0] = 27H)**

| OP7               | OP6        | OP5     | OP4        | OP3 | OP2 | OP1 | OP0   |
|-------------------|------------|---------|------------|-----|-----|-----|-------|
| Valid 0 or 1      |            |         |            |     |     |     |       |
| Function          | Type       | Operand | Data       |     |     |     | Notes |
| SDRAM will ignore | Write-only | OP[7:0] | Don't care |     |     |     | 1     |

**Notes:**

1. This register is reserved for testing purposes. The logical data values written to OP[7:0] shall have no effect on SDRAM operation, however timings need to be observed as for any other MR access command.

**Table 62. MR40 Register Information (MA[5:0] = 28H)**

| OP7                                          | OP6        | OP5     | OP4                                                                                                                                                       | OP3 | OP2 | OP1 | OP0   |
|----------------------------------------------|------------|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|-------|
| DQ Calibration Pattern "B" (default = 3CH)   |            |         |                                                                                                                                                           |     |     |     |       |
| Function                                     | Type       | Operand | Data                                                                                                                                                      |     |     |     | Notes |
| Return DQ Calibration Pattern<br>MR32 + MR40 | Write-only | OP[7:0] | XB: A default pattern "3CH" is loaded at power-up or RESET, or the pattern may be overwritten with a MRW to this register. See MR32 for more information. |     |     |     | 1,2,3 |

**Notes:**

1. The pattern contained in MR40 is concatenated to the end of MR32 and transmitted on DQ[15:0] and DMI[1:0] when DQ Read Calibration is initiated via a MPC command. The pattern transmitted serially on each data lane, organized "little endian" such that the low-order bit in a byte is transmitted first. If the data pattern in MR40 is 27H, then the first bit transmitted will be a '1', followed by '1', '1', '0', '0', '1', '0', and '0'. The bit stream will be 00100111B.
2. MR15 and MR20 may be used to invert the MR32/MR40 data patterns on the DQ pins. See MR15 and MR20 for more information. Data is never inverted on the DMI[1:0] pins.
3. The data pattern is not transmitted on the DMI[1:0] pins if DBI-RD is disabled via MR3-OP[6].
4. No Data Bus Inversion (DBI) function is enacted during DQ Read Calibration, even if DBI is enabled in MR3-OP[6].

## Refresh Requirement

Between SRX command and SRE command, at least one extra refresh command is required. After the DRAM Self Refresh Exit command, in addition to the normal Refresh command at tREFI interval, the DRAM requires minimum of one extra Refresh command prior to Self Refresh Entry command.

**Table 63. Refresh Requirement Parameters per die for Dual Channel devices**

| Refresh Requirements                                     |       | Symbol   | 16Gb  | Units |
|----------------------------------------------------------|-------|----------|-------|-------|
| Density per Channel                                      |       |          | 8Gb   |       |
| Number of banks per channel                              |       |          | 8     |       |
| Refresh Window (TCASE $\leq$ 105°C)                      |       | tREFW    | 32    | ms    |
| Required Number of Refresh Commands in a tREFW window    |       | R        | 8192  | -     |
| Average Refresh Interval (TCASE $\leq$ 105°C)            | REFAB | tREFI    | 3.904 | us    |
|                                                          | REFPB | tREFIpb  | 488   | ns    |
| Refresh Cycle Time (All Banks)                           |       | tRFCab   | 280   | ns    |
| Refresh Cycle Time (Per Bank)                            |       | tRFCpb   | 140   | ns    |
| Per-bank Refresh to Per-bank Refresh different bank Time |       | tpbR2pbR | 90    | ns    |

**Notes:**

1. Refresh for each channel is independent of the other channel on the die, or other channels in a package. Power delivery in the user's system should be verified to make sure the DC operating conditions are maintained when multiple channels are refreshed simultaneously.
2. Refer to MR4 OP[2:0] for detailed Refresh Rate and its multipliers.

## Absolute Maximum Ratings

Stresses greater than those listed may cause permanent damage to the device.

This is a stress rating only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

**Table 64. Absolute Maximum DC Ratings**

| Symbol    | Parameter                                       | Min  | Max | Units | Notes |
|-----------|-------------------------------------------------|------|-----|-------|-------|
| VDD1      | VDD1 supply voltage relative to Vss             | -0.4 | 2.1 | V     | 1     |
| VDD2      | VDD2 supply voltage relative to Vss             | -0.4 | 1.5 | V     | 1     |
| VDDQ      | VDDQ supply voltage relative to VSSQ            | -0.4 | 1.5 | V     | 1     |
| VIN, VOUT | Voltage on any ball except VDD1 relative to Vss | -0.4 | 1.5 | V     |       |
| TSTG      | Storage Temperature                             | -55  | 125 | °C    | 2     |

**Notes:**

1. See "Power-Ramp" for relationships between power supplies.
2. Storage Temperature is the case surface temperature on the center/top side of the LPDDR4 device. For the measurement conditions, please refer to JESD51-2.

**Table 65. Operating Temperature Range**

| Symbol | Parameter  | Min | Max | Units | Notes |
|--------|------------|-----|-----|-------|-------|
| TOPER  | Standard   | -25 | 85  | °C    | 1~3   |
|        | Automotive | -40 | 105 | °C    | 1~3   |

**Notes:**

- Operating Temperature is the case surface temperature on the center-top side of the device. For the measurement conditions, please refer to JESD51-2.
- Either the device case temperature rating or the temperature sensor may be used to set an appropriate refresh rate, determine the need for AC timing de-rating and/or monitor the operating temperature. When using the temperature sensor, the actual device case temperature may be higher than the TOPER rating that applies for the Standard or Elevated Temperature Ranges. For example, TCASE may be above 85°C when the temperature sensor indicates a temperature of less than 85°C.
- Some applications require operation of LPDDR4X in the maximum temperature conditions in the Elevated Temperature Range between 85 °C and 105 °C case temperature. For LPDDR4X devices, derating may be necessary to operate in this range. See MR4.

**AC and DC Operating Conditions****Table 66. Recommended DC Operating Conditions**

| Symbol | Parameter                       | Min  | Typ  | Max  | Units | Notes |
|--------|---------------------------------|------|------|------|-------|-------|
| VDD1   | Core 1 Power                    | 1.70 | 1.80 | 1.95 | V     | 1,2   |
| VDD2   | Core 2 Power/Input Buffer Power | 1.06 | 1.10 | 1.17 | V     | 1,2,3 |
| VDDQ   | I/O Buffer Power                | 1.06 | 1.10 | 1.17 | V     | 2,3   |

**Notes:**

- VDD1 uses significantly less current than VDD2.
- The voltage range is for DC voltage only. DC is defined as the voltage supplied at the DRAM and is inclusive of all noise up to 20MHz at the DRAM package ball.
- VdIVW and TdIVW limits described elsewhere in this document apply for voltage noise on supply voltages of up to 45 mV (peak-to- peak) from DC to 20MHz.

**Table 67. Input Leakage Current**

| Symbol | Parameter             | Min | Max | Units | Notes |
|--------|-----------------------|-----|-----|-------|-------|
| IL     | Input Leakage current | -4  | 4   | uA    | 1,2   |

**Notes:**

- For CK, CK#, CKE, CS, CA, ODT\_CA and RESET#. Any input  $0V \leq V_{IN} \leq VDD2$  (All other pins not under test = 0V).
- CA ODT is disabled for CK, CK#, CS, and CA.

**Table 68. Input/Output Leakage Current**

| Symbol | Parameter                    | Min | Max | Units | Notes |
|--------|------------------------------|-----|-----|-------|-------|
| IOZ    | Input/Output Leakage current | -5  | 5   | uA    | 1,2   |

**Notes:**

- For DQ, DQS, DQS# and DMI. Any I/O  $0V \leq V_{OUT} \leq VDDQ$ .
- I/Os status are disabled: High Impedance and ODT Off.

**Table 69. Input/output capacitance**

| Symbol | Parameter                                          | Min   | Max  | Units | Notes |
|--------|----------------------------------------------------|-------|------|-------|-------|
| CCK    | Input capacitance, CK and CK#                      | 0.5   | 1.6  | pF    | 1,2   |
| CDCK   | Input capacitance delta, CK and CK#                | 0     | 0.09 | pF    | 1,2,3 |
| CI     | Input capacitance, All other input-only pins       | 0.5   | 1.6  | pF    | 1,2,4 |
| CDI    | Input capacitance delta, All other input-only pins | -0.1  | 0.2  | pF    | 1,2,5 |
| CIO    | Input/output capacitance, DQ, DMI, DQS, DQS#       | 0.7   | 2    | pF    | 1,2,6 |
| CDDQS  | Input/output capacitance delta, DQS,DQS#           | 0     | 0.1  | pF    | 1,2,7 |
| CDIO   | Input/output capacitance delta, DQ, DMI            | -0.15 | 0.25 | pF    | 1,2,8 |
| CZQ    | Input/output capacitance, ZQ pin                   | 0     | 5    | pF    | 1,2   |

**Notes:**

1. This parameter applies to die device only (does not include package capacitance).
2. This parameter is not subject to production test. It is verified by design and characterization. The capacitance is measured according to JEP147 (Procedure for measuring input capacitance using a vector network analyzer (VNA) with VDD1, VDD2, VDDQ, VSS, VSSQ applied and all other pins floating).
3. Absolute value of CCK, CCK#.
4. CI applies to CS, CKE, CA0~CA5.
5.  $CDI = CI - 0.5 \times (CCK + CCK\#)$
6. DMI loading matches DQ and DQS.
7. Absolute value of CDQS and CDQS#.
8.  $CDIO = CIO - 0.5 \times (CDQS + CDQS\#)$  in byte-lane.

## IDD Measurement Conditions

The following definitions are used within the IDD measurement tables unless stated otherwise:

LOW:  $V_{IN} \leq V_{IL}(DC) \text{ MAX}$

HIGH:  $V_{IN} \geq V_{IH}(DC) \text{ MIN}$

STABLE: Inputs are stable at a HIGH or LOW level

SWITCHING: Please refer to the following two tables below:

**Table 70. Definition of Switching for CA Input Signals**

| Switching for CA |      |      |      |      |      |      |      |      |
|------------------|------|------|------|------|------|------|------|------|
| CK Edge          | R1   | R2   | R3   | R4   | R5   | R6   | R7   | R8   |
| CKE              | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH | HIGH |
| CS               | LOW  | LOW  | LOW  | LOW  | LOW  | LOW  | LOW  | LOW  |
| CA0              | HIGH | LOW  | LOW  | LOW  | LOW  | HIGH | HIGH | HIGH |
| CA1              | HIGH | HIGH | HIGH | LOW  | LOW  | LOW  | LOW  | HIGH |
| CA2              | HIGH | LOW  | LOW  | LOW  | LOW  | HIGH | HIGH | HIGH |
| CA3              | HIGH | HIGH | HIGH | LOW  | LOW  | LOW  | LOW  | HIGH |
| CA4              | HIGH | LOW  | LOW  | LOW  | LOW  | HIGH | HIGH | HIGH |
| CA5              | HIGH | HIGH | HIGH | LOW  | LOW  | LOW  | LOW  | HIGH |

**Notes:**

1. CS must always be driven LOW.
2. 50% of CA bus is changing between HIGH and LOW once per clock for the CA bus.
3. The above pattern is used continuously during IDD measurement for IDD values that require switching on the CA bus.

**Table 71. CA pattern for IDD4R for BL=16**

| Clock Cycle Number | CKE  | CS   | Command | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |
|--------------------|------|------|---------|-----|-----|-----|-----|-----|-----|
| N                  | HIGH | HIGH | Read-1  | L   | H   | L   | L   | L   | L   |
| N+1                | HIGH | LOW  |         | L   | H   | L   | L   | L   | L   |
| N+2                | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | L   |
| N+3                | HIGH | LOW  |         | L   | L   | L   | L   | L   | L   |
| N+4                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+5                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+6                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+7                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+8                | HIGH | HIGH | Read-1  | L   | H   | L   | L   | L   | L   |
| N+9                | HIGH | LOW  |         | L   | H   | L   | L   | H   | L   |
| N+10               | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | H   |
| N+11               | HIGH | LOW  |         | H   | H   | H   | H   | H   | H   |
| N+12               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+13               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+14               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+15               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |

**Notes:**

1. BA[2:0] = 010, C[9:4] = 000000 or 111111, Burst Order C[3:2] = 00 or 11 (Same as LPDDR3 IDD4R Spec)
2. Difference from LPDDR3 (JESD209-3): CA pins are kept low with DES CMD to reduce ODT current.

**Table 72. CA pattern for IDD4W for BL=16**

| Clock Cycle Number | CKE  | CS   | Command | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |
|--------------------|------|------|---------|-----|-----|-----|-----|-----|-----|
| N                  | HIGH | HIGH | Write-1 | L   | L   | H   | L   | L   | L   |
| N+1                | HIGH | LOW  |         | L   | H   | L   | L   | L   | L   |
| N+2                | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | L   |
| N+3                | HIGH | LOW  |         | L   | L   | L   | L   | L   | L   |
| N+4                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+5                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+6                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+7                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+8                | HIGH | HIGH | Write-1 | L   | L   | H   | L   | L   | L   |
| N+9                | HIGH | LOW  |         | L   | H   | L   | L   | H   | L   |
| N+10               | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | H   |
| N+11               | HIGH | LOW  |         | L   | L   | H   | H   | H   | H   |
| N+12               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+13               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+14               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+15               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |

**Notes:**

1. BA[2:0] = 010, CA[9:4] = 000000 or 111111 (Same as LPDDR3 IDD4W).
2. Difference from LPDDR3 (JESD209-3): 1)-No burst ordering, and 2) CA pins are kept low with DES CMD to reduce ODT current.

**Table 73. Data Pattern for IDD4W (DBI off) for BL=16**

| DBI OFF Case |       |       |       |       |       |       |       |       |     | No. of 1's |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|              | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0          | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL1          | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2          | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3          | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4          | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5          | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6          | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL7          | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8          | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL9          | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14         | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL15         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16         | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL17         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL19         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL21         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL22         | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL23         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL24         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL25         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26         | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL27         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28         | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL29         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL30         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL31         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| No. of 1's   | 16    | 16    | 16    | 16    | 16    | 16    | 16    | 16    |     |            |

**Notes:**

1. Same data pattern was applied to DQ[4], DQ[5], DQ[6], DQ[7] for reducing complexity for IDD4W/R pattern programming.

**Table 74. Data Pattern for IDD4R (DBI off) for BL=16**

| DBI OFF Case |       |       |       |       |       |       |       |       |     | No. of 1's |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|              | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0          | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL1          | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2          | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3          | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4          | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5          | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6          | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL7          | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8          | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL9          | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14         | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL15         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16         | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL17         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL19         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20         | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL21         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL22         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL23         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL24         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL25         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26         | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL27         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL29         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL30         | 1     | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL31         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| No. of 1's   | 16    | 16    | 16    | 16    | 16    | 16    | 16    | 16    |     |            |

**Notes:**

1. Same data pattern was applied to DQ[4], DQ[5], DQ[6], DQ[7] for reducing complexity for IDD4W/R pattern programming.

**Table 75. Data Pattern for IDD4W (DBI On) for BL=16**

| DBI ON Case |       |       |       |       |       |       |       |       |     | No. of 1's |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|             | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL1         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL7         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL9         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL15        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL17        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL19        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL21        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL22        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL23        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL24        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL25        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL27        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL29        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL30        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL31        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| No. of 1's  | 8     | 8     | 8     | 8     | 8     | 8     | 16    | 16    | 8   |            |

**Notes:**

1. DBI enabled burst: BL0, BL6, BL8, BL14, BL16, BL22, BL26, and BL28.

**Table 76. Data Pattern for IDD4R (DBI On) for BL=16**

| DBI ON Case |       |       |       |       |       |       |       |       |     | No. of 1's |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|             | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL1         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5         | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6         | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL7         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8         | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL9         | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL15        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL17        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL19        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL21        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL22        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL23        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL24        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL25        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26        | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL27        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL29        | 0     | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL30        | 0     | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL31        | 1     | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| No. of 1's  | 8     | 8     | 8     | 8     | 8     | 8     | 16    | 16    | 8   |            |

**Notes:**

1. DBI enabled burst: BL0, BL6, BL8, BL14, BL16, BL20, BL26, and BL30.

**Table 77. CA pattern for IDD4R for BL=32**

| Clock Cycle Number | CKE  | CS   | Command | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |
|--------------------|------|------|---------|-----|-----|-----|-----|-----|-----|
| N                  | HIGH | HIGH | Read-1  | L   | H   | L   | L   | L   | L   |
| N+1                | HIGH | LOW  |         | L   | H   | L   | L   | L   | L   |
| N+2                | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | L   |
| N+3                | HIGH | LOW  |         | L   | L   | L   | L   | L   | L   |
| N+4                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+5                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+6                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+7                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+8                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+9                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+10               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+11               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+12               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+13               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+14               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+15               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+16               | HIGH | HIGH | Read-1  | L   | H   | L   | L   | L   | L   |
| N+17               | HIGH | LOW  |         | L   | H   | L   | L   | H   | L   |
| N+18               | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | H   |
| N+19               | HIGH | LOW  |         | H   | H   | L   | H   | H   | H   |
| N+20               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+21               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+22               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+23               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+24               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+25               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+26               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+27               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+28               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+29               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+30               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+31               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |

**Note:** BA[2:0] = 010, C[9:4] = 00000 or 11111, Burst Order C[4:2] = 000 or 111.

**Table 78. CA pattern for IDD4W for BL=32**

| Clock Cycle Number | CKE  | CS   | Command | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |
|--------------------|------|------|---------|-----|-----|-----|-----|-----|-----|
| N                  | HIGH | HIGH | Write-1 | L   | L   | H   | L   | L   | L   |
| N+1                | HIGH | LOW  |         | L   | H   | L   | L   | L   | L   |
| N+2                | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | L   |
| N+3                | HIGH | LOW  |         | L   | L   | L   | L   | L   | L   |
| N+4                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+5                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+6                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+7                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+8                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+9                | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+10               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+11               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+12               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+13               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+14               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+15               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+16               | HIGH | HIGH | Write-1 | L   | L   | H   | L   | L   | L   |
| N+17               | HIGH | LOW  |         | L   | H   | L   | L   | H   | L   |
| N+18               | HIGH | HIGH | CAS-2   | L   | H   | L   | L   | H   | H   |
| N+19               | HIGH | LOW  |         | L   | L   | L   | H   | H   | H   |
| N+20               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+21               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+22               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+23               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+24               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+25               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+26               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+27               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+28               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+29               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+30               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |
| N+31               | HIGH | LOW  | DES     | L   | L   | L   | L   | L   | L   |

**Note:** BA[2:0] = 010, CA[9:5] = 00000 or 11111.

Table 79. Data Pattern for IDD4W (DBI off) for BL=32

|            | DBI OFF Case |       |       |       |       |       |       |       |     | No. of 1's |
|------------|--------------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|            | DQ[7]        | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0        | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL1        | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2        | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3        | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4        | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5        | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6        | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL7        | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8        | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL9        | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL15       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL17       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL19       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL21       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL22       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL23       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL24       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL25       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL27       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL29       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL30       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL31       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL32       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL33       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL34       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL35       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL36       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL37       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL38       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL39       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL40       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL41       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL42       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL43       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL44       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL45       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL46       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL47       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL48       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL49       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL50       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL51       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL52       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL53       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL54       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL55       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL56       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL57       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL58       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL59       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL60       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL61       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL62       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL63       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| No. of 1's | 32           | 32    | 32    | 32    | 32    | 32    | 32    | 32    |     |            |

**Note:** Same data pattern was applied to DQ[4], DQ[5], DQ[6], DQ[7] for reducing complexity for IDD4W/R pattern programming.

