

# LPDDR4 SDRAM

## RS384M32LZ4D2ANP, RS768M32LZ4D4ANQ

### Features

- Ultra-low-voltage core and I/O power supplies
  - $V_{DD1} = 1.70\text{--}1.95\text{V}$ ; 1.8V nominal
  - $V_{DD2}/V_{DDQ} = 1.06\text{--}1.17\text{V}$ ; 1.1V nominal
- Frequency range
  - 1866–10 MHz (data rate range: 3733–20 Mb/s/pin)
- 16n prefetch DDR architecture
- 1-channel partitioned architecture for low RD/WR energy and low average latency
- 8 internal banks per channel for concurrent operation
- Single-data-rate CMD/ADR entry
- Bidirectional/differential data strobe per byte lane
- Programmable READ and WRITE latencies (RL/WL)
- Programmable and on-the-fly burst lengths (BL = 16, 32)
- Directed per-bank refresh for concurrent bank operation and ease of command scheduling
- Up to 7.5 GB/s per die
- On-chip temperature sensor to control self refresh rate
- Partial-array self refresh (PASR)
- Selectable output drive strength (DS)
- Clock-stop capability
- RoHS-compliant, “green” packaging
- Programmable  $V_{SS}$  (ODT) termination

### Options

- $V_{DD1}/V_{DD2}$ : 1.8V/1.1V
- Array configuration
  - 384 Meg x 32 (2 channels x16 I/O)
  - 768 Meg x 32 (4 channels x16 I/O)
- Device configuration
  - 384M16 x 2 die in package
  - 384M16 x 4 die in package
- FBGA “green” package
  - 200-ball WFBGA (10mm x 14.5mm x 0.8mm, Ø0.28 SMD)
  - 200-ball VFBGA (10mm x 14.5mm x 0.95mm, Ø0.28 SMD)
  - 200-ball WFBGA (10mm x 14.5mm x 0.8mm, Ø0.35 SMD)
  - 200-ball VFBGA (10mm x 14.5mm x 0.95mm, Ø0.35 SMD)
  - Speed grade, cycle time
    - 755ps @ RL = 24/28
    - 625ps @ RL = 28/32
    - 535ps @ RL = 32/36
- Operating temperature range
  - $-25^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$
- Revision

### Marking

A

384M32

768M32

D2

D4

NP

NQ

DS<sup>1</sup>

DT<sup>1</sup>

-75

-62

-53

**Table 1: Key Timing Parameters**

Speed Grade	Clock Rate (MHz)	Data Rate (Mb/s/pin)	WRITE Latency		READ Latency	
			Set A	Set B	(DBI Disabled)	(DBI Enabled)
-75	1333	2667	12	22	24	28
-62	1600	3200	14	26	28	32
-53	1866	3733	16	30	32	36

## SDRAM Addressing

The table below shows the addressing for the 6Gb die density. All bank, row, and column addresses are shown per die.

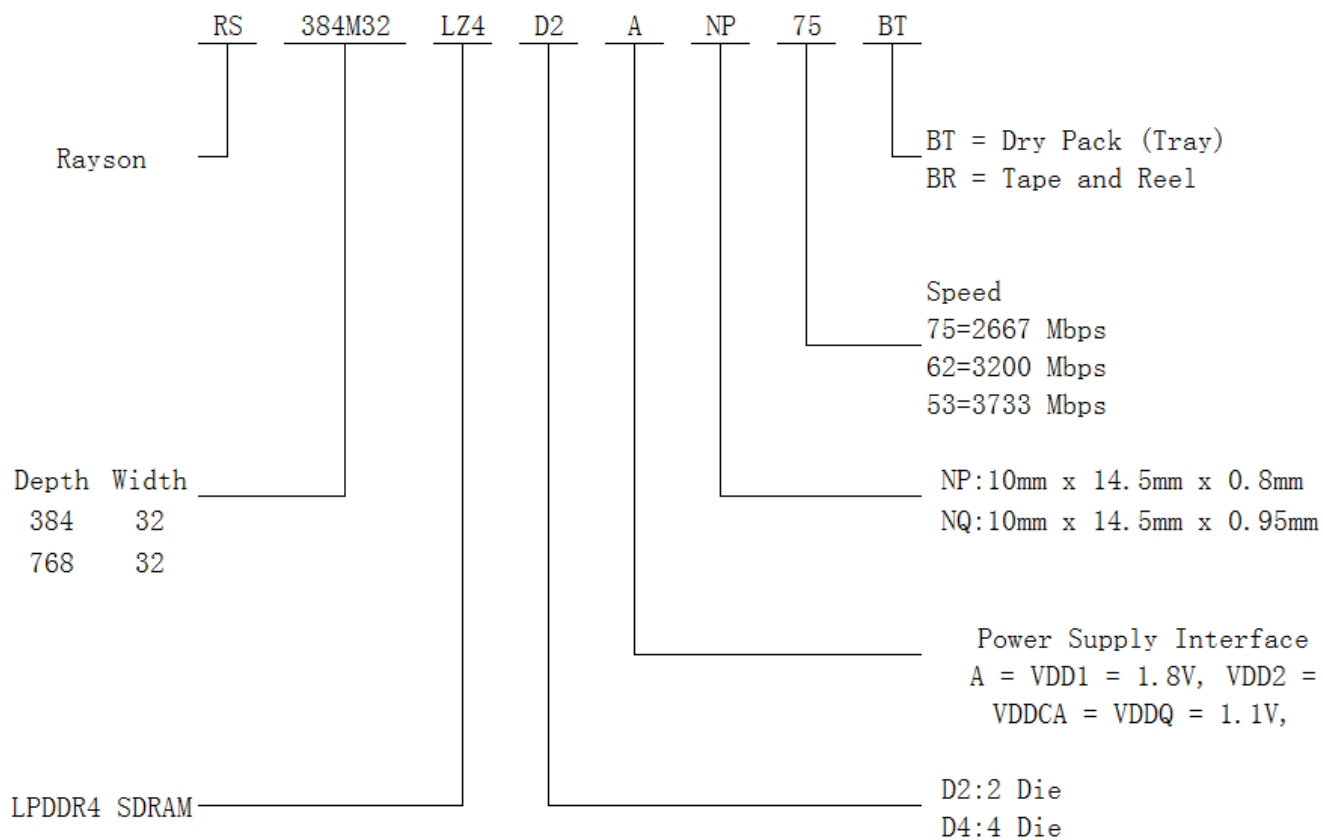
**Table 2: Device Addressing**

Configuration		384M32 (12Gb)	768M32 (24Gb)
<b>Die per package</b>		<b>2</b>	<b>4</b>
<b>Device density (per die)</b>		<b>6Gb</b>	<b>6Gb</b>
<b>Device density (per channel)</b>		<b>6Gb</b>	<b>6Gb</b>
Configuration		48Mb x 16 DQ x 8 banks x 2 channels	96Mb x 16 DQ x 8 banks x 2 channels
Number of channels (per die)		1	1
Number of ranks per channel		1	2
Number of banks (per channel)		8	8
Array prefetch (bits) (per channel)		256	256
Number of rows (per bank)		49,152	49,152
Number of columns (fetch boundaries)		64	64
Page size (bytes)		2048	2048
Channel density (bits per channel)		6,442,450,944	6,442,450,944
Total density (bits per die)		6,442,450,944	6,442,450,944
Bank address		BA[2:0]	BA[2:0]
x16	Row addresses	R[15:0]	R[15:0]
	Column addresses	C[9:0]	C[9:0]
Burst starting address boundary		64-bit	64-bit

- Notes:
1. The lower two column addresses (C0–C1) are assumed to be zero and are not transmitted on the CA bus.
  2. Row and column address values on the CA bus that are not used for a particular density are "Don't Care."
  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.

**Part Number Ordering Information**

**Figure 1: Part Number Chart**



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## General Description

The 6Gb Mobile Low-Power DDR4 SDRAM (LPDDR4) is a high-speed CMOS, dynamic random-access memory. The device is internally configured with x16 I/O, 8-banks.

Each of the x16's 805,306,368-bit banks is organized as 49,152 rows by 1024 columns by 16 bits.

## General Notes

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

"DQS" and "CK" should be interpreted as DQS\_t, DQS\_c and CK\_t, CK\_c respectively, unless specifically stated otherwise. "CA" includes all CA pins used for a given density.

In timing diagrams, "CMD" is used as an indicator only. Actual signals occur on CA[5:0].  $V_{REF}$  indicates  $V_{REF(CA)}$  and  $V_{REF(DQ)}$ .

Complete functionality may be described throughout the entire document. Any page or diagram may have been simplified to convey a topic and may not be inclusive of all requirements.

Any specific requirement takes precedence over a general statement.

Any functionality not specifically stated herein is considered undefined, illegal, is not supported, and will result in unknown operation.



## Package Block Diagrams

Figure 2: Dual-Die, Dual-Channel, Single-Rank Package Block Diagram

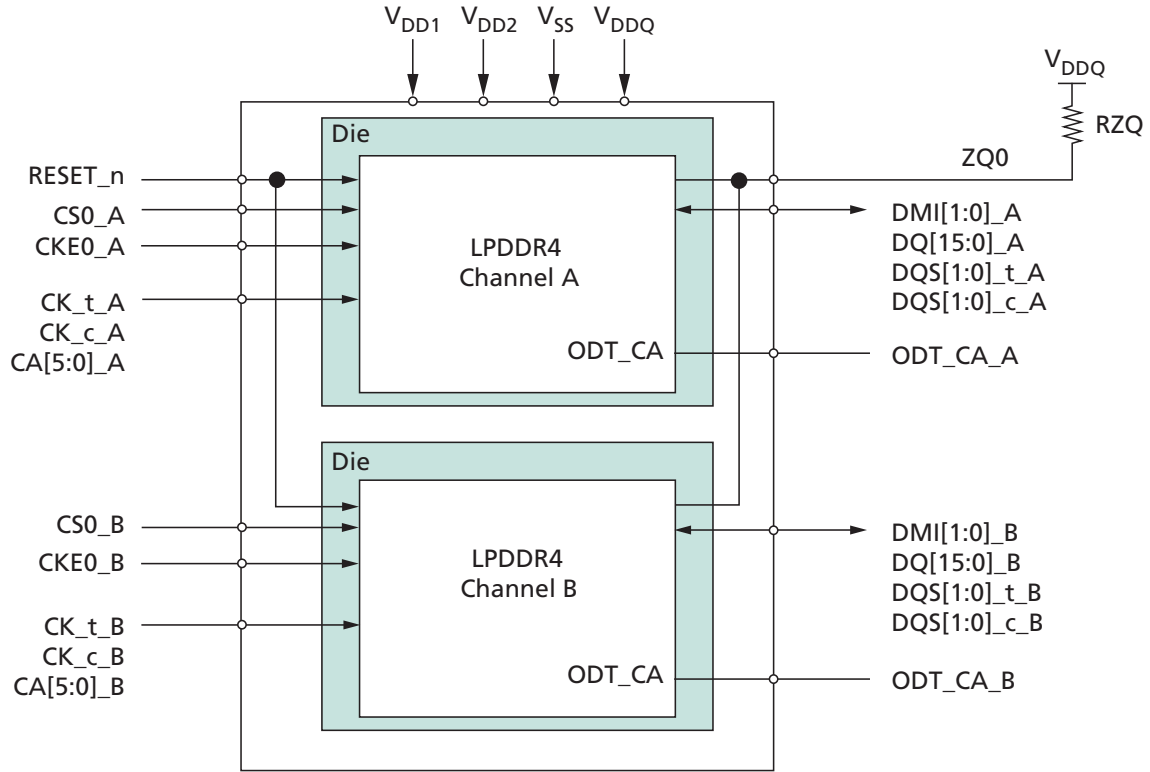
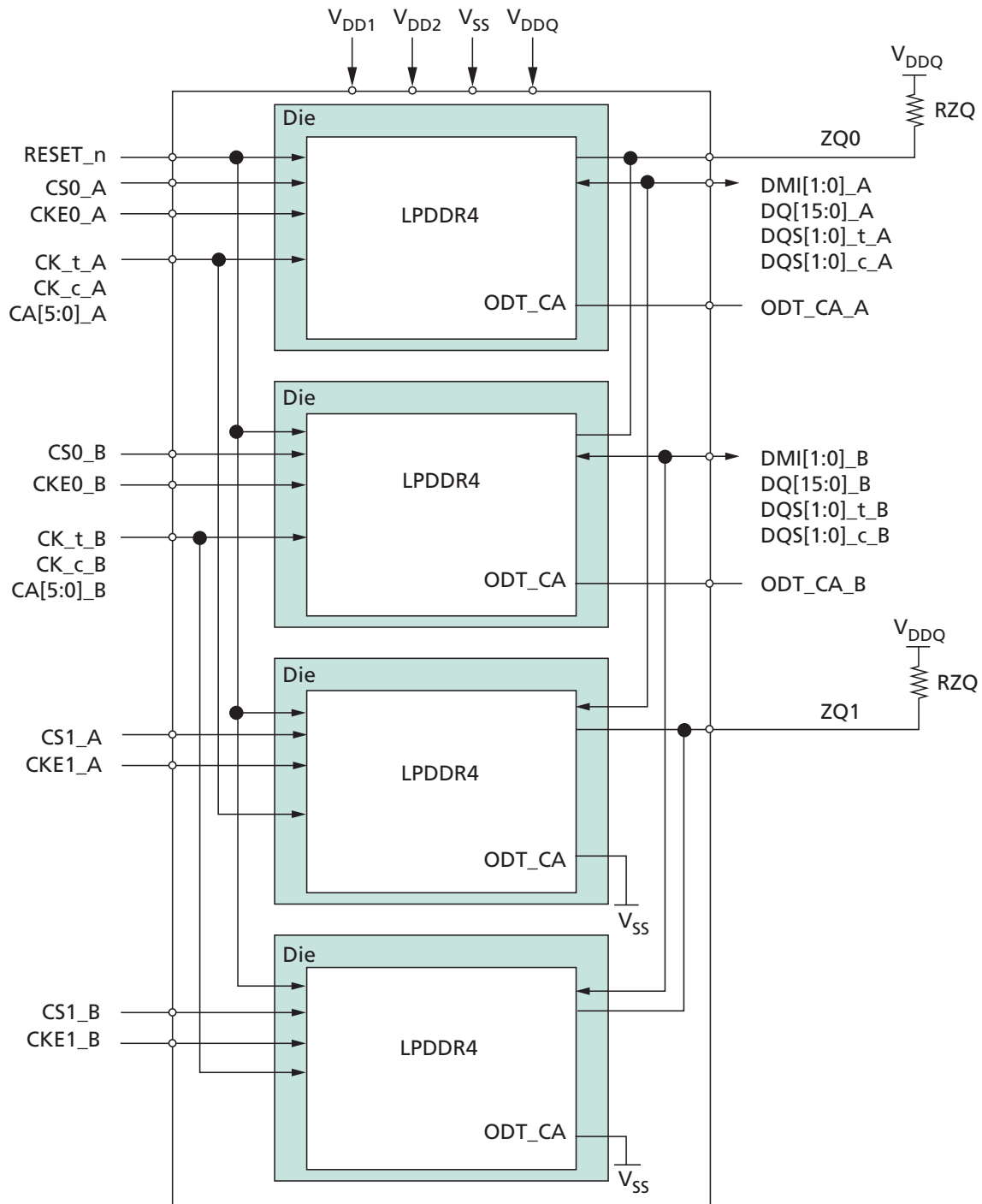


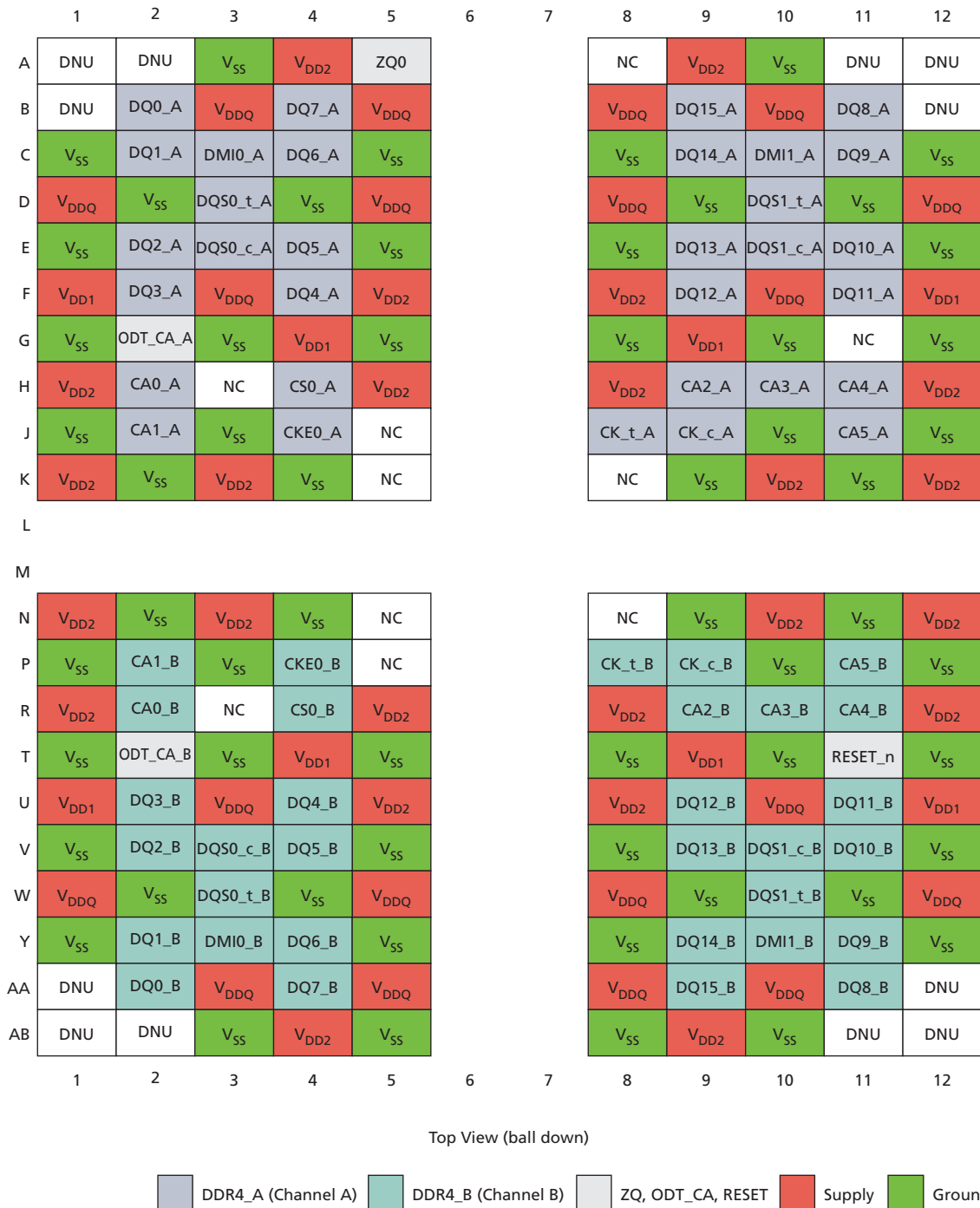
Figure 3: Quad-Die, Dual-Channel, Dual-Rank Package Block Diagram



Note: 1. ODT(ca) for Rank 0 of each channel is wired to the respective ODT ball. ODT(ca) for Rank 1 of each channel is wired to  $V_{SS}$  in the package.

## Ball Assignments and Descriptions

Figure 4: 200-Ball Dual-Channel, Single-Rank Discrete FBGA



**Figure 5: 200-Ball Dual-Channel, Dual-Rank Discrete FBGA**

	1	2	3	4	5	6	7	8	9	10	11	12
A	DNU	DNU	V <sub>SS</sub>	V <sub>DD2</sub>	ZQ0			ZQ1	V <sub>DD2</sub>	V <sub>SS</sub>	DNU	DNU
B	DNU	DQ0_A	V <sub>DDQ</sub>	DQ7_A	V <sub>DDQ</sub>			V <sub>DDQ</sub>	DQ15_A	V <sub>DDQ</sub>	DQ8_A	DNU
C	V <sub>SS</sub>	DQ1_A	DMI0_A	DQ6_A	V <sub>SS</sub>			V <sub>SS</sub>	DQ14_A	DMI1_A	DQ9_A	V <sub>SS</sub>
D	V <sub>DDQ</sub>	V <sub>SS</sub>	DQS0_t_A	V <sub>SS</sub>	V <sub>DDQ</sub>			V <sub>DDQ</sub>	V <sub>SS</sub>	DQS1_t_A	V <sub>SS</sub>	V <sub>DDQ</sub>
E	V <sub>SS</sub>	DQ2_A	DQS0_c_A	DQ5_A	V <sub>SS</sub>			V <sub>SS</sub>	DQ13_A	DQS1_c_A	DQ10_A	V <sub>SS</sub>
F	V <sub>DD1</sub>	DQ3_A	V <sub>DDQ</sub>	DQ4_A	V <sub>DD2</sub>			V <sub>DD2</sub>	DQ12_A	V <sub>DDQ</sub>	DQ11_A	V <sub>DD1</sub>
G	V <sub>SS</sub>	ODT_CA_A	V <sub>SS</sub>	V <sub>DD1</sub>	V <sub>SS</sub>			V <sub>SS</sub>	V <sub>DD1</sub>	V <sub>SS</sub>	NC	V <sub>SS</sub>
H	V <sub>DD2</sub>	CA0_A	CS1_A	CS0_A	V <sub>DD2</sub>			V <sub>DD2</sub>	CA2_A	CA3_A	CA4_A	V <sub>DD2</sub>
J	V <sub>SS</sub>	CA1_A	V <sub>SS</sub>	CKE0_A	CKE1_A			CK_t_A	CK_c_A	V <sub>SS</sub>	CA5_A	V <sub>SS</sub>
K	V <sub>DD2</sub>	V <sub>SS</sub>	V <sub>DD2</sub>	V <sub>SS</sub>	NC			NC	V <sub>SS</sub>	V <sub>DD2</sub>	V <sub>SS</sub>	V <sub>DD2</sub>
L												
M												
N	V <sub>DD2</sub>	V <sub>SS</sub>	V <sub>DD2</sub>	V <sub>SS</sub>	NC			NC	V <sub>SS</sub>	V <sub>DD2</sub>	V <sub>SS</sub>	V <sub>DD2</sub>
P	V <sub>SS</sub>	CA1_B	V <sub>SS</sub>	CKE0_B	CKE1_B			CK_t_B	CK_c_B	V <sub>SS</sub>	CA5_B	V <sub>SS</sub>
R	V <sub>DD2</sub>	CA0_B	CS1_B	CS0_B	V <sub>DD2</sub>			V <sub>DD2</sub>	CA2_B	CA3_B	CA4_B	V <sub>DD2</sub>
T	V <sub>SS</sub>	ODT_CA_B	V <sub>SS</sub>	V <sub>DD1</sub>	V <sub>SS</sub>			V <sub>SS</sub>	V <sub>DD1</sub>	V <sub>SS</sub>	RESET_n	V <sub>SS</sub>
U	V <sub>DD1</sub>	DQ3_B	V <sub>DDQ</sub>	DQ4_B	V <sub>DD2</sub>			V <sub>DD2</sub>	DQ12_B	V <sub>DDQ</sub>	DQ11_B	V <sub>DD1</sub>
V	V <sub>SS</sub>	DQ2_B	DQS0_c_B	DQ5_B	V <sub>SS</sub>			V <sub>SS</sub>	DQ13_B	DQS1_c_B	DQ10_B	V <sub>SS</sub>
W	V <sub>DDQ</sub>	V <sub>SS</sub>	DQS0_t_B	V <sub>SS</sub>	V <sub>DDQ</sub>			V <sub>DDQ</sub>	V <sub>SS</sub>	DQS1_t_B	V <sub>SS</sub>	V <sub>DDQ</sub>
Y	V <sub>SS</sub>	DQ1_B	DMI0_B	DQ6_B	V <sub>SS</sub>			V <sub>SS</sub>	DQ14_B	DMI1_B	DQ9_B	V <sub>SS</sub>
AA	DNU	DQ0_B	V <sub>DDQ</sub>	DQ7_B	V <sub>DDQ</sub>			V <sub>DDQ</sub>	DQ15_B	V <sub>DDQ</sub>	DQ8_B	DNU
AB	DNU	DNU	V <sub>SS</sub>	V <sub>DD2</sub>	V <sub>SS</sub>			V <sub>SS</sub>	V <sub>DD2</sub>	V <sub>SS</sub>	DNU	DNU

Top View (ball down)