Table 80. Data Pattern for IDD4R (DBI off) for BL=32

|            | DBI OFF Case |       |       |       |       |       |       |       |     | No. of 1's |
|------------|--------------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|            | DQ[7]        | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0        | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL1        | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2        | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3        | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4        | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5        | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6        | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL7        | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8        | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL9        | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL15       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL17       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL19       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL21       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL22       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL23       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL24       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL25       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL27       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL29       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL30       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL31       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL32       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL33       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL34       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL35       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL36       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL37       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL38       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL39       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL40       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL41       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL42       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL43       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL44       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL45       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL46       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL47       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL48       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL49       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL50       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL51       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL52       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL53       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL54       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL55       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL56       | 0            | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL57       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL58       | 1            | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 0   | 8          |
| BL59       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL60       | 0            | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL61       | 0            | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL62       | 1            | 1     | 1     | 1     | 1     | 1     | 0     | 0     | 0   | 6          |
| BL63       | 1            | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| No. of 1's | 32           | 32    | 32    | 32    | 32    | 32    | 32    | 32    |     |            |

**Note:** Same data pattern was applied to DQ[4], DQ[5], DQ[6], DQ[7] for reducing complexity for IDD4W/R pattern programming.

Table 81. Data Pattern for IDD4W (DBI On) for BL=32

|            | DBI ON Case |       |       |       |       |       |       |       |     | No. of 1's |
|------------|-------------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|            | DQ[7]       | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0        | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL1        | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2        | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3        | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4        | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5        | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6        | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL7        | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8        | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL9        | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL15       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL17       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL19       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL21       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL22       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL23       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL24       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL25       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL27       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL29       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL30       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL31       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL32       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL33       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL34       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL35       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL36       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL37       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL38       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL39       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL40       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL41       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL42       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL43       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL44       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL45       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL46       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL47       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL48       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL49       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL50       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL51       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL52       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL53       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL54       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL55       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL56       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL57       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL58       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL59       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL60       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL61       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL62       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL63       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| No. of 1's | 16          | 16    | 16    | 16    | 16    | 16    | 32    | 32    | 16  |            |

**Note:** DBI enabled burst: BL0, BL6, BL8, BL14, BL16, BL22, BL26, BL28, BL32, BL38, BL40, BL46, BL48, BL54, BL58, and BL60.

Table 82. Data Pattern for IDD4R (DBI On) for BL=32

|            | DBI ON Case |       |       |       |       |       |       |       |     | No. of 1's |
|------------|-------------|-------|-------|-------|-------|-------|-------|-------|-----|------------|
|            | DQ[7]       | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI |            |
| BL0        | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL1        | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL2        | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL3        | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL4        | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL5        | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL6        | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL7        | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL8        | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL9        | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL10       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL11       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL12       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL13       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL14       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL15       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL16       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL17       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL18       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL19       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL20       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL21       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL22       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL23       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL24       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL25       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL26       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL27       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL28       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL29       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL30       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL31       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL32       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL33       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL34       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL35       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL36       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL37       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL38       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL39       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL40       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL41       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL42       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL43       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL44       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL45       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL46       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL47       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL48       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL49       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL50       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL51       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL52       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL53       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL54       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL55       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL56       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0   | 0          |
| BL57       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL58       | 0           | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 1   | 1          |
| BL59       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| BL60       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 0   | 2          |
| BL61       | 0           | 0     | 0     | 0     | 1     | 1     | 1     | 1     | 0   | 4          |
| BL62       | 0           | 0     | 0     | 0     | 0     | 0     | 1     | 1     | 1   | 3          |
| BL63       | 1           | 1     | 1     | 1     | 0     | 0     | 0     | 0     | 0   | 4          |
| No. of 1's | 16          | 16    | 16    | 16    | 16    | 16    | 32    | 32    | 16  |            |

**Note:** DBI enabled burst: BL0, BL6, BL8, BL14, BL16, BL22, BL26, BL28, BL34, BL36, BL42, BL44, BL48, BL52, BL58, and BL62.

## IDD Specifications

IDD values are for the entire operating voltage range, and all of them are for the entire standard range and for the elevated temperature range.

**Table 83. IDD Specification Parameters and Operating Conditions**

| Parameter/Condition                                                                                                                                                                                             | Symbol  | Power Supply | Note       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|--------------|------------|
| Operating one bank active-precharge current:<br>tCK = tCKmin; tRC = tRCmin; CKE is HIGH; CS is LOW between valid commands; CA bus inputs are switching; Data bus inputs are stable, ODT disabled                | IDD01   | VDD1         |            |
|                                                                                                                                                                                                                 | IDD02   | VDD2         |            |
|                                                                                                                                                                                                                 | IDD0Q   | VDDQ         | 3          |
| Idle power-down standby current:<br>tCK = tCKmin; CKE is LOW; CS is LOW; All banks are idle; CA bus inputs are switching; Data bus inputs are stable, ODT disabled                                              | IDD2P1  | VDD1         |            |
|                                                                                                                                                                                                                 | IDD2P2  | VDD2         |            |
|                                                                                                                                                                                                                 | IDD2PQ  | VDDQ         | 3          |
| Idle power-down standby current with clock stop:<br>CK = LOW, CK# = HIGH; CKE is LOW; CS is LOW; All banks are idle; CA bus inputs are stable; Data bus inputs are stable, ODT disabled                         | IDD2PS1 | VDD1         |            |
|                                                                                                                                                                                                                 | IDD2PS2 | VDD2         |            |
|                                                                                                                                                                                                                 | IDD2PSQ | VDDQ         | 3          |
| Idle non-power-down standby current:<br>tCK = tCKmin; CKE is HIGH; CS is LOW; All banks are idle; CA bus inputs are switching; Data bus inputs are stable, ODT disabled                                         | IDD2N1  | VDD1         |            |
|                                                                                                                                                                                                                 | IDD2N2  | VDD2         |            |
|                                                                                                                                                                                                                 | IDD2NQ  | VDDQ         | 3          |
| Idle non-power-down standby current with clock stopped:<br>CK = LOW; CK# = HIGH; CKE is HIGH; CS is LOW; All banks are idle; CA bus inputs are stable; Data bus inputs are stable, ODT disabled                 | IDD2NS1 | VDD1         |            |
|                                                                                                                                                                                                                 | IDD2NS2 | VDD2         |            |
|                                                                                                                                                                                                                 | IDD2NSQ | VDDQ         | 3          |
| Active power-down standby current:<br>tCK = tCKmin; CKE is LOW; CS is LOW; One bank is active; CA bus inputs are switching; Data bus inputs are stable, ODT disabled                                            | IDD3P1  | VDD1         |            |
|                                                                                                                                                                                                                 | IDD3P2  | VDD2         |            |
|                                                                                                                                                                                                                 | IDD3PQ  | VDDQ         | 3          |
| Active power-down standby current with clock stop:<br>CK = LOW, CK# = HIGH; CKE is LOW; CS is LOW; One bank is active; CA bus inputs are stable; Data bus inputs are stable, ODT disabled                       | IDD3PS1 | VDD1         |            |
|                                                                                                                                                                                                                 | IDD3PS2 | VDD2         |            |
|                                                                                                                                                                                                                 | IDD3PSQ | VDDQ         | 4          |
| Active non-power-down standby current:<br>tCK = tCKmin; CKE is HIGH; CS is LOW; One bank is active; CA bus inputs are switching; Data bus inputs are stable, ODT disabled                                       | IDD3N1  | VDD1         |            |
|                                                                                                                                                                                                                 | IDD3N2  | VDD2         |            |
|                                                                                                                                                                                                                 | IDD3NQ  | VDDQ         | 4          |
| Active non-power-down standby current with clock stopped:<br>CK = LOW, CK# = HIGH; CKE is HIGH; CS is LOW; One bank is active; CA bus inputs are stable; Data bus inputs are stable, ODT disabled               | IDD3NS1 | VDD1         |            |
|                                                                                                                                                                                                                 | IDD3NS2 | VDD2         |            |
|                                                                                                                                                                                                                 | IDD3NSQ | VDDQ         | 4          |
| Operating burst READ current:<br>tCK = tCKmin; CS is LOW between valid commands; One bank is active; BL = 16 or 32; RL = RL(MIN); CA bus inputs are switching; 50% data change each burst transfer ODT disabled | IDD4R1  | VDD1         |            |
|                                                                                                                                                                                                                 | IDD4R2  | VDD2         |            |
|                                                                                                                                                                                                                 | IDD4RQ  | VDDQ         | 5          |
| Operating burst WRITE current:<br>tCK = tCKmin; CS is LOW between valid commands; One bank is active; BL = 16 or 32; WL = WLmin; CA bus inputs are switching; 50% data change each burst transfer ODT disabled  | IDD4W1  | VDD1         |            |
|                                                                                                                                                                                                                 | IDD4W2  | VDD2         |            |
|                                                                                                                                                                                                                 | IDD4WQ  | VDDQ         | 4          |
| All bank REFRESH Burst current:<br>tCK = tCKmin; CKE is HIGH between valid commands; tRC = tRFCabmin; Burst refresh; CA bus inputs are switching; Data bus inputs are stable; ODT disabled                      | IDD51   | VDD1         |            |
|                                                                                                                                                                                                                 | IDD52   | VDD2         |            |
|                                                                                                                                                                                                                 | IDD5Q   | VDDQ         | 4          |
| All bank REFRESH Average current:<br>tCK = tCKmin; CKE is HIGH between valid commands; tRC = tREFI; CA bus inputs are switching; Data bus inputs are stable; ODT disabled                                       | IDD5AB1 | VDD1         |            |
|                                                                                                                                                                                                                 | IDD5AB2 | VDD2         |            |
|                                                                                                                                                                                                                 | IDD5ABQ | VDDQ         | 4          |
| Per bank REFRESH Average current:<br>tCK = tCKmin; CKE is HIGH between valid commands; tRC = tREFI/8; CA bus inputs are switching; Data bus inputs are stable; ODT disabled                                     | IDD5PB1 | VDD1         |            |
|                                                                                                                                                                                                                 | IDD5PB2 | VDD2         |            |
|                                                                                                                                                                                                                 | IDD5PBQ | VDDQ         | 4          |
| Self Refresh current (-25 °C to +85 °C):<br>CK = LOW, CK# = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable; Maximum 1x Self Refresh Rate; ODT disabled                                  | IDD61   | VDD1         | 6,7,8,10   |
|                                                                                                                                                                                                                 | IDD62   | VDD2         | 6,7,8,10   |
|                                                                                                                                                                                                                 | IDD6Q   | VDDQ         | 4,6,7,8,10 |

**Notes:**

1. Published IDD values are the maximum of the distribution of the arithmetic mean.
2. ODT disabled: MR11[2:0] = 000B.
3. IDD current specifications are tested after the device is properly initialized.
4. Measured currents are the summation of VDDQ and VDD2.
5. Guaranteed by design with output load = 5pF and RON = 40  $\Omega$ .
6. The 1x Self Refresh Rate is the rate at which the LPDDR4 device is refreshed internally during Self Refresh, before going into the elevated Temperature range.
7. This is the general definition that applies to full array Self Refresh.
8. Supplier data sheets may contain additional Self Refresh IDD values for temperature subranges within the Standard or elevated Temperature Ranges.
9. For all IDD measurements, VIHCKE = 0.8 x VDD2, VILCKE = 0.2 x VDD2.
10. Dual Channel devices are specified in dual channel operation (both channels operating together).

**Table 84. IDD Specification Parameters**  
 (T<sub>OPER</sub>, V<sub>DDQ</sub> = 1.06-1.17V, V<sub>DD1</sub> = 1.70-1.95V, V<sub>DD2</sub> = 1.06-1.17V)

| Parameter | Supply | 3733Mbps | 4266Mbps | Unit |
|-----------|--------|----------|----------|------|
| IDD01     | VDD1   | 20       | 21       | mA   |
| IDD02     | VDD2   | 170      | 185      | mA   |
| IDD0Q     | VDDQ   | 0.66     | 0.66     | mA   |
| IDD2P1    | VDD1   | 5.53     | 5.53     | mA   |
| IDD2P2    | VDD2   | 15.7     | 15.7     | mA   |
| IDD2PQ    | VDDQ   | 0.065    | 0.065    | mA   |
| IDD2PS1   | VDD1   | 5.5      | 5.5      | mA   |
| IDD2PS2   | VDD2   | 15.7     | 15.7     | mA   |
| IDD2PSQ   | VDDQ   | 0.065    | 0.065    | mA   |
| IDD2N1    | VDD1   | 7.03     | 7.03     | mA   |
| IDD2N2    | VDD2   | 100      | 120      | mA   |
| IDD2NQ    | VDDQ   | 0.68     | 0.68     | mA   |
| IDD2NS1   | VDD1   | 7.01     | 7.01     | mA   |
| IDD2NS2   | VDD2   | 58       | 60       | mA   |
| IDD2NSQ   | VDDQ   | 0.685    | 0.685    | mA   |
| IDD3P1    | VDD1   | 8.5      | 8.5      | mA   |
| IDD3P2    | VDD2   | 48       | 48       | mA   |
| IDD3PQ    | VDDQ   | 0.065    | 0.065    | mA   |
| IDD3PS1   | VDD1   | 8.5      | 8.5      | mA   |
| IDD3PS2   | VDD2   | 48       | 48       | mA   |
| IDD3PSQ   | VDDQ   | 0.065    | 0.065    | mA   |
| IDD3N1    | VDD1   | 9.2      | 9.2      | mA   |
| IDD3N2    | VDD2   | 145      | 155      | mA   |
| IDD3NQ    | VDDQ   | 0.69     | 0.7      | mA   |
| IDD3NS1   | VDD1   | 9.5      | 9.5      | mA   |
| IDD3NS2   | VDD2   | 85       | 85       | mA   |
| IDD3NSQ   | VDDQ   | 0.685    | 0.685    | mA   |
| IDD4R1    | VDD1   | 10       | 10       | mA   |
| IDD4R2    | VDD2   | 640      | 760      | mA   |
| IDD4RQ    | VDDQ   | 330      | 345      | mA   |
| IDD4W1    | VDD1   | 10       | 10       | mA   |
| IDD4W2    | VDD2   | 480      | 550      | mA   |
| IDD4WQ    | VDDQ   | 6.9      | 6.9      | mA   |
| IDD51     | VDD1   | 65       | 65       | mA   |
| IDD52     | VDD2   | 215      | 215      | mA   |
| IDD5Q     | VDDQ   | 0.68     | 0.68     | mA   |
| IDD5AB1   | VDD1   | 13       | 13       | mA   |
| IDD5AB2   | VDD2   | 110      | 130      | mA   |
| IDD5ABQ   | VDDQ   | 0.68     | 0.68     | mA   |
| IDD5PB1   | VDD1   | 12       | 12       | mA   |
| IDD5PB2   | VDD2   | 115      | 130      | mA   |
| IDD5PBQ   | VDDQ   | 0.68     | 0.68     | mA   |
| IDD61     | VDD1   | 23       | 23       | mA   |
| IDD62     | VDD2   | 58       | 58       | mA   |
| IDD6Q     | VDDQ   | 0.065    | 0.065    | mA   |

## Clock Specification

The jitter specified is a random jitter meeting a Gaussian distribution. Input clocks violating the min/max values may result in malfunction of the device.

### Definitions for $t_{CK(avg)}$ and $nCK$ :

$t_{CK(avg)}$  is calculated as the average clock period across any consecutive 200 cycle window, where each clock period is calculated from rising edge to rising edge.

$$t_{CK(avg)} = \left( \sum_{j=1}^N t_{CK(abs)_j} \right) / N$$

Where  $N=200$

Unit ' $t_{CK(avg)}$ ' represents the actual clock average  $t_{CK(avg)}$  of the input clock under operation. Unit ' $nCK$ ' represents one clock cycle of the input clock, counting the actual clock edges.

$t_{CK(avg)}$  may change by up to  $\pm 1\%$  within a 100 clock cycle window, provided that all jitter and timing specs are met.

### Definitions for $t_{CK(abs)}$ :

$t_{CK(abs)}$  is defined as the absolute clock period, as measured from one rising edge to the next consecutive rising edge.  $t_{CK(abs)}$  is not subject to production test.