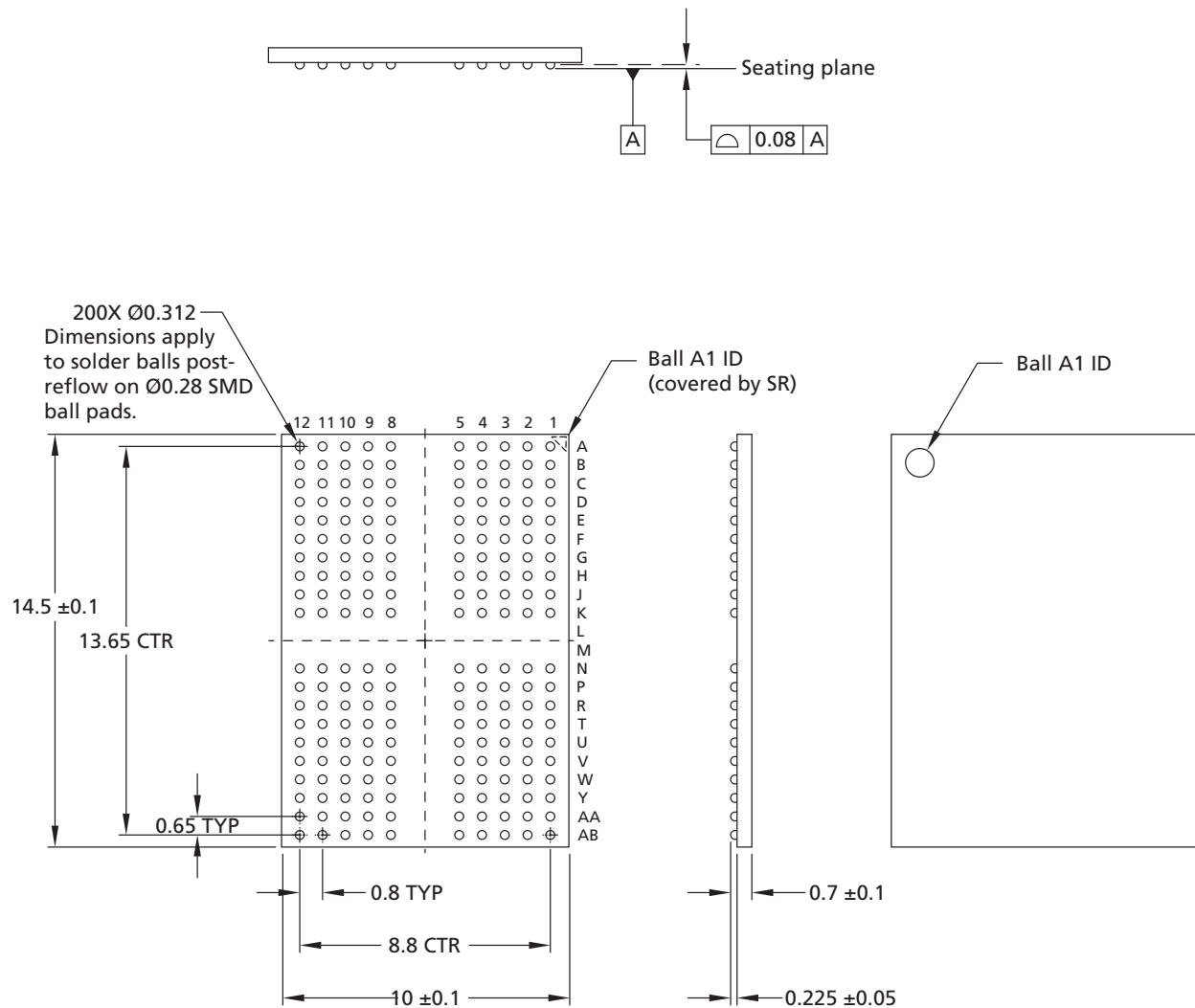


**Table 3: Ball/Pad Descriptions**

Symbol	Type	Description
CK_t_A, CK_c_A, CK_t_B, CK_c_B	Input	<b>Clock:</b> CK_t and CK_c are differential clock inputs. All address, command and control input signals are sampled on positive edge of CK_t and the negative edge of CK_c. AC timings for CA parameters are referenced to clock. Each channel (A, B) has its own clock pair.
CKE0_A, CKE1_A, CKE0_B, CKE1_B	Input	<b>Clock enable:</b> CKE HIGH activates and CKE LOW deactivates the internal clock signals, input buffers, and output drivers. Power-saving modes are entered and exited via CKE transitions. CKE is sampled at the rising edge of CK.
CS0_A, CS1_A, CS0_B, CS1_B	Input	<b>Chip select:</b> Each channel (A, B) has its own CS signals.
CA[5:0]_A, CA[5:0]_B	Input	<b>Command/address inputs:</b> Provide the command and address inputs according to the command truth table. Each channel (A, B) has its own CA signals.
ODT_CA_A, 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. It is bonded to V <sub>DD2</sub> within the package, or at the package ball, for the terminating rank, and the non-terminating ranks are bonded to V <sub>SS</sub> (or left floating with a weak pull-down on the DRAM die). The terminating rank is the DRAM that terminates the CA bus for all die on the same channel.
DQ[15:0]_A, DQ[15:0]_B	I/O	<b>Data input/output:</b> Bidirectional data bus.
DQS[1:0]_t_A, DQS[1:0]_c_A, DQS[1:0]_t_B, DQS[1:0]_c_B	I/O	<b>Data strobe:</b> DQS_t and DQS_c 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 SoC memory controller for a WRITE and is trained to precede data. Each byte of data has a data strobe signal pair. Each channel (A, B) has its own DQS_t and DQS_c strobes.
DMI[1:0]_A, DMI[1:0]_B	I/O	<b>Data Mask/Data Bus Inversion:</b> DMI is a dual use bi-directional signal used to indicate data to be masked, and data which is inverted on the bus. For data bus inversion (DBI), the DMI signal is driven HIGH when the data on the data bus is inverted, or driven LOW when the data is in its normal state. DBI can be disabled via a mode register setting. For data mask, the DMI signal is used in combination with the data lines to indicate data to be masked in a MASK WRITE command (see the Data Mask (DM) and Data Bus Inversion (DBI) sections for details). The data mask function can be disabled via a mode register setting. Each byte of data has a DMI signal. Each channel has its own DMI signals.
ZQ0, ZQ1	Reference	<b>ZQ 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 V <sub>DDQ</sub> through a 240Ω ±1% resistor.
V <sub>DDQ</sub> , V <sub>DD1</sub> , V <sub>DD2</sub>	Supply	<b>Power supplies:</b> Isolated on the die for improved noise immunity.
V <sub>SS</sub>	Supply	<b>Ground Reference:</b> Power supply ground reference.
RESET_n	Input	<b>RESET:</b> When asserted LOW, the RESET pin resets all channels of the die.
DNU	–	<b>Do not use:</b> Must be grounded or left floating.
NC	–	<b>No connect:</b> Not internally connected.

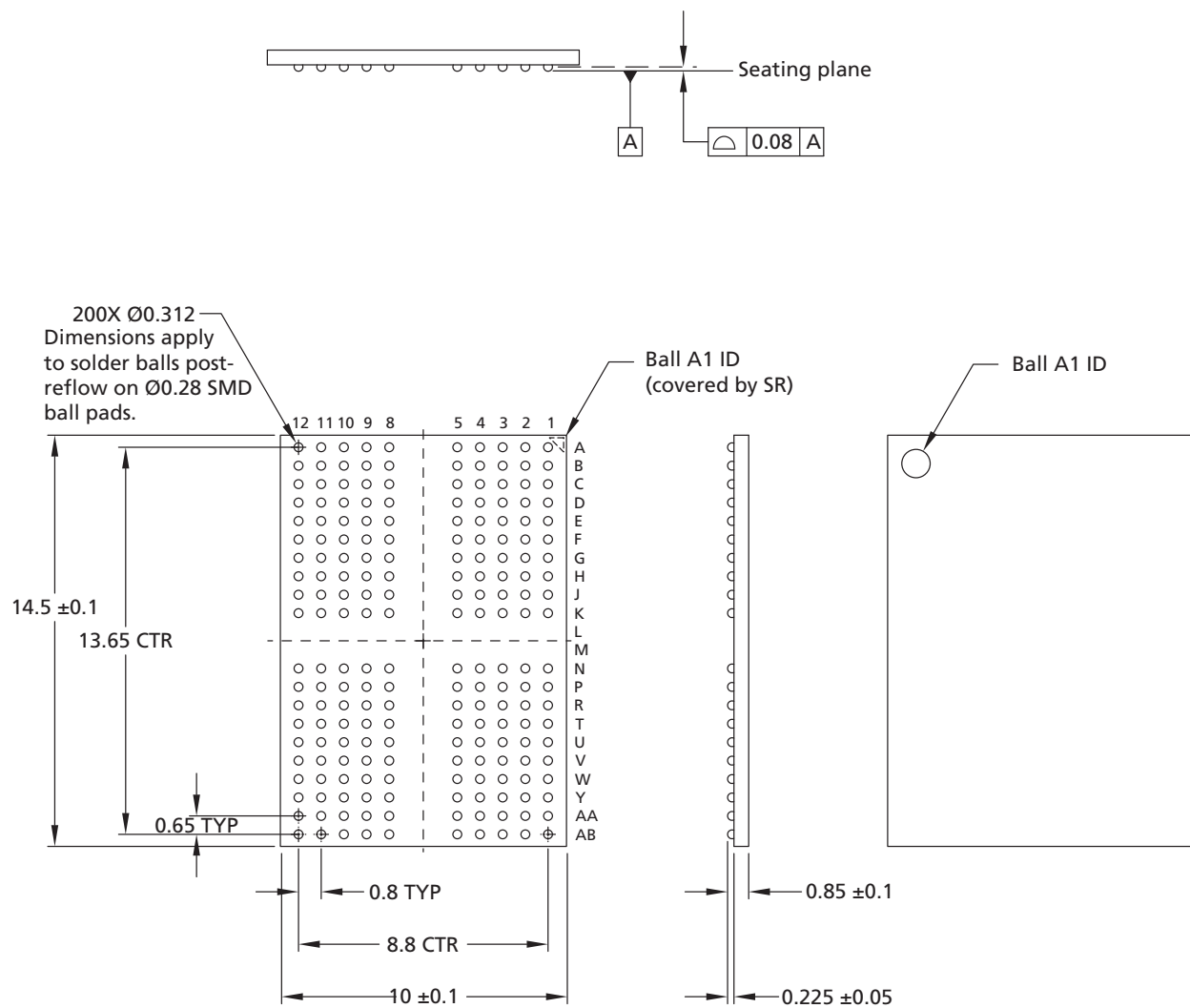
## Package Dimensions

**Figure 6: 200-Ball WFBGA – 10mm × 14.5mm (Package Code: NP)**



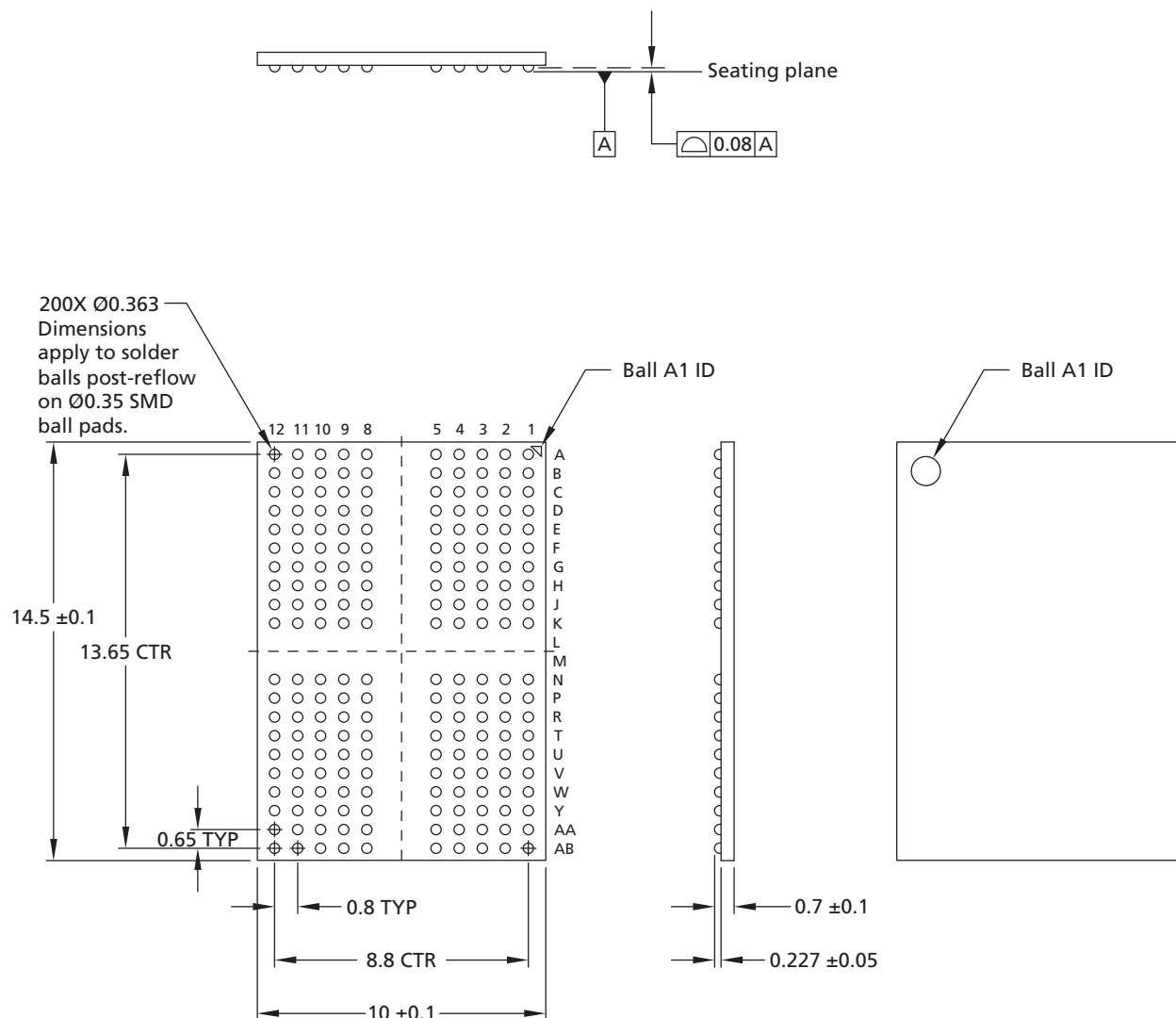
- Notes:
1. All dimensions are in millimeters.
  2. Solder ball composition: SAC302 with NiAu pads (96.8% Sn, 3Ag, 0.2% Cu).
  3. The package height does not include room temperature warpage.

Figure 7: 200-Ball VFBGA – 10mm × 14.5mm (Package Code: NQ)



- Notes:
1. All dimensions are in millimeters.
  2. Solder ball composition: SAC302 with NiAu pads (96.8% Sn, 3Ag, 0.2% Cu).
  3. The package height does not include room temperature warpage.

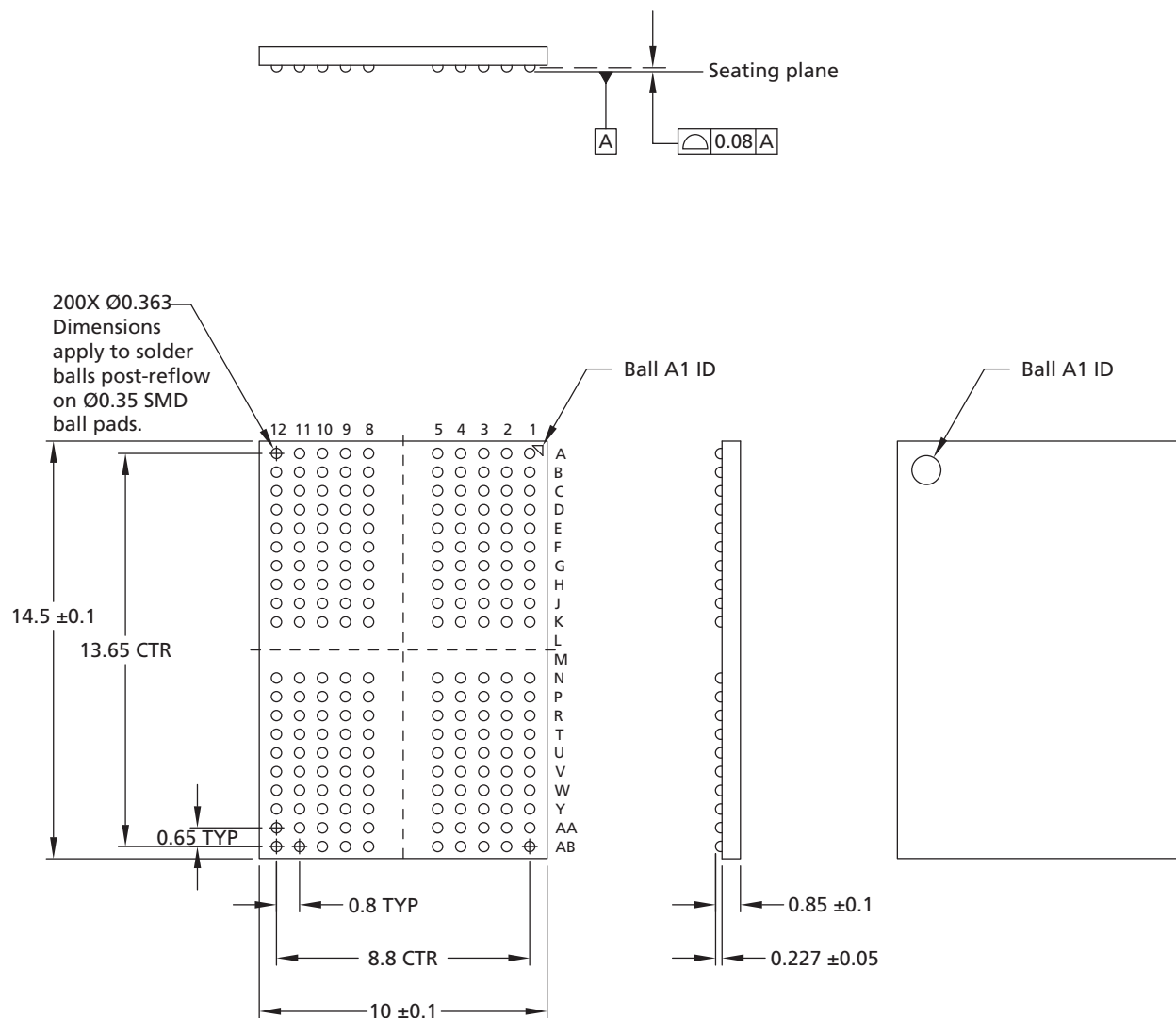
**Figure 8: 200-Ball WFBGA – 10mm × 14.5mm (Package Code: DS)**



- Notes:
1. All dimensions are in millimeters.
  2. Solder ball composition: SAC302 with NiAu pads (96.8% Sn, 3Ag, 0.2% Cu).
  3. The package height does not include room temperature warpage.



Figure 9: 200-Ball WFBGA – 10mm × 14.5mm (Package Code: DT)



- Notes:
1. All dimensions are in millimeters.
  2. Solder ball composition: SAC302 with NiAu pads (96.8% Sn, 3Ag, 0.2% Cu).
  3. The package height does not include room temperature warpage.

## MR0, MR[6:4], MR8, MR13 Readout

Table 4: Mode Register Contents

Mode Register	OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
MR0								<b>REF</b>
	0b: Both legacy and modified refresh mode supported							
MR4					<b>SR Abort</b>			
	0b: Disable (default) 1b: Enable							
MR5	<b>Manufacturer ID</b>							
	1111 1111b : Micron							
MR6	<b>Revision ID1</b>							
	0000 0001b							
MR8				<b>Density</b>				
	OP[5:2] = 0011b: 6Gb per die (6Gb per channel)							
MR13						<b>VRO</b>		
	0b: Normal operation (default) 1b: Output the $V_{REF(CA)}$ value on DQ7 and $V_{REF(DQ)}$ value on DQ6							

- Notes:
1. The contents of MR0, MR[6:4], MR8, and MR13 will reflect information specific to each in these packages.
  2. Other bits not defined above and other mode registers are referred to in Mode Register Assignments and Definitions section.

## I<sub>DD</sub> Parameters

Refer to I<sub>DD</sub> Specification Parameters and Test Conditions section for detailed conditions.

**Table 5: I<sub>DD</sub> Parameters – Single-Die**

V<sub>DD2</sub>, V<sub>DDQ</sub> = 1.06–1.17V; V<sub>DD1</sub> = 1.70–1.95V; T<sub>C</sub> = -25°C to +85°C

Parameter	Supply	Speed Grade		Unit	Note
		3200 Mbps	3733 Mbps		
I <sub>DD01</sub>	V <sub>DD1</sub>	3.5	3.5	mA	
I <sub>DD02</sub>	V <sub>DD2</sub>	45	45		
I <sub>DD0Q</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2P1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD2P2</sub>	V <sub>DD2</sub>	3	3		
I <sub>DD2PQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2PS1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD2PS2</sub>	V <sub>DD2</sub>	3	3		
I <sub>DD2PSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2N1</sub>	V <sub>DD1</sub>	2	2	mA	
I <sub>DD2N2</sub>	V <sub>DD2</sub>	27	27		
I <sub>DD2NQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2NS1</sub>	V <sub>DD1</sub>	2	2	mA	
I <sub>DD2NS2</sub>	V <sub>DD2</sub>	23	23		
I <sub>DD2NSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3P1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD3P2</sub>	V <sub>DD2</sub>	9	9		
I <sub>DD3PQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3PS1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD3PS2</sub>	V <sub>DD2</sub>	9	9		
I <sub>DD3PSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3N1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	
I <sub>DD3N2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD3NQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3NS1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	
I <sub>DD3NS2</sub>	V <sub>DD2</sub>	26	26		
I <sub>DD3NSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD4R1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	3
I <sub>DD4R2</sub>	V <sub>DD2</sub>	275	315		
I <sub>DD4RQ</sub>	V <sub>DDQ</sub>	150	160		
I <sub>DD4W1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	
I <sub>DD4W2</sub>	V <sub>DD2</sub>	210	240		
I <sub>DD4WQ</sub>	V <sub>DDQ</sub>	55	65		

**Table 5: I<sub>DD</sub> Parameters – Single-Die (Continued)**
 $V_{DD2}, V_{DDQ} = 1.06\text{--}1.17\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}; T_C = -25^\circ\text{C to } +85^\circ\text{C}$ 

Parameter	Supply	Speed Grade		Unit	Note
		3200 Mbps	3733 Mbps		
I <sub>DD51</sub>	V <sub>DD1</sub>	10	10	mA	
I <sub>DD52</sub>	V <sub>DD2</sub>	90	90		
I <sub>DD5Q</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD5AB1</sub>	V <sub>DD1</sub>	2.5	2.5	mA	
I <sub>DD5AB2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD5ABQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD5PB1</sub>	V <sub>DD1</sub>	2.5	2.5	mA	
I <sub>DD5PB2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD5PBQ</sub>	V <sub>DDQ</sub>	0.75	0.75		

- Notes: 1. Published I<sub>DD</sub> values except I<sub>DD4RQ</sub> are the maximum of the distribution of the arithmetic mean. Refer to the following note for I<sub>DD4RQ</sub>; refer to I<sub>DD6</sub> Full-Array Self Refresh Current table for I<sub>DD6</sub>.
2. I<sub>DD4RQ</sub> value is reference only. Typical value. DBI disabled, V<sub>OH</sub> = V<sub>DDQ</sub>/3, T<sub>C</sub> = 25°C.

**Table 6: I<sub>DD6</sub> Full-Array Self Refresh Current**
 $V_{DD2}, V_{DDQ} = 1.06\text{--}1.17\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

Temperature	Supply	Full-Array Self Refresh Current	Unit
25°C	V <sub>DD1</sub>	0.3	mA
	V <sub>DD2</sub>	0.5	
	V <sub>DDQ</sub>	0.1	
85°C	V <sub>DD1</sub>	2.0	
	V <sub>DD2</sub>	5.0	
	V <sub>DDQ</sub>	0.75	

- Note: 1. I<sub>DD6</sub> 25°C is the typical, and I<sub>DD6</sub> 85°C is the maximum of the distribution of the arithmetic mean.

**Table 7: I<sub>DD</sub> Parameters – Single-Die**
 $V_{DD2}, V_{DDQ} = 1.06\text{--}1.17\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}; T_C = 0^\circ\text{C to } +105^\circ\text{C}$ 

Parameter	Supply	Speed Grade		Unit	Note
		3200 Mbps	3733 Mbps		
I <sub>DD01</sub>	V <sub>DD1</sub>	3.5	3.5	mA	
I <sub>DD02</sub>	V <sub>DD2</sub>	45	45		
I <sub>DD0Q</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2P1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD2P2</sub>	V <sub>DD2</sub>	3	3		
I <sub>DD2PQ</sub>	V <sub>DDQ</sub>	0.75	0.75		

**Table 7: I<sub>DD</sub> Parameters – Single-Die (Continued)**
 $V_{DD2}, V_{DDQ} = 1.06\text{--}1.17\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}; T_C = -25^\circ\text{C to } +85^\circ\text{C}$ 

Parameter	Supply	Speed Grade		Unit	Note
		3200 Mbps	3733 Mbps		
I <sub>DD2PS1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD2PS2</sub>	V <sub>DD2</sub>	3	3		
I <sub>DD2PSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2N1</sub>	V <sub>DD1</sub>	2	2	mA	
I <sub>DD2N2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD2NQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD2NS1</sub>	V <sub>DD1</sub>	2	2	mA	
I <sub>DD2NS2</sub>	V <sub>DD2</sub>	23	23		
I <sub>DD2NSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3P1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD3P2</sub>	V <sub>DD2</sub>	9	9		
I <sub>DD3PQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3PS1</sub>	V <sub>DD1</sub>	1.2	1.2	mA	
I <sub>DD3PS2</sub>	V <sub>DD2</sub>	9	9		
I <sub>DD3PSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3N1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	
I <sub>DD3N2</sub>	V <sub>DD2</sub>	36	36		
I <sub>DD3NQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD3NS1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	
I <sub>DD3NS2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD3NSQ</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD4R1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	3
I <sub>DD4R2</sub>	V <sub>DD2</sub>	310	350		
I <sub>DD4RQ</sub>	V <sub>DDQ</sub>	165	170		
I <sub>DD4W1</sub>	V <sub>DD1</sub>	2.25	2.25	mA	
I <sub>DD4W2</sub>	V <sub>DD2</sub>	235	265		
I <sub>DD4WQ</sub>	V <sub>DDQ</sub>	60	70		
I <sub>DD51</sub>	V <sub>DD1</sub>	10	10	mA	
I <sub>DD52</sub>	V <sub>DD2</sub>	90	90		
I <sub>DD5Q</sub>	V <sub>DDQ</sub>	0.75	0.75		
I <sub>DD5AB1</sub>	V <sub>DD1</sub>	2.5	2.5	mA	
I <sub>DD5AB2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD5ABQ</sub>	V <sub>DDQ</sub>	0.75	0.75		

**Table 7: I<sub>DD</sub> Parameters – Single-Die (Continued)**
 $V_{DD2}, V_{DDQ} = 1.06\text{--}1.17\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}; T_C = -25^\circ\text{C to } +105^\circ\text{C}$ 

Parameter	Supply	Speed Grade		Unit	Note
		3200 Mbps	3733 Mbps		
I <sub>DD5PB1</sub>	V <sub>DD1</sub>	2.5	2.5	mA	
I <sub>DD5PB2</sub>	V <sub>DD2</sub>	30	30		
I <sub>DD5PBQ</sub>	V <sub>DDQ</sub>	0.75	0.75		

- Notes: 1. Published I<sub>DD</sub> values except I<sub>DD4RQ</sub> are the maximum of the distribution of the arithmetic mean. Refer to another note for I<sub>DD4RQ</sub>. And refer to another table for I<sub>DD6</sub>.  
 2. I<sub>DD4RQ</sub> value is reference only. Typical value. DBI disabled, V<sub>OH</sub> = V<sub>DDQ</sub>/3, T<sub>C</sub> = 25°C

**Table 8: I<sub>DD6</sub> Full-Array Self Refresh Current**
 $V_{DD2}, V_{DDQ} = 1.06\text{--}1.17\text{V}; V_{DD1} = 1.70\text{--}1.95\text{V}$ 

Temperature	Supply	Full-Array Self Refresh Current	Unit
105°C	V <sub>DD1</sub>	2	mA
	V <sub>DD2</sub>	8	
	V <sub>DDQ</sub>	1	

- Note: 1. I<sub>DD6</sub> 105°C is the maximum of the distribution of the arithmetic mean.

## Functional Description

The Mobile Low-Power DDR4 SDRAM (LPDDR4) is a high-speed CMOS, dynamic random-access memory internally configured with either 1 or 2 channels. Each channel is comprised of 16 DQs and 8 banks.

LPDDR4 uses a 2-tick, single-data-rate (SDR) protocol on the CA bus to reduce the number of input signals in the system. The term "2-tick" means that the command/address is decoded across two transactions, such that half of the command/address is captured with each of two consecutive rising edges of CK. The 6-bit CA bus contains command, address, and bank information. Some commands such as READ, WRITE, MASKED WRITE, and ACTIVATE require two consecutive 2-tick SDR commands to complete the instruction.

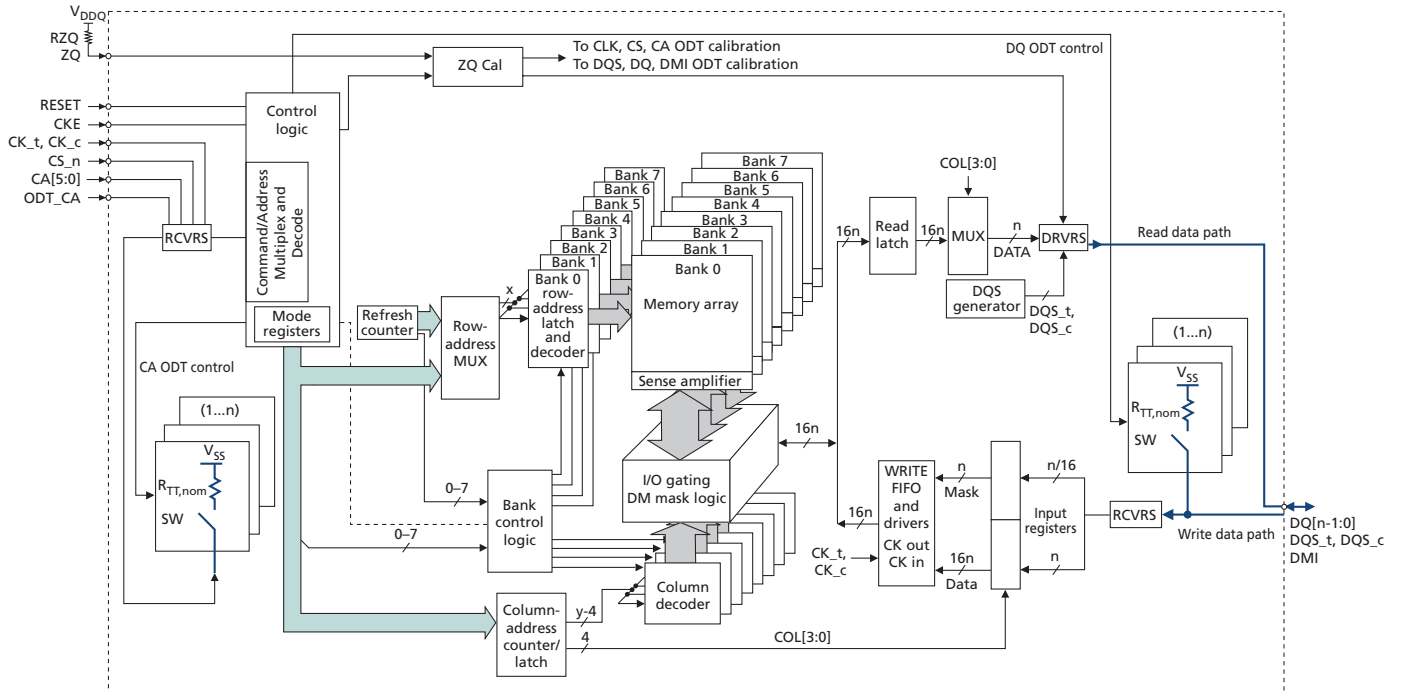
LPDDR4 uses a double-data-rate (DDR) protocol on the DQ bus to achieve high-speed operation. The DDR interface transfers two data bits to each DQ lane in one clock cycle and is matched to a  $16n$ -prefetch DRAM architecture. A write/read access consists of a single  $16n$ -bit-wide data transfer to/from the DRAM core and 16 corresponding  $n$ -bit-wide data transfers at the I/O pins.

Read and write accesses to the device are burst-oriented. Accesses start at a selected column address and continue for a programmed number of columns in a programmed sequence.

Accesses begin with the registration of an ACTIVATE command to open a row in the memory core, followed by a WRITE or READ command to access column data within the open row. The address and bank address (BA) bits registered by the ACTIVATE command are used to select the bank and row to be opened. The address and BA bits registered with the WRITE or READ command are used to select the bank and the starting column address for the burst access.

Prior to normal operation, the LPDDR4 SDRAM must be initialized. Following sections provide detailed information about device initialization, register definition, command descriptions and device operations.

**Figure 10: Functional Block Diagram**



## Monolithic Device Addressing

The table below includes all monolithic device addressing options defined by JEDEC. Under the SDRAM Addressing heading near the beginning of this data sheet are addressing details for this product data sheet.



**Table 9: Monolithic Device Addressing – 2 Channels per Die**

<b>Memory density (per die)</b>	<b>4Gb</b>	<b>6Gb</b>	<b>8Gb</b>	<b>12Gb</b>	<b>16Gb</b>
Memory density (per channel)	2Gb	3Gb	4Gb	6Gb	8Gb
Configuration	16Mb x 16DQ x 8 banks x 2 channels	24Mb x 16DQ x 8 banks x 2 channels	32Mb x 16DQ x 8 banks x 2 channels	48Mb x 16DQ x 8 banks x 2 channels	64Mb x 16DQ x 8 banks x 2 channels
Number of channels (per die)	2	2	2	2	2
Number of banks (per channel)	8	8	8	8	8
Array prefetch (bits, per channel)	256	256	256	256	256
Number of rows (per channel)	16,384	24,576	32,768	49,152	65,536
Number of columns (fetch boundaries)	64	64	64	64	64
Page size (bytes)	2048	2048	2048	2048	2048
Channel density (bits per channel)	2,147,483,648	3,221,225,472	4,294,967,296	6,442,450,944	8,589,934,592
Total density (bits per die)	4,294,967,296	6,442,450,944	8,589,934,592	12,884,901,888	17,179,869,184
Bank address	BA[2:0]	BA[2:0]	BA[2:0]	BA[2:0]	BA[2:0]
x16	Row add	R[13:0]	R[14:0] (R13 = 0 when R14 = 1)	R[15:0] (R14 = 0 when R15 = 1)	R[15:0]
	Col. add	C[9:0]	C[9:0]	C[9:0]	C[9:0]
Burst starting address boundary	64 bit	64 bit	64 bit	64 bit	64 bit

**Table 10: Monolithic Device Addressing – 1 Channel per Die**

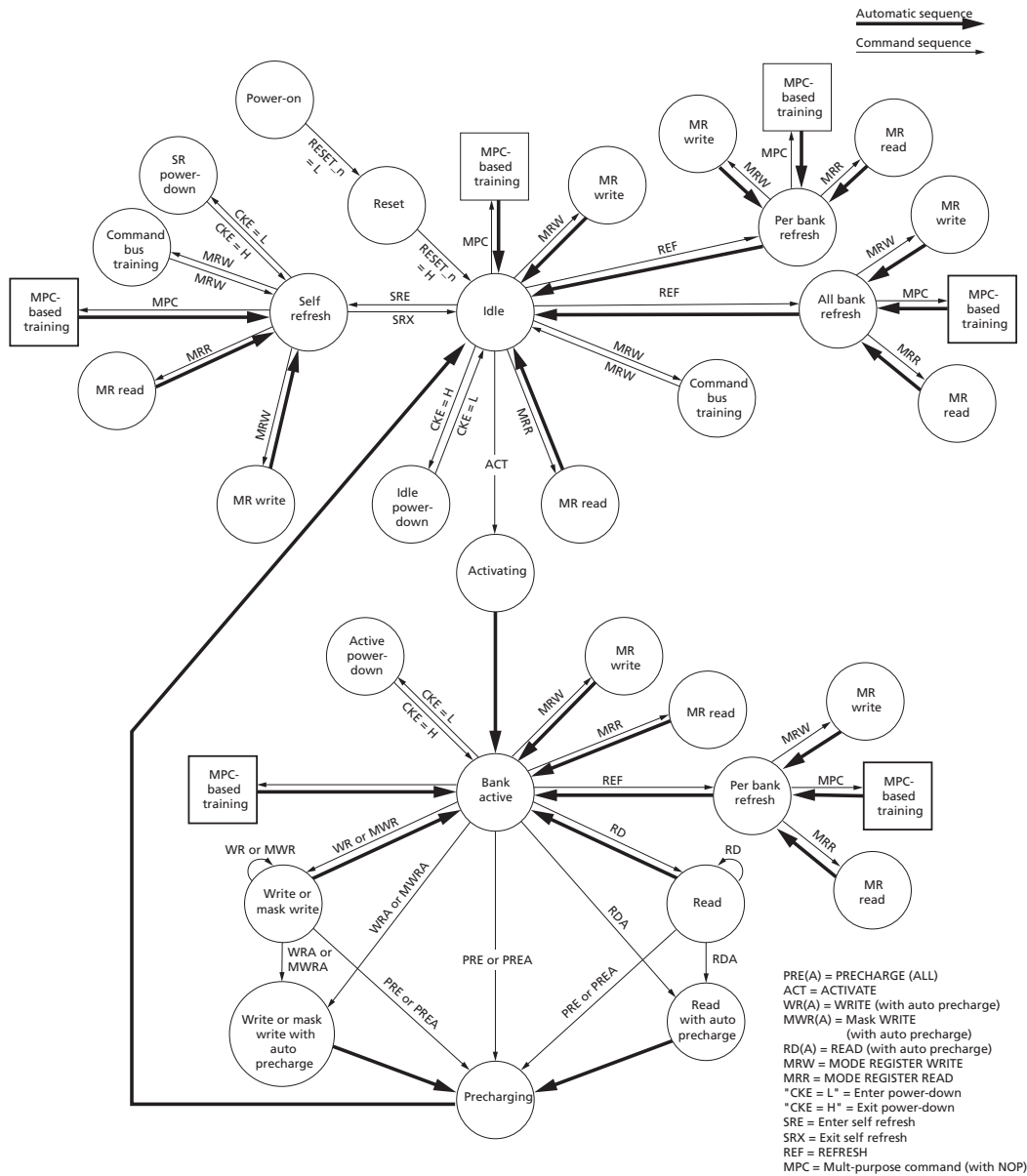
<b>Memory density (per die)</b>		<b>4Gb</b>	<b>6Gb</b>	<b>8Gb</b>
Memory density (per channel)		4Gb	6Gb	8Gb
Configuration		32Mb x 16 DQ x 8 banks	48Mb x 16 DQ x 8 banks	64Mb x 16 DQ x 8 banks
Number of channels (per die)		1	1	1
Number of banks (per channel)		8	8	8
Array prefetch (bits, per channel)		256	256	256
Number of rows (per channel)		32,768	49,152	65,536
Number of columns (fetch boundaries)		64	64	64
Page size (bytes)		2048	2048	2048
Channel density (bits per channel)		4,294,967,296	6,442,450,944	8,589,934,592
Total density (bits per die)		4,294,967,296	6,442,450,944	8,589,934,592
Bank address		BA[2:0]	BA[2:0]	BA[2:0]
x16	Row add	R[14:0]	R[15:0] (R14 = 0 when R15 = 1)	R[15:0]
	Column add	C[9:0]	C[9:0]	C[9:0]
Burst starting address boundary		64 bit	64 bit	64 bit

- Notes:
1. The lower two column addresses (C[1:0]) are assumed to be zero and are not transmitted on the CA bus.
  2. Row and column address values on the CA bus that are not used for a particular density should be at valid logic levels.
  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.

## Simplified Bus Interface State Diagram

The state diagram provides a simplified illustration of the bus interface, supported state transitions, and the commands that control them. For a complete description of device behavior, use the information provided in the state diagram with the truth tables and timing specifications. The truth tables describe device behavior and applicable restrictions when considering the actual state of all banks. For command descriptions, see the Commands and Timing section.

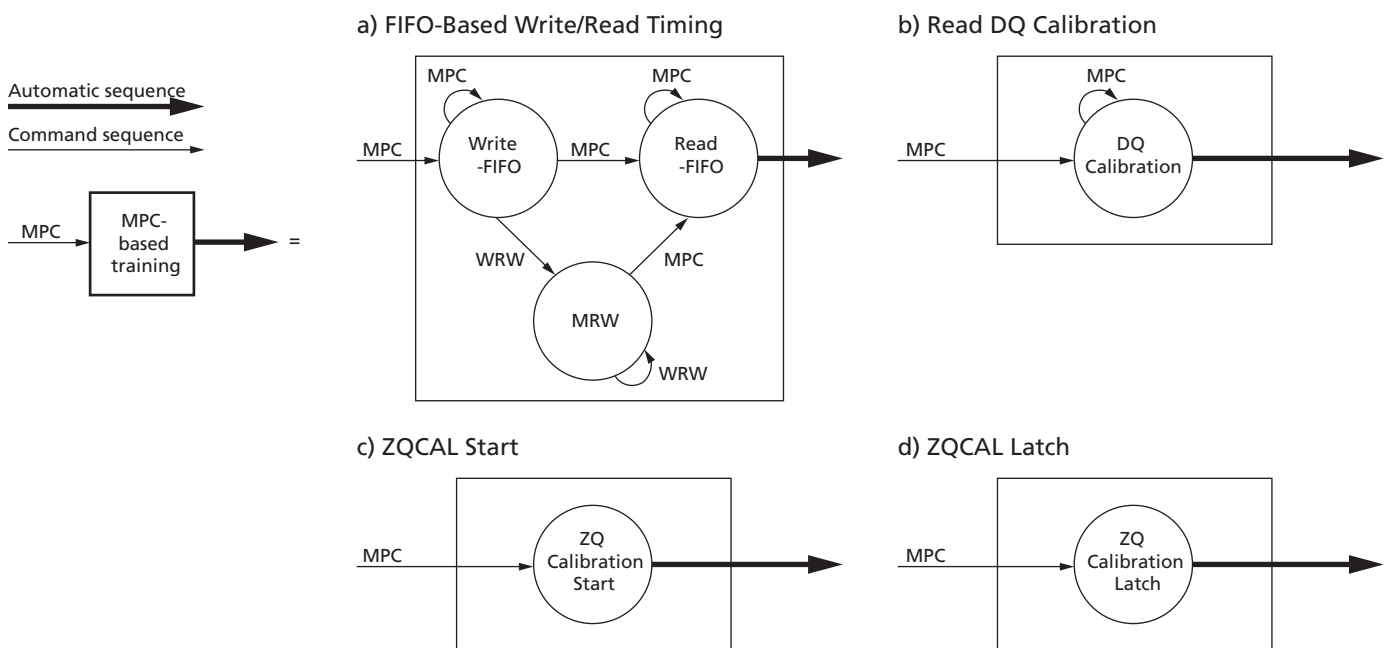
Figure 11: Simplified State Diagram



Notes: 1. From the self refresh state, the device can enter power-down, MRR, MRW, or any of the training modes initiated with the MPC command. See the Self Refresh section.

2. All banks are precharged in the idle state.
3. In the case of using an 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 applicable training section for more information.
4. In the case of an 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 applicable training section for more information.
5. This diagram is intended to provide an overview of the possible state transitions and commands to control them; however, it does not contain the details necessary to operate the device. In particular, situations involving more than one bank are not captured in complete detail.
6. States that have an "automatic return" and can be accessed from more than one prior state (that is, MRW from either idle or active states) will return to the state where they were initiated (that is, MRW from idle will return to idle).
7. The RESET pin can be asserted from any state and will cause the device to enter the reset state. The diagram shows RESET applied from the power-on and idle states as an example, but this should not be construed as a restriction on RESET.
8. MRW commands from the active state cannot change operating parameters of the device that affect timing. Mode register fields which may be changed via MRW from the active state include: MR1-OP[3:0], MR1-OP[7], MR3-OP[7:6], MR10-OP[7:0], MR11-OP[7:0], MR13-OP[5], MR15-OP[7:0], MR16-OP[7:0], MR17-OP[7:0], MR20-OP[7:0], and MR22-OP[4:0].

**Figure 12: Simplified State Diagram**



## Power-Up and Initialization

To ensure proper functionality for power-up and reset initialization, default values for the MR settings are provided in the table below.

**Table 11: Mode Register Default Settings**

Item	Mode Register Setting	Default Setting	Description
FSP-OP/WR	MR13 OP[7:6]	00b	FSP-OP/WR[0] are enabled
WLS	MR2 OP[6]	0b	WRITE latency set A is selected
WL	MR2 OP[5:3]	000b	WL = 4
RL	MR2 OP[2:0]	000b	RL = 6, nRTP = 8
nWR	MR1 OP[6:4]	000b	nWR = 6
DBI-WR/RD	MR3 OP[7:6]	00b	Write and read DBI are disabled
CA ODT	MR11 OP[6:4]	000b	CA ODT is disabled
DQ ODT	MR11 OP[2:0]	000b	DQ ODT is disabled
V <sub>REF(CA)</sub> setting	MR12 OP[6]	1b	V <sub>REF(CA)</sub> range[1] is enabled
V <sub>REF(CA)</sub> value	MR12 OP[5:0]	001101b	Range1: 27.2% of V <sub>DD2</sub>
V <sub>REF(DQ)</sub> setting	MR14 OP[6]	1b	V <sub>REF(DQ)</sub> range[1] enabled
V <sub>REF(DQ)</sub> value	MR14 OP[5:0]	001101b	Range1: 27.2% of V <sub>DDQ</sub>

The following sequence must be used to power up the device. Unless specified otherwise, this procedure is mandatory. The power-up sequence of all channels must proceed simultaneously.

## Voltage Ramp

1. While applying power (after Ta), RESET\_n should be held LOW ( $\leq 0.2 \times V_{DD2}$ ), and all other inputs must be between V<sub>IL,min</sub> and V<sub>IH,max</sub>. The device outputs remain at High-Z while RESET\_n is held LOW. Power supply voltage ramp requirements are provided in the table below. V<sub>DD1</sub> must ramp at the same time or earlier than V<sub>DD2</sub>. V<sub>DD2</sub> must ramp at the same time or earlier than V<sub>DDQ</sub>.

**Table 12: Voltage Ramp Conditions**

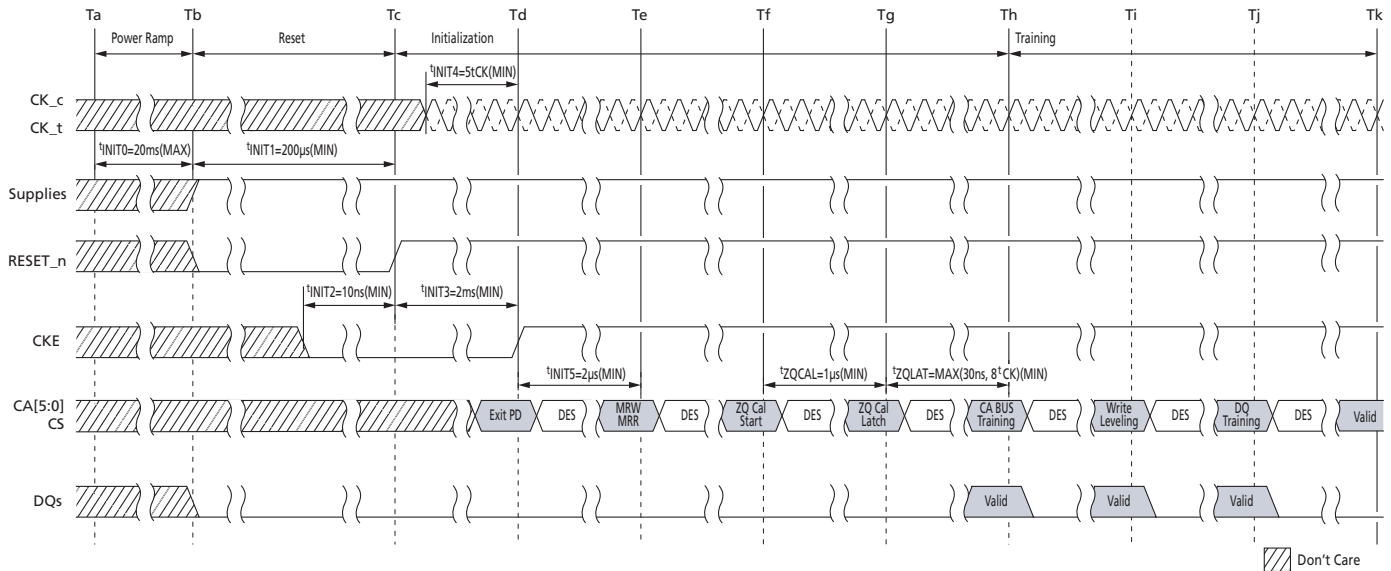
After...	Applicable Conditions
Ta is reached	V <sub>DD1</sub> must be greater than V <sub>DD2</sub>
	V <sub>DD2</sub> must be greater than V <sub>DDQ</sub> - 200mV

- Notes:
1. Ta is the point when any power supply first reaches 300mV.
  2. Voltage ramp conditions in above table apply between Ta and power-off (controlled or uncontrolled).
  3. Tb is the point at which all supply and reference voltages are within their defined operating ranges.
  4. Power ramp duration <sup>t</sup>INIT0 (Tb-Ta) must not exceed 20ms.
  5. The voltage difference between any V<sub>SS</sub> and V<sub>SSQ</sub> must not exceed 100mV.

2. Following completion of the of the voltage ramp (Tb), RESET\_n must be held LOW for <sup>t</sup>INIT1. DQ, DMI, DQS\_t, and DQS\_c voltage levels must be between V<sub>SSQ</sub> and V<sub>DDQ</sub> during voltage ramp to avoid latch-up. CK\_t and CK\_c, CS, and CA input levels must be between V<sub>SS</sub> and V<sub>DD2</sub> during voltage ramp to avoid latch-up. Voltage ramp power supply requirements are provided in the table below.

3. Beginning at  $T_b$ , RESET\_n must remain LOW for at least  $t_{INIT1}(T_c)$ , after which RESET\_n can be de-asserted to HIGH( $T_c$ ). At least 10ns before CKE de-assertion, CKE is required to be set LOW. All other input signals are "Don't Care."

**Figure 13: Voltage 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\_n is de-asserted( $T_c$ ), wait at least  $t_{INIT3}$  before activating CKE. CK\_t, CK\_c must be started and stabilized for  $t_{INIT4}$  before CKE goes active( $T_d$ ). CS must remain LOW when the controller activates CKE.

5. After CKE is set to HIGH, wait a minimum of  $t_{INIT5}$  to issue any MRR or MRW commands( $T_e$ ). For 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  $t_{DQSCkb}$ ) before the system is appropriately configured.

6. After completing all MRW commands to set the pull-up, pull-down, and Rx termination values, the controller can issue the ZQCAL START command to the memory( $T_f$ ). This command is used to calibrate the  $V_{OH}$  level and the output impedance over process, voltage, and temperature. In systems where more than one device share one external ZQ resistor, the controller must not overlap the ZQ calibration sequence of each device. The ZQ calibration sequence is completed after  $t_{ZQCAL}$  ( $T_g$ ). 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 device will power-up with receivers configured for low-speed operations and with  $V_{REF(CA)}$  set to a default factory setting. Normal device operation at clock speeds higher than  $t_{CKb}$  may not be possible until command bus training is complete. The command bus training MRW command uses the CA bus as inputs for the calibration data stream, and it outputs the results asynchro-

nously 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, the controller must perform write leveling. Write leveling mode is enabled when MR2 OP[7] is HIGH(Ti). See the Write Leveling section for a detailed description of the write leveling entry and exit sequence. In write leveling mode, the 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  $V_{REF(DQ)}$ . The device will power-up with receivers configured for low-speed operations and with  $V_{REF(DQ)}$  set to a default factory setting. Normal device operation at clock speeds higher than  $t_{CKb}$  should not be attempted until DQ bus training is complete. The MPC[READ DQ CALIBRATION] command is used together with MPC[READ-FIFO] or MPC[WRITE-FIFO] commands to train the DQ bus without disturbing the memory array contents. See the DQ Bus Training section for more information on the DQ bus training sequence.

10. At  $T_k$ , the device is ready for normal operation and is ready to accept any valid command. Any mode registers that have not previously been configured for normal operation should be written at this time.

**Table 13: Initialization Timing Parameters**

Parameter	Min	Max	Unit	Comment
$t_{INIT0}$	–	20	ms	Maximum voltage ramp time
$t_{INIT1}$	200	–	$\mu$ s	Minimum RESET_n LOW time after completion of voltage ramp
$t_{INIT2}$	10	–	ns	Minimum CKE LOW time before RESET_n goes HIGH
$t_{INIT3}$	2	–	ms	Minimum CKE LOW time after RESET_n goes HIGH
$t_{INIT4}$	5	–	$t_{CK}$	Minimum stable clock before first CKE HIGH
$t_{INIT5}$	2	–	$\mu$ s	Minimum idle time before first MRW/MRR command
$t_{CKb}$	Note 1, 2	Note 1, 2	ns	Clock cycle time during boot

- Notes:
1. Minimum  $t_{CKb}$  guaranteed by DRAM test is 18ns.
  2. The system may boot at a higher frequency than dictated by minimum  $t_{CKb}$ . 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\_n below  $0.2 \times V_{DD2}$  anytime when reset is needed. RESET\_n needs to be maintained for minimum  $t_{PW\_RESET}$ . CKE must be pulled LOW at least 10ns before de-asserting RESET\_n.
2. Repeat steps 4–10 in Voltage Ramp section.