### Definitions for $t_{CH(avg)}$ and $t_{CL(avg)}$ :

$t_{CH(avg)}$  is defined as the average high pulse width, as calculated across any consecutive 200 high pulses.

$$t_{CH(avg)} = \left( \sum_{j=1}^N t_{CH_j} \right) / (N \times t_{CK(avg)})$$

Where  $N=200$

$t_{CL(avg)}$  is defined as the average low pulse width, as calculated across any consecutive 200 low pulses.

$$t_{CL(avg)} = \left( \sum_{j=1}^N t_{CL_j} \right) / (N \times t_{CK(avg)})$$

Where  $N=200$

### Definitions for $t_{CH(abs)}$ and $t_{CL(abs)}$ :

$t_{CH(abs)}$  is the absolute instantaneous clock high pulse width, as measured from one rising edge to the following falling edge.

$t_{CL(abs)}$  is the absolute instantaneous clock low pulse width, as measured from one falling edge to the following rising edge.

Both  $t_{CH(abs)}$  and  $t_{CL(abs)}$  are not subject to production test.

### Definitions for $t_{JIT(per)}$ :

$t_{JIT(per)}$  is the single period jitter defined as the largest deviation of any signal  $t_{CK}$  from  $t_{CK(avg)}$ .  $t_{JIT(per)} = \text{Min/max of } \{t_{CK_i} - t_{CK(avg)} \text{ where } i = 1 \text{ to } 200\}$ .

$t_{JIT(per),act}$  is the actual clock jitter for a given system.  $t_{JIT(per),allowed}$  is the specified allowed clock period jitter.  $t_{JIT(per)}$  is not subject to production test.

**Definitions for  $t_{JIT(cc)}$ :**

$t_{JIT(cc)}$  is defined as the absolute difference in clock period between two consecutive clock cycles.  $t_{JIT(cc)} = \text{Max of } | \{ t_{CK(i+1)} - t_{CK(i)} \} |$ .

$t_{JIT(cc)}$  defines the cycle to cycle jitter.

$t_{JIT(cc)}$  is not subject to production test.

## Electrical Characteristics and AC Timing

**Table 85. AC Timing** ( $T_{\text{OPER}}$ ,  $V_{\text{DDQ}} = 1.06\text{-}1.17\text{V}$ ,  $V_{\text{DD1}} = 1.70\text{-}1.95\text{V}$ ,  $V_{\text{DD2}} = 1.06\text{-}1.17\text{V}$ )

| Symbol                                        | Parameter                                                      | Data Rate                                                                             |      |                  |      | Unit | Note |
|-----------------------------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------------------|------|------------------|------|------|------|
|                                               |                                                                | 4266                                                                                  |      | 3733             |      |      |      |
|                                               |                                                                | Min.                                                                                  | Max. | Min.             | Max. |      |      |
| Clock Timing                                  |                                                                |                                                                                       |      |                  |      |      |      |
| tCK(avg)                                      | Average clock period                                           | 0.468                                                                                 | 20   | 0.535            | 20   | ns   |      |
| tCH(avg)                                      | Average High pulse width                                       | 0.46                                                                                  | 0.54 | 0.46             | 0.54 | tCK  |      |
| tCL(avg)                                      | Average Low pulse width                                        | 0.46                                                                                  | 0.54 | 0.46             | 0.54 | tCK  |      |
| tCK(abs)                                      | Absolute clock period                                          | Min: tCK(avg)min + tJIT(per)min                                                       |      |                  |      | ns   |      |
| tCH(abs)                                      | Absolute High clock pulse width                                | 0.43                                                                                  | 0.57 | 0.43             | 0.57 | tCK  |      |
| tCL(abs)                                      | Absolute Low clock pulse width                                 | 0.43                                                                                  | 0.57 | 0.43             | 0.57 | tCK  |      |
| tJIT(per)                                     | Clock period jitter                                            | -30                                                                                   | 30   | -36              | 36   | ps   |      |
| tJIT(cc)                                      | Maximum Clock Jitter between consecutive cycles                | -                                                                                     | 60   | -                | 72   | ps   |      |
| Core Parameters                               |                                                                |                                                                                       |      |                  |      |      |      |
| tRC                                           | Activate-to-Activate command period (same bank)                | Min: tRAS + tRPab (with all bank precharge)<br>tRAS + tRPpb (with per bank precharge) |      |                  |      | ns   |      |
| tSR                                           | Minimum Self Refresh Time (Entry to Exit)                      | Min: max(15ns, 3nCK)                                                                  |      |                  |      | ns   |      |
| tXSR                                          | Self Refresh exit to next valid command delay                  | Min: max(tRFCab + 7.5ns, 2nCK)                                                        |      |                  |      | ns   |      |
| tXP                                           | Exit Power-Down to next valid command delay                    | Min: max(7.5ns, 5nCK)                                                                 |      |                  |      | ns   | 3    |
| tCCD                                          | CAS-to-CAS delay                                               | Min: 8                                                                                |      |                  |      | tCK  |      |
| tRTP                                          | Internal Read to Precharge command delay                       | Min: max(7.5ns, 8nCK)                                                                 |      |                  |      | ns   |      |
| tRCD                                          | RAS-to-CAS delay                                               | Min: max(18ns, 4nCK)                                                                  |      |                  |      | ns   |      |
| tRPpb                                         | Row precharge time (single bank)                               | Min: max(18ns, 4nCK)                                                                  |      |                  |      | ns   |      |
| tRPab                                         | Row precharge time (all banks)                                 | Min: max(21ns, 4nCK)                                                                  |      |                  |      | ns   |      |
| tRAS                                          | Row active time                                                | Min: max(42ns, 3nCK)                                                                  |      |                  |      | ns   |      |
|                                               |                                                                | Max: min(9 x tREFI x Refresh Rate, 70.2)                                              |      |                  |      | us   | 4    |
| tWR                                           | Write recovery time                                            | Min: max(18ns, 6nCK)                                                                  |      |                  |      | ns   |      |
| tWTR                                          | Write-to-Read delay                                            | Min: max(10ns, 8nCK)                                                                  |      |                  |      | ns   |      |
| tRRD                                          | Active bank-A to active bank-B                                 | max (7.5ns, 4nCK)                                                                     | -    | max (10ns, 4nCK) | -    | ns   | 2    |
| tPPD                                          | Precharge to Precharge Delay                                   | Min: 4                                                                                |      |                  |      | tCK  | 1    |
| tFAW                                          | Four-bank Activate window                                      | 30                                                                                    | -    | 40               | -    | ns   | 2    |
| Read output timings (Unit UI = tCK(avg)min/2) |                                                                |                                                                                       |      |                  |      |      |      |
| tDQSQ                                         | DQS,DQS# to DQ Skew total, per group,per access (DBI-Disabled) | -                                                                                     | 0.18 | -                | 0.18 | UI   |      |
| tQH                                           | DQ output hold time total from DQS, DQS# (DBI Disabled)        | Min: min(tQSH, tQSL)                                                                  |      |                  |      | UI   |      |
| tQW_total                                     | DQ output window timetotal, per pin (DBI-Disabled)             | 0.7                                                                                   | -    | 0.7              | -    | UI   | 7    |
| tDQSQ_DBI                                     | DQS,DQS# to DQSkew total, per group,per access (DBI-Enabled)   | -                                                                                     | 0.18 | -                | 0.18 | UI   |      |
| tQH_DBI                                       | DQ output hold time total from DQS, DQS# (DBI-Enabled)         | Min: min(tQSH_DBI, tQSL_DBI)                                                          |      |                  |      | UI   |      |
| tQW_total_DBI                                 | DQ output window timetotal, per pin (DBI-Enabled)              | 0.7                                                                                   | -    | 0.7              | -    | UI   | 7    |
| tQSL                                          | DQS, DQS# differential output low time (DBI-Disabled)          | Min: tCL(abs)-0.05                                                                    |      |                  |      | tCK  | 7,8  |
| tQSH                                          | DQS, DQS# differential output high time (DBI-Disabled)         | Min: tCH(abs)-0.05                                                                    |      |                  |      | tCK  | 7,9  |
| tQSL_DBI                                      | DQS, DQS# differential output low time (DBI-Enabled)           | Min: tCL(abs)-0.045                                                                   |      |                  |      | tCK  | 8,10 |
| tQSH_DBI                                      | DQS, DQS# differential output high time (DBI-Enabled)          | Min: tCH(abs)-0.045                                                                   |      |                  |      | tCK  | 9,10 |
| Read AC Timing (Unit UI = tCK(avg)min/2)      |                                                                |                                                                                       |      |                  |      |      |      |
| tRPRE                                         | Read preamble                                                  | 1.8                                                                                   | -    | 1.8              | -    | tCK  |      |
| tRPST                                         | 0.5 tCK Read postamble                                         | 0.4                                                                                   | -    | 0.4              | -    | tCK  |      |
| tRPST                                         | 1.5 tCK Read postamble                                         | 1.4                                                                                   | -    | 1.4              | -    | tCK  |      |

|                                    |                                                                                       |                                                                          |      |      |      |       |       |
|------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------|------|------|------|-------|-------|
| tLZ(DQ)                            | DQ low-impedance time from CK, CK#                                                    | Min: (RL x tck) + tDQSCK(min) - 200ps                                    |      |      |      | ps    |       |
| tHZ(DQ)                            | DQ high impedance time from CK, CK#                                                   | Max: (RL x tck) + tDQSCK(max) + tDQSQ(max) + (BL/2xtck) - 100ps          |      |      |      | ps    |       |
| tLZ(DQS)                           | DQS# low-impedance time from CK, CK#                                                  | Min: (RL x tck) + tDQSCK(min) - (tRPRE(max) X tck) - 200ps               |      |      |      | ps    |       |
| tHZ(DQS)                           | DQS# high impedance time from CK, CK#                                                 | Max: (RL x tck) + tDQSCK(max) +(BL/2 x tck) + (tRPST(max) X tck) - 100ps |      |      |      | ps    |       |
| tDQSQ                              | DQS-DQ skew                                                                           | -                                                                        | 0.18 | -    | 0.18 | UI    |       |
| tDQSCK Timing                      |                                                                                       |                                                                          |      |      |      |       |       |
| tDQSCK                             | DQS Output Access Time from CK/CK#                                                    | 1.5                                                                      | 3.5  | 1.5  | 3.5  | ns    | 11-13 |
| tDQSCK_temp                        | DQS Output Access Time from CK/CK# - Temperature Variation                            | -                                                                        | 4    | -    | 4    | ps/°C | 11-13 |
| tDQSCK_volt                        | DQS Output Access Time from CK/CK# - Voltage Variation                                | -                                                                        | 7    | -    | 7    | ps/mV | 11-13 |
| tDQSCK_rank2rank                   | CK to DQS Rank to Rank variation                                                      | -                                                                        | 1.0  | -    | 1.0  | ns    | 14,15 |
| Write AC Timing                    |                                                                                       |                                                                          |      |      |      |       |       |
| tDQSS                              | Write command to 1st DQS latching                                                     | 0.75                                                                     | 1.25 | 0.75 | 1.25 | tck   |       |
| tDQSH                              | DQS input high-level                                                                  | 0.4                                                                      | -    | 0.4  | -    | tck   |       |
| tDQSL                              | DQS input low-level width                                                             | 0.4                                                                      | -    | 0.4  | -    | tck   |       |
| tDSS                               | DQS falling edge to CK setup time                                                     | 0.2                                                                      | -    | 0.2  | -    | tck   |       |
| tDSH                               | DQS falling edge hold time from CK                                                    | 0.2                                                                      | -    | 0.2  | -    | tck   |       |
| tWPRE                              | Write preamble                                                                        | 1.8                                                                      | -    | 1.8  | -    | tck   |       |
| tWPST                              | 0.5 tCK Write postamble                                                               | 0.4                                                                      | -    | 0.4  | -    | tck   | 16    |
| tWPST                              | 1.5 tCK Write postamble                                                               | 1.4                                                                      | -    | 1.4  | -    | tck   | 16    |
| Write Leveling Timing              |                                                                                       |                                                                          |      |      |      |       |       |
| twLDQSEN                           | DQS/DQS# delay after write leveling mode is programmed                                | 20                                                                       | -    | 20   | -    | tck   |       |
| twLWPRE                            | Write preamble for Write Leveling                                                     | 20                                                                       | -    | 20   | -    | tck   |       |
| twLMRD                             | First DQS/DQS# edge after write leveling mode is programmed                           | 40                                                                       | -    | 40   | -    | tck   |       |
| twLO                               | Write leveling output delay                                                           | 0                                                                        | 20   | 0    | 20   | ns    |       |
| tMRD                               | Mode register set command delay                                                       | Min: max(14ns, 10nCK)                                                    |      |      |      | ns    |       |
| tCKPRDQS                           | Valid Clock Requirement before DQS Toggle                                             | Min: max(7.5ns, 4nCK)                                                    |      |      |      | -     |       |
| tCKPSTDQS                          | Valid Clock Requirement after DQS Toggle                                              | Min: max(7.5ns, 4nCK)                                                    |      |      |      | -     |       |
| twLH                               | Write leveling hold time                                                              | 50                                                                       | -    | 60   | -    | ps    |       |
| twLS                               | Write leveling setup time                                                             | 50                                                                       | -    | 60   | -    | ps    |       |
| twLIVW                             | Write leveling input valid window                                                     | 90                                                                       | -    | 100  | -    | ps    |       |
| Power-Down AC Timing               |                                                                                       |                                                                          |      |      |      |       |       |
| tCKE                               | CKE minimum pulse width (HIGH and LOW pulse width)                                    | Min: max(7.5ns, 4nCK)                                                    |      |      |      | -     |       |
| tCMDCKE                            | Delay from valid command to CKE input LOW                                             | Min: max(1.75ns, 3nCK)                                                   |      |      |      | ns    | 17    |
| tCKELCK                            | Valid Clock Requirement after CKE Input low                                           | Min: max(5ns, 5nCK)                                                      |      |      |      | ns    | 17    |
| tCSCKE                             | Valid CS Requirement before CKE Input Low                                             | Min: 1.75                                                                |      |      |      | ns    |       |
| tCKELCS                            | Valid CS Requirement after CKE Input low                                              | Min: max(5ns, 5nCK)                                                      |      |      |      | ns    |       |
| tCKCKEH                            | Valid Clock Requirement before CKE Input High                                         | Min: max(1.75ns, 3nCK)                                                   |      |      |      | ns    | 17    |
| txP                                | Exit power- down to next valid command delay                                          | Min: max(7.5ns, 5nCK)                                                    |      |      |      | ns    | 17    |
| tCSCKEH                            | Valid CS Requirement before CKE Input High                                            | Min: 1.75                                                                |      |      |      | ns    |       |
| tCKEHCS                            | Valid CS Requirement after CKE Input High                                             | Min: max(7.5ns, 5nCK)                                                    |      |      |      | ns    |       |
| tMRWCKEL                           | Valid Clock and CS Requirement after CKE Input low after MRW Command                  | Min: max(14ns, 10nCK)                                                    |      |      |      | ns    | 17    |
| tZQCKE                             | Valid Clock and CS Requirement after CKE Input low after ZQ Calibration Start Command | Min: max(1.75ns, 3nCK)                                                   |      |      |      | ns    | 17    |
| Mode Register Read/Write AC timing |                                                                                       |                                                                          |      |      |      |       |       |
| tMRRI                              | Additional time after txP has expired until MRR command may be issued                 | Min: tRCD + 3nCK                                                         |      |      |      | -     |       |