**Table 14: Reset Timing Parameter**

Parameter	Value		Unit	Comment
	Min	Max		
tPW_RESET	100	–	ns	Minimum RESET_n LOW time for reset initialization with stable power

## Power-Off Sequence

### Controlled Power-Off

While powering off, CKE must be held LOW ( $\leq 0.2 \times V_{DD2}$ ); all other inputs must be between  $V_{IL,min}$  and  $V_{IH,max}$ . The device outputs remain at High-Z while CKE is held LOW.

DQ, DMI, DQS\_t, and DQS\_c voltage levels must be between  $V_{SSQ}$  and  $V_{DDQ}$  during the power-off sequence to avoid latch-up. CK\_t, CK\_c, CS, and CA input levels must be between  $V_{SS}$  and  $V_{DD2}$  during the power-off sequence to avoid latch-up.

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

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

**Table 15: Power Supply Conditions**

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

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

### Uncontrolled Power-Off

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

- At Tx, when the power supply drops below the minimum values specified in the Recommended DC Operating Conditions table, all power supplies must be turned off and all power supply current capacity must be at zero, except for any static charge remaining in the system.
- After Tz (the point at which all power supplies first reach 300mV), the device must power off. 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 16: Power-Off Timing**

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

## Mode Registers

### Mode Register Assignments and Definitions

Mode register definitions are provided in the Mode Register Assignments table. In the access column of the table, R indicates read-only; W indicates write-only; R/W indicates read- or write-capable or enabled. The MRR command is used to read from a register. The MRW command is used to write to a register.

**Table 17: Mode Register Assignments**

Notes 1–5 apply to entire table

MR#	MA[7:0]	Function	Access	OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0	Link
0	00h	Device info	R	CATR	RFU	RFU	RZQI		RFU	REF		Go to MR0
1	01h	Device feature 1	W	RD-PST	nWR (for AP)			RD-PRE	WR-PRE	BL		Go to MR1
2	02h	Device feature 2	W	WR Lev	WLS	WL		RL			Go to MR2	
3	03h	I/O config-1	W	DBI-WR	DBI-RD	PDDS			PPRP	WR-PST	PU-CAL	Go to MR3
4	04h	Refresh and training	R/W	TUF	Thermal offset	PPRE	SR abort	Refresh rate			Go to MR4	
5	05h	Basic config-1	R	Manufacturer ID							Go to MR5	
6	06h	Basic config-2	R	Revision ID1							Go to MR6	
7	07h	Basic config-3	R	Revision ID2							Go to MR7	
8	08h	Basic config-4	R	I/O width	Density			Type			Go to MR8	
9	09h	Test mode	W	Vendor-specific test mode							Go to MR9	
10	0Ah	I/O calibration	W	RFU							ZQ RST	Go to MR10
11	0Bh	ODT	W	RFU	CA ODT			RFU	DQ ODT			Go to MR11
12	0Ch	$V_{REF(CA)}$	R/W	RFU	$VR_{CA}$	$V_{REF(CA)}$					Go to MR12	
13	0Dh	Register control	W	FSP-OP	FSP-WR	DMD	RRO	VRCG	VRO	RPT	CBT	Go to MR13
14	0Eh	$V_{REF(DQ)}$	R/W	RFU	$VR_{DQ}$	$V_{REF(DQ)}$					Go to MR14	
15	0Fh	DQI-LB	W	Lower-byte invert register for DQ calibration							Go to MR15	
16	10h	PASR_Bank	W	PASR bank mask							Go to MR16	
17	11h	PASR_Seg	W	PASR segment mask							Go to MR17	
18	12h	IT-LSB	R	DQS oscillator count – LSB							Go to MR18	
19	13h	IT-MSB	R	DQS oscillator count – MSB							Go to MR19	
20	14h	DQI-UB	W	Upper-byte invert register for DQ calibration							Go to MR20	
21	15h	Vendor use	W	RFU							Go to MR21	

**Table 17: Mode Register Assignments (Continued)**

Notes 1–5 apply to entire table

MR#	MA[7:0]	Function	Access	OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0	Link
22	16h	ODT feature 2	W	RFU		ODTD-CA	ODTE-CS	ODTE-CK	SoC ODT			Go to MR22
23	17h	DQS oscillator stop	W	DQS oscillator run-time setting								Go to MR23
24	18h	TRR control	R/W	TRR mode	TRR mode BAn			Unltd MAC	MAC value			Go to MR24
25	19h	PPR resources	R	B7	B6	B5	B4	B3	B2	B1	B0	Go to MR25
26–31	1Ah~1Fh	–	–	Reserved for future use								
32	20h	DQ calibration pattern A	W	See DQ calibration section								Go to MR32
33–39	21h~27h	Do not use	–	Do not use								
40	28h	DQ calibration pattern B	W	See DQ calibration section								Go to MR40
41–47	29h~2Fh	Do not use	–	Do not use								
48–63	30h~3Fh	Reserved	–	Reserved for future use								

- Notes:
1. RFU bits must be set to 0 during MRW commands.
  2. RFU bits are read as 0 during MRR commands.
  3. All mode registers that are specified as RFU or write-only shall return undefined data when read via an MRR command.
  4. RFU mode registers must not be written.
  5. Writes to read-only registers will not affect the functionality of the device.

**Table 18: MR0 Device Feature 0 (MA[7:0] = 00h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
CATR	RFU		RZQI		RFU		REF

**Table 19: MR0 Op-Code Bit Definitions**

Register Information	Tag	Type	OP	Definition	Notes
Refresh mode	REF	Read only	OP[0]	0b: Both legacy and modified refresh mode supported 1b: Only modified refresh mode supported	
Built-in self-test for RZQ information	RZQI	Read only	OP[4:3]	00b: RZQ self-test not supported 01b: ZQ may connect to V <sub>SSQ</sub> or float 10b: ZQ may short to V <sub>DDQ</sub> 11b: ZQ pin self-test completed, no error condition detected (ZQ may not connect to V <sub>SSQ</sub> , float, or short to V <sub>DDQ</sub> )	1–4

**Table 19: MR0 Op-Code Bit Definitions (Continued)**

Register Information	Tag	Type	OP	Definition	Notes
CA terminating rank	CATR	Read only	OP[7]	0b: CA for this rank is not terminated 1b: CA for this rank is terminated	

- Notes:
1. RZQI, if supported, will be set upon completion of MPC[ZQCAL START] command. (<sup>t</sup>ZQCAL after MPC[ZQCAL START] command.) RZQI value will be lost after reset.
  2. If ZQ is connected to V<sub>SSQ</sub> to set default calibration, OP[4:3] must be set to 01b. If ZQ is not connected to V<sub>SSQ</sub>, either OP[4:3] = 01b or OP[4:3] = 10b might indicate a ZQ pin assembly error. It is recommended that the assembly error be corrected.
  3. In the case of possible assembly error, the device will default to factory trim settings for R<sub>ON</sub>, and will ignore ZQ CALIBRATION commands. In either case, the device may not function as intended.
  4. If the ZQ pin 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 meets the specified limits (that is, 240Ω ±1%).

**Table 20: MR1 Device Feature 1 (MA[7:0] = 01h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
RD-PST	nWR (for AP)			RD-PRE	WR-PRE	BL	

**Table 21: MR1 Op-Code Bit Definitions**

Feature	Type	OP	Definition	Notes
BL Burst length	Write only	OP[1:0]	00b: BL = 16 sequential (default) 01b: BL = 32 sequential 10b: BL = 16 or 32 sequential (on-the-fly) 11b: Reserved	1, 5, 6
WR-PRE Write preamble length	Write only	OP[2]	0b: Reserved 1b: WR preamble = 2 × <sup>t</sup> CK	5, 6
RD-PRE Read preamble type	Write only	OP[3]	0b: RD preamble = Static (default) 1b: RD preamble = Toggle	3, 5, 6
nWR Write-recovery for auto-precharge command	Write only	OP[6:4]	000b: nWR = 6 (default) 001b: nWR = 10 010b: nWR = 16 011b: nWR = 20 100b: nWR = 24 101b: nWR = 30 110b: nWR = 34 111b: nWR = 40	2, 5, 6

**Table 21: MR1 Op-Code Bit Definitions (Continued)**

Feature	Type	OP	Definition	Notes
RD-PST Read postamble length	Write only	OP[7]	0b: RD postamble = $0.5 \times t_{CK}$ (default) 1b: RD postamble = $1.5 \times t_{CK}$	4, 5, 6

- Notes:
1. 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.
  2. The programmed value of  $nWR$  is the number of clock cycles the device uses to determine the starting point of an internal precharge after a write burst with auto precharge (AP) enabled. See Frequency Ranges for RL, WL, and  $nWR$  Settings table.
  3. For READ operations, this bit must be set to select between a toggling preamble and a non-toggling preamble. (See the Preamble section.)
  4. OP[7] provides an optional READ postamble with an additional rising and falling edge of DQS<sub>t</sub>. The optional postamble cycle is provided for the benefit of certain memory controllers.
  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.
  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, that is, 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 22: Burst Sequence for Read**

C4	C3	C2	C1	C0	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			
<b>16-Bit READ Operation</b>																																							
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																			
<b>32-Bit READ Operation</b>																																							
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. C[1:0] are not present on the CA bus; they are implied to be zero.
  2. The starting burst address is on 64-bit (4n) boundaries.

**Table 23: Burst Sequence for Write**

C4	C3	C2	C1	C0	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			
<b>16-Bit WRITE Operation</b>																																							
V	0	0	0	0	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F																			
<b>32-Bit WRITE Operation</b>																																							
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. C[1:0] are not present on the CA bus; they are implied to be zero.
  2. The starting burst address is on 256-bit (16n) boundaries for burst length 16.
  3. The starting burst address is on 512-bit (32n) boundaries for burst length 32.
  4. C[3:2] must be set to 0 for all WRITE operations.

**Table 24: MR2 Device Feature 2 (MA[7:0] = 02h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
WR Lev	WLS	WL			RL		

**Table 25: MR2 Op-Code Bit Definitions**

Feature	Type	OP	Definition	Notes
RL READ latency	Write- only	OP[2:0]	RL and <i>nRTP</i> for DBI-RD disabled (MR3 OP[6] = 0b) 000b: RL = 6, <i>nRTP</i> = 8 (default) 001b: RL = 10, <i>nRTP</i> = 8 010b: RL = 14, <i>nRTP</i> = 8 011b: RL = 20, <i>nRTP</i> = 8 100b: RL = 24, <i>nRTP</i> = 10 101b: RL = 28, <i>nRTP</i> = 12 110b: RL = 32, <i>nRTP</i> = 14 111b: RL = 36, <i>nRTP</i> = 16	1, 3, 4
			RL and <i>nRTP</i> for DBI-RD enabled (MR3 OP[6] = 1b) 000b: RL = 6, <i>nRTP</i> = 8 001b: RL = 12, <i>nRTP</i> = 8 010b: RL = 16, <i>nRTP</i> = 8 011b: RL = 22, <i>nRTP</i> = 8 100b: RL = 28, <i>nRTP</i> = 10 101b: RL = 32, <i>nRTP</i> = 12 110b: RL = 36, <i>nRTP</i> = 14 111b: RL = 40, <i>nRTP</i> = 16	

**Table 25: MR2 Op-Code Bit Definitions (Continued)**

Feature	Type	OP	Definition	Notes
WL WRITE latency	Write- only	OP[5:3]	WL set A (MR2 OP[6] = 0b) 000b: WL = 4 (default) 001b: WL = 6 010b: WL = 8 011b: WL = 10 100b: WL = 12 101b: WL = 14 110b: WL = 16 111b: WL = 18 <hr/> WL set B (MR2 OP[6] = 1b) 000b: WL = 4 001b: WL = 8 010b: WL = 12 011b: WL = 18 100b: WL = 22 101b: WL = 26 110b: WL = 30 111b: WL = 34	1, 3, 4
WLS WRITE latency set	Write- only	OP[6]	0b: Use WL set A (default) 1b: Use WL set B	1, 3, 4
WR Lev Write leveling	Write- only	OP[7]	0b: Disable write leveling (default) 1b: Enable write leveling	2

- Notes:
1. See Latency Code Frequency Table for allowable frequency ranges for RL/WL/nWR.
  2. After an MRW command 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 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, that is, 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.
  5. nRTP is valid for BL16 only. For BL32, the SDRAM will add 8 clocks to the nRTP value before starting a precharge.



**Table 26: Frequency Ranges for RL, WL, *n*WR, and *n*RTP Settings**

READ Latency		WRITE Latency		<i>n</i> WR	<i>n</i> RTP	Lower Frequency Limit (>)	Upper Frequency Limit(≤)	Units	Notes
No DBI	w/DBI	Set A	Set B						
6	6	4	4	6	8	10	266	MHz	1–6
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, or *n*WR value.
  2. DBI for READ operations is enabled in MR3 OPO[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 are 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 for *n*RTP 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 precharge) enabled. It is determined by  $RU^{(tRTP/tCK)}$ .
  5. The programmed value of *n*WR 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 precharge) enabled. It is determined by  $RU^{(tWR/tCK)}$ .
  6. *n*RTP shown in this table is valid for BL16 only. For BL32, the device will add 8 clocks to the *n*RTP value before starting a precharge.

**Table 27: MR3 I/O Configuration 1 (MA[7:0] = 03h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DBI-WR	DBI-RD	PDDS			PPRP	WR-PST	PU-CAL

**Table 28: MR3 Op-Code Bit Definitions**

Feature	Type	OP	Definition	Notes
PU-CAL (Pull-up calibration point)	Write-only	OP[0]	0b: $V_{DDQ}/2.5$ 1b: $V_{DDQ}/3$ (default)	1–4
WR-PST (WR postamble length)		OP[1]	0b: WR post-amble= $0.5 \times t_{CK}$ (default) 1b: WR post-amble= $1.5 \times t_{CK}$	2, 3, 5
PPRP (Post-package repair protection)		OP[2]	0b: PPR protection disabled (default) 1b: PPR protection enabled	6
PDDS (Pull-down drive strength)		OP[5:3]	000b: RFU 001b: $R_{ZQ}/1$ 010b: $R_{ZQ}/2$ 011b: $R_{ZQ}/3$ 100b: $R_{ZQ}/4$ 101b: $R_{ZQ}/5$ 110b: $R_{ZQ}/6$ (default) 111b: Reserved	1, 2, 3
DBI-RD (DBI-read enable)		OP[6]	0b: Disabled (default) 1b: Enabled	2, 3
DBI-WR (DBI-write enable)		OP[7]	0b: Disabled (default) 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. Recalibration 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 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 device, PU-CAL (MR3-OP[0]) must be set the same for both channels on a die. The SDRAM will read the value of only one register (Ch.A or Ch.B), vendor-specific, so both channels must be set the same.
  5. Refer to the supplier data sheet for vendor-specific function.  $1.5 \times t_{CK}$  apply  $\geq 1.6\text{GHz}$  clock.
  6. If MR3 OP[2] is set to 1b, 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 the DRAM will not allow writing of 1b to MR4 OP[4].

**Table 29: MR4 Device Temperature (MA[7:0] = 04h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
TUF	Thermal offset		PPRE	SR abort	Refresh rate		

**Table 30: MR4 Op-Code Bit Definitions**

Feature	Type	OP	Definition	Notes
Refresh rate	Read-only	OP[2:0]	000b: SDRAM low temperature operating limit exceeded 001b: 4x refresh 010b: 2x refresh 011b: 1x refresh (default) 100b: 0.5x refresh 101b: 0.25x refresh, no derating 110b: 0.25x refresh, with derating 111b: SDRAM high temperature operating limit exceeded	1–4, 7–9
SR abort (Self Refresh Abort)	Write	OP[3]	0b: Disable (default) 1b: Device dependent	9
PPRE (Post-package repair entry/exit)	Write	OP[4]	0b: Exit PPR mode (default) 1b: Enter PPR mode (Reference MR25 OP[7:0] for available PPR resources)	5, 9,
Thermal Offset-Control-ler offset to TCSR (Vendor-specific function)	Write	OP[6:5]	00b: No offset, 0~5°C gradient (default) 01b: 5°C offset, 5~10°C gradient 10b: 10°C offset, 10~15°C gradient 11b: Reserved	9
TUF (Temperature update flag)	Read-only	OP7	0b: OP[2:0] No change in OP[2:0] since last MR4 read (default) 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  $t_{REFI}$ ,  $t_{REFIpb}$ , and  $t_{REFW}$ . MR4 OP[2:0] = 011b corresponds to a device temperature of 85°C. Other values require either a longer (2x, 4x) refresh interval at lower temperatures or a shorter (0.5x, 0.25x) refresh interval at higher temperatures. If MR4 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 device will set MR4 OP[2:0] = 110b. See derating timing requirements in the AC Timing section.
  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 MR4 OP[2:0] = 000b or 111b.
  5. Post-package repair can be entered or exited by writing to MR4 OP[4].
  6. When MR4 OP[7] = 1b, the refresh rate reported in MR4 OP[2:0] has changed since the last MR4 read. A mode register read from MR4 will reset MR4 OP[7] to 0b.
  7. MR4 OP[7] = 0b at power-up. MR4 OP[2:0] bits are undefined at power-up.

8. See the Temperature Sensor section for information on the recommended frequency of reading MR4.
9. MR4 OP[6:3] can be written in this register. All other bits will be ignored by the device during an MRW command to this register.

**Table 31: MR5 Basic Configuration 1 (MA[7:0] = 05h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Manufacturer ID							

**Table 32: MR5 Op-Code Bit Definitions**

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

**Table 33: MR6 Basic Configuration 2 (MA[7:0] = 06h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Revision ID1							

Note: 1. MR6 is vendor-specific.

**Table 34: MR6 Op-Code Bit Definitions**

Feature	Type	OP	Definition
Revision ID1	Read-only	OP[7:0]	xxxx xxxxb: Revision ID1

Note: 1. MR6 is vendor-specific.

**Table 35: MR7 Basic Configuration 3 (MA[7:0] = 07h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Revision ID2							

**Table 36: MR7 Op-Code Bit Definitions**

Feature	Type	OP	Definition
Revision ID2	Read-only	OP[7:0]	xxxx xxxxb: Revision ID2

Note: 1. MR7 is vendor-specific.

**Table 37: MR8 Basic Configuration 4 (MA[7:0] = 08h)**

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

**Table 38: MR8 Op-Code Bit Definitions**

Feature	Type	OP	Definition
Type	Read-only	OP[1:0]	00b: S16 SDRAM (16n prefetch) All others: Reserved
Density	Read-only	OP[5:2]	0000b: 4Gb per die (2Gb per channel) 0001b: 6Gb per die (3Gb per channel) 0010b: 8Gb per die (4Gb per channel) or 4Gb per die (4Gb per channel) 0011b: 12Gb per die (6Gb per channel) or 6Gb per die (6Gb per channel) 0100b: 16Gb per die (8Gb per channel) or 8Gb per die (8Gb per channel) 0101b: 24Gb per die (12Gb per channel) 0110b: 32Gb per die (16Gb per channel) All others: Reserved
I/O width	Read-only	OP[7:6]	00b: x16/channel All others: Reserved

**Table 39: MR9 Test Mode (MA[7:0] = 09h)**

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

**Table 40: MR9 Op-Code Definitions**

Feature	Type	OP	Definition
Test mode	Write-only	OP[7:0]	0000000b; Vendor-specific test mode disabled (default)

**Table 41: MR10 Calibration (MA[7:0] = 0Ah)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
RFU							ZQ RESET

**Table 42: MR10 Op-Code Bit Definitions**

Feature	Type	OP	Definition
ZQ reset	Write-only	OP[0]	0b: Normal operation (default) 1b: ZQ reset

- Notes:
1. See AC Timing table for calibration latency and timing.
  2. If ZQ is connected to  $V_{DDQ}$  through  $R_{ZQ}$ , either the ZQ CALIBRATION function or default calibration (via ZQ reset) is supported. If ZQ is connected to  $V_{SS}$ , the device operates with default calibration and ZQ CALIBRATION commands are ignored. In both cases, the ZQ connection must not change after power is supplied to the device.

**Table 43: MR11 ODT Control (MA[7:0] = 0Bh)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
RFU	CA ODT			RFU	DQ ODT		

**Table 44: MR11 Op-Code Bit Definitions**

Notes 1-3 apply to entire table

Feature	Type	OP	Definition
DQ ODT DQ bus receiver on-die-termination	Write-only	OP[2:0]	000b: Disable (default) 001b: RZQ/1 010b: RZQ/2 011b: RZQ/3 100b: RZQ/4 101b: RZQ/5 110b: RZQ/6 111b: RFU
CA ODT CA bus receiver on-die-termination	Write-only	OP[6:4]	000b: Disable (default) 001b: RZQ/1 010b: RZQ/2 011b: RZQ/3 100b: RZQ/4 101b: RZQ/5 110b: RZQ/6 111b: RFU

- 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.

- 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 45: MR12 Register Information (MA[7:0] = 0Ch)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
RFU	VR <sub>CA</sub>	V <sub>REF(CA)</sub>					

**Table 46: MR12 Op-Code Bit Definitions**

Feature	Type	OP	Data	Notes
V <sub>REF(CA)</sub> V <sub>REF(CA)</sub> settings	Read/ Write	OP[5:0]	000000b–110010b: See V <sub>REF</sub> Settings Table All others: Reserved	1–3, 5, 6
VR <sub>CA</sub> V <sub>REF(CA)</sub> range	Read/ Write	OP[6]	0b: V <sub>REF(CA)</sub> range[0] enabled 1b: V <sub>REF(CA)</sub> range[1] enabled (default)	1, 2, 4, 5, 6

- Notes:
- This register controls the V<sub>REF(CA)</sub> levels for frequency set point[1:0]. Values from either VR(ca)[0] or VR(ca)[1] may be selected by setting MR12 OP[6] appropriately.
  - A read to MR12 places the contents of OP[7:0] on DQ[7:0]. Any RFU bits and unused DQ will be set to 0. See the MRR Operation section.
  - A write to MR12 OP[5:0] sets the internal V<sub>REF(CA)</sub> level for FSP[0] when MR13 OP[6] = 0b or sets the internal V<sub>REF(CA)</sub> level for FSP[1] when MR13 OP[6] = 1b. The time required for V<sub>REF(CA)</sub> to reach the set level depends on the step size from the current level to the new level. See the V<sub>REF(CA)</sub> training section.
  - A write to MR12 OP[6] switches the device between two internal V<sub>REF(CA)</sub> ranges. The range (range[0] or range[1]) must be selected when setting the V<sub>REF(CA)</sub> register. The value, once set, will be retained until overwritten or until the next power-on or reset event.
  - 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.

**Table 47: MR13 Register Control (MA[7:0] = 0Dh)**

OP[7]	OP[6]	OP[5]	OP[4]	OP[3]	OP[2]	OP[1]	OP[0]
FSP-OP	FSP-WR	DMD	RRO	VRCG	VRO	RPT	CBT

**Table 48: MR13 Op-Code Bit Definition**

Feature	Type	OP	Definition	Notes
CBT Command bus training	Write-only	OP[0]	0b: Normal operation (default) 1b: Command bus training mode enabled	1
RPT Read preamble training		OP[1]	0b: Disabled (default) 1b: Read preamble training mode enabled	
VRO $V_{REF}$ output		OP[2]	0b: Normal operation (default) 1b: Output the $V_{REF(CA)}$ and $V_{REF(DQ)}$ values on DQ bits	2
VRCG $V_{REF}$ current generator		OP[3]	0b: Normal operation (default) 1b: Fast response (high current) mode	3
RRO Refresh rate option		OP[4]	0b: Disable MR4 OP[2:0] (default) 1b: Enable MR4 OP[2:0]	4, 5
DMD Data mask disable		OP[5]	0b: DATA MASK operation enabled (default) 1b: DATA MASK operation disabled	6
FSP-WR Frequency set point write / read		OP[6]	0b: Frequency set point[0] (default) 1b: Frequency set point[1]	7
FSP-OP Frequency set point operation mode		OP[7]	0b: Frequency set point[0] (default) 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 device will output the  $V_{REF(CA)}$  and  $V_{REF(DQ)}$  voltage 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  $V_{REF}$  levels. The DQ pins used for  $V_{REF}$  output are vendor-specific.
  3. When OP[3] = 1, the  $V_{REF}$  circuit uses a high current mode to improve  $V_{REF}$  settling time.
  4. MR13 OP[4] RRO bit is valid only when MR0 OP[0] = 1. For LPDDR4-SDRAM with MR0 OP[0] = 0, MR4 OP[2:0] bits are not dependent on MR13 OP[4].
  5. When OP[4] = 0, only 001b and 010b in MR4 OP[2:0] are disabled. LPDDR4-SDRAM 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), the device will ignore any mask patterns issued during a MASKED WRITE command. See the Data Mask section for more information.
  7. FSP-WR determines which frequency set point registers are accessed with MRW and MRR commands for the following functions such as  $V_{REF(CA)}$  setting,  $V_{REF(CA)}$  range,  $V_{REF(DQ)}$  setting,  $V_{REF(DQ)}$  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  $V_{REF(CA)}$  setting,  $V_{REF(CA)}$  range,  $V_{REF(DQ)}$  setting,  $V_{REF(DQ)}$  range. For more information, refer to Frequency Set Point section.



**Table 49: Mode Register14 (MA[7:0] = 0Eh)**

OP[7]	OP[6]	OP[5]	OP[4]	OP[3]	OP[2]	OP[1]	OP[0]
RFU	VR <sub>DQ</sub>	V <sub>REF(DQ)</sub>					

**Table 50: MR14 Op-Code Bit Definition**

Feature	Type	OP	Definition	Notes
V <sub>REF(DQ)</sub> V <sub>REF(DQ)</sub> setting	Read/ Write	OP[5:0]	000000b–110010b: See V <sub>REF</sub> Settings Table All others: Reserved	1–3, 5, 6
VR <sub>DQ</sub> V <sub>REF(DQ)</sub> range		OP[6]	0b: V <sub>REF(DQ)</sub> range[0] enabled 1b: V <sub>REF(DQ)</sub> range[1] enabled (default)	1, 2, 4–6

- Notes:
1. This register controls the V<sub>REF(DQ)</sub> levels for frequency set point[1:0]. Values from either VR<sub>DQ</sub>[v<sub>endor</sub> defined] or VR<sub>DQ</sub>[v<sub>endor</sub> defined] 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 will be set to 0. See the MRR Operation section.
  3. A write to OP[5:0] sets the internal V<sub>REF(DQ)</sub> level for FSP[0] when MR13 OP[6] = 0b, or sets FSP[1] when MR13 OP[6] = 1b. The time required for V<sub>REF(DQ)</sub> to reach the set level depends on the step size from the current level to the new level. See the V<sub>REF(DQ)</sub> training section.
  4. A write to OP[6] switches the device between two internal V<sub>REF(DQ)</sub> ranges. The range (range[0] or range[1]) must be selected when setting the V<sub>REF(DQ)</sub> 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 51: V<sub>REF</sub> Setting for Range[0] and Range[1]**

Notes 1-3 apply to entire table

Function	OP	Range[0] Values		Range[1] Values	
		V <sub>REF(CA)</sub> (% of V <sub>DD2</sub> )		V <sub>REF(CA)</sub> (% of V <sub>DD2</sub> )	
		V <sub>REF(DQ)</sub> (% of V <sub>DDQ</sub> )		V <sub>REF(DQ)</sub> (% of V <sub>DDQ</sub> )	
V <sub>REF</sub> Setting for MR12 and MR14	OP[5:0]	000000b: 10.0%	011010b: 20.4%	000000b: 22.0%	011010b: 32.4%
		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] and MR12 OP[5:0] to set the V<sub>REF(CA)</sub> or V<sub>REF(DQ)</sub> levels in the device.
  2. The range may be selected in each of the MR14 or MR12 registers by setting OP[6] appropriately.
  3. Each of the MR14 or 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 settings, which may use different terminations values.

**Table 52: MR15 Register Information (MA[7:0] = 0Fh)**

OP[7]	OP[6]	OP[5]	OP[4]	OP[3]	OP[2]	OP[1]	OP[0]
Lower-byte invert register for DQ calibration							

**Table 53: MR15 Op-code Bit Definition**

Feature	Type	OP	Definition	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 0b: Do not invert 1b: Invert the DQ calibration patterns in MR32 and MR40 Default value for OP[7:0] = 55h	1–3

- Notes:
1. This register will invert the DQ Calibration pattern found in MR32 and MR40 for any single DQ or any combination of DQ. 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. DM[0] is not inverted and always transmits the "true" data contained in MR32 and MR40.
  3. No data bus inversion (DBI) function is enacted during DQ read calibration, even if DBI is enabled in MR3-OP[6].

**Table 54: MR15 Invert Register Pin Mapping**

PIN	DQ0	DQ1	DQ2	DQ3	DMIO	DQ4	DQ5	DQ6	DQ7
MR15	OP0	OP1	OP2	OP3	No invert	OP4	OP5	OP6	OP7

**Table 55: MR16 PASR Bank Mask (MA[7:0] = 010h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
PASR bank mask							

**Table 56: MR16 Op-Code Bit Definitions**

Feature	Type	OP	Definition
Bank[7:0] mask	Write-only	OP[7:0]	0b: Bank refresh enabled (default) 1b: Bank refresh disabled

OP[n]	Bank Mask	8-Bank SDRAM
0	xxxxxxx1	Bank 0
1	xxxxxxx1x	Bank 1

OP <sub>[n]</sub>	Bank Mask	8-Bank SDRAM
2	xxxxx1xx	Bank 2
3	xxxx1xxx	Bank 3
4	xxx1xxxx	Bank 4
5	xx1xxxxx	Bank 5
6	x1xxxxxx	Bank 6
7	1xxxxxxx	Bank 7

- Notes:
1. When a mask bit is asserted (OP<sub>[n]</sub> = 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.

**Table 57: MR17 PASR Segment Mask (MA[7:0] = 11h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
PASR segment mask							

**Table 58: MR17 PASR Segment Mask Definitions**

Feature	Type	OP	Definition
Segment[7:0] mask	Write-only	OP[7:0]	0b: Segment refresh enabled (default) 1b: Segment refresh disabled

**Table 59: MR17 PASR Segment Mask**

Segment	OP	Segment Mask	Density (per channel)						
			2Gb	3Gb	4Gb	6Gb	8Gb	12Gb	16Gb
			R[13:11]	R[14:12]	R[14:12]	R[15:13]	R[15:13]	TBD	TBD
0	0	XXXXXXXX1	000b						
1	1	XXXXXXXX1X	001b						
2	2	XXXXX1XX	010b						
3	3	XXXX1XXX	011b						
4	4	XXX1XXXX	100b						
5	5	XX1XXXXX	101b						
6	6	X1XXXXXX	110b	Not allowed	110b	Not allowed	110b	Not allowed	110b
7	7	1XXXXXXX	111b		111b		111b		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.
  3. For 3Gb, 6Gb, and 12Gb density per channel, OP[7:6] must always be LOW (= 00b).

**Table 60: MR18 Register Information (MA[7:0]=12h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DQS oscillator count - LSB							

**Table 61: MR18 LSB DQS Oscillator Count**

Notes 1–3 apply to entire table

Function	Type	OP	Definition
DQS oscillator count (WR training DQS oscillator)	Read-only	OP[7:0]	0h–FFh LSB DRAM DQS oscillator count

- 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. The value in this register is reset each time an MPC command is issued to start in the DQS oscillator counter.

**Table 62: MR19 Register Information (MA[7:0] = 13h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DQS oscillator count – MSB							

**Table 63: MR19 DQS Oscillator Count**

Notes 1–3 apply to the entire table

Function	Type	OP	Definition
DQS oscillator count – MSB (WR training DQS oscillator)	Read-only	OP[7:0]	0h–FFh MSB DRAM DQS oscillator count

- Notes:
1. 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.
  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 64: MR20 Register Information (MA[7:0] = 14h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Upper-byte invert register for DQ calibration							

**Table 65: MR20 Register Information**

Notes 1–3 apply to entire table

Function	Type	OP	Definition
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 0b: Do not invert 1b: Invert the DQ calibration patterns in MR32 and MR40 Default value for OP[7:0] = 55h

- Notes:
1. This register will invert the DQ calibration pattern found in MR32 and MR40 for any single DQ or any combination of DQ. For example, if MR20 OP[7:0] = 00010101b, 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.
  2. DM[1] is not inverted and always transmits the true data contained in MR32 and MR40.
  3. No data bus inversion (DBI) function is enacted during DQ read calibration, even if DBI is enabled in MR3 OP[6].

**Table 66: 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

**Table 67: MR21 Register Information (MA[7:0] = 15h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
RFU							

**Table 68: MR22 Register Information (MA[7:0] = 16h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
RFU		ODTD-CA	ODTE-CS	ODTE-CK	SOC ODT		

**Table 69: MR22 Register Information**

Function	Type	OP	Data	Notes
SOC ODT (controller ODT value for V <sub>OH</sub> calibration)	Write-only	OP[2:0]	000b: Disable (default) 001b: R <sub>ZQ</sub> /1 010b: R <sub>ZQ</sub> /2 011b: R <sub>ZQ</sub> /3 100b: R <sub>ZQ</sub> /4 101b: R <sub>ZQ</sub> /5 110b: R <sub>ZQ</sub> /6 111b: RFU	1, 2, 3
ODTE-CK (CK ODT enabled for non-terminating rank)	Write-only	OP[3]	0b: ODT-CK override disabled (default) 1b: ODT-CK override enabled	2, 3, 4, 6, 8
ODTE-CS (CS ODT enabled for non-terminating rank)	Write-only	OP[4]	0b: ODT-CS override disabled (default) 1b: ODT-CS override enabled	2, 3, 5, 6, 8
ODTD-CA (CA ODT termination disable)	Write-only	OP[5]	0b: CA ODT obeys ODT_CA bond pad (default) 1b: CA ODT disabled	2, 3, 6, 7, 8

- Notes:
1. All values are typical.
  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 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 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. When OP[3] = 1 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 devices but CK is not, enabling CK to terminate on all devices.
  5. When OP[4] = 1 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 devices but CS is not, enabling CS to terminate on all devices.
  6. 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.
  7. 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 disable 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].
  8. 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 ODT\_CA 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 70: MR23 Register Information (MA[7:0] = 17h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DQS interval timer run-time setting							

**Table 71: MR23 Register Information**

Notes 1–2 apply to entire table

Function	Type	OP	Data
DQS interval timer run-time	Write-only	OP[7:0]	00000000b: Disabled (default)
			00000001b: DQS timer stops automatically at the 16 <sup>th</sup> clock after timer start
			00000010b: DQS timer stops automatically at the 32 <sup>nd</sup> clock after timer start
			00000011b: DQS timer stops automatically at the 48 <sup>th</sup> clock after timer start
			00000100b: DQS timer stops automatically at the 64 <sup>th</sup> clock after timer start
			----- Through -----
			00111111b: DQS timer stops automatically at the (63 × 16) <sup>th</sup> clock after timer start
			01XXXXXXb: DQS timer stops automatically at the 2048 <sup>th</sup> clock after timer start
			10XXXXXXb: DQS timer stops automatically at the 4096 <sup>th</sup> clock after timer start
			11XXXXXXb: DQS timer stops automatically at the 8192 <sup>nd</sup> clock after timer start

- Notes: 1. MPC command with OP[6:0] = 1001101b (stop DQS Interval Oscillator) stops the DQS interval timer in the case of MR23 OP[7:0] = 00000000b.  
2. MPC command with OP[6:0] = 1001101b (stop DQS Interval Oscillator) is illegal with valid nonzero values in MR23 OP[7:0].

**Table 72: MR24 Register Information (MA[7:0] = 18h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
TRR mode	TRR mode BAn			Unlimited MAC	MAC value		



**Table 73: MR24 Register Information**

Function	Type	OP	Data	Notes
MAC value	Read	OP[2:0]	000b: Unknown (OP[3] = 0) or Unlimited (OP[3]=1) 001b: 700K 010b: 600K 011b: 500K 100b: 400K 101b: 300K 110b: 200K 111b: Reserved	1, 2
Unlimited MAC	Read	OP[3]	0b: OP[2:0] defines the MAC value 1b: Unlimited MAC value	2, 3
TRR mode BAn	Write	OP[6:4]	000b: Bank 0 001b: Bank 1 010b: Bank 2 011b: Bank 3 100b: Bank 4 101b: Bank 5 110b: Bank 6 111b: Bank 7	
TRR mode	Write	OP[7]	0b: Disabled (default) 1b: Enabled	

- Notes:
1. Unknown means that the device is not tested for <sup>t</sup>MAC and pass/fail values are unknown. Unlimited means that there is no restriction on the number of activates between refresh windows.
  2. There is no restriction to the number of activates.
  3. MR24 OP[2:0] set to 000b.

**Table 74: MR25 Register Information (MA[7:0] = 19h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Bank 7	Bank 6	Bank 5	Bank 4	Bank 3	Bank 2	Bank 1	Bank 0

**Table 75: MR25 Register Information**

Function	Type	OP	Data
PPR resources	Read-only	OP[7:0]	0b: PPR resource is not available 1b: PPR resource is available

- Note:
1. When OP[n] = 0, there is no PPR resource available for that bank. When OP[n] = 1, there is a PPR resource available for that bank, and PPR can be initiated by the controller.

**Table 76: MR26:31 Register Information (MA[7:0] = 1Ah–1Fh)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Reserved for future use							

**Table 77: MR32 Register Information (MA[7:0] = 20h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DQ calibration pattern A (default = 5Ah)							

**Table 78: MR32 Register Information**

Function	Type	OP	Data	Notes
Return DQ calibration pattern MR32 + MR40	Write-only	OP[7:0]	Xb: An MPC command issued 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 MR32/MR40 data pattern for a given DQ (see MR15/MR20 for more information).	1, 2, 3

- Notes:
1. The patterns contained in MR32 and MR40 are transmitted on DQ[15:0] and DMI[1:0] when DQ read calibration is initiated via an MPC command. The pattern is transmitted serially on each data lane and organized little endian such that the low-order bit in a byte is transmitted first. If the data pattern is 27H, the first bit transmitted is a 1 followed by 1, 1, 0, 0, 1, 0, and 0. The bit stream will be 00100111.
  2. MR15 and MR20 may be used to invert the MR32/MR40 data pattern 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].

**Table 79: MR33:39 Register Information (MA[7:0] = 21h–27h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Do not use							

**Table 80: MR40 Register Information (MA[7:0] = 28h)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DQ calibration pattern B (default = 3Ch)							

**Table 81: MR40 Register Information**

Function	Type	OP	Data	Notes
Return DQ calibration pattern 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 an MPC command. The pattern is transmitted serially on each data lane and organized little endian such that the low-order bit in a byte is transmitted first. If the data pattern in MR40 is 27H, the first bit transmitted will be a 1, followed by 1, 1, 0, 0, 1, 0, and 0. The bit stream will be 00100111.
  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].

**Table 82: MR41:47 Register Information (MA[7:0] = 29h–2Fh)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Do not use							

**Table 83: MR48:63 Register Information (MA[7:0] = 30h–3Fh)**

OP7	OP6	OP5	OP4	OP3	OP2	OP1	OP0
Reserved for future use							

## Commands and Timing

Commands transmitted on the CA bus are encoded into two parts and are latched on two consecutive rising edges of the clock. This is called 2-tick CA capture because each command requires two clock edges to latch and decode the entire command.

## Truth Tables































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

Unspecified operations and timings are illegal. To ensure proper operation after an illegal event, the device must be either reset by asserting the RESET\_n command or powered down and then restarted using 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 84: Command Truth Table**

Commands are transmitted to the device across a six-lane interface and use CK, CKE, and CS to control the capture of transmitted data

Command	CS	SDR CA Pins						CK Edge	Notes
		CA0	CA1	CA2	CA3	CA4	CA5		
MRW-1	H	L	H	H	L	L	OP7		1, 11
	L	MA0	MA1	MA2	MA3	MA4	MA5		
MRW-2	H	L	H	H	L	H	OP6		1, 11
	L	OP0	OP1	OP2	OP3	OP4	OP5		
MRR-1	H	L	H	H	H	L	V		1, 2, 12
	L	MA0	MA1	MA2	MA3	MA4	MA5		
REFRESH (all/per bank)	H	L	L	L	H	L	AB		1, 2, 3, 4
	L	BA0	BA1	BA2	V	V	V		
ENTER SELF RE- FRESH	H	L	L	L	H	H	V		1, 2
	L	V							
ACTIVATE-1	H	H	L	R12	R13	R14	R15		1, 2, 3, 11
	L	BA0	BA1	BA2	R16	R10	R11		
ACTIVATE-2	H	H	H	R6	R7	R8	R9		1, 11
	L	R0	R1	R2	R3	R4	R5		
WRITE-1	H	L	L	H	L	L	BL		1, 2, 3, 6, 7, 9
	L	BA0	BA1	BA2	V	C9	AP		
EXIT SELF RE- FRESH	H	L	L	H	L	H	V		1, 2
	L	V							
MASK WRITE-1	H	L	L	H	H	L	BL		1, 2, 3, 5, 6, 7, 9
	L	BA0	BA1	BA2	V	C9	AP		
RFU	H	L	L	H	H	H	V		1, 2
	L	V							
RFU	H	L	H	L	H	L	V		1, 2
	L	V							
RFU	H	L	H	L	H	H	V		1, 2
	L	V							
READ-1	H	L	H	L	L	L	BL		1, 2, 3, 6, 7, 9
	L	BA0	BA1	BA2	V	C9	AP		
CAS-2 (WRITE-2, MASKED WRITE-2, READ-2, MRR-2, MPC (except NOP)	H	L	H	L	L	H	C8		1, 8, 9
	L	C2	C3	C4	C5	C6	C7		

**Table 84: Command Truth Table (Continued)**

Commands are transmitted to the device across a six-lane interface and use CK, CKE, and CS to control the capture of transmitted data

Command	CS	SDR CA Pins						CK Edge	Notes
		CA0	CA1	CA2	CA3	CA4	CA5		
PRECHARGE (all/per bank)	H	L	L	L	L	H	AB		1, 2, 3, 4
	L	BA0	BA1	BA2	V	V	V		
MPC (TRAIN, NOP)	H	L	L	L	L	L	OP6		1, 2, 13
	L	OP0	OP1	OP2	OP3	OP4	OP5		
DESELECT	L	X							1, 2

- Notes:
1. All commands except for DESELECT are two clock cycles and are defined by the current state of CS and CA[5:0] at the rising edge of the clock. DESELECT command is one clock cycle and is not latched by the device.
  2. V = H or L (a defined logic level); X = "Don't Care," in which case CS, CK\_t, CK\_c, and CA[5:0] can be floated.
  3. Bank addresses BA[2:0] determine which bank is to be operated upon.
  4. AB HIGH during PRECHARGE or REFRESH commands indicate the command must be applied to all banks, and the bank addresses are "Don't Care."
  5. MASK WRITE-1 command only supports BL16. For MASK WRITE-1 commands, CA5 must be driven LOW on the first rising clock cycle (R1).
  6. AP HIGH during a WRITE-1, MASK WRITE-1, or READ-1 command indicates that an auto precharge will occur to the bank the command is operating on. AP LOW indicates that no auto precharge will occur and the bank will remain open upon completion of the command.
  7. When enabled in the mode register, BL HIGH during a WRITE-1, MASK-WRITE-1, or READ-1 command indicates the burst length should be set on-the-fly to BL = 32; BL LOW during one of these commands indicates the burst length should be set on-the-fly to BL = 16. If on-the-fly burst length is not enabled in the mode register, this bit should be driven to a valid level and is ignored by the device.
  8. For CAS-2 commands (WRITE-2, MASK WRITE-2, READ-2, MRR-2, or MPC (only WRITE-FIFO, READ-FIFO, and 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.
  9. WRITE-1, MASK-WRITE-1, READ-1, MODE REGISTER READ-1, or MPC (only WRITE-FIFO, READ-FIFO, and READ DQ CALIBRATION) command must be immediately followed by CAS-2 command consecutively without any other command in between. WRITE-1, MASK WRITE-1, READ-1, MRR-1, or MPC (only WRITE-FIFO, READ-FIFO, and READ DQ CALIBRATION) command must be issued first before issuing CAS-2 command. MPC (only START and STOP DQS OSCILLATOR, ZQCAL START and LATCH) commands do not require CAS-2 command; they require two additional DES or NOP commands consecutively before issuing any other commands.
  10. The ACTIVATE-1 command must be followed by the ACTIVATE-2 command consecutively without any other command between them. The ACTIVATE-1 command must be issued prior to the ACTIVATE-2 command. When the ACTIVATE-1 command is issued, the ACTIVATE-2 command must be issued before issuing another ACTIVATE-1 command.
  11. The MRW-1 command must be followed by the MRW-2 command consecutively without any other command between them. The MRW-1 command must be issued prior to the MRW-2 command.

12. The MRR-1 command must be followed by the CAS-2 command consecutively without any other commands between them. The MRR-1 command must be issued prior to the CAS-2 command.
13. The MPC command for READ or WRITE TRAINING operations must be followed by the CAS-2 command consecutively without any other commands between them. The MPC command must be issued prior to the CAS-2 command.

## ACTIVATE Command

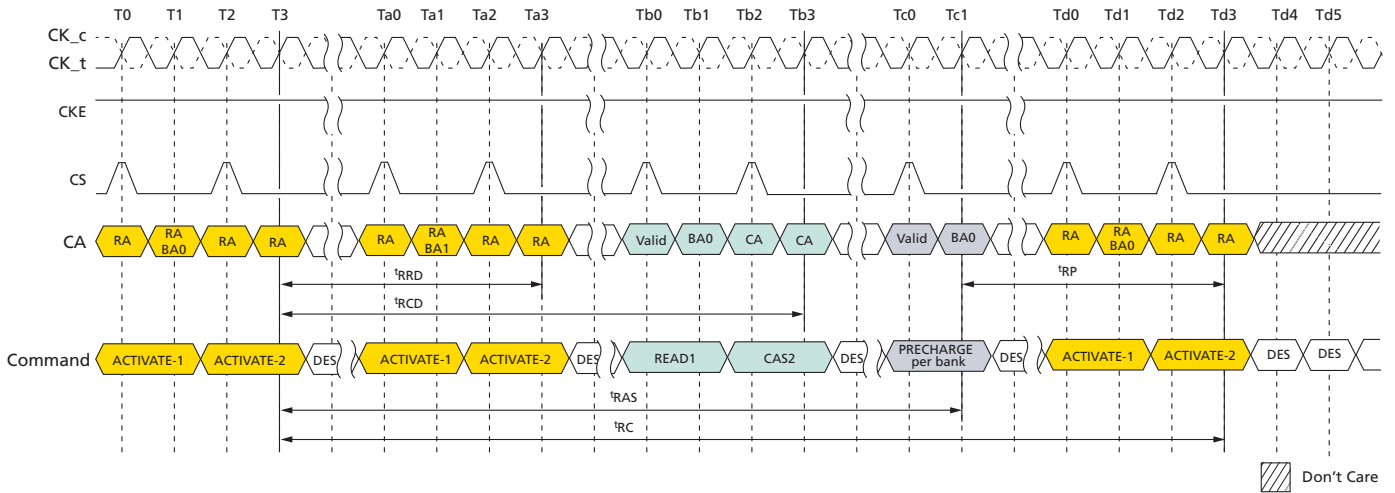
The ACTIVATE command must be executed before a READ or WRITE command can be issued. The ACTIVATE command is issued in two parts: The bank and upper-row addresses are entered with activate-1 and the lower-row addresses are entered with ACTIVATE-2. ACTIVATE-1 and ACTIVATE-2 are executed by strobing CS HIGH while setting CA[5:0] at valid levels (see Command table) at the rising edge of CK.

The bank addresses (BA[2:0]) are used to select the desired bank. The row addresses (R[15:0]) are used to determine which row to activate in the selected bank. The ACTIVATE-2 command must be applied before any READ or WRITE operation can be executed. The device can accept a READ or WRITE command at time  $t_{RCD}$  after the ACTIVATE-2 command is sent. After a bank has been activated, it must be precharged to close the active row before another ACTIVATE-2 command can be applied to the same bank. The bank active and precharge times are defined as  $t_{RAS}$  and  $t_{RP}$ , respectively. The minimum time interval between successive ACTIVATE-2 commands to the same bank is determined by the row cycle time of the device ( $t_{RC}$ ). The minimum time interval between ACTIVATE-2 commands to different banks is  $t_{RRD}$ .

Certain restrictions must be observed for bank ACTIVATE and REFpb operations.

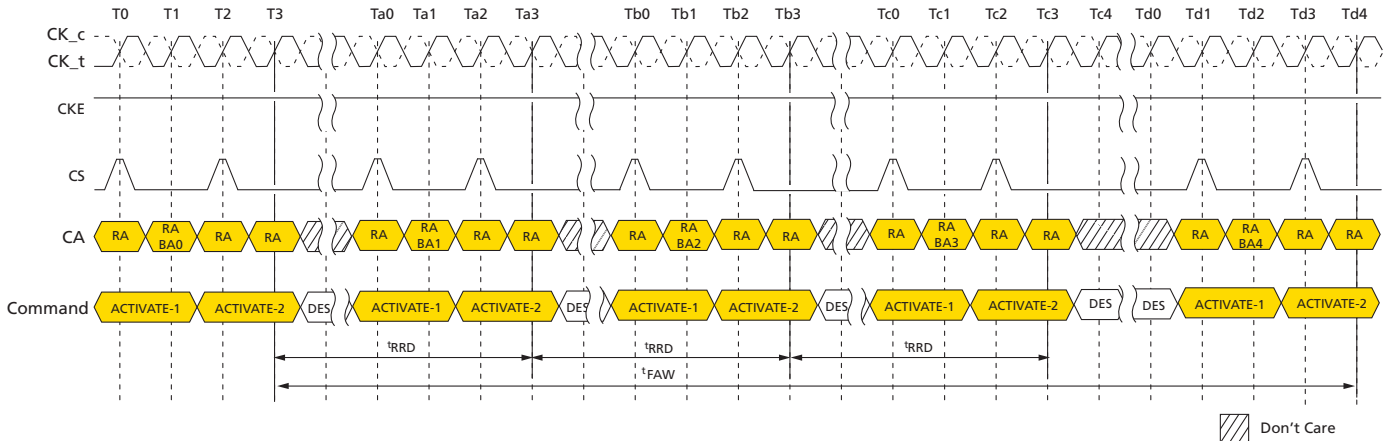
- Four-activate window ( $t_{FAW}$ ): No more than 4 banks may be activated (or refreshed, in the case of REFpb) per channel in a rolling  $t_{FAW}$  window. Convert to clocks by dividing  $t_{FAW}[ns]$  by  $t_{CK}[ns]$  and rounding up to the next integer value. As an example of the rolling window, if  $RU[(t_{FAW}/t_{CK})]$  is 64 clocks, and an ACTIVATE command is issued on clock N, no more than three additional ACTIVATE commands may be issued between clock N + 1 and N + 63. REFpb also counts as bank activation for the purposes of  $t_{FAW}$ .
- 8-bank per channel, precharge all banks (AB) allowance:  $t_{RP}$  for a PRECHARGE ALL BANKS command for an 8-bank device must equal  $t_{RPab}$ , which is greater than  $t_{RPpb}$ .

**Figure 14: ACTIVATE Command**



Note: 1. A PRECHARGE command uses  $t_{RPab}$  timing for all-bank precharge and  $t_{RPpb}$  timing for single-bank precharge. In this figure,  $t_{RP}$  is used to denote either all-bank precharge or a single-bank precharge.  $t_{CCD} = \text{MIN}, 1.5n\text{CK}$  postamble,  $533 \text{ MHz} < \text{clock frequency} \leq 800 \text{ MHz}$ , ODT worst timing case.

**Figure 15:  $t_{FAW}$  Timing**



Note: 1. REFpb may be substituted for one of the ACTIVATE commands for the purposes of  $t_{FAW}$ .

## Read and Write Access Modes

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) on the 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 device on successive clock cycles. Burst interrupts are not allowed; however, the optimal burst length may be set on-the-fly (see Command Truth Table).