|                                   |                                                                                    |                                            |     |     |     |                 |       |
|-----------------------------------|------------------------------------------------------------------------------------|--------------------------------------------|-----|-----|-----|-----------------|-------|
| tMRR                              | Mode Register Read command period                                                  | Min: 8                                     |     |     |     | nCK             |       |
| tMRW                              | Mode Register Write command period                                                 | Min: max(10ns, 10nCK)                      |     |     |     | -               |       |
| tMRD                              | Mode register set command delay                                                    | Min: max(14ns, 10nCK)                      |     |     |     | -               |       |
| Asynchronous ODT Timing           |                                                                                    |                                            |     |     |     |                 |       |
| tODT <sub>on</sub>                | Asynchronous ODT Turn On                                                           | 1.5                                        | 3.5 | 1.5 | 3.5 | ns              |       |
| tODT <sub>off</sub>               | Asynchronous ODT Turn Off                                                          | 1.5                                        | 3.5 | 1.5 | 3.5 | ns              |       |
| Self-Refresh Timing Parameters    |                                                                                    |                                            |     |     |     |                 |       |
| tESCKE                            | Delay from SRE command to CKE Input low                                            | Min: max(1.75ns, 3tCK)                     |     |     |     | ns              | 18    |
| tSR                               | Minimum Self Refresh Time                                                          | Min: max(15ns, 3tCK)                       |     |     |     | ns              | 18    |
| tXSR                              | Exit Self Refresh to Valid commands                                                | Min: max(tRFC <sub>ab</sub> + 7.5ns, 2tCK) |     |     |     | ns              | 18,19 |
| Command Bus Training AC Timing    |                                                                                    |                                            |     |     |     |                 |       |
| tCKELCK                           | Valid Clock Requirement after CKE Input low                                        | Min: max(5ns, 5nCK)                        |     |     |     | -               |       |
| tDStrain                          | Data Setup for VREF Training Mode                                                  | 2                                          | -   | 2   | -   | ns              |       |
| tDHtrain                          | Data Hold for VREF Training Mode                                                   | 2                                          | -   | 2   | -   | ns              |       |
| tADR                              | Asynchronous Data Read                                                             | -                                          | 20  | -   | 20  | ns              |       |
| tCACD                             | CA Bus Training Command to CA Bus Training Command Delay                           | Min: RU(tADR/tCK )                         |     |     |     | t <sub>CK</sub> | 21    |
| tDQSCKE                           | Valid Strobe Requirement before CKE Low                                            | 10                                         | -   | 10  | -   | ns              | 20    |
| tCAENT                            | First CA Bus Training Command Following CKE Low                                    | 250                                        | -   | 250 | -   | ns              |       |
| tVREFCA_LONG                      | VREF Step Time – multiple steps                                                    | -                                          | 250 | -   | 250 | ns              |       |
| tVREFCA_SHORT                     | Vref Step Time -one step                                                           | -                                          | 80  | -   | 80  | ns              |       |
| tCKPRECS                          | Valid Clock Requirement before CS High                                             | Min: 2tCK + tXP                            |     |     |     | -               |       |
| tCKPSTCS                          | Valid Clock Requirement after CS High                                              | Min: max(7.5ns, 5nCK)                      |     |     |     | -               |       |
| tCS_VREF                          | Minimum delay from CS to DQS toggle in command bus training                        | 2                                          | -   | 2   | -   | t <sub>CK</sub> |       |
| tCKEHDQS                          | Minimum delay from CKE High to Strobe High Impedance                               | 10                                         | -   | 10  | -   | ns              |       |
| tCKCKEH                           | Valid Clock Requirement before CKE input High                                      | Min: max(1.75ns, 3nCK)                     |     |     |     | -               |       |
| tMRZ                              | CA Bus Training CKE High to DQ Tri-state                                           | 1.5                                        | -   | 1.5 | -   | ns              |       |
| tCKELOD <sub>on</sub>             | ODT turn-on Latency from CKE                                                       | 20                                         | -   | 20  | -   | ns              |       |
| tCKELOD <sub>off</sub>            | ODT turn-off Latency from CKE                                                      | 20                                         | -   | 20  | -   | ns              |       |
| tXCBT_Short                       | Exit Command Bus Training Mode to next valid command delay                         | Min: max(5nCK, 200ns)                      |     |     |     | -               | 22    |
| tXCBT_Middle                      |                                                                                    | Min: max(5nCK, 200ns)                      |     |     |     | -               | 22    |
| tXCBT_Long                        |                                                                                    | Min: max(5nCK, 250ns)                      |     |     |     | -               | 22    |
| MPC Write FIFO Timing             |                                                                                    |                                            |     |     |     |                 |       |
| tMPCW <sub>R</sub>                | Additional time after tXP has expired until MPC [Write FIFO] command may be issued | Min: tRCD + 3nCK                           |     |     |     |                 |       |
| DQS Interval Oscillator AC Timing |                                                                                    |                                            |     |     |     |                 |       |
| t <sub>OSCO</sub>                 | Delay time from OSC stop to Mode Register Readout                                  | Min: max(40ns, 8nCK)                       |     |     |     | ns              | 23    |
| Read Preamble Training Timing     |                                                                                    |                                            |     |     |     |                 |       |
| t <sub>SDO</sub>                  | Delay from MRW command to DQS Driven                                               | Max: max(12nCK, 20ns)                      |     |     |     | ns              |       |
| ZQ Calibration Timing             |                                                                                    |                                            |     |     |     |                 |       |
| t <sub>ZQCAL</sub>                | ZQ Calibration Time                                                                | Min: 1                                     |     |     |     | us              |       |
| t <sub>ZQLAT</sub>                | ZQ Calibration Latch Time                                                          | Min: max(30ns, 8nCK)                       |     |     |     | ns              |       |
| t <sub>ZQRESET</sub>              | ZQ Calibration Reset Time                                                          | Min: max(50ns, 3nCK)                       |     |     |     | ns              |       |
| ODT CA Timing                     |                                                                                    |                                            |     |     |     |                 |       |
| t <sub>ODTUP</sub>                | ODT CA Value Update Time                                                           | Min: RU(20ns/tCK(avg))                     |     |     |     |                 |       |
| Frequency Set Point Timing        |                                                                                    |                                            |     |     |     |                 |       |
| t <sub>FC_Short</sub>             | Frequency Set Point Switching Time                                                 | 200                                        | -   | 200 | -   | ns              | 6     |
| t <sub>FC_Middle</sub>            | Minimum Self Refresh Time                                                          | 200                                        | -   | 200 | -   | ns              | 6     |

|                                    |                                                                   |                   |   |     |   |    |   |
|------------------------------------|-------------------------------------------------------------------|-------------------|---|-----|---|----|---|
| t <sub>FC_Long</sub>               | Exit Self Refresh to Valid command                                | 250               | - | 250 | - | ns | 6 |
| t <sub>CKFSPE</sub>                | Valid Clock Requirement after Entering FSP Change                 | max(7.5ns, 4nCK)  |   |     |   | -  |   |
| t <sub>CKFSPX</sub>                | Valid Clock Requirement before 1st Valid Command after FSP change | max(7.5ns, 4nCK)  |   |     |   | -  |   |
| Temperature Derating <sup>24</sup> |                                                                   |                   |   |     |   |    |   |
| t <sub>DQSCK</sub>                 | DQS output access time from CK/CK# (derated)                      | Max: 3600         |   |     |   | ps |   |
| t <sub>RCD</sub>                   | RAS-to-CAS delay (derated)                                        | Min: tRCD + 1.875 |   |     |   | ns |   |
| t <sub>RC</sub>                    | ACTIVATE-to- ACTIVATE command period (derated)                    | Min: tRC + 3.75   |   |     |   | ns |   |
| t <sub>RAS</sub>                   | Row active time (derated)                                         | Min: tRAS + 1.875 |   |     |   | ns |   |
| t <sub>RP</sub>                    | Row precharge time (derated)                                      | Min: tRP + 1.875  |   |     |   | ns |   |
| t <sub>RRD</sub>                   | Active bank A to active bank B (derated)                          | Min: tRRD + 1.875 |   |     |   | ns |   |

**Notes:**

1. Precharge to precharge timing restriction does not apply to Auto-Precharge commands.
2. Devices supporting 4267 Mbps specification shall support these timings at lower data rates.
3. The value is based on BL16. For BL32 need additional 8 tCK(avg) delay.
4. Refresh Rate is specified by MR4, OP[2:0]
5. The deterministic component of the total timing. Measurement method tbd.
6. Frequency Set Point Switching Time depends on value of VREF(CA) setting: MR12 OP[5:0] and VREF(CA) Range:MR12 OP[6] of FSP-OP 0 and 1. Additionally change of Frequency Set Point may affect VREF(DQ) setting. Settling time of VREF(DQ) level is same as VREF(CA) level.
7. This parameter is function of input clock jitter. These values assume the min tCH(abs) and tCL(abs). When the input clock jitter min tCH(abs) and tCL(abs) is 0.44 or greater of tck(avg) the min value of tQSL will be tCL(abs)-0.04 and tQSH will be tCH(abs) - 0.04.
8. tQSL describes the instantaneous differential output low pulse width on DQS – DQS#, as it measured the next rising edge from an arbitrary falling edge.
9. tQSH describes the instantaneous differential output high pulse width on DQS – DQS#, as it measured the next rising edge from an arbitrary falling edge.
10. This parameter is function of input clock jitter. These values assume the min tCH(abs) and tCL(abs). When the input clock jitter min tCH(abs) and tCL(abs) is 0.44 or greater of tck(avg) the min value of tQSL will be tCL(abs)-0.04 and tQSH will be tCH(abs) - 0.04.
11. Includes DRAM process, voltage and temperature variation. It includes the AC noise impact for frequencies > 20 MHz and max voltage of 45 mV pk-pk from DC-20 MHz at a fixed temperature on the package. The voltage supply noise must comply to the component Min-Max DC Operating conditions.
12. tDQSCK\_temp max delay variation as a function of Temperature.
13. tDQSCK\_volt max delay variation as a function of DC voltage variation for VDDQ and VDD2. tDQSCK\_volt should be used to calculate timing variation due to VDDQ and VDD2 noise < 20 MHz. Host controller do not need to account for any variation due to VDDQ and VDD2 noise > 20 MHz. The voltage supply noise must comply to the component Min-Max DC Operating conditions. The voltage variation is defined as the Max[abs{tDQSCKmin@V1- tDQSCKmax@V2}, abs{tDQSCKmax@V1- tDQSCKmin@V2}]/abs{V1- V2}. For tester measurement VDDQ = VDD2 is assumed.
14. The same voltage and temperature are applied to tDQS2CK\_rank2rank.
15. tDQSCK\_rank2rank parameter is applied to multi-ranks per byte lane within a package consisting of the same design dies.
16. The length of Write Postamble depends on MR3 OP1 setting.
17. Delay time has to satisfy both analog time(ns) and clock count(nCK).
18. Delay time has to satisfy both analog time(ns) and clock count(tCK). It means that tESCKE will not expire until CK has toggled through at least 3 full cycles (3 x tCK) and 1.75ns has transpired.
19. MRR-1, CAS-2, DES, MPC, MRW-1 and MRW-2 except PASR Bank/Segment setting are only allowed during this period.
20. DQS has to retain a low level during tDQSCKE period, as well as DQS# has to retain a high level.
21. If tCACD is violated, the data for samples which violate tCACD will not be available, except for the last sample (where tCACD after this sample is met). Valid data for the last sample will be available after tADR.
22. Exit Command Bus Training Mode to next valid command delay Time depends on value of VREF(CA) setting: MR12 OP[5:0] and VREF(CA) Range: MR12 OP[6] of FSP-OP 0 and 1. Additionally exit Command Bus Training Mode to next valid command delay Time may affect VREF(DQ) setting. Settling time of VREF(DQ) level is same as VREF(CA) level.
23. Start DQS OSC command is prohibited until tOSCO(Min) is satisfied.
24. Timing derating applies for operation at 85 °C to 105 °C.

## Single Ended Output Slew Rate

Figure 46. Single Ended Output Slew Rate Definition

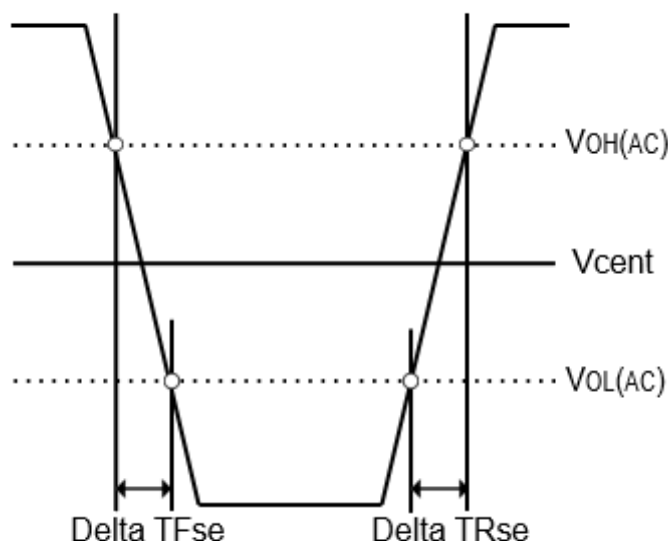


Table 83. Output Slew Rate (Single-ended)

| Symbol | Parameter                                              | Value             |                   | Unit |
|--------|--------------------------------------------------------|-------------------|-------------------|------|
|        |                                                        | Min. <sup>1</sup> | Max. <sup>2</sup> |      |
| SRQse  | Single-ended Output Slew Rate ( $V_{OH} = V_{DDQ}/3$ ) | 3.5               | 9                 | V/ns |
| -      | Output slew-rate matching Ratio (Rise to Fall)         | 0.8               | 1.2               | -    |

**Notes:**

- Description:  
SR: Slew Rate  
Q: Query Output (like in DQ, which stands for Data-in, Query-Output)  
se: Single-ended Signals
- Measured with output reference load.
- 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, it represents the maximum difference between pull-up and pull-down drivers due to process variation.
- The output slew rate for falling and rising edges is defined and measured between  $V_{OL(AC)} = 0.2 \times V_{OH(DC)}$  and  $V_{OH(AC)} = 0.8 \times V_{OH(DC)}$ .
- Slew rates are measured under average SSO conditions, with 50% of DQ signals per data byte switching.

## Differential Output Slew Rate

Figure 47. Differential Output Slew Rate Definition

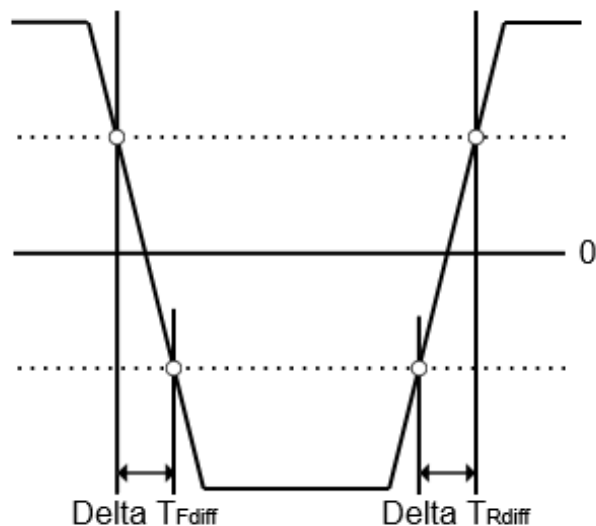


Table 84. Differential Output Slew Rate

| Symbol  | Parameter                                              | Value |      | Unit |
|---------|--------------------------------------------------------|-------|------|------|
|         |                                                        | Min.  | Max. |      |
| SRQdiff | Differential Output Slew Rate ( $V_{OH} = V_{DDQ}/3$ ) | 7     | 18   | V/ns |

**Notes:**

- Description:  
SR: Slew Rate  
Q: Query Output (like in DQ, which stands for Data-in, Query-Output)  
diff: Differential Signals
- Measured with output reference load.
- The output slew rate for falling and rising edges is defined and measured between  $V_{OL(AC)} = -0.8 \times V_{OH(DC)}$  and  $V_{OH(AC)} = 0.8 \times V_{OH(DC)}$ .
- Slew rates are measured under average SSO conditions, with 50% of DQ signals per data byte switching.

## AC and DC Input/Output Measurement Levels

### 1.1 V High speed LVCMOS (HS LLVCMOS)

**Standard specifications:** All voltages are referenced to ground except where noted.

#### DC electrical characteristics

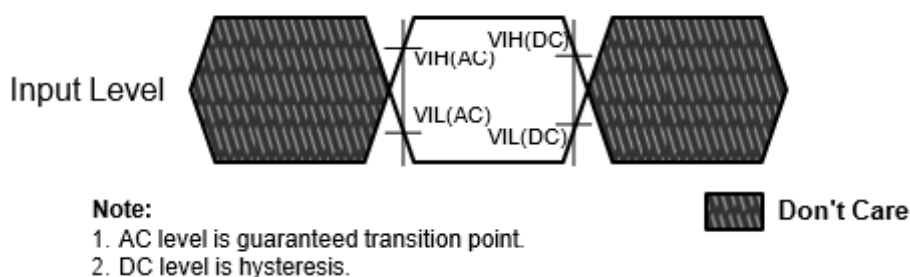
**Table 85. Input Level for CKE**

| Symbol  | Parameter             | Value                 |                       | Unit | Note |
|---------|-----------------------|-----------------------|-----------------------|------|------|
|         |                       | Min.                  | Max.                  |      |      |
| VIH(AC) | Input high level (AC) | $0.75 \times V_{DD2}$ | $V_{DD2} + 0.2$       | V    | 1    |
| VIL(AC) | Input low level (AC)  | -0.2                  | $0.25 \times V_{DD2}$ | V    | 1    |
| VIH(DC) | Input high level (DC) | $0.65 \times V_{DD2}$ | $V_{DD2} + 0.2$       | V    |      |
| VIL(DC) | Input low level (DC)  | -0.2                  | $0.35 \times V_{DD2}$ | V    |      |

**Notes:**

1. Refer AC Overshoot and Undershoot.

**Figure 48. Input AC timing definition for CKE**

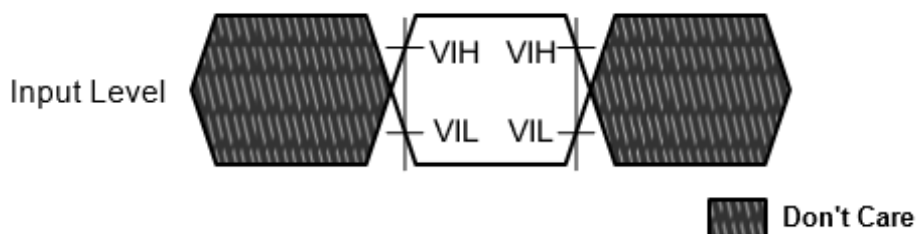


**Table 86. Input Level for Reset# and ODT\_CA**

| Symbol | Parameter        | Value                |                      | Unit | Note |
|--------|------------------|----------------------|----------------------|------|------|
|        |                  | Min.                 | Max.                 |      |      |
| VIH    | Input high level | $0.8 \times V_{DD2}$ | $V_{DD2} + 0.2$      | V    | 1    |
| VIL    | Input low level  | -0.2                 | $0.2 \times V_{DD2}$ | V    | 1    |

**Notes:**

1. Refer AC Overshoot and Undershoot.

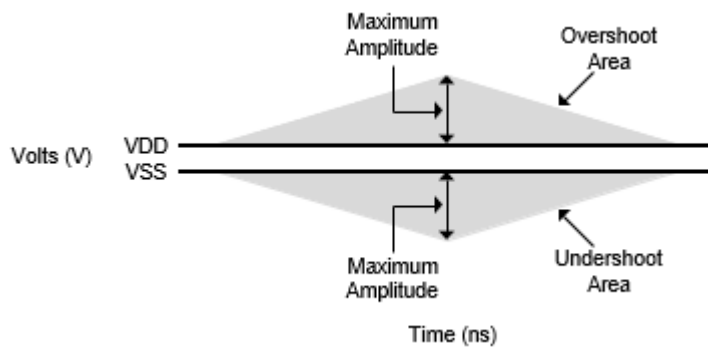
**Figure 49. Input AC timing definition for Reset# and ODT\_CA**

## AC Overshoot/Undershoot Specifications

**Table 83. AC Overshoot/Undershoot**

| Parameter                                          | Values | Unit |
|----------------------------------------------------|--------|------|
| Maximum peak Amplitude allowed for overshoot area  | 0.35   | V    |
| Maximum peak Amplitude allowed for undershoot area | 0.35   | V    |
| Maximum overshoot area above VDD                   | 0.8    | V-ns |
| Maximum undershoot area below VSS                  | 0.8    | V-ns |

**Figure 50. AC Overshoot and Undershoot Definition for Address and Control Pins**

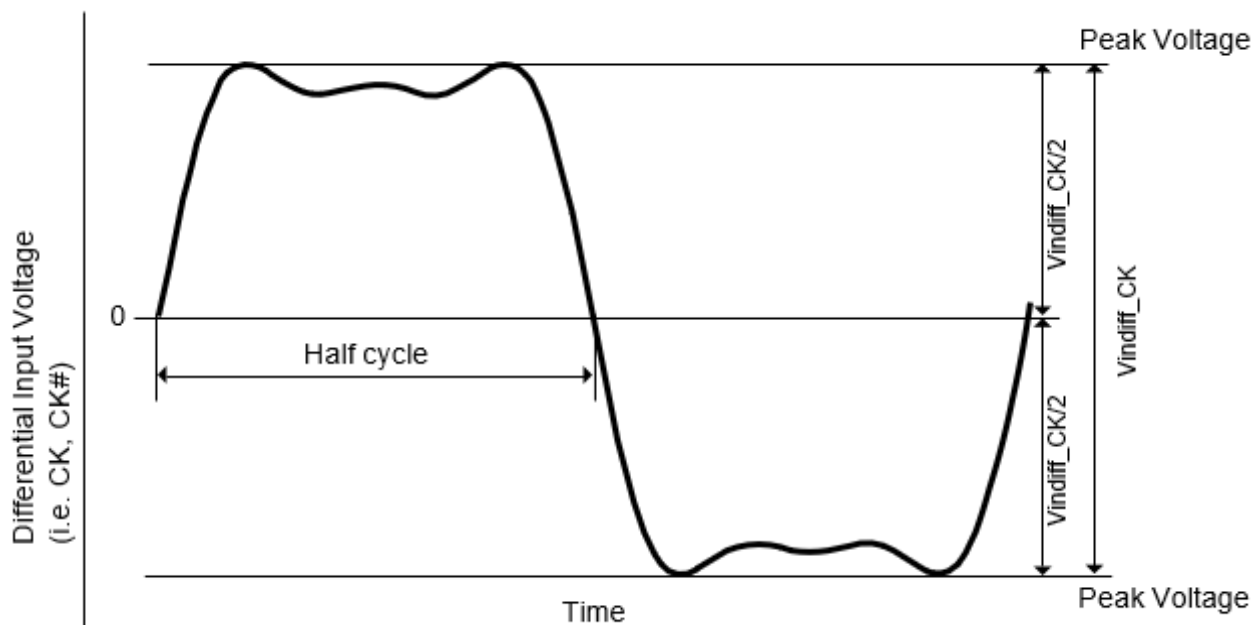


## Differential Input Voltage

### Differential Input Voltage for CK

The minimum input voltage need to satisfy both Vindiff\_CK and Vindiff\_CK/2 specification at input receiver and their measurement period is 1tCK. Vindiff\_CK is the peak to peak voltage centered on 0 volts differential and Vindiff\_CK/2 is max and min peak voltage from 0V.

**Figure 51. CK Differential Input Voltage**



**Table 87. CK Differential Input Voltage**

| Symbol     | Parameter                     | 4266/3733 |      | Unit | Note |
|------------|-------------------------------|-----------|------|------|------|
|            |                               | Min.      | Max. |      |      |
| Vindiff_CK | CK differential input voltage | 360       | -    | mV   | 1    |

**Notes:**

- The peak voltage of Differential CK signals is calculated in a following equation.  

$$\text{Vindiff\_CK} = (\text{Max Peak Voltage}) - (\text{Min Peak Voltage})$$

$$\text{Max Peak Voltage} = \text{Max}(f(t))$$

$$\text{Min Peak Voltage} = \text{Min}(f(t))$$

$$f(t) = \text{VCK} - \text{VCK\#}$$

**Peak voltage calculation method**

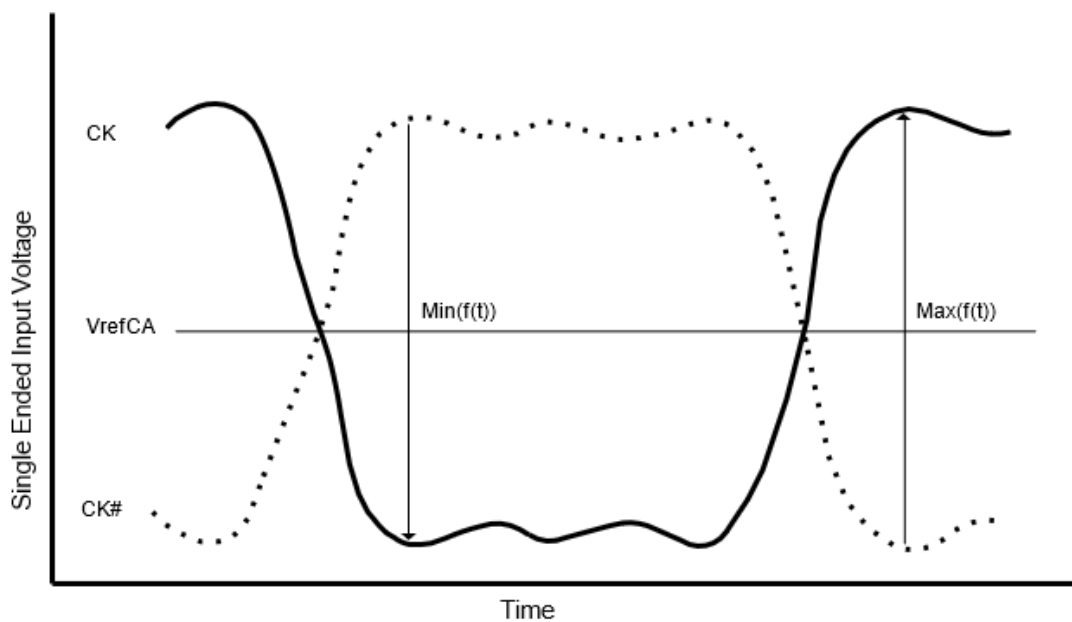
The peak voltage of Differential Clock signals are calculated in the following equation.

$$VIH.DIFF.Peak\ Voltage = \text{Max}(f(t))$$

$$VIL.DIFF.Peak\ Voltage = \text{Min}(f(t))$$

$$f(t) = VCK - VCK\#$$

**Figure 52. Definition of differential Clock Peak Voltage**

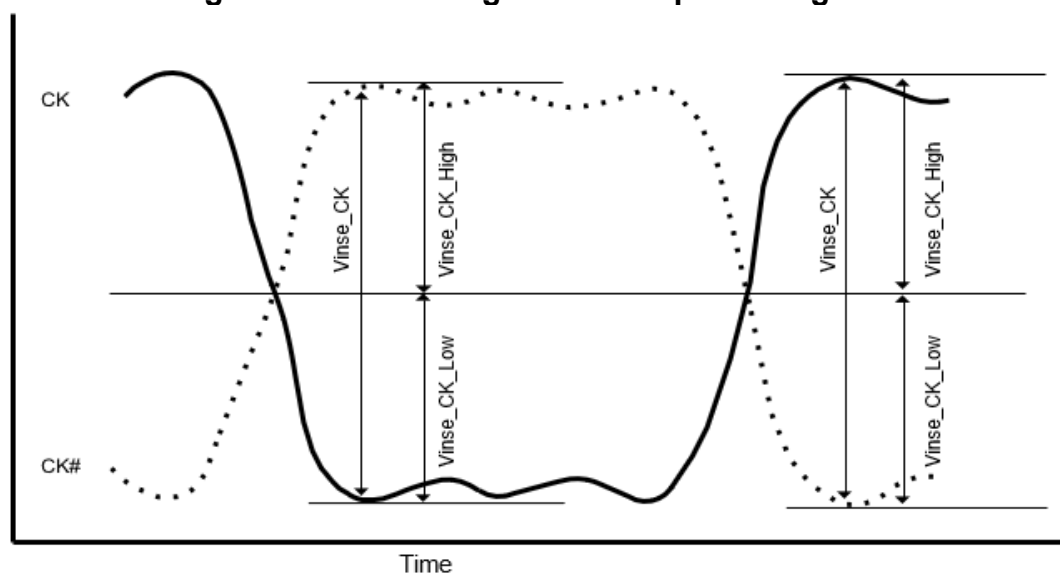


NOTES : 1. VREFCA is LPDDR4 SDRAM internal setting value by VREF Training.

### Single-Ended Input Voltage for Clock

The minimum input voltage needs to satisfy both  $V_{inse\_CK}$ ,  $V_{inse\_CK\_High/Low}$  specification at input receiver.

**Figure 53. Clock Single-Ended Input Voltage**



NOTES : 1. VREFCA is LPDDR4 SDRAM internal setting value by VREF Training

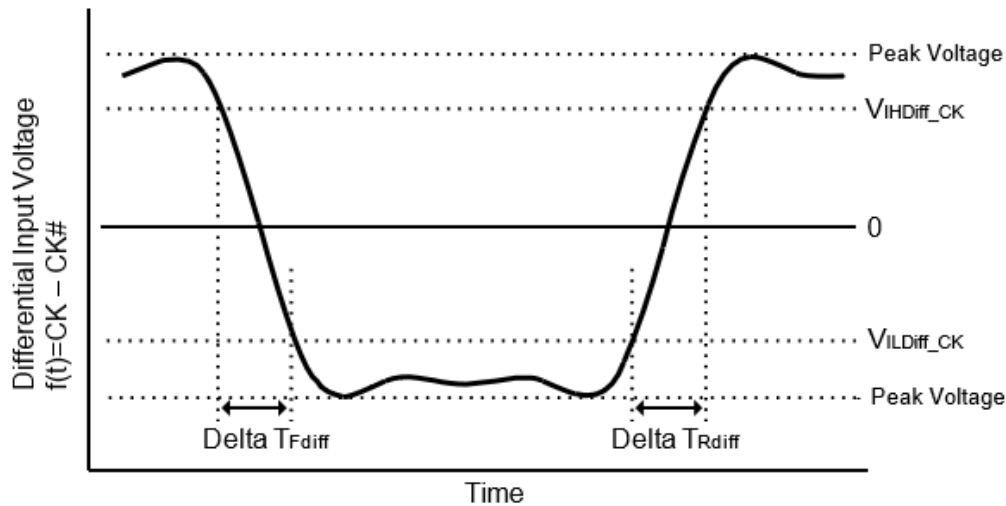
**Table 83. Clock Single-Ended Input Voltage**

| Symbol               | Parameter                                              | 4266/3733 |      | Unit |
|----------------------|--------------------------------------------------------|-----------|------|------|
|                      |                                                        | Min.      | Max. |      |
| $V_{inse\_CK}$       | Clock Single-Ended input voltage                       | 180       | -    | mV   |
| $V_{inse\_CK\_High}$ | Clock Single-Ended input voltage High from $V_{REFDQ}$ | 90        | -    | mV   |
| $V_{inse\_CK\_Low}$  | Clock Single-Ended input voltage Low from $V_{REFDQ}$  | 90        | -    | mV   |

### Differential Input Slew Rate Definition for Clock

Input slew rate for differential signals (CK, CK#) are defined and measured as shown below in figure and the tables.

**Figure 54. Differential Input Slew Rate Definition for CK, CK#**



NOTE 1. Differential signal rising edge from VILdiff\_CK to VIHdiff\_CK must be monotonic slope.  
NOTE 2. Differential signal falling edge from VIHdiff\_CK to VILdiff\_CK must be monotonic slope.

**Table 83. Differential Input Slew Rate Definition for CK, CK#**

| Description                                              | From       | To         | Defined by                                    |
|----------------------------------------------------------|------------|------------|-----------------------------------------------|
| Differential input slew rate for rising edge (CK – CK#)  | VILdiff_CK | VIHdiff_CK | $ VILdiff\_CK - VIHdiff\_CK  / \Delta TRdiff$ |
| Differential input slew rate for falling edge (CK – CK#) | VIHdiff_CK | VILdiff_CK | $ VILdiff\_CK - VIHdiff\_CK  / \Delta TFdiff$ |

**Table 83. Differential Input Level for CK, CK#**

| Symbol     | Parameter               | 4266/3733 |      | Unit |
|------------|-------------------------|-----------|------|------|
|            |                         | Min.      | Max. |      |
| VIHdiff_CK | Differential Input High | 145       | -    | mV   |
| VILdiff_CK | Differential Input Low  | -         | -145 | mV   |

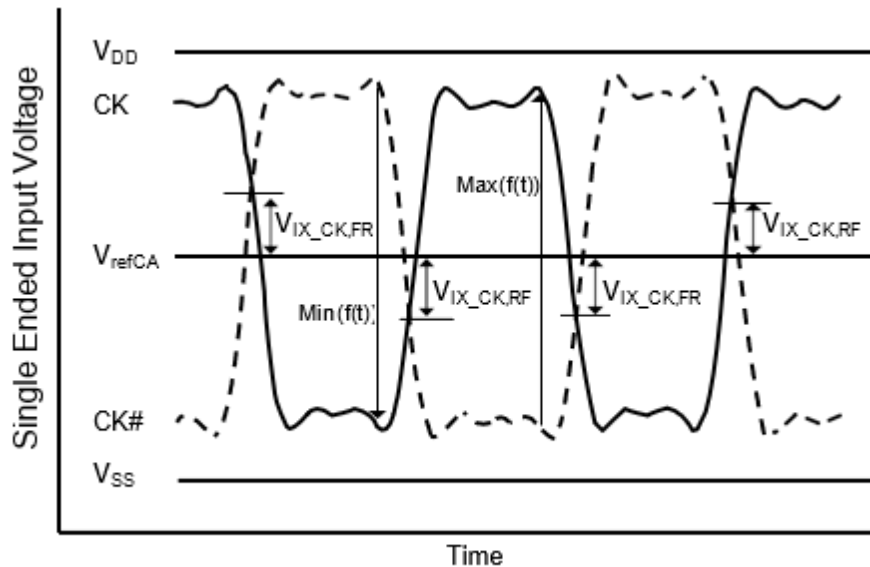
**Table 84. Differential Input Slew Rate Definition for CK, CK#**

| Symbol     | Parameter                              | 4266/3733 |      | Unit |
|------------|----------------------------------------|-----------|------|------|
|            |                                        | Min.      | Max. |      |
| SRIdiff_CK | Differential Input Slew Rate for Clock | 2         | 14   | V/ns |

### Differential Input Cross Point Voltage

The cross point voltage of differential input signals (CK, CK#) must meet the requirements in table below. The differential input cross point voltage VIX is measured from the actual cross point of true and complement signals to the mid level that is VREF(CA).

**Figure 55. Vix Definition (Clock)**



NOTES :

1. The base level of Vix\_CK\_FR/RF is VREFCA that is LPDDR4 SDRAM internal setting value by VREF Training.

**Table 85. Cross point voltage for differential input signals (Clock)**

| Symbol       | Parameter                                          | 4266/3733 |      | Unit | Note |
|--------------|----------------------------------------------------|-----------|------|------|------|
|              |                                                    | Min.      | Max. |      |      |
| Vix_CK_ratio | Clock Differential input cross point voltage ratio | -         | 25   | %    | 1,2  |

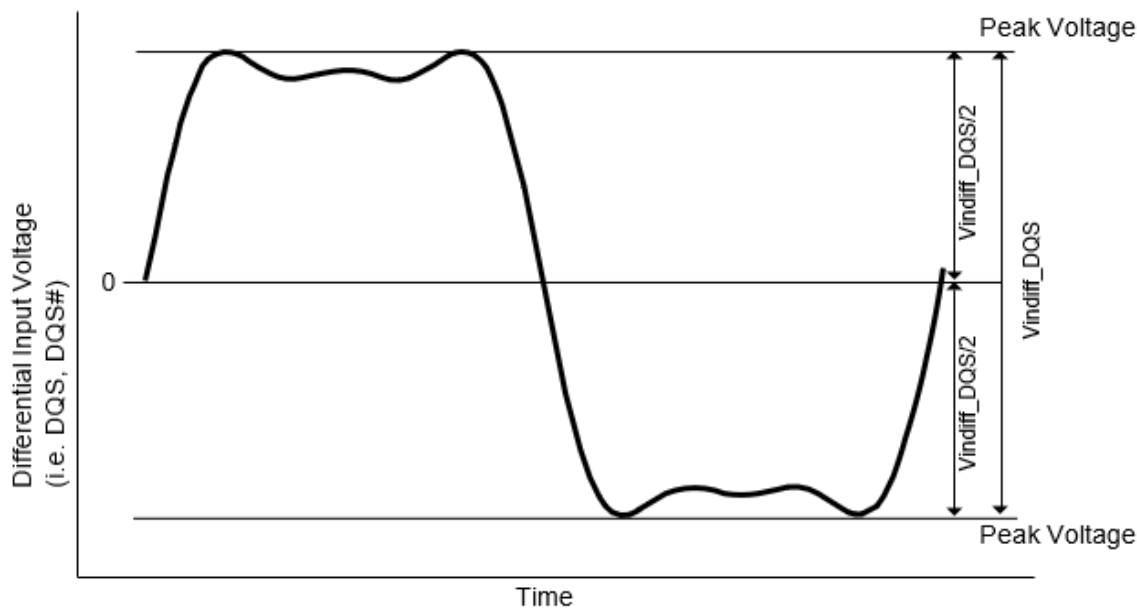
**Notes:**

1. Vix\_CK\_Ratio is defined by this equation:  $Vix\_CK\_Ratio = Vix\_CK\_FR / |Min(f(t))|$
2. Vix\_CK\_Ratio is defined by this equation:  $Vix\_CK\_Ratio = Vix\_CK\_RF / Max(f(t))$
3. Vix\_CK\_FR is defined as delta between cross point (CK\_t fall, CK\_c rise) to  $Min(f(t))/2$ .
4. Vix\_CK\_RF is defined as delta between cross point (CK\_t rise, CK\_c fall) to  $Max(f(t))/2$ .
5. In LPDDR4 un-terminated case, Mid-level must be equal or lower than 369mV (33.6% of VDD2).