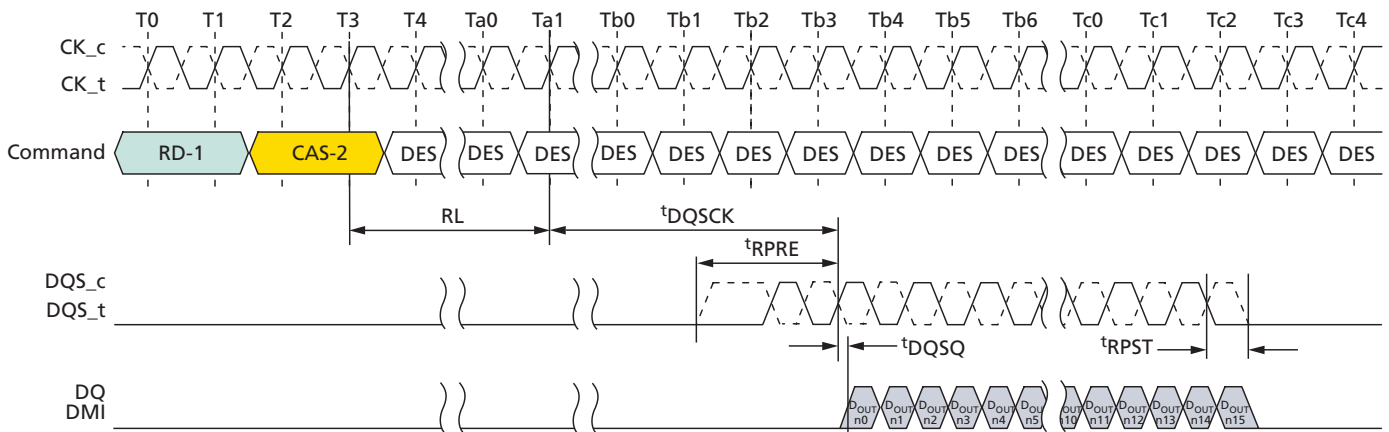
## Preamble and Postamble

The DQS strobe for the device requires a preamble prior to the first latching edge (the rising edge of DQS\_t with data valid), and it requires a postamble after the last latching edge. The preamble and postamble options are set via MODE REGISTER WRITE commands.

The read preamble is two  $t_{CK}$  in length and is either static or has one clock toggle before the first latching edge. The read preamble option is enabled via MRW to MR1 OP[3] (0 = Static; 1 = Toggle).

The read postamble has a programmable option to extend the postamble by  $1nCK$  ( $t_{RPSTE}$ ). The extended postamble option is enabled via MRW to MR1 OP[7] (0 =  $0.5nCK$ ; 1 =  $1.5nCK$ ).

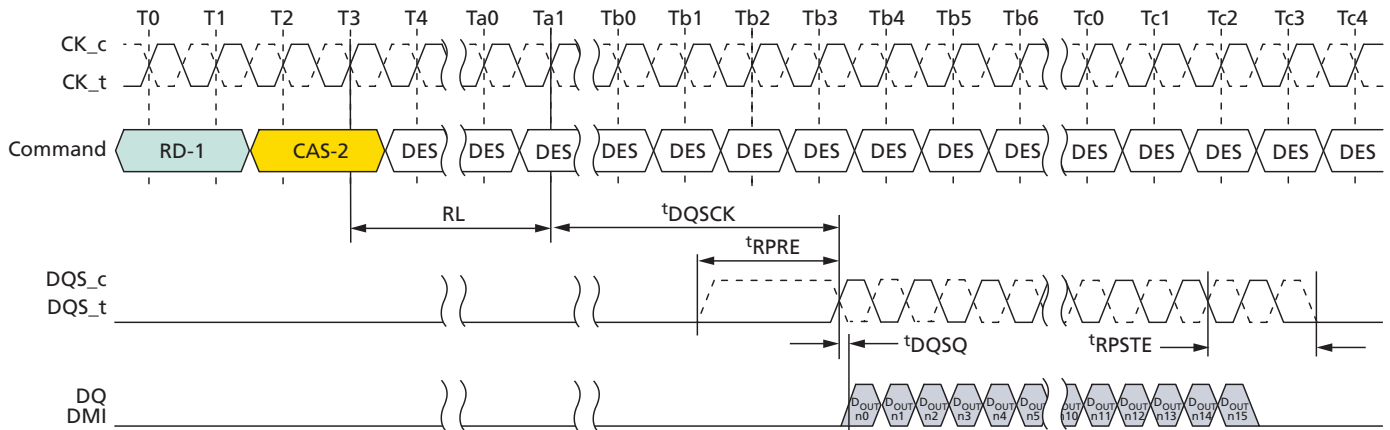
**Figure 16: DQS Read Preamble and Postamble – Toggling Preamble and  $0.5nCK$  Postamble**



- Notes:
1. BL = 16, Preamble = Toggling, Postamble =  $0.5nCK$ .
  2. DQS and DQ terminated  $V_{SSQ}$ .
  3. DQS\_t/DQS\_c is "Don't Care" prior to the start of  $t_{RPRE}$ . No transition of DQS is implied, as DQS\_t/DQS\_c can be HIGH, LOW, or High-Z prior to  $t_{RPRE}$ .

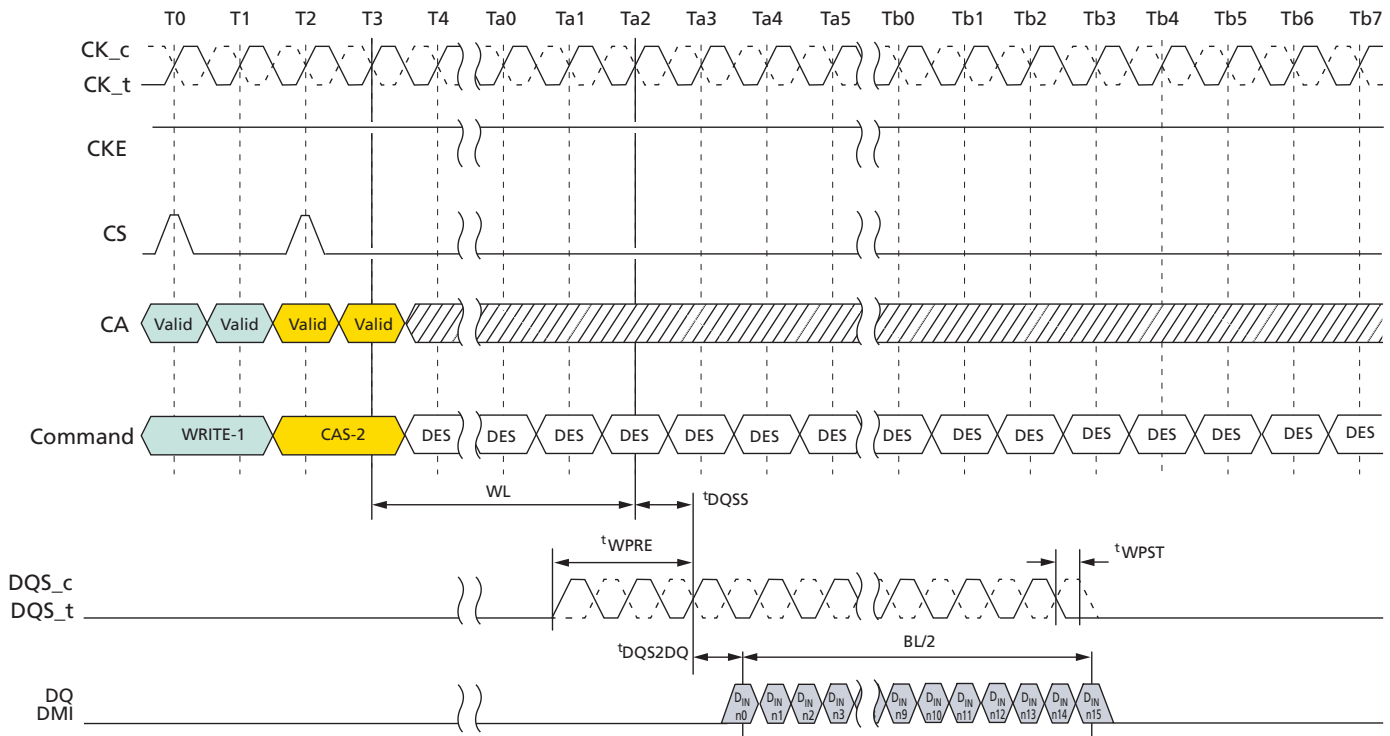


Figure 17: DQS Read Preamble and Postamble – Static Preamble and 1.5nCK Postamble



- Notes:
1. BL = 16, Preamble = Static, Postamble = 1.5nCK (extended).
  2. DQS and DQ terminated  $V_{SSQ}$ .
  3. DQS\_t/DQS\_c is "Don't Care" prior to the start of  $t_{RPRE}$ . No transition of DQS is implied, as DQS\_t/DQS\_c can be HIGH, LOW, or High-Z prior to  $t_{RPRE}$ .

Figure 18: DQS Write Preamble and Postamble – 0.5nCK Postamble

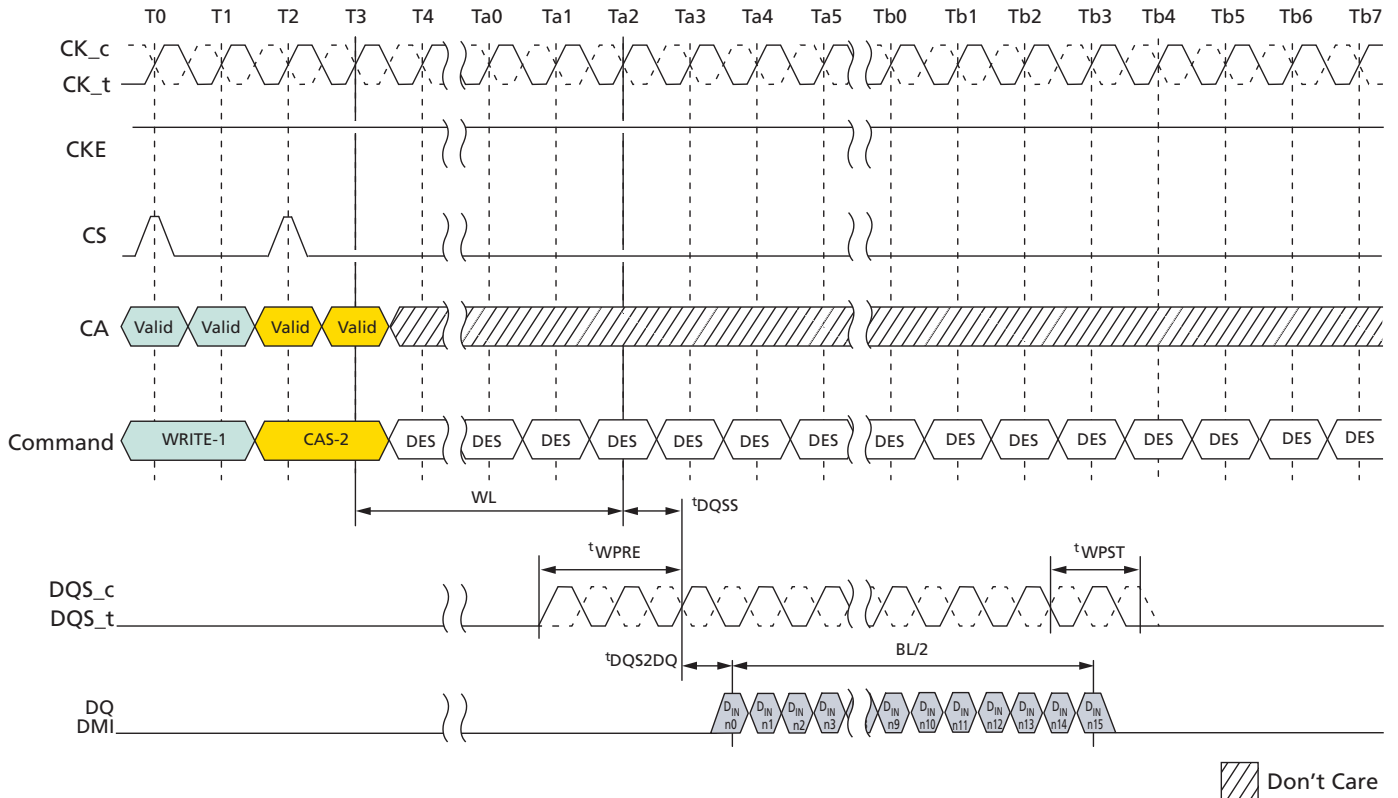


Don't Care

- Notes:
1. BL = 16, Postamble = 0.5nCK.
  2. DQS and DQ terminated  $V_{SSQ}$ .

3. DQS<sub>t</sub>/DQS<sub>c</sub> is "Don't Care" prior to the start of  $t_{WPRE}$ . No transition of DQS is implied, as DQS<sub>t</sub>/DQS<sub>c</sub> can be HIGH, LOW, or High-Z prior to  $t_{WPRE}$ .

Figure 19: DQS Write Preamble and Postamble – 1.5nCK Postamble



- Notes:
1. BL = 16, Postamble = 1.5nCK.
  2. DQS and DQ terminated  $V_{SSQ}$ .
  3. DQS<sub>t</sub>/DQS<sub>c</sub> is "Don't Care" prior to the start of  $t_{WPRE}$ . No transition of DQS is implied, as DQS<sub>t</sub>/DQS<sub>c</sub> can be HIGH, LOW, or High-Z prior to  $t_{WPRE}$ .

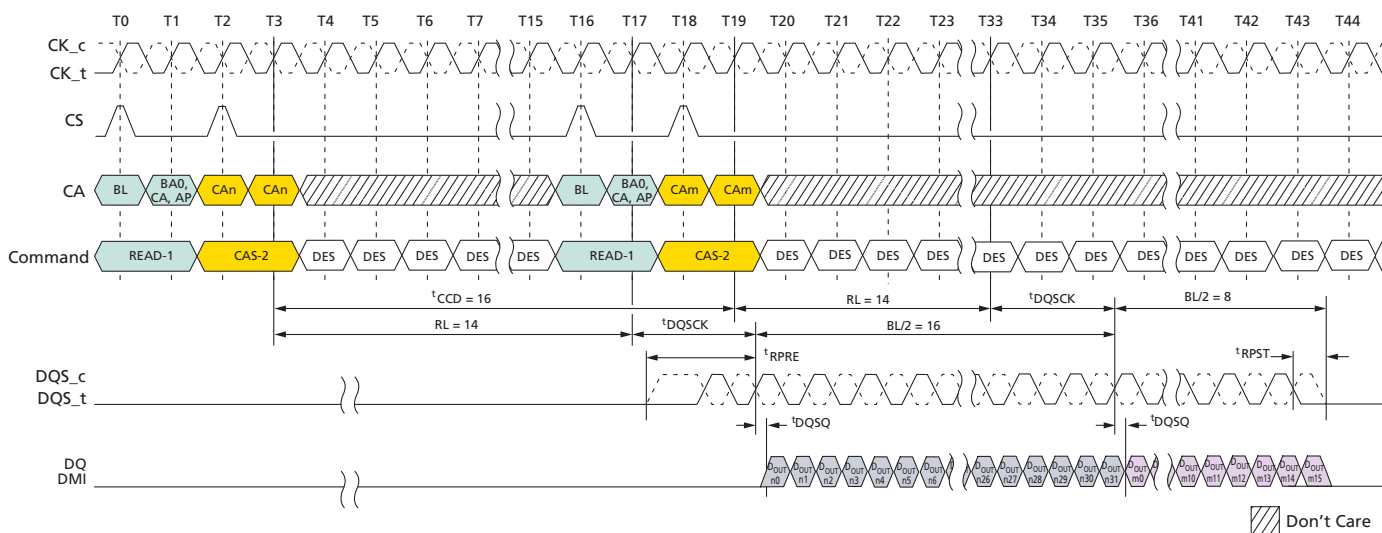
## Burst READ Operation

A burst READ command is initiated with CKE, CS, and CA[5:0] asserted to the proper state on 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; therefore, the starting burst address is always a multiple of four (that is, 0x0, 0x4, 0x8, 0xC).

The READ latency (RL) is defined from the last rising edge of the clock that completes a READ command (for example, the second rising edge of the CAS-2 command) to the rising edge of the clock from which the  $t^{\text{DQSCK}}$  delay is measured. The first valid data is available  $RL \times t^{\text{CK}} + t^{\text{DQSCK}} + t^{\text{DQSQ}}$  after the rising edge of clock that completes a READ command.

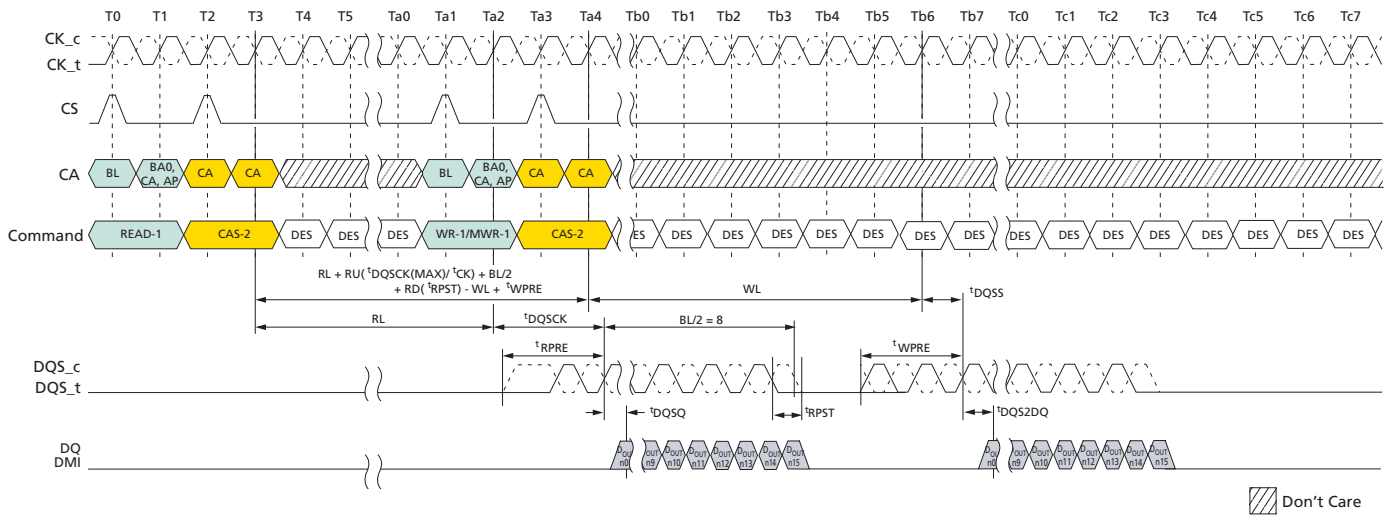
The data strobe output is driven  $t^{\text{RPRE}}$  before the first valid rising strobe edge. The first data bit of the burst is synchronized with the first valid (post-preamble) rising edge of the data strobe. Each subsequent data-out appears on each DQ pin, edge-aligned with the data strobe. At the end of a burst, the DQS signals are driven for another half cycle postamble, or for a 1.5-cycle postamble if the programmable postamble 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  $DQS\_t$  and  $DQS\_c$ .

Figure 20: Burst Read Timing



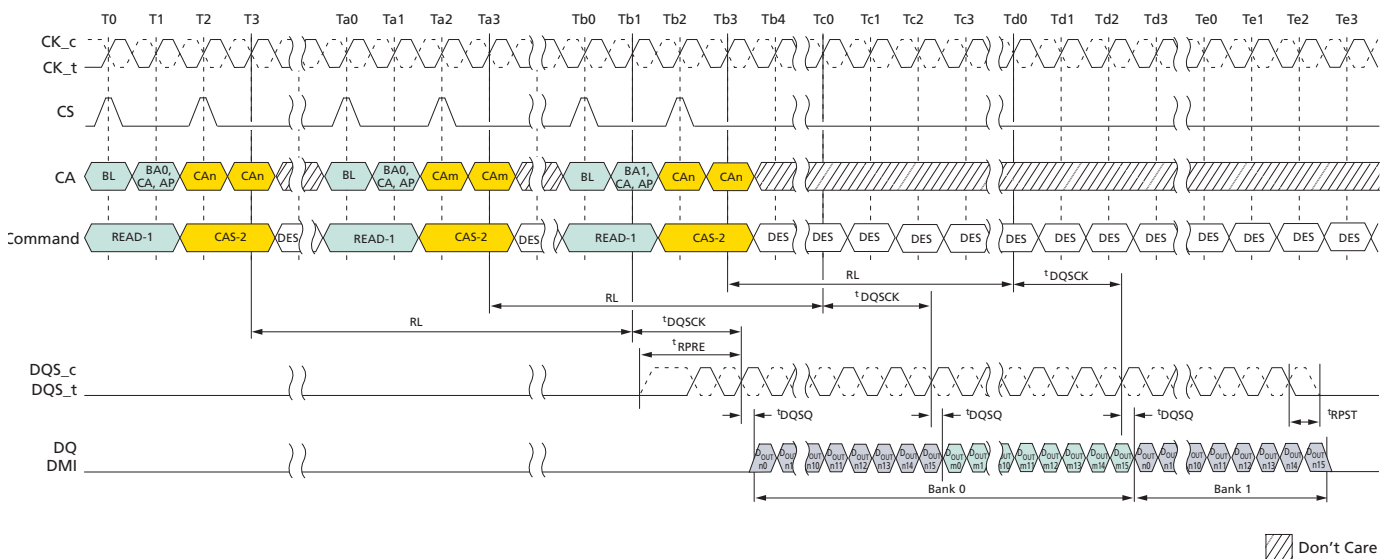
- Notes:
1. BL = 32 for column  $n$ , BL = 16 for column  $m$ , RL = 14, Preamble = Toggle, Postamble =  $0.5nCK$ , DQ/DQS:  $V_{SSQ}$  termination.
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 21: Burst Read Followed by Burst Write or Burst Mask Write



- Notes:
1. BL=16, Read preamble = Toggle, Read postamble =  $0.5nCK$ , Write preamble =  $2nCK$ , Write postamble =  $0.5nCK$ , DQ/DQS:  $V_{SSQ}$  termination.
  2.  $D_{OUT} n$  = data-out from column  $n$  and  $D_{IN} n$  = data-in to column  $n$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

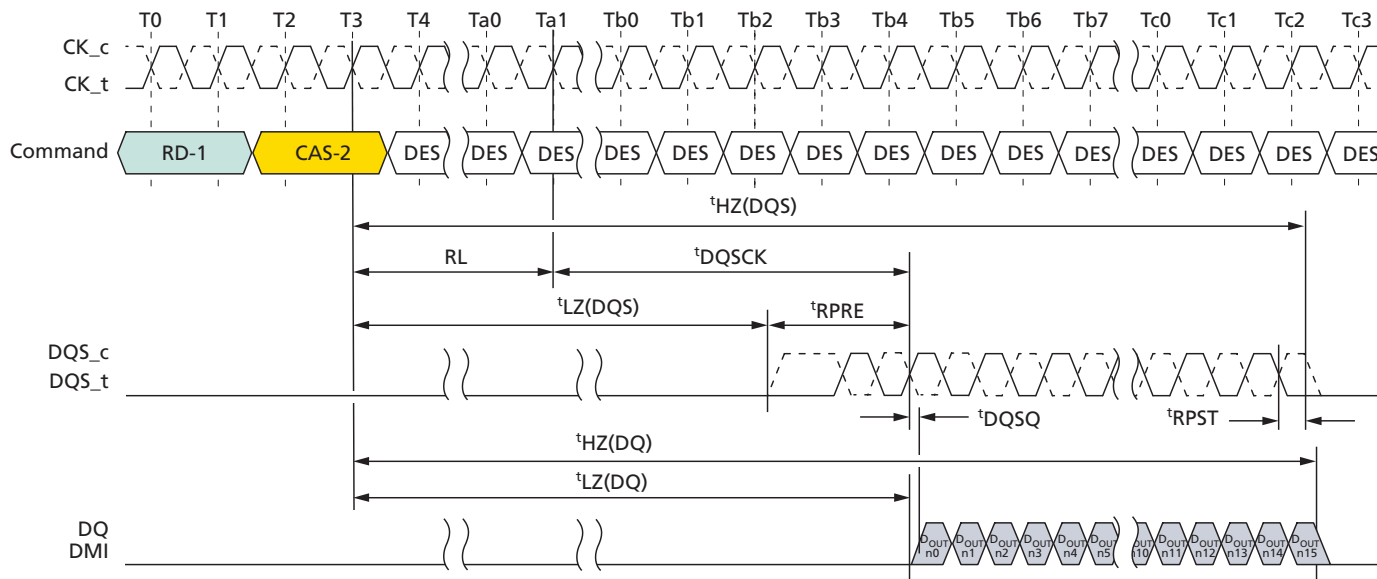
Figure 22: Seamless Burst Read



- Notes:
1. BL = 16,  $t_{CCD} = 8$ , Preamble = Toggle, Postamble =  $0.5nCK$ , DQ/DQS:  $V_{SSQ}$  termination.
  2.  $D_{OUT} n/m$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

## Read Timing

Figure 23: Read Timing



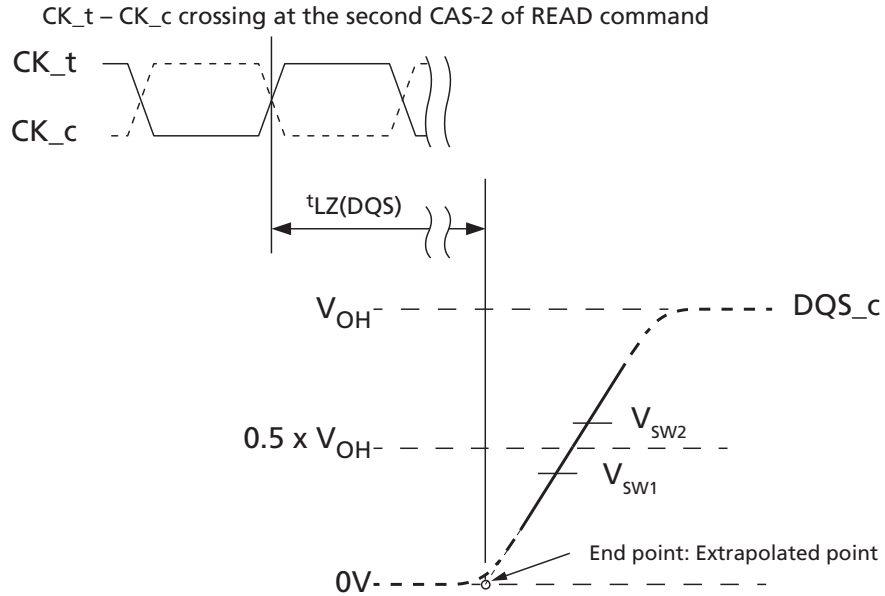
- Notes:
1. BL = 16, Preamble = Toggling, Postamble =  $0.5nCK$ .
  2. DQS, DQ, and DMI terminated  $V_{SSQ}$ .
  3. Output driver does not turn on before an endpoint of  $t_{LZ}(DQS)$  and  $t_{LZ}(DQ)$ .
  4. Output driver does not turn off before an endpoint of  $t_{HZ}(DQS)$  and  $t_{HZ}(DQ)$ .