### Differential Input Voltage for DQS

The minimum input voltage need to satisfy both Vindiff\_DQS and Vindiff\_DQS/2 specification at input receiver and their measurement period is 1UI (tCK/2). Vindiff\_DQS is the peak to peak voltage centered on 0 volts differential and Vindiff\_DQS/2 is max and min peak voltage from 0V.

**Figure 56. DQS Differential Input Voltage**



**Table 86. DQS Differential Input Voltage**

| Symbol      | Parameter              | 4266/3733 |      | Unit | Note |
|-------------|------------------------|-----------|------|------|------|
|             |                        | Min.      | Max. |      |      |
| Vindiff_DQS | DQS differential input | 340       | -    | mV   | 1    |

**Notes:**

- The peak voltage of Differential DQS signals is calculated in a following equation.  

$$\text{Vindiff\_DQS} = (\text{Max Peak Voltage}) - (\text{Min Peak Voltage})$$

$$\text{Max Peak Voltage} = \text{Max}(f(t))$$

$$\text{Min Peak Voltage} = \text{Min}(f(t))$$

$$f(t) = \text{VDQS} - \text{VDQS\#}$$

**Peak voltage calculation method**

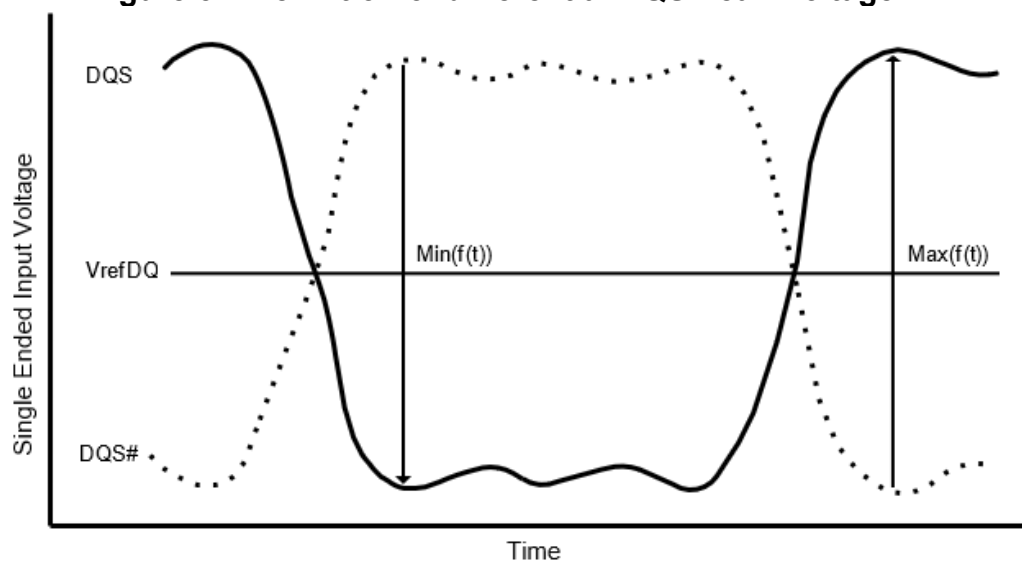
The peak voltage of Differential DQS signals are calculated in a following equation.  $V_{IH.DIFF.Peak}$

Voltage =  $\text{Max}(f(t))$

$V_{IL.DIFF.Peak}$  Voltage =  $\text{Min}(f(t))$   $f(t) =$

$V_{DQS} - V_{DQS\#}$

**Figure 57. Definition of differential DQS Peak Voltage**

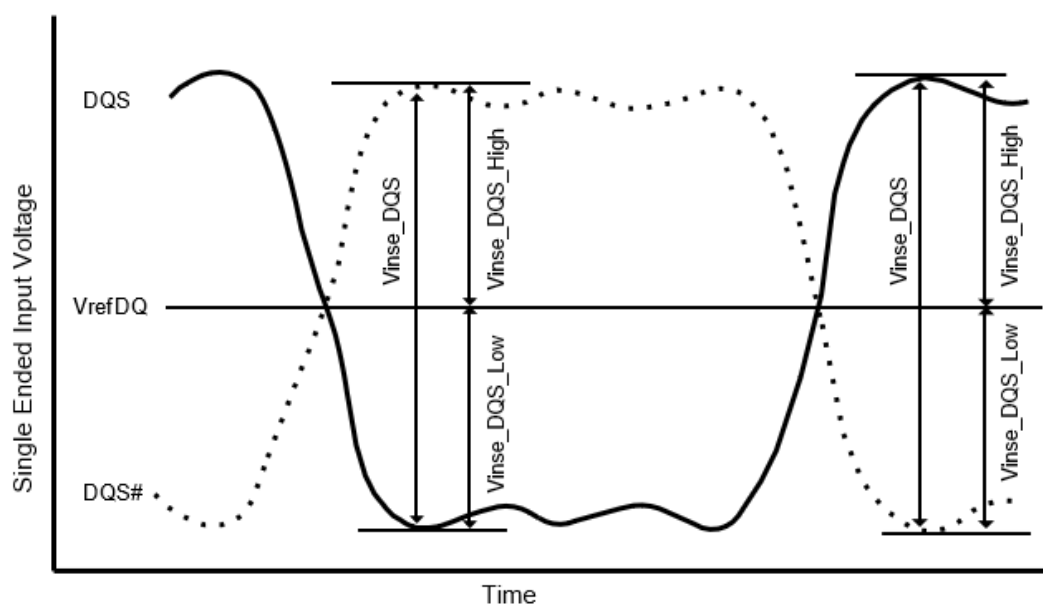


NOTES : 1.  $V_{refDQ}$  is LPDDR4 SDRAM internal setting value by  $V_{ref}$  Training.

### Single-Ended Input Voltage for DQS

The minimum input voltage need to satisfy both  $V_{inse\_DQS}$ ,  $V_{inse\_DQS\_High/Low}$  specification at input receiver.

**Figure 58. DQS Single-Ended Input Voltage**



NOTES : 1.  $V_{refDQ}$  is LPDDR4 SDRAM internal setting value by Vref Training.

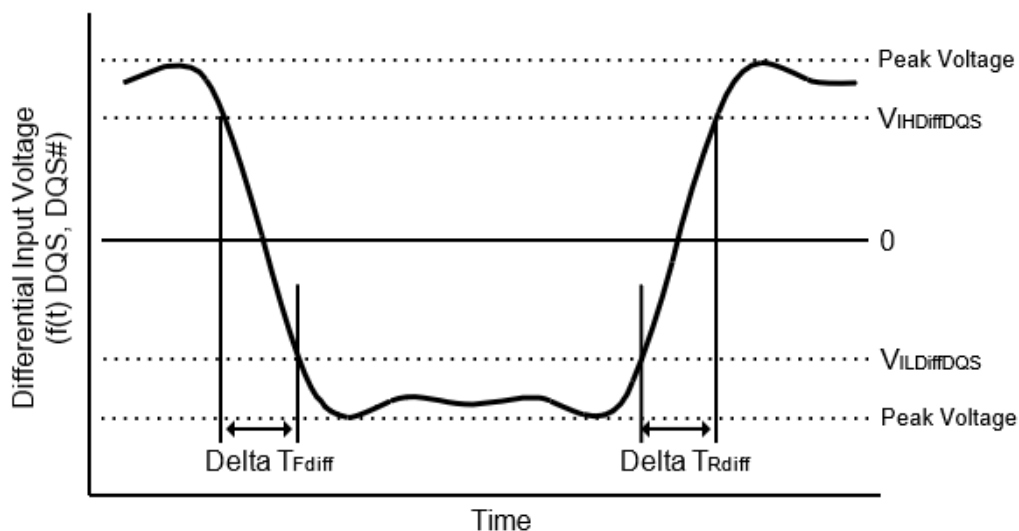
**Table 83. DQS Single-Ended Input Voltage**

| Symbol                | Parameter                                            | 4266/3733 |      | Unit |
|-----------------------|------------------------------------------------------|-----------|------|------|
|                       |                                                      | Min.      | Max. |      |
| $V_{inse\_DQS}$       | DQS Single-Ended input voltage                       | 170       | -    | mV   |
| $V_{inse\_DQS\_High}$ | DQS Single-Ended input voltage High from $V_{REFDQ}$ | 85        | -    | mV   |
| $V_{inse\_DQS\_Low}$  | DQS Single-Ended input voltage Low from $V_{REFDQ}$  | 85        | -    | mV   |

## Differential Input Slew Rate Definition for DQS

Input slew rate for differential signals (DQS, DQS#) are defined and measured as shown below in figure and the tables.

**Figure 59. Differential Input Slew Rate Definition for DQS, DQS#**



NOTE 1. Differential signal rising edge from VILdiff\_DQS to VIHdiff\_DQS must be monotonic slope.

NOTE 2. Differential signal falling edge from VIHdiff\_DQS to VILdiff\_DQS must be monotonic slope.

**Table 84. Differential Input Slew Rate Definition for DQS, DQS#**

| Description                                                | From        | To          | Defined by                                      |
|------------------------------------------------------------|-------------|-------------|-------------------------------------------------|
| Differential input slew rate for rising edge (DQS – DQS#)  | VILdiff_DQS | VIHdiff_DQS | $ VILdiff\_DQS - VIHdiff\_DQS  / \Delta TRdiff$ |
| Differential input slew rate for falling edge (DQS – DQS#) | VIHdiff_DQS | VILdiff_DQS | $ VILdiff\_DQS - VIHdiff\_DQS  / \Delta TFdiff$ |

**Table 85. Differential Input Level for DQS, DQS#**

| Symbol      | Parameter               | 4266/3733 |      | Unit |
|-------------|-------------------------|-----------|------|------|
|             |                         | Min.      | Max. |      |
| VIHdiff_DQS | Differential Input High | 120       | -    | mV   |
| VILdiff_DQS | Differential Input Low  | -         | -120 | mV   |

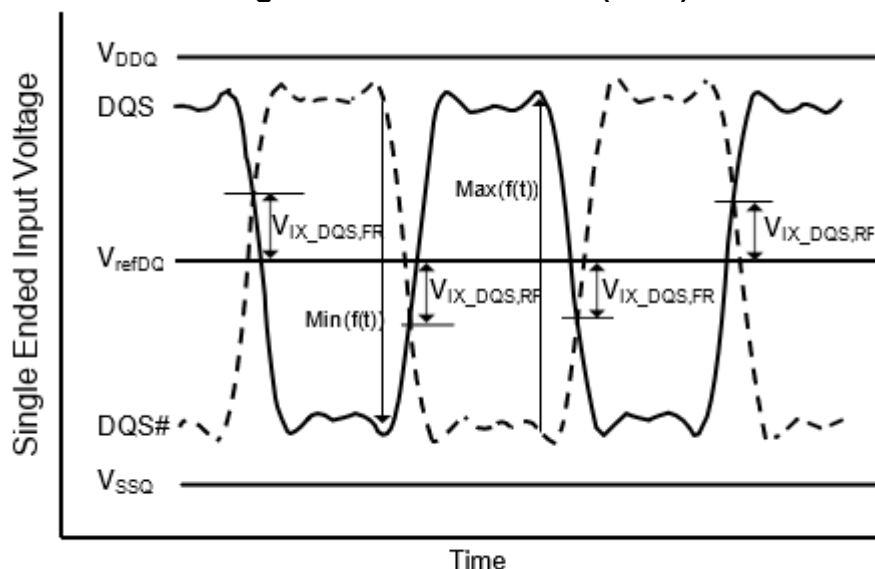
**Table 86. Differential Input Slew Rate Definition for DQS, DQS#**

| Symbol  | Parameter                    | 4266/3733 |      | Unit |
|---------|------------------------------|-----------|------|------|
|         |                              | Min.      | Max. |      |
| SRIdiff | Differential Input Slew Rate | 2         | 14   | V/ns |

## Differential Input Cross Point Voltage

The cross point voltage of differential input signals (DQS, DQS#) must meet the requirements in table below. The differential input cross point voltage VIX is measured from the actual cross point of true and complement signals to the mid level that is VREFDQ.

**Figure 60. Vix Definition (DQS)**



NOTES :

1. The base level of Vix\_DQS\_FR/RF is VrefDQ that is LPDDR4 SDRAM internal setting value by Vref Training.

**Table 87. Cross point voltage for differential input signals (DQS)**

| Symbol        | Parameter                                        | 4266/3733 |      | Unit | Note |
|---------------|--------------------------------------------------|-----------|------|------|------|
|               |                                                  | Min.      | Max. |      |      |
| Vix_DQS_ratio | DQS Differential input cross point voltage ratio | -         | 20   | %    | 1,2  |

Notes:

1. Vix\_DQS\_Ratio is defined by this equation:  $Vix\_DQS\_Ratio = Vix\_DQS\_FR / |Min(f(t))|$
2. Vix\_DQS\_Ratio is defined by this equation:  $Vix\_DQS\_Ratio = Vix\_DQS\_RF / Max(f(t))$

## Input Level for ODT (CA) Input

**Table 88. Input Level for ODT(CA)**

| Symbol | Parameter            | Value                 |                       | Unit |
|--------|----------------------|-----------------------|-----------------------|------|
|        |                      | Min.                  | Max.                  |      |
| VIHODT | ODT Input high level | $0.75 \times V_{DD2}$ | $V_{DD2} + 0.2$       | V    |
| VILODT | ODT Input low level  | -0.2                  | $0.25 \times V_{DD2}$ | V    |

**Note:** See Overshoot and Undershoot Specifications.

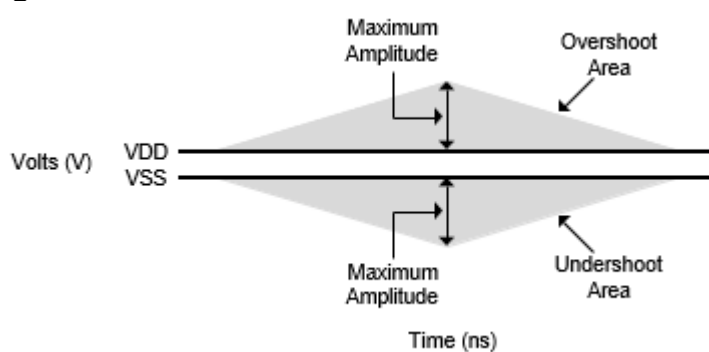
## Overshoot and Undershoot for LVSTL

**Table 83. AC Overshoot/Undershoot Specifications**

| Parameter                                          | 4266/3733 | Unit |
|----------------------------------------------------|-----------|------|
| Maximum peak Amplitude allowed for overshoot area  | 0.3       | V    |
| Maximum peak Amplitude allowed for undershoot area | 0.3       | V    |
| Maximum overshoot area above VDD/VDDQ              | 0.1       | V-ns |
| Maximum undershoot area below VSS/VSSQ             | 0.1       | V-ns |

**Notes:**

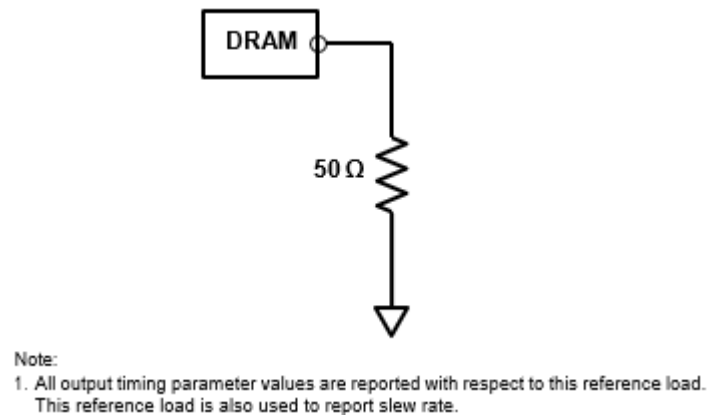
1. VDD stands for VDD2 for CA[5:0], CK, CK#, CS, CKE and ODT. VDD stands for VDDQ for DQ, DMI, DQS and DQS#.
2. VSS stands for VSS for CA[5:0], CK, CK#, CS, CKE and ODT. VSS stands for VSSQ for DQ, DMI, DQS and DQS#.
3. Maximum peak amplitude values are referenced from actual VDD and VSS values.
4. Maximum area values are referenced from maximum operating VDD and VSS values.

**Figure 1. Overshoot and Undershoot Definition**

## Driver Output Timing Reference Load

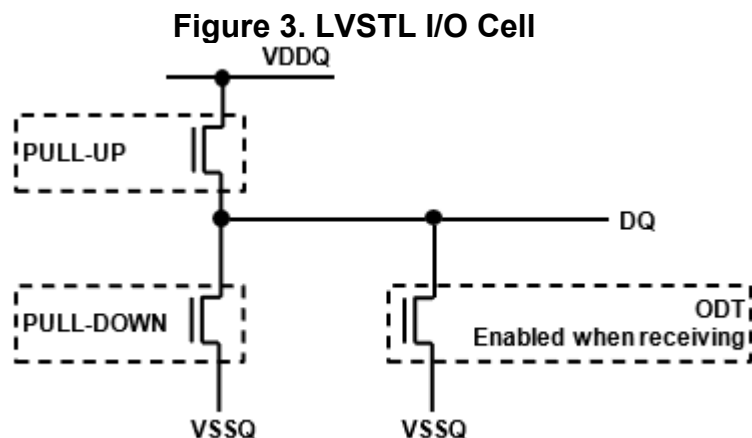
These 'Timing Reference Loads' are not intended as a precise representation of any particular system environment or a depiction of the actual load presented by a production tester. System designers should use IBIS or other simulation tools to correlate the timing reference load to a system environment.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

**Figure 2. Driver Output Reference Load for Timing and Slew Rate**



## LVSTL (Low Voltage Swing Terminated Logic) IO System

LVSTL I/O cell is comprised of pull-up, pull-down driver and a terminator. The basic cell is shown in figure below.

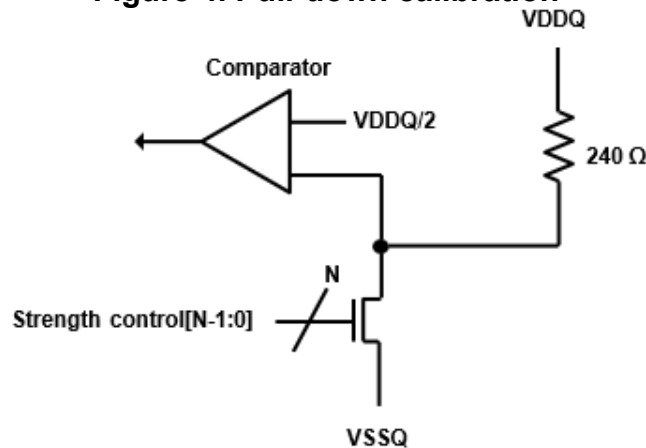


To ensure that the target impedance is achieved, calibrate the LVSTL I/O cell as following example:

1. First calibrate the pull-down device against a 240  $\Omega$  resistor to VDDQ via the ZQ pin.

- Set Strength Control to minimum setting.
- Increase drive strength until comparator detects data bit is less than VDDQ/2.
- NMOS pull-down device is calibrated to 240  $\Omega$

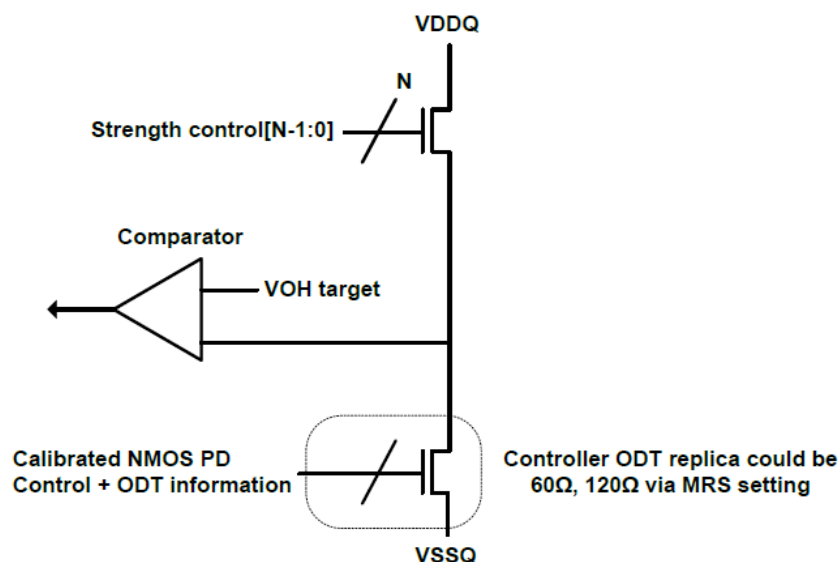
**Figure 4. Pull-down calibration**



2. Then calibrate the pull-up device against the calibrated pull-down device.

- Set VOH target and NMOS controller ODT replica via MRS VOH can be automatically controlled by ODT MRS).
- Set Strength Control to minimum setting.
- Increase drive strength until comparator detects data bit is greater than VOH target.
- NMOS pull-up device is now calibrated to VOH target.

**Figure 5. Pull-up calibration**

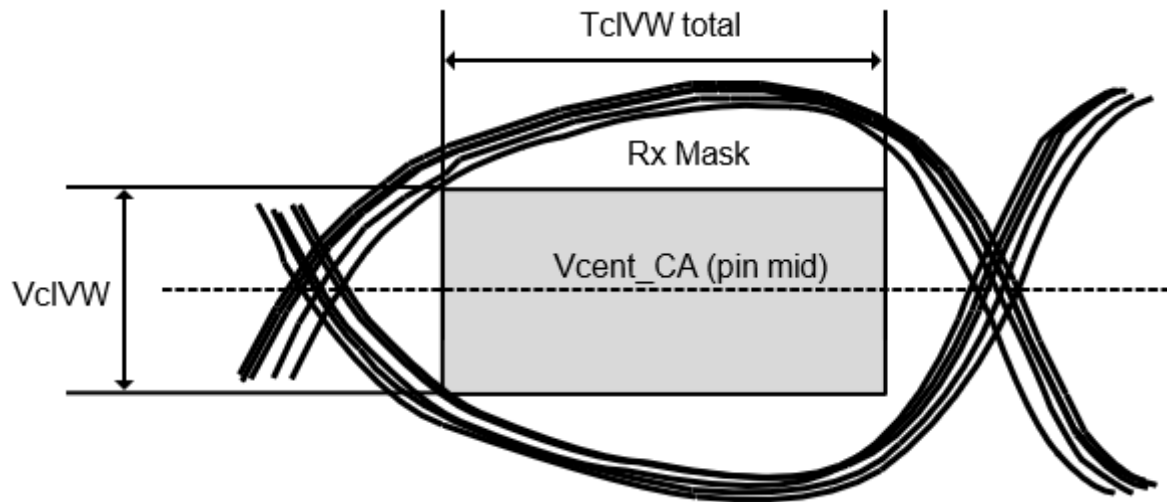


## CA Rx Voltage and Timing

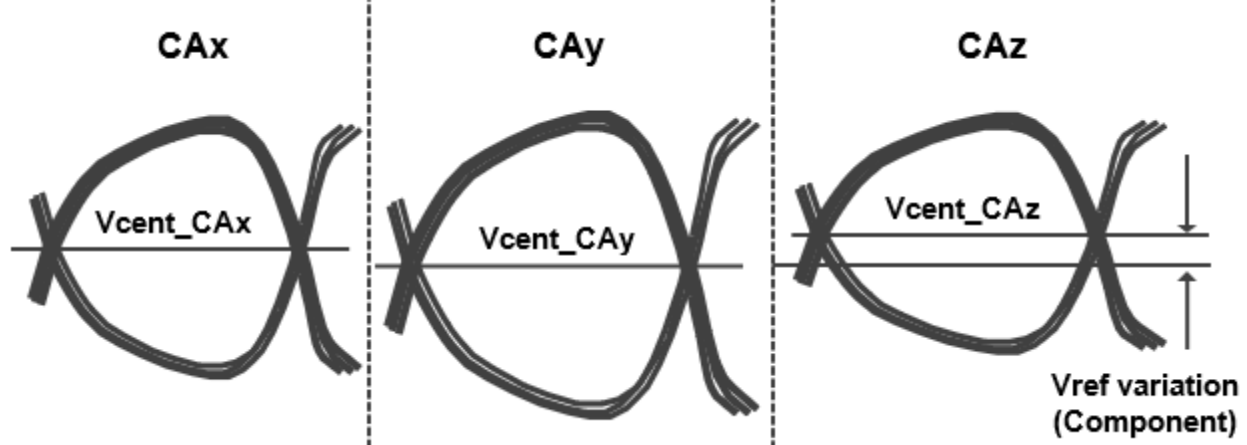
The command and address (CA) including CS input receiver compliance mask for voltage and timing is shown in the CA Receiver (Rx) Mask figure below. All CA, CS signals apply the same compliance mask and operate in single data rate mode.

The CA input Rx mask for voltage and timing is applied across all pins, as shown in the figure below. The receiver mask (Rx Mask) defines the area that the input signal must not encroach in order for the DRAM input receiver to be expected to be able to successfully capture a valid input signal; it is not the valid data-eye.

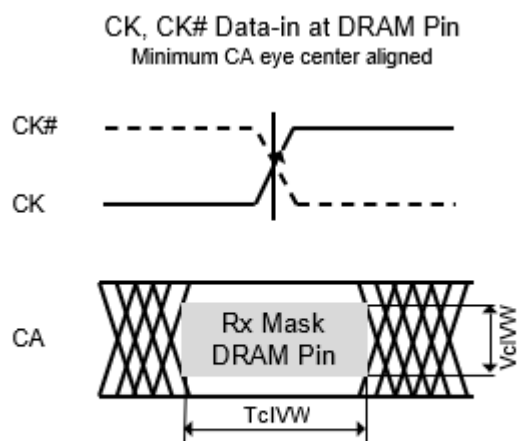
**Figure 6. CA Receiver (Rx) mask**



**Figure 7. Across pin VREFCA voltage variation**

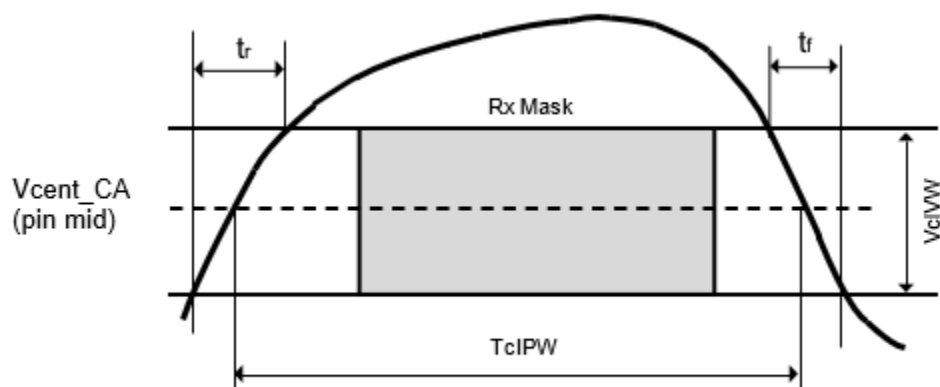


$V_{cent\_CA}(\text{pin mid})$  is defined as the midpoint between the largest  $V_{cent\_CA}$  voltage level and the smallest  $V_{cent\_CA}$  voltage level across all CA and CS pins for a given DRAM component. Each CA  $V_{cent}$  level is defined by the center, i.e., widest opening, of the cumulative data input eye as depicted in the figure above. This clarifies that any DRAM component level variation must be accounted for within the DRAM CA Rx mask. The component level VREF will be set by the system to account for Ron and ODT settings.

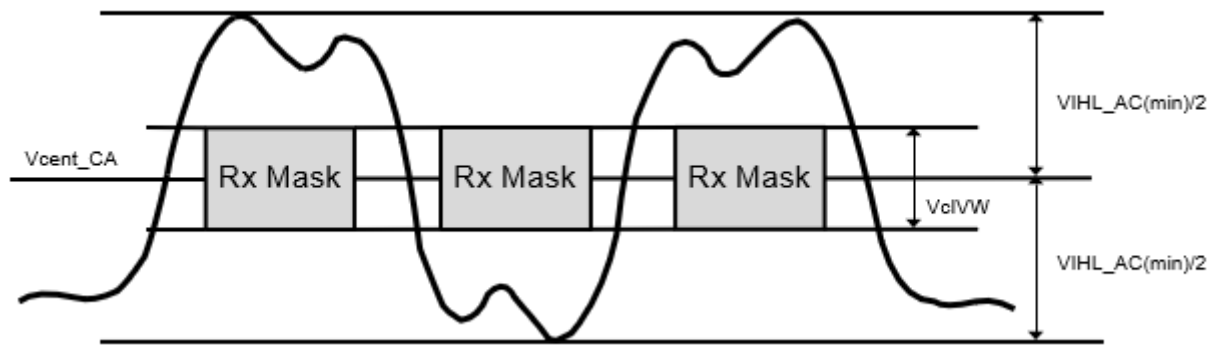
**Figure 8. CA Timings at the DRAM Pins**

TcIVW for all CA signals is defined as centered on The CK/CK# crossing at the DRAM pin.

All of the timing terms in above figure are measured from the CK/CK# to the center (midpoint) of the TcIVW window taken at the VcIVW\_total voltage levels centered around Vcent\_CA(pin mid).

**Figure 9. CA TcIPW and SRIN\_cIVW definition (for each input pulse)**

NOTE:  
SRIN\_cIVW=VcIVW\_Total/(tr or tf), signal must be monotonic within tr and tf range.

**Figure 10. CA VIH<sub>L</sub>\_AC definition (for each input pulse)****Table 83. DRAM CMD/ADR, CS** (UI=tck(avg)min)

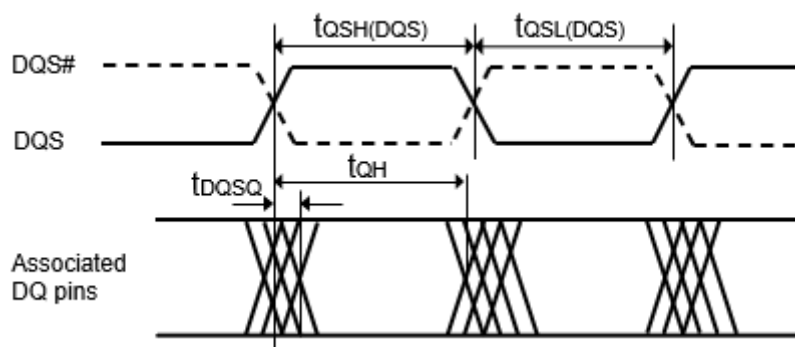
| Symbol                | Parameter                              | 4266 |      | 3733 |      | Unit | Note  |
|-----------------------|----------------------------------------|------|------|------|------|------|-------|
|                       |                                        | Min. | Max. | Min. | Max. |      |       |
| V <sub>clVW</sub>     | Rx Mask voltage - p-p                  | -    | 145  | -    | 150  | mV   | 1,2,3 |
| T <sub>clVW</sub>     | Rx timing window                       | -    | 0.3  | -    | 0.3  | UI   | 1,2,3 |
| VIH <sub>L</sub> _AC  | CA AC input pulse amplitude pk-pk      | 180  | -    | 180  | -    | mV   | 4,7   |
| T <sub>clPW</sub>     | CA input pulse width                   | 0.6  | -    | 0.6  | -    | UI   | 5     |
| SRIN <sub>_clVW</sub> | Input Slew Rate over V <sub>clVW</sub> | 1    | 7    | 1    | 7    | V/ns | 6     |

**Notes:**

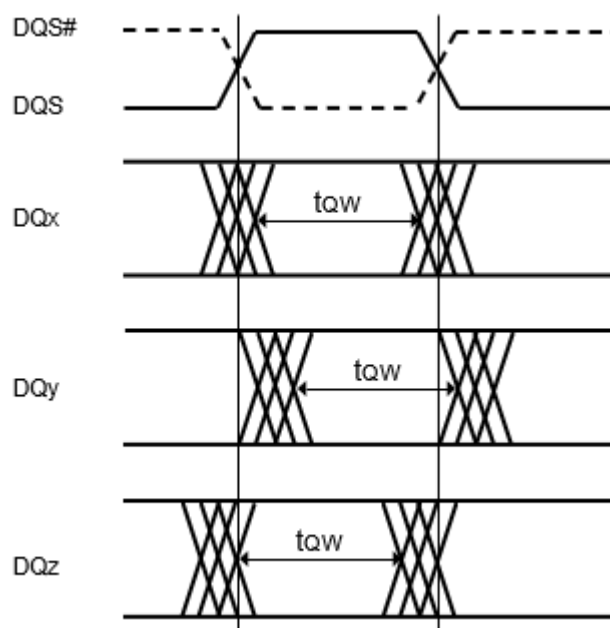
1. CA Rx mask voltage and timing parameters at the pin including voltage and temperature drift.
2. Rx mask voltage V<sub>clVW</sub> total(max) must be centered around V<sub>cent\_CA</sub>(pin mid).
3. Defined over the CA internal V<sub>ref</sub> range. The Rx mask at the pin must be within the internal V<sub>ref</sub> CA range irrespective of the input signal common mode.
4. CA only input pulse signal amplitude into the receiver must meet or exceed VIH<sub>L</sub> AC at any point over the total UI. No timing requirement above level. VIH<sub>L</sub> AC is the peak to peak voltage centered around V<sub>cent\_CA</sub>(pin mid) such that VIH<sub>L</sub>\_AC/2 min must be met both above and below V<sub>cent\_CA</sub>.
5. CA only minimum input pulse width defined at the V<sub>cent\_CA</sub>(pin mid).
6. Input slew rate over V<sub>clVW</sub> Mask centered at V<sub>cent\_CA</sub>(pin mid).
7. VIH<sub>L</sub>\_AC does not have to be met when no transitions are occurring.
8. UI=tck(avg)min

## DRAM Data Timing

**Figure 11. Read data timing definitions  $t_{QH}$  and  $t_{DQSQ}$  across all DQ signals per DQS group**



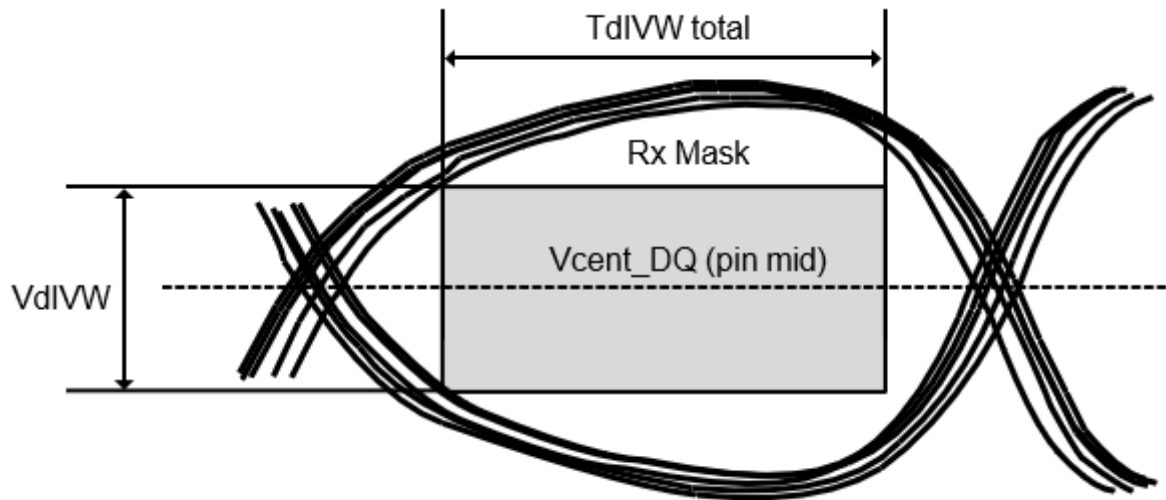
**Figure 12. Read Data Timing  $t_{QW}$  Valid Window Defined per DQ Signal**



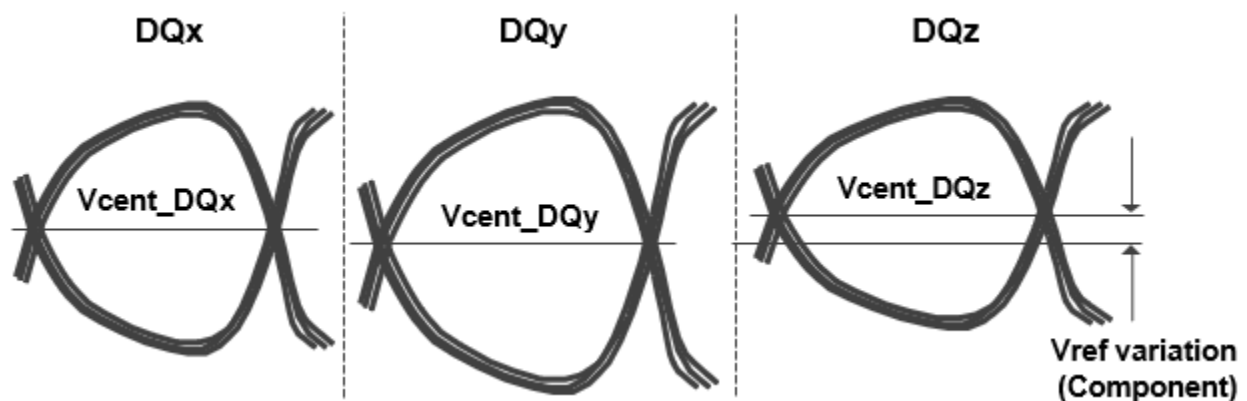
## DQ Rx Voltage and Timing

The DQ input receiver mask for voltage and timing is applied per pin, as shown in the figure below. The “total” mask ( $V_{dIVW\_total}$ ,  $T_{dIVW\_total}$ ) defines the area the input signal must not encroach in order for the DQ input receiver to successfully capture an input signal with a BER of lower than tbd. The mask is a receiver property and it is not the valid data-eye.