### $t_{LZ}(DQS)$ , $t_{LZ}(DQ)$ , $t_{HZ}(DQS)$ , $t_{HZ}(DQ)$ Calculation

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

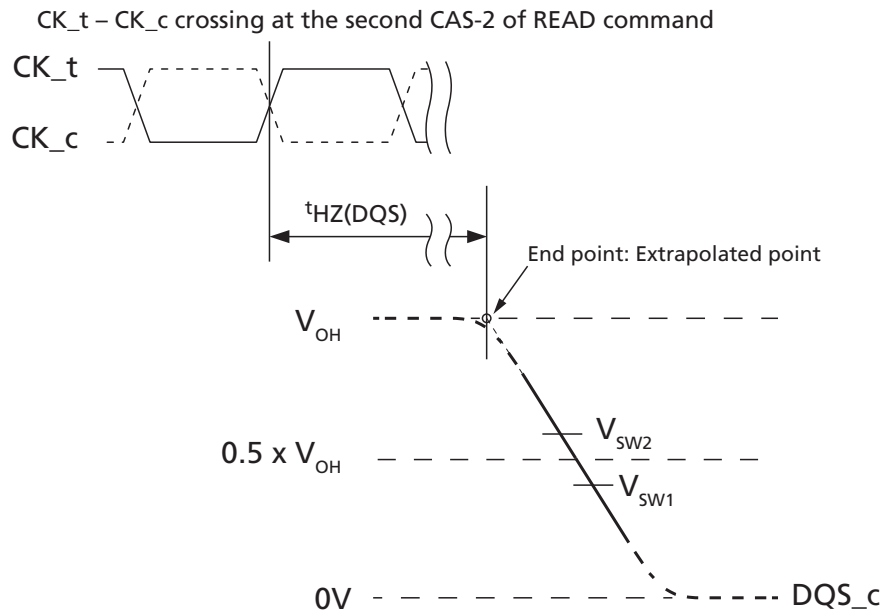
### $t_{LZ}(DQS)$ and $t_{HZ}(DQS)$ Calculation for ATE (Automatic Test Equipment)

Figure 24:  $t_{LZ}(DQS)$  Method for Calculating Transitions and Endpoint



- Notes:
1. Conditions for calibration: Pull down driver  $R_{ON} = 40$  ohm,  $V_{OH} = V_{DDQ}/3$ .
  2. Termination condition for DQS<sub>t</sub> and DQS<sub>c</sub> = 50 ohm to  $V_{SSQ}$ .
  3. The  $V_{OH}$  level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances. Use the actual  $V_{OH}$  value for  $t_{HZ}$  and  $t_{LZ}$  measurements.

Figure 25:  $t_{HZ}(DQS)$  Method for Calculating Transitions and Endpoint



- Notes:
1. Conditions for calibration: Pull down driver  $R_{ON} = 40$  ohm,  $V_{OH} = V_{DDQ}/3$ .
  2. Termination condition for DQS<sub>t</sub> and DQS<sub>c</sub> = 50 ohm to  $V_{SSQ}$ .

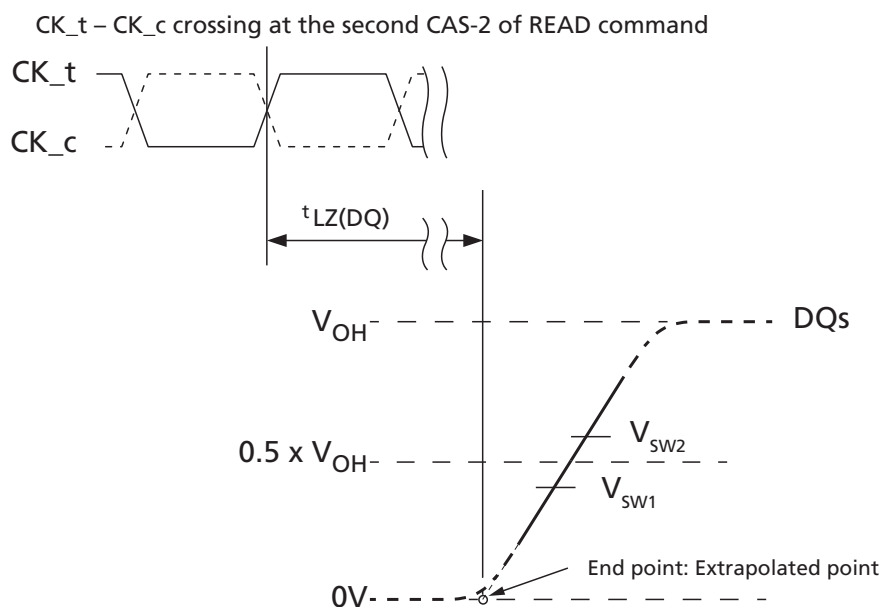
- The  $V_{OH}$  level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances. Use the actual  $V_{OH}$  value for  $t_{HZ}$  and  $t_{LZ}$  measurements.

**Table 85: Reference Voltage for  $t_{LZ}(DQS)$ ,  $t_{HZ}(DQS)$  Timing Measurements**

Measured Parameter	Measured Parameter Symbol	Vsw1	Vsw2	Unit
DQS_c Low-Z time from CK_t, CK_c	$t_{LZ}(DQS)$	$0.4 \times V_{OH}$	$0.6 \times V_{OH}$	V
DQS_c High-Z time from CK_t, CK_c	$t_{HZ}(DQS)$	$0.4 \times V_{OH}$	$0.6 \times V_{OH}$	

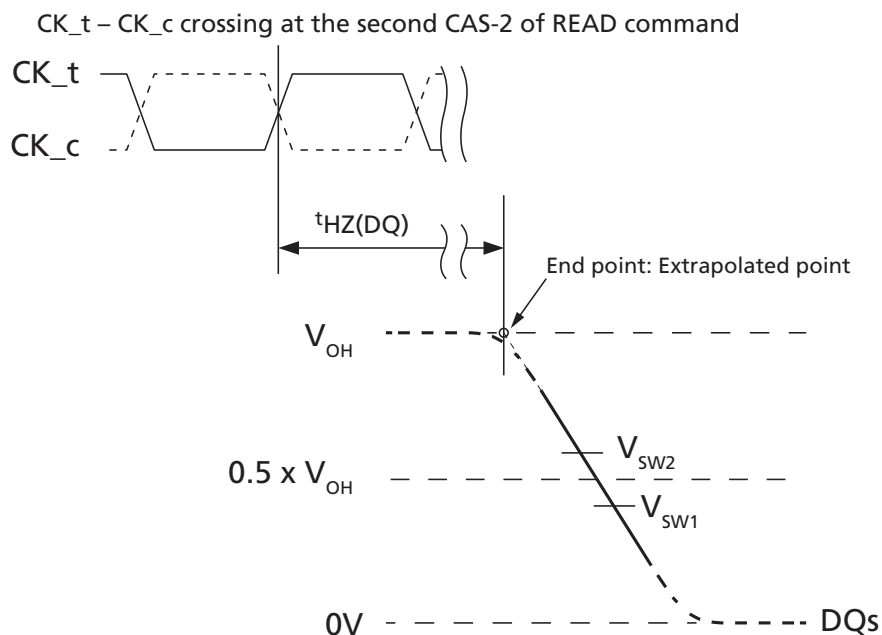
### $t_{LZ}(DQ)$ and $t_{HZ}(DQ)$ Calculation for ATE (Automatic Test Equipment)

**Figure 26:  $t_{LZ}(DQ)$  Method for Calculating Transitions and Endpoint**



- Notes:
- Conditions for calibration: Pull down driver  $R_{ON} = 40$  ohm,  $V_{OH} = V_{DDQ}/3$ .
  - Termination condition for DQ and DMI = 50 ohm to  $V_{SSQ}$ .
  - The  $V_{OH}$  level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances. Use the actual  $V_{OH}$  value for  $t_{HZ}$  and  $t_{LZ}$  measurements.

Figure 27:  $t_{HZ}(DQ)$  Method for Calculating Transitions and Endpoint



- Notes:
1. Conditions for calibration: Pull down driver  $R_{ON} = 40 \text{ ohm}$ ,  $V_{OH} = V_{DDQ}/3$ .
  2. Termination condition for DQ and DMI = 50 ohm to  $V_{SSQ}$ .
  3. The  $V_{OH}$  level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances. Use the actual  $V_{OH}$  value for  $t_{HZ}$  and  $t_{LZ}$  measurements.

Table 86: Reference Voltage for  $t_{LZ}(DQ)$ ,  $t_{HZ}(DQ)$  Timing Measurements

Measured Parameter	Measured Parameter Symbol	Vsw1	Vsw2	Unit
DQ Low-Z time from CK_t, CK_c	$t_{LZ}(DQ)$	$0.4 \times V_{OH}$	$0.6 \times V_{OH}$	V
DQ High-Z time from CK_t, CK_c	$t_{HZ}(DQ)$	$0.4 \times V_{OH}$	$0.6 \times V_{OH}$	

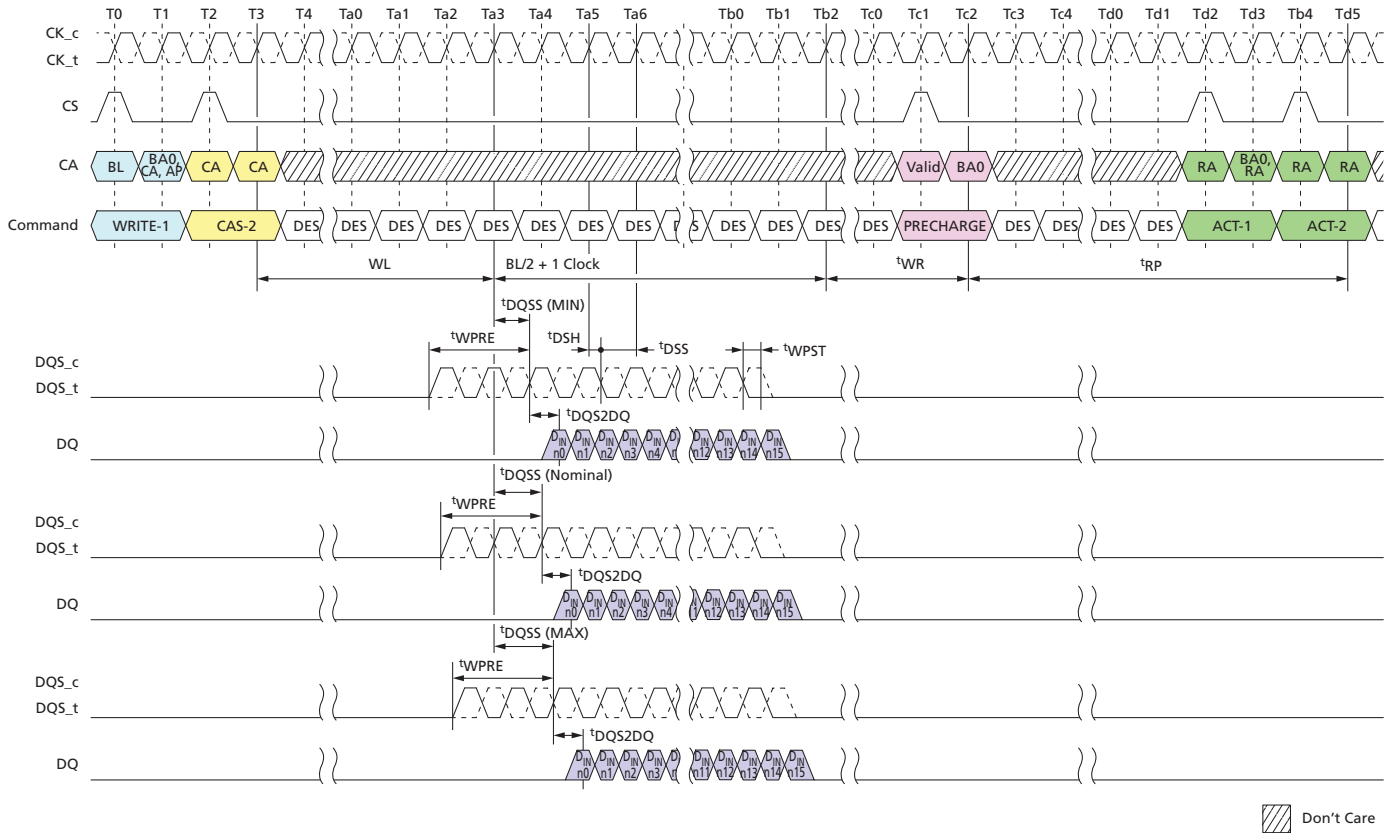


## Burst WRITE Operation

A burst WRITE command is initiated with CKE, 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 32-byte boundary. The WRITE latency (WL) is defined from the last rising edge of the clock that completes a WRITE command (for example, the second rising edge of the CAS-2 command) to the rising edge of the clock from which  $t_{DQSS}$  is measured. The first valid latching edge of DQS must be driven  $WL \times t_{CK} + t_{DQSS}$  after the rising edge of clock that completes a WRITE command.

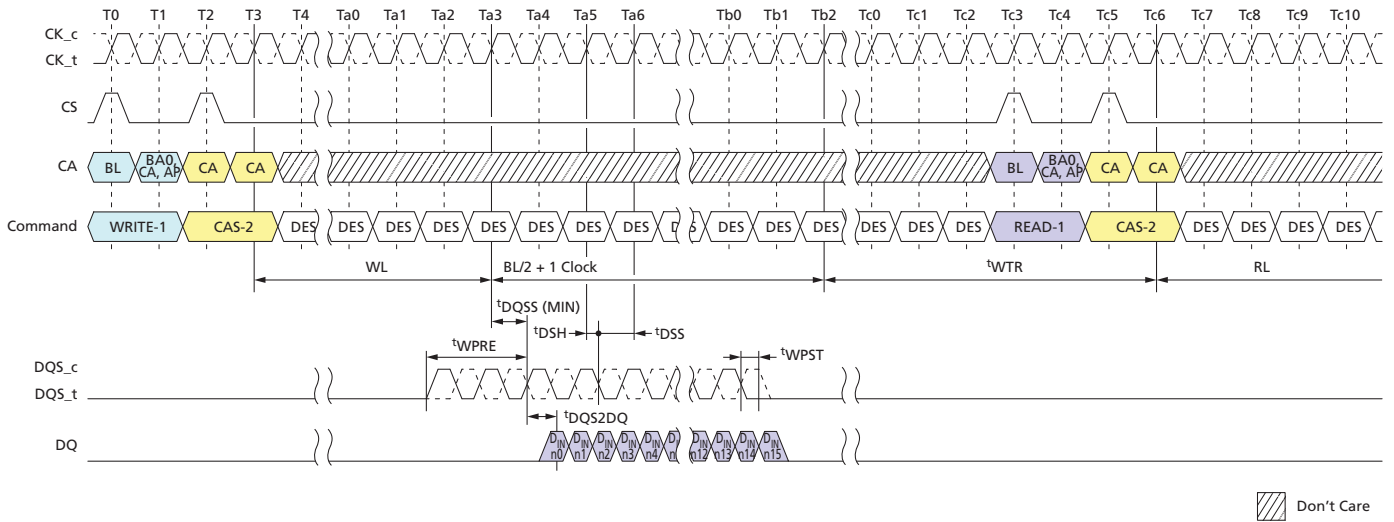
The device uses an unmatched DQS DQ path for lower power, so the DQS strobe must arrive at the SDRAM ball prior to the DQ signal by  $t_{DQS2DQ}$ . The DQS strobe output must be driven  $t_{WPRE}$  before the first valid rising strobe edge. The  $t_{WPRE}$  preamble is required to be  $2 \times t_{CK}$  at any speed ranges. The DQS strobe must be trained to arrive at the DQ pad latch center-aligned with the DQ data. The DQ data must be held for  $T_{diVW}$ , and the DQS must be periodically trained to stay roughly centered in the  $T_{diVW}$ . 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 postamble) 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. Signal input timings are measured relative to the cross point of  $DQS_t$  and  $DQS_c$ .

Figure 28: Burst WRITE Operation



- Notes:
1. BL = 16, Write postamble = 0.5nCK, DQ/DQS: V<sub>SSQ</sub> termination.
  2. D<sub>IN</sub> n = data-in to column n.
  3. t<sub>WR</sub> starts at the rising edge of CK after the last latching edge of DQS.
  4. DES commands are shown for ease of illustration; other commands may be valid at these times.

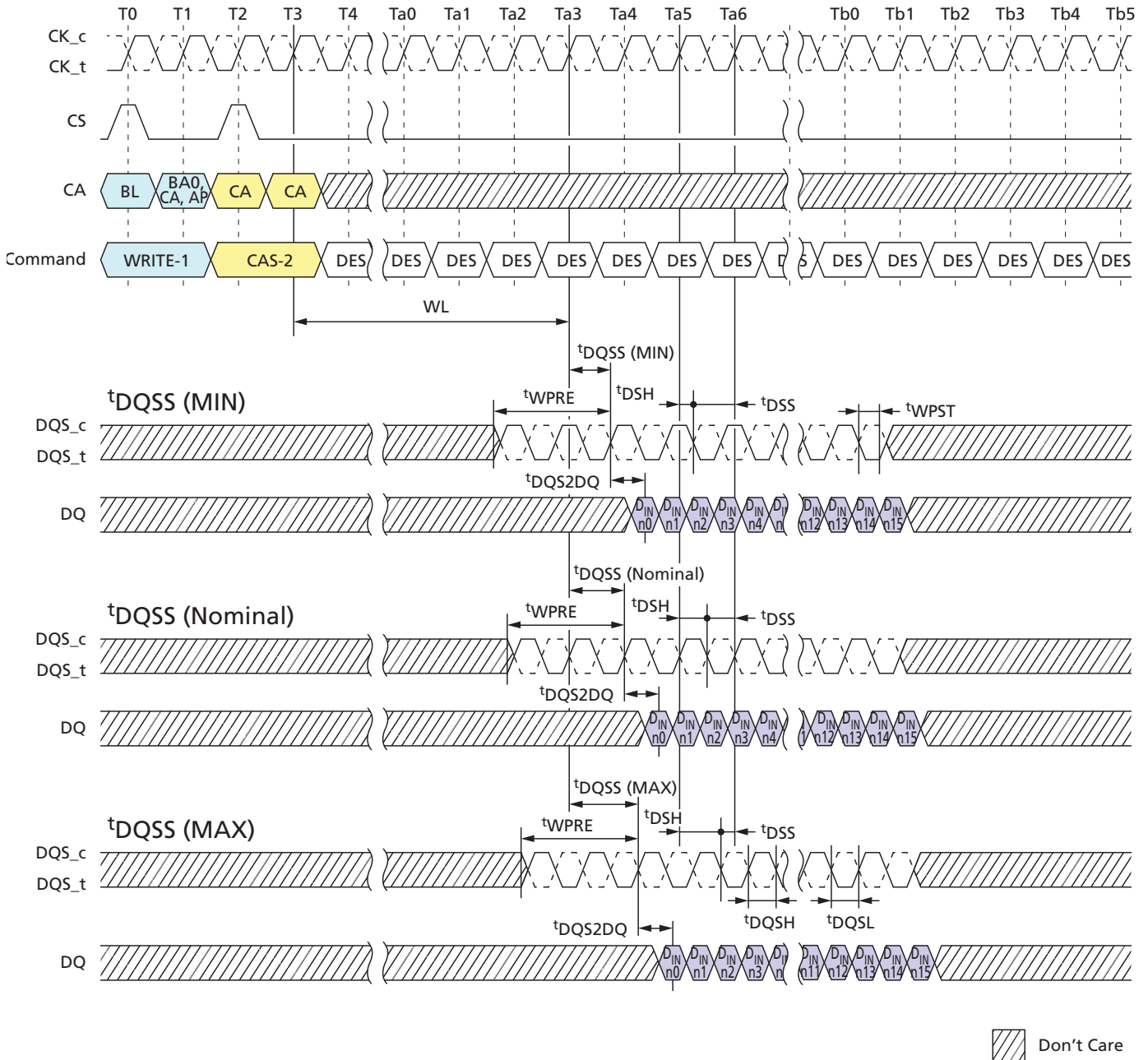
Figure 29: Burst Write Followed by Burst Read



- Notes:
1. BL = 16, Write postamble =  $0.5nCK$ , DQ/DQS:  $V_{SSQ}$  termination.
  2.  $D_{IN} n$  = data-in to column  $n$ .
  3. The minimum number of clock cycles from the burst WRITE command to the burst READ command for any bank is  $[WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})]$ .
  4.  $t_{WTR}$  starts at the rising edge of CK after the last latching edge of DQS.
  5. DES commands are shown for ease of illustration; other commands may be valid at these times.

## Write Timing

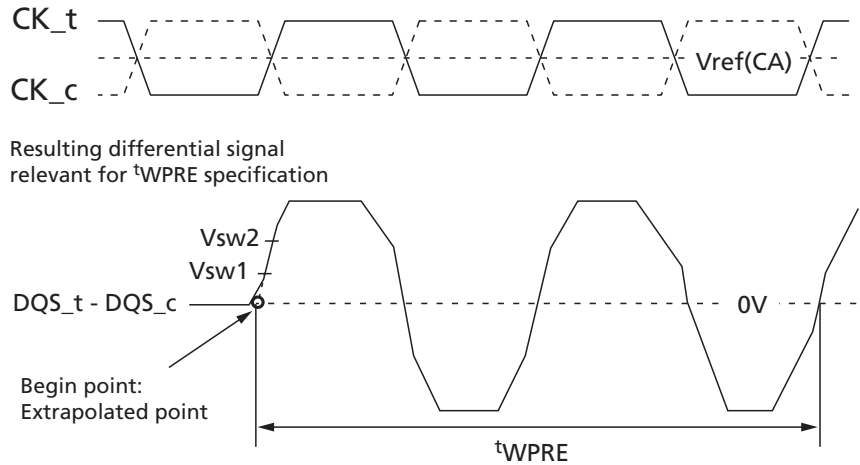
Figure 30: Write Timing



- Notes:
1. BL = 16, Write postamble =  $0.5nCK$ .
  2.  $D_{IN} n$  = data-in to column  $n$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

### <sup>t</sup>WPRE Calculation for ATE (Automatic Test Equipment)

Figure 31: Method for Calculating <sup>t</sup>WPRE Transitions and Endpoints



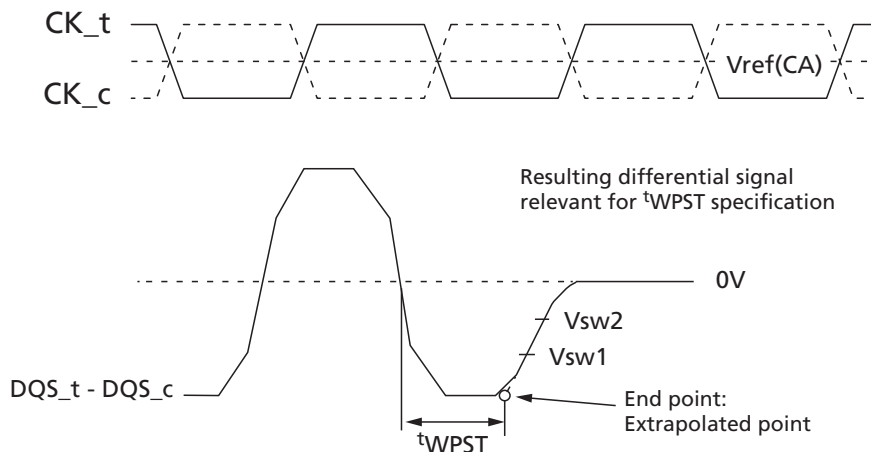
Note: 1. Termination condition for DQS\_t, DQS\_c, DQ, and DMI = 50 ohm to V<sub>SSQ</sub>.

Table 87: Method for Calculating <sup>t</sup>WPRE Transitions and Endpoints

Measured Parameter	Measured Parameter Symbol	Vsw1	Vsw2	Unit
DQS_t, DQS_c differential write preamble	<sup>t</sup> WPRE	V <sub>IHL_AC</sub> × 0.3	V <sub>IHL_AC</sub> × 0.7	V

### <sup>t</sup>WPST Calculation for ATE (Automatic Test Equipment)

Figure 32: Method for Calculating <sup>t</sup>WPST Transitions and Endpoints



- Notes:
1. Termination condition for DQS\_t, DQS\_c, DQ, and DMI = 50 ohm to V<sub>SSQ</sub>.
  2. Write postamble: 0.5<sup>t</sup>CK
  3. The method for calculating differential pulse widths for 1.5<sup>t</sup>CK postamble is same as 0.5<sup>t</sup>CK postamble.