**Figure 13. DQ Receiver (Rx) mask**

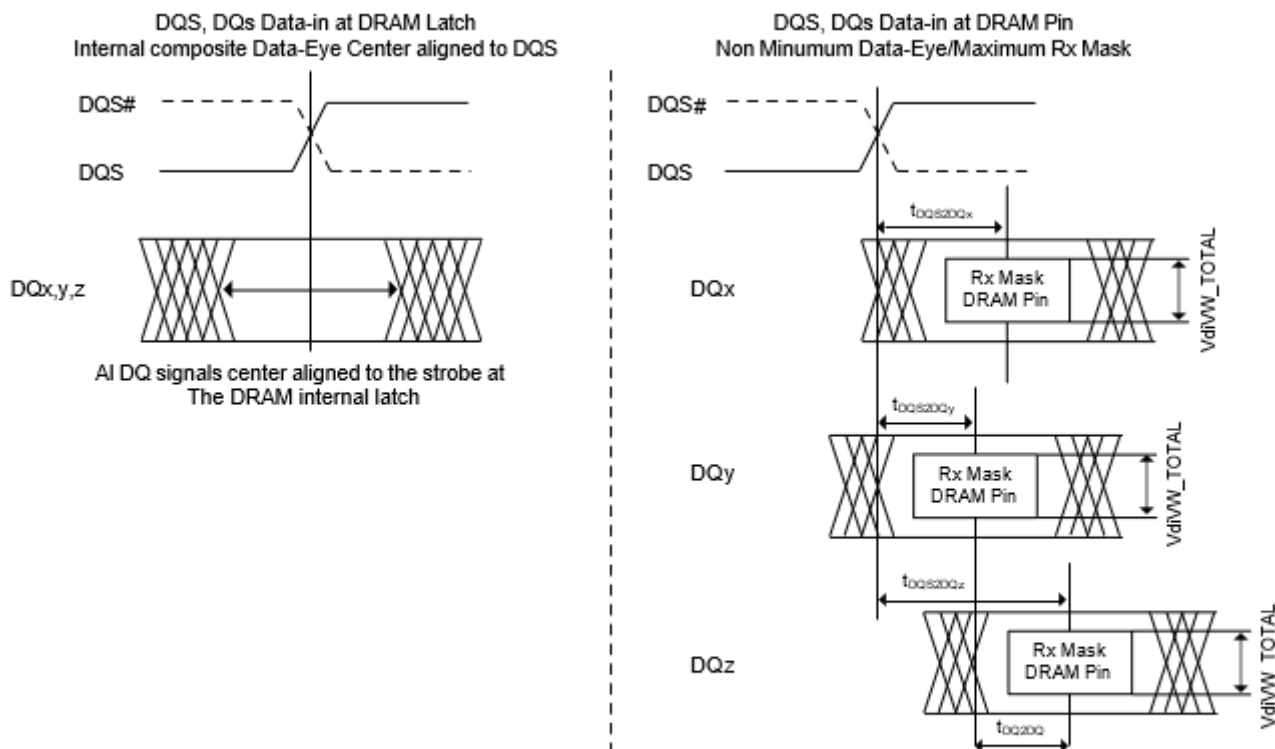


**Figure 14. Across Pin Vref DQ Voltage Variation**



$V_{cent\_DQ}(\text{pin\_mid})$  is defined as the midpoint between the largest  $V_{cent\_DQ}$  voltage level and the smallest  $V_{cent\_DQ}$  voltage level across all DQ pins for a given DRAM component. Each DQ  $V_{cent}$  is defined by the center, i.e., widest opening, of the cumulative data input eye as depicted in the figure above. This clarifies that any DRAM component level variation must be accounted for within the DRAM Rx mask. The component level VREF will be set by the system to account for Ron and ODT settings.

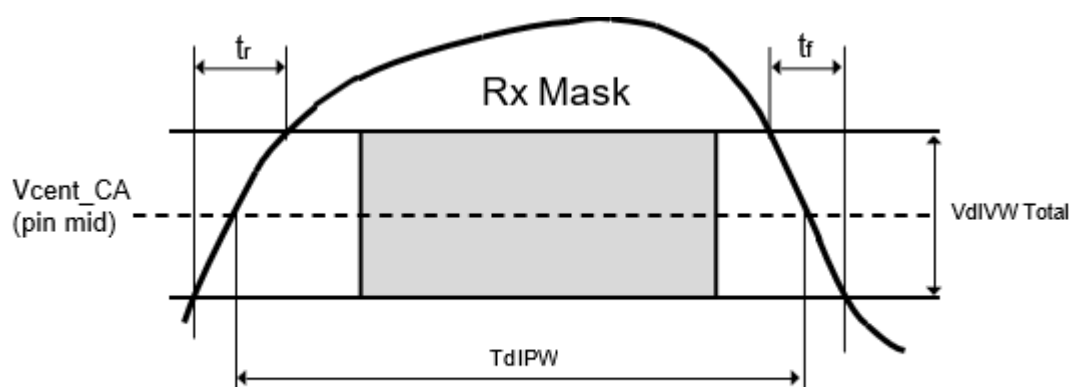
**Figure 15. DQ to DQS  $t_{DQS2DQ}$  and  $t_{DQ2DQ}$  Timings at the DRAM pins referenced from the internal latch**



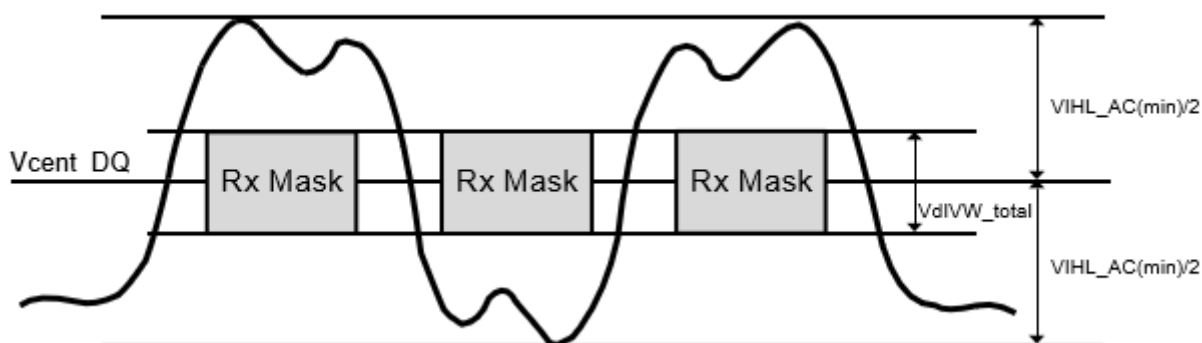
**NOTE:**

1. The  $t_{DQS2DQ}$  is measured at the center(midpoint) of the TdiVW window.
2. The DQz represents the max  $t_{DQS2DQ}$  in this example.
3. DQy represents the min  $t_{DQS2DQ}$  in this example.

Figure 16. DQ TdIPW and SRIN\_dIVW definition (for each input pulse)



NOTE:

$$SRIN\_dIVW = VdIVW\_Total / (tr \text{ or } tf)$$
 signal must be monotonic within tr and tf range.
Figure 17. DQ VIH<sub>L</sub>\_AC definition (for each input pulse)

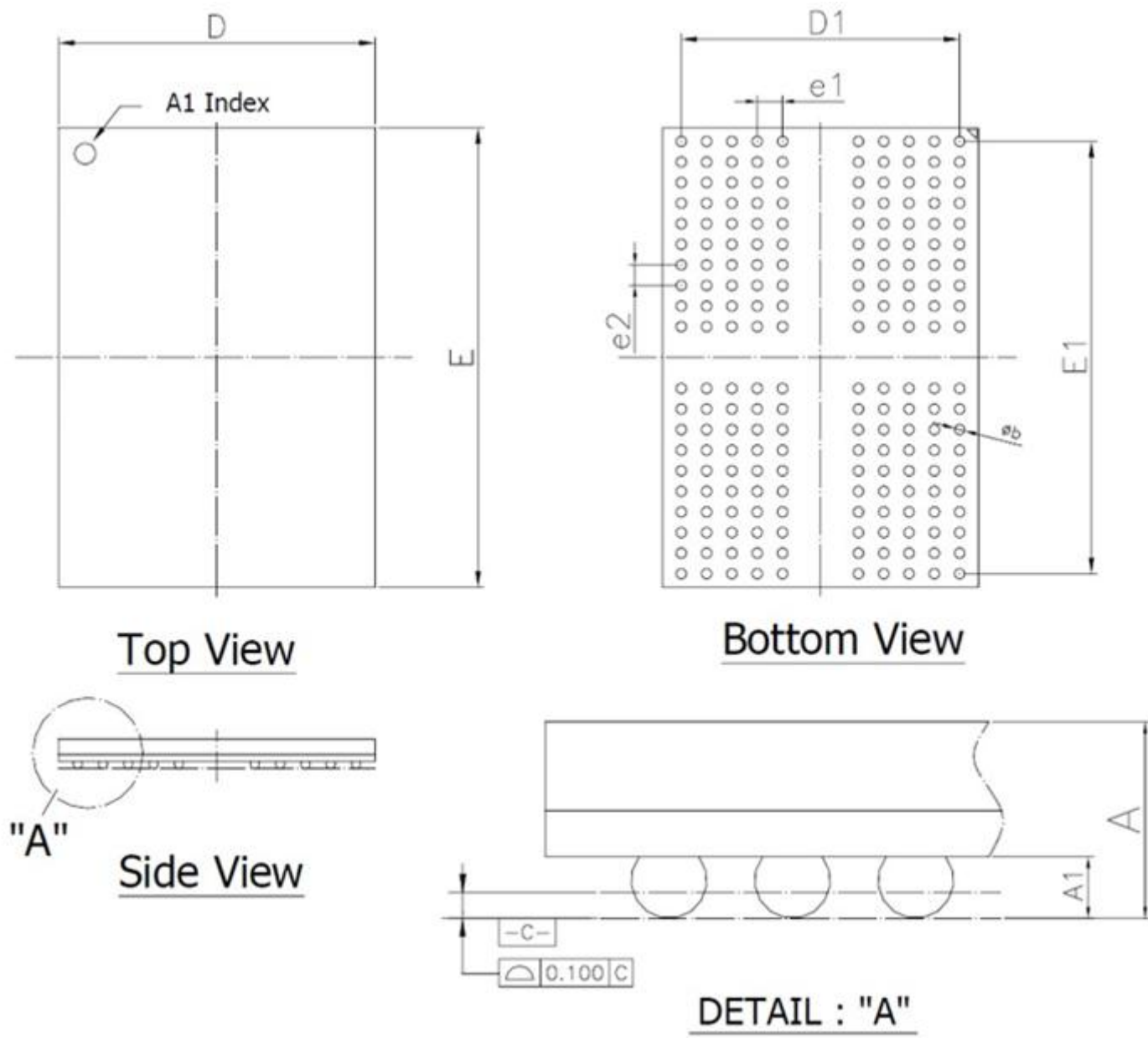
**Table 83. DRAM DQs In Receive Mode** (Unit UI = tCK(avg)min/2)

| Symbol            | Parameter                                               | 4266 |      | 3733 |      | Unit    | Note     |
|-------------------|---------------------------------------------------------|------|------|------|------|---------|----------|
|                   |                                                         | Min. | Max. | Min. | Max. |         |          |
| VdIVW_total       | Rx Mask voltage - p-p total                             | -    | 120  | -    | 130  | mV      | 1-4      |
| TdIVW_total       | Rx timing window total (At VdIVW voltage levels)        | -    | 0.25 | -    | 0.25 | UI      | 1,2,4    |
| TdIVW_1bit        | Rx timing window 1 bit toggle (At VdIVW voltage levels) | -    | TBD  | -    | TBD  | UI      | 1,2,4,12 |
| VIHL_AC           | DQ AC input pulse amplitude pk-pk                       | 170  | -    | 180  | -    | mV      | 5,13     |
| TdIPW DQ          | Input pulse width (At Vcent_DQ)                         | 0.45 | -    | 0.45 | -    | UI      | 6        |
| tdQS2DQ           | DQ to DQS offset                                        | 200  | 800  | 200  | 800  | ps      | 7        |
| tdQ2DQ            | DQ to DQ offset                                         | -    | 30   | -    | 30   | ps      | 8        |
| tdQS2DQ_temp      | DQ to DQS offset temperature variation                  | -    | 0.6  | -    | 0.6  | ps/°C   | 9        |
| tdQS2DQ_volt      | DQ to DQS offset voltage variation                      | -    | 33   | -    | 33   | ps/50mV | 10       |
| SRIN_dIVW         | Input Slew Rate over VdIVWJotal                         | 1    | 7    | 1    | 7    | V/ns    | 11       |
| tdQS2DQ_rank2rank | DQ to DQS offset rank to rank variation                 | -    | 200  | -    | 200  | ps      | 14,15    |

**Notes:**

1. Data Rx mask voltage and timing parameters are applied per pin and includes the DRAM DQ to DQS voltage AC noise impact for frequencies >20 MHz and max voltage of 45mv pk-pk from DC-20MHz at a fixed temperature on the package. The voltage supply noise must comply to the component Min-Max DC operating conditions.
2. The design specification is a BER <TBD. The BER will be characterized and extrapolated if necessary using a dual dirac method.
3. Rx mask voltage VdIVW total(max) must be centered around Vcent\_DQ(pin\_mid).
4. Vcent\_DQ must be within the adjustment range of the DQ internal Vref.
5. DQ only input pulse amplitude into the receiver must meet or exceed VIHL AC at any point over the total UI. No timing requirement above level. VIHL AC is the peak to peak voltage centered around Vcent\_DQ(pin\_mid) such that VIHL\_AC/2 min must be met both above and below Vcent\_DQ.
6. DQ only minimum input pulse width defined at the Vcent\_DQ(pin\_mid).
7. DQ to DQS offset is within byte from DRAM pin to DRAM internal latch. Includes all DRAM process, voltage and temperature variation.
8. DQ to DQ offset defined within byte from DRAM pin to DRAM internal latch for a given component.
9. TDQS2DQ max delay variation as a function of temperature.
10. TDQS2DQ max delay variation as a function of the DC voltage variation for VDDQ and VDD2. It includes the VDDQ and VDD2 AC noise impact for frequencies > 20MHz and max voltage of 45mv pk-pk from DC-20MHz at a fixed temperature on the package. For tester measurement VDDQ = VDD2 is assumed.
11. Input slew rate over VdIVW Mask centered at Vcent\_DQ(pin\_mid).
12. Rx mask defined for a one pin toggling with other DQ signals in a steady state.
13. VIHL\_AC does not have to be met when no transitions are occurring.
14. The same voltage and temperature are applied to tdQS2DQ\_rank2rank.
15. tdQS2DQ\_rank2rank parameter is applied to multi-ranks per byte lane within a package consisting of the same design dies.

## 200-Ball FBGA Package 10x15.0x1.00mm (max) Outline Drawing Information



| Symbol | Dimension in inch |        |        | Dimension in mm |       |       |
|--------|-------------------|--------|--------|-----------------|-------|-------|
|        | Min               | Nom    | Max    | Min             | Nom   | Max   |
| A      | --                | --     | 0.0394 | --              | --    | 1.00  |
| A1     | 0.0098            | 0.0118 | 0.0138 | 0.25            | 0.30  | 0.35  |
| D      | 0.3898            | 0.3937 | 0.3976 | 9.90            | 10.00 | 10.10 |
| E      | 0.5866            | 0.5906 | 0.5945 | 14.90           | 15.00 | 15.10 |
| D1     | --                | 0.3465 | --     | --              | 8.80  | --    |
| E1     | --                | 0.5374 | --     | --              | 13.65 | --    |
| e1     | --                | 0.0315 | --     | --              | 0.80  | --    |
| e2     | --                | 0.0256 | --     | --              | 0.65  | --    |
| b      | 0.0118            | 0.0138 | 0.0157 | 0.30            | 0.35  | 0.40  |