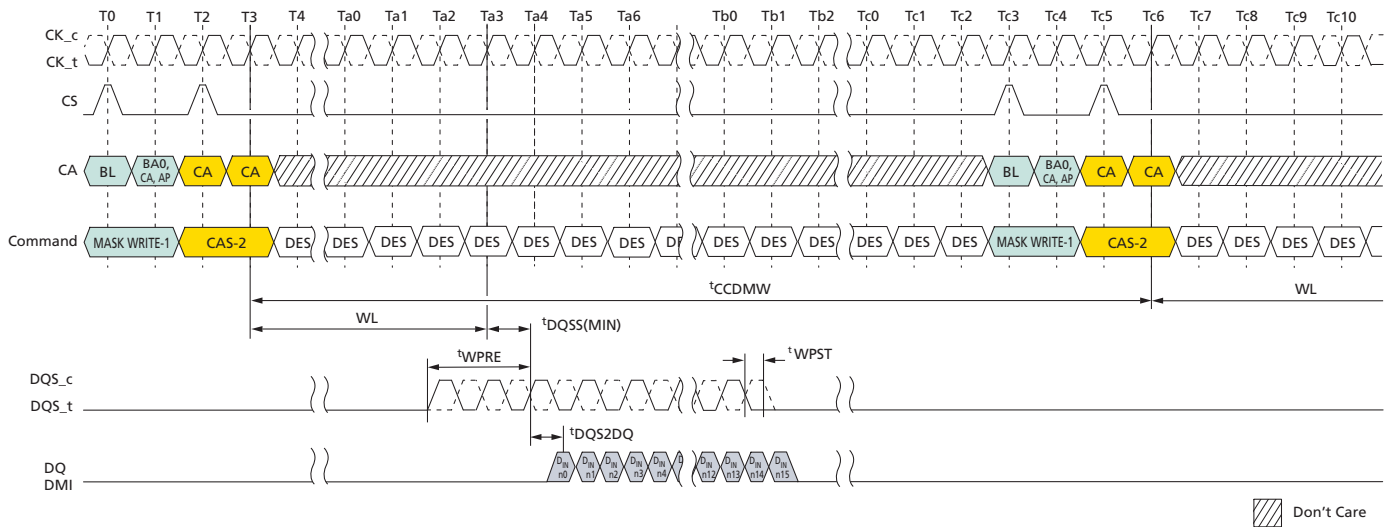
Table 88: Reference Voltage for  $t_{WPST}$  Timing Measurements

Measured Parameter	Measured Parameter Symbol	Vsw1	Vsw2	Unit
DQS_t, DQS_c differential write postamble	$t_{WPST}$	$-(V_{IHL\_AC} \times 0.7)$	$-(V_{IHL\_AC} \times 0.3)$	V

## MASK WRITE Operation

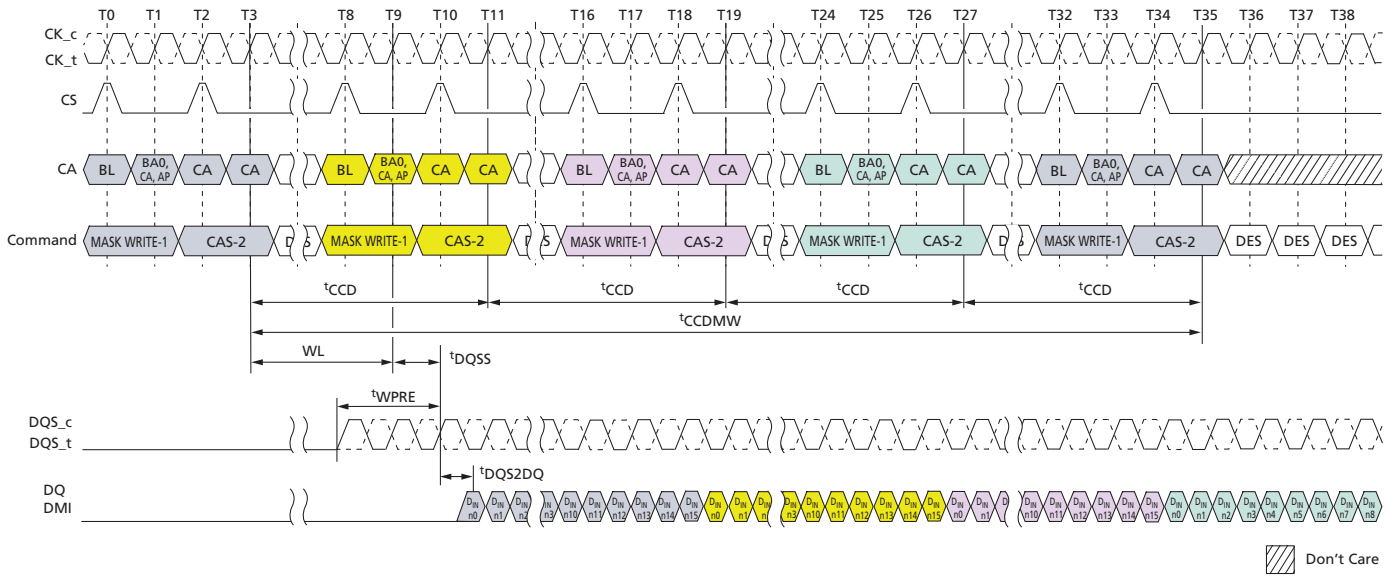
The device requires that WRITE operations that include a byte mask anywhere in the burst sequence must use the MASK WRITE command. This allows the device to implement efficient data protection schemes based on larger data blocks. The MASK WRITE-1 command is used to begin the operation, followed by a CAS-2 command. A MASKED WRITE command to the same bank cannot be issued until  $t_{CCDMW}$  later, to allow the device to finish the internal READ-MODIFY-WRITE operation. One data-mask-invert (DMI) pin is provided per byte lane, and the data-mask-invert timings match data bit (DQ) timing. See Data Mask Invert for more information on the use of the DMI signal.

Figure 33: MASK WRITE Command – Same Bank



- Notes:
1. BL = 16, Write postamble =  $0.5nCK$ , DQ/DQS:  $V_{SSQ}$  termination.
  2.  $D_{IN} n$  = data-in to column  $n$ .
  3. Mask-write supports only BL16 operations. For BL32 configuration, the system needs to insert only 16-bit wide data for MASKED WRITE operation.
  4. DES commands are shown for ease of illustration; other commands may be valid at these time.

**Figure 34: MASK WRITE Command – Different Bank**



- Notes:
1. BL = 16, DQ/DQS/DMI:  $V_{SSQ}$  termination.
  2.  $D_{IN}$   $n$  = data-in to column  $n$ .
  3. Mask-write supports only BL16 operations. For BL32 configuration, the system needs to insert only 16-bit wide data for MASKED WRITE operation.
  4. DES commands are shown for ease of illustration; other commands may be valid at these time.

**Mask Write Timing Constraints for BL16**
**Table 89: Same Bank (ODT Disabled)**

Next CMD Current CMD	ACTIVE	READ (BL = 16 or 32)	WRITE (BL = 16 or 32)	MASK WRITE	PRECHARGE
ACTIVE	Illegal	$RU(t_{RCD}/t_{CK})$	$RU(t_{RCD}/t_{CK})$	$RU(t_{RCD}/t_{CK})$	$RU(t_{RAS}/t_{CK})$
READ (with BL = 16)	Illegal	$8^1$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$BL/2 + \text{MAX}\{(8, RU(t_{RTP}/t_{CK}))\} - 8$
READ (with BL = 32)	Illegal	$16^2$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$BL/2 + \text{MAX}\{(8, RU(t_{RTP}/t_{CK}))\} - 8$
WRITE (with BL = 16)	Illegal	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$8^1$	$t_{CCDMW}^3$	$WL + 1 + BL/2 + RU(t_{WR}/t_{CK})$
WRITE (with BL = 32)	Illegal	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$16^2$	$t_{CCDMW} + 8^4$	$WL + 1 + BL/2 + RU(t_{WR}/t_{CK})$
MASK WRITE	Illegal	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$t_{CCD}$	$t_{CCDMW}^3$	$WL + 1 + BL/2 + RU(t_{WR}/t_{CK})$
PRECHARGE	$RU(t_{RP}/t_{CK}), RU(t_{RPab}/t_{CK})$	Illegal	Illegal	Illegal	4

- Notes:
1. In the case of BL = 16,  $t_{CCD}$  is  $8 \times t_{CK}$ .
  2. In the case of BL = 32,  $t_{CCD}$  is  $16 \times t_{CK}$ .
  3.  $t_{CCDMW} = 32 \times t_{CK}$  ( $4 \times t_{CCD}$  at BL = 16).
  4. WRITE with BL = 32 operation is  $8 \times t_{CK}$  longer than BL = 16.

**Table 90: Different Bank (ODT Disabled)**

Next CMD Current CMD	ACTIVE	READ (BL = 16 or 32)	WRITE (BL = 16 or 32)	MASK WRITE	PRECHARGE
ACTIVE	$RU(t_{RRD}/t_{CK})$	4	4	4	$2^2$
READ (with BL = 16)	4	$8^1$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$2^2$
READ (with BL = 32)	4	$16^2$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$RL + RU(t_{DQSCK}(MAX)/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$	$2^2$
WRITE (with BL = 16)	4	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$8^1$	$8^1$	$2^2$
WRITE (with BL = 32)	4	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$16^2$	$16^2$	$2^2$
MASK WRITE	4	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$8^1$	$8^1$	$2^2$



**Table 90: Different Bank (ODT Disabled) (Continued)**

Next CMD Current CMD	ACTIVE	READ (BL = 16 or 32)	WRITE (BL = 16 or 32)	MASK WRITE	PRECHARGE
PRECHARGE	4	4	4	4	4

- Notes: 1. In the case of BL = 16,  $t_{CCD}$  is  $8 \times t_{CK}$   
 2. In the case of BL = 32,  $t_{CCD}$  is  $16 \times t_{CK}$

**Table 91: Same Bank (ODT Enabled)**

Next CMD Current CMD	ACTIVE	READ (BL = 16 or 32)	WRITE (BL = 16 or 32)	MASK WRITE	PRECHARGE
ACTIVE	Illegal	$RU(t_{RCD}/t_{CK})$	$RU(t_{RCD}/t_{CK})$	$RU(t_{RCD}/t_{CK})$	$RU(t_{RAS}/t_{CK})$
READ (with BL = 16)	Illegal	$8^1$	$RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + RD(t_{RPST}) - ODT_{Lon} - RD(t_{ODTon}(\text{MIN})/t_{CK})$	$RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + RD(t_{RPST}) - ODT_{Lon} - RD(t_{ODTon}(\text{MIN})/t_{CK})$	$BL/2 + \text{MAX}\{(8, RU(t_{RTP}/t_{CK}))\} - 8$
READ (with BL = 32)	Illegal	$16^2$	$RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + RD(t_{RPST}) - ODT_{Lon} - RD(t_{ODTon}(\text{MIN})/t_{CK})$	$RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + RD(t_{RPST}) - ODT_{Lon} - RD(t_{ODTon}(\text{MIN})/t_{CK})$	$BL/2 + \text{MAX}\{(8, RU(t_{RTP}/t_{CK}))\} - 8$
WRITE (with BL = 16)	Illegal	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$8^1$	$t_{CCDMW}^3$	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$
WRITE (with BL = 32)	Illegal	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$16^2$	$t_{CCDMW} + 8^4$	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$
MASK WRITE	Illegal	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$	$t_{CCD}$	$t_{CCDMW}^3$	$WL + 1 + BL/2 + RU(t_{WTR}/t_{CK})$
PRECHARGE	$RU(t_{RP}/t_{CK}), RU(t_{RPab}/t_{CK})$	Illegal	Illegal	Illegal	4

- Notes: 1. In the case of BL = 16,  $t_{CCD}$  is  $8 \times t_{CK}$ .  
 2. In the case of BL = 32,  $t_{CCD}$  is  $16 \times t_{CK}$ .  
 3.  $t_{CCDMW} = 32 \times t_{CK}$  ( $4 \times t_{CCD}$  at BL = 16).  
 4. WRITE with BL = 32 operation is  $8 \times t_{CK}$  longer than BL = 16.

**Table 92: Different Bank (ODT Enabled)**

Next CMD Current CMD	ACTIVE	READ (BL = 16 or 32)	WRITE (BL = 16 or 32)	MASK WRITE	PRECHARGE
ACTIVE	$RU(t_{RRD}/t_{CK})$	4	4	4	$2^2$
READ (with BL = 16)	4	$8^1$	$RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + RD(t_{RPST}) - ODT_{Lon} - RD(t_{ODTon}(\text{MIN})/t_{CK})$	$RL + RU(t_{DQSK}(\text{MAX})/t_{CK}) + BL/2 + RD(t_{RPST}) - ODT_{Lon} - RD(t_{ODTon}(\text{MIN})/t_{CK})$	$2^2$

**Table 92: Different Bank (ODT Enabled) (Continued)**

Next CMD Current CMD	ACTIVE	READ (BL = 16 or 32)	WRITE (BL = 16 or 32)	MASK WRITE	PRECHARGE
READ (with BL = 32)	4	16 <sup>2</sup>	RL + RU( tDQ <sub>SCK</sub> (MAX)/t <sub>CK</sub> + BL/2 + RD(t <sub>RPST</sub> ) - ODT <sub>Lon</sub> - RD( t <sub>ODTon</sub> (MIN)/t <sub>CK</sub> )	RL + RU( tDQ <sub>SCK</sub> (MAX)/t <sub>CK</sub> + BL/2 + RD(t <sub>RPST</sub> ) - ODT <sub>Lon</sub> - RD( t <sub>ODTon</sub> (MIN)/t <sub>CK</sub> )	2 <sup>2</sup>
WRITE (with BL = 16)	4	WL + 1 + BL/2 + RU(t <sub>WTR</sub> /t <sub>CK</sub> )	8 <sup>1</sup>	8 <sup>1</sup>	2 <sup>2</sup>
WRITE (with BL = 32)	4	WL + 1 + BL/2 + RU(t <sub>WTR</sub> /t <sub>CK</sub> )	16 <sup>2</sup>	16 <sup>2</sup>	2 <sup>2</sup>
MASK WRITE	4	WL + 1 + BL/2 + RU(t <sub>WTR</sub> /t <sub>CK</sub> )	8 <sup>1</sup>	8 <sup>1</sup>	2 <sup>2</sup>
PRECHARGE	4	4	4	4	4

- Notes: 1. In the case of BL = 16, t<sub>CCD</sub> is 8 × t<sub>CK</sub>.  
2. In the case of BL = 32, t<sub>CCD</sub> is 16 × t<sub>CK</sub>.

## Data Mask and Data Bus Inversion (DBI [DC]) Function

Data mask (DM) is supported for WRITE operations and the data bus inversion DBI (DC) is supported for READ, WRITE, MASK WRITE, MRR, and MRW operations. DM and DBI (DC) functions are supported with byte granularity. DBI (DC) for READ operations (READ, MRR) can be enabled or disabled via MR3 OP[6]. DBI (DC) for WRITE operations (WRITE, MASK WRITE, MRW) can be enabled or disabled via MR3 OP[7]. DM for MASK WRITE operations can be enabled or disabled via MR13 OP[5]. The device has one data mask inversion (DMI) pin per byte and a total of two DMI pins per channel. The DMI signal is a bidirectional DDR signal, is sampled with the DQ signals, and is electrically identical to a DQ signal.

There are eight possible states for the device with the DM and DBI (DC) functions.

**Table 93: Function Behavior of DMI Signal During WRITE, MASKED WRITE, and READ Operations**

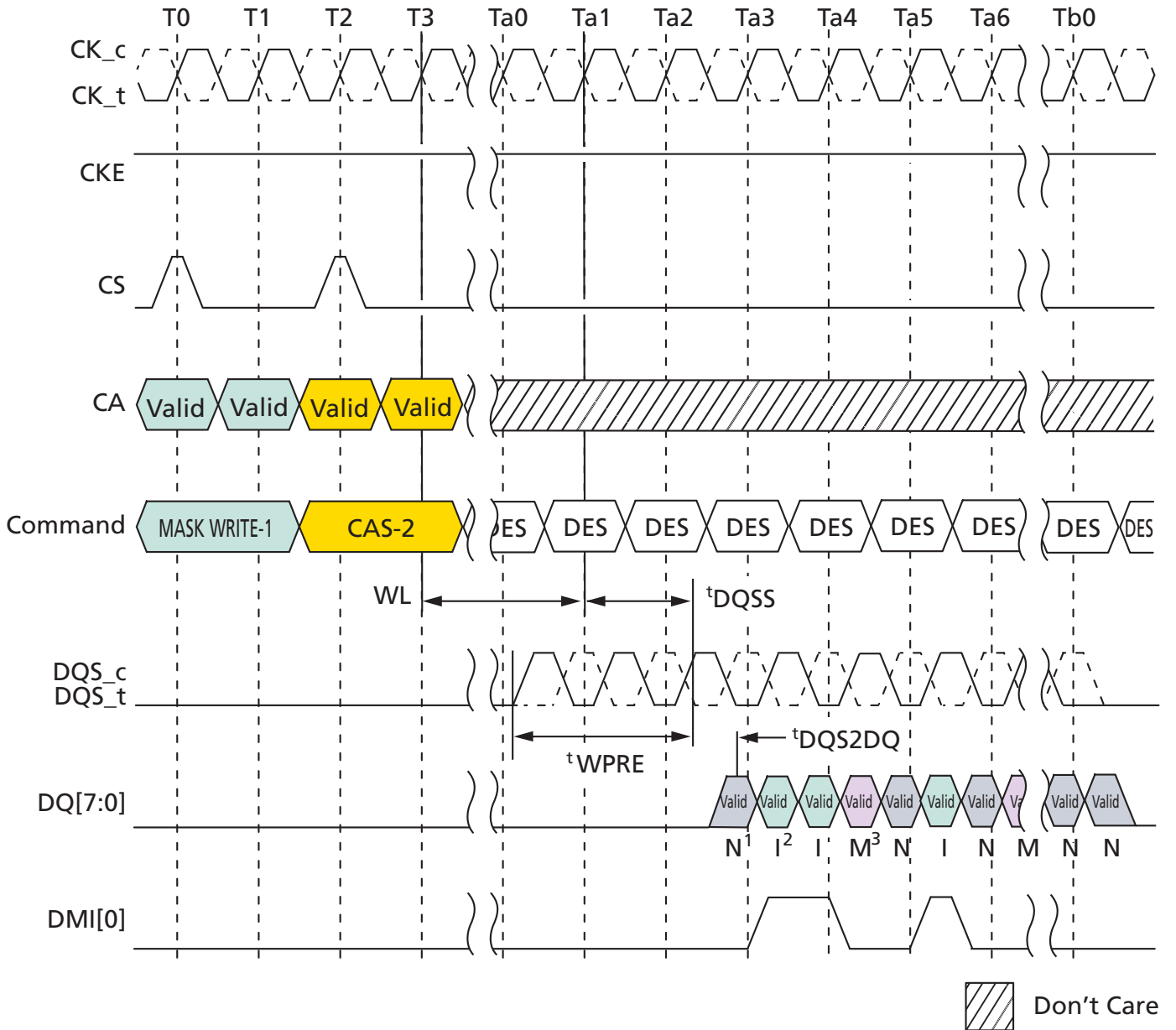
DM Function	Write DBI (DC)	Read DBI (DC)	DMI Signal					
			During WRITE	During MASKED WRITE	During READ	During MPC[WRITE-FIFO]	During MPC[READ-FIFO]	During MPC[READ-DQ CAL]
Disabled	Disabled	Disabled	Don't Care <sup>1</sup>	Illegal <sup>1, 3</sup>	High-Z <sup>2</sup>	Don't Care <sup>1</sup>	High-Z <sup>2</sup>	High-Z <sup>2</sup>
Disabled	Enabled	Disabled	DBI (DC) <sup>4</sup>	Illegal <sup>3</sup>	High-Z <sup>2</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>
Disabled	Disabled	Enabled	Don't Care <sup>1</sup>	Illegal <sup>3</sup>	DBI (DC) <sup>5</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>
Disabled	Enabled	Enabled	DBI (DC) <sup>4</sup>	Illegal <sup>3</sup>	DBI (DC) <sup>5</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>
Enabled	Disabled	Disabled	Don't Care <sup>6</sup>	DM <sup>7</sup>	High-Z <sup>2</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>
Enabled	Enabled	Disabled	DBI (DC) <sup>4</sup>	DBI (DC) <sup>8</sup>	High-Z <sup>2</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>
Enabled	Disabled	Enabled	Don't Care <sup>6</sup>	DM <sup>7</sup>	DBI (DC) <sup>5</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>

**Table 93: Function Behavior of DMI Signal During WRITE, MASKED WRITE, and READ Operations (Continued)**

DM Function	Write DBI (DC)	Read DBI (DC)	DMI Signal					
			During WRITE	During MASKED WRITE	During READ	During MPC[WRITE-FIFO]	During MPC[READ-FIFO]	During MPC[READ DQ CAL]
Enabled	Enabled	Enabled	DBI (DC) <sup>4</sup>	DBI (DC) <sup>8</sup>	DBI (DC) <sup>5</sup>	Train <sup>9</sup>	Train <sup>10</sup>	Train <sup>11</sup>

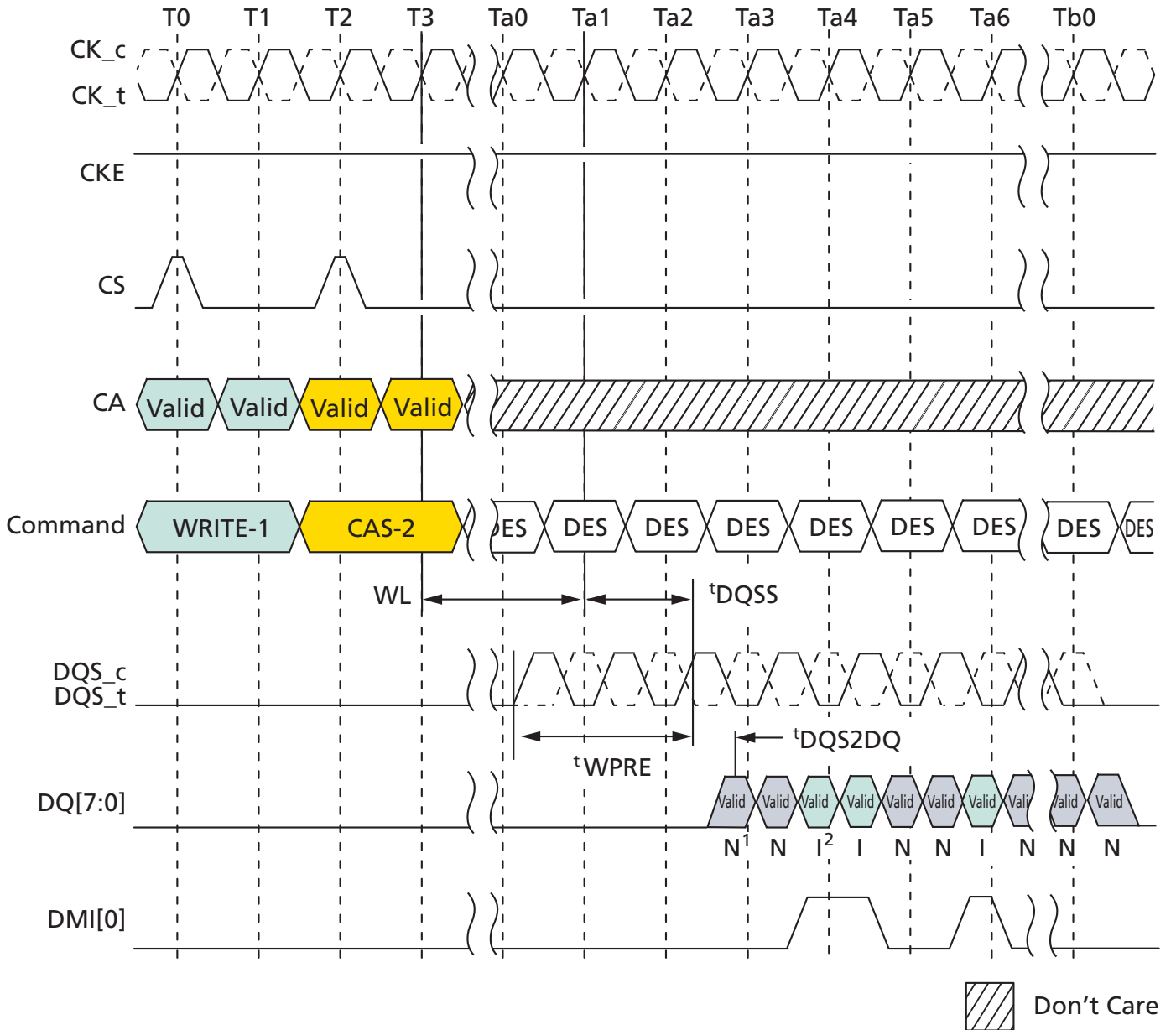
- Notes:
1. The DMI input signal is "Don't Care." DMI input receivers are turned off.
  2. DMI output drivers are turned off.
  3. The MASK WRITE command is not allowed and is considered an illegal command when the DM function is disabled.
  4. The DMI signal is treated as DBI and indicates whether the device needs to invert the write data received on DQ within a byte. The device inverts write data received on the DQ inputs if DMI is sampled HIGH and leaves the write data non-inverted if DMI is sampled LOW.
  5. The device inverts read data on its DQ outputs associated within a byte and drives the DMI signal HIGH when more than four data bits = 1 within a given byte lane; otherwise, the device does not invert the read data and drives DMI signal LOW.
  6. The device does not perform a MASK operation when it receives a WRITE (or MRW) command. During the WRITE burst, the DMI signal must be driven LOW.
  7. The device requires an explicit MASKED WRITE command for all MASKED WRITE operations. The DMI signal is treated as a data mask (DM) and indicates which bytes within a burst will be masked. When the DMI signal is sampled HIGH, the device masks that beat of the burst for the given byte lane. All DQ input signals within a byte are "Don't Care" (either HIGH or LOW) when DMI is HIGH. When the DMI signal is sampled LOW, the device does not perform a MASK operation and data received on the DQ inputs is written to the array.
  8. The device requires an explicit MASKED WRITE command for all MASKED WRITE operations. The device masks the write data received on the DQ inputs if five or more data bits = 1 on DQ[2:7] or DQ[10:15] (for lower byte or upper byte respectively) and the DMI signal is LOW. Otherwise, the device does not perform the MASK operation and treats it as a legal DBI pattern. The DMI signal is treated as a DBI signal, and data received on the DQ input is written to the array.
  9. The DMI signal is treated as a training pattern. The device does not perform any MASK operation and does not invert write data received on the DQ inputs.
  10. The DMI signal is treated as a training pattern. The device returns the data pattern written to the WRITE-FIFO.
  11. The DMI signal is treated as a training pattern. For more information, see the Read DQ Calibration Training section.

Figure 35: MASKED WRITE Command with Write DBI Enabled; DM Enabled



- Notes:
1. N: Input data is written to DRAM cell.
  2. I: Input data is inverted, then written to DRAM cell.
  3. M: Input data is masked. The total count of 1 data bits on DQ[7:2] is equal to or greater than five.
  4. Data mask (DM) is enable: MR13 OP [5] = 0, Data bus inversion (DBI) write is enable: MR3 OP[7] = 1.

Figure 36: WRITE Command with Write DBI Enabled; DM Disabled



- Notes:
1. N: Input data is written to DRAM cell.
  2. I: Input data is inverted, then written to DRAM cell.
  3. Data mask (DM) is disable: MR13 OP [5] = 1, Data bus inversion (DBI) write is enable: MR3 OP[7] = 1.

## Preamble and Postamble Behavior

### Preamble, Postamble Behavior in READ-to-READ Operations

The following illustrations show the behavior of the device's read DQS<sub>t</sub> and DQS<sub>c</sub> pins during cases where the preamble, postamble, and/or data clocking overlap.

DQS will be driven with the following priority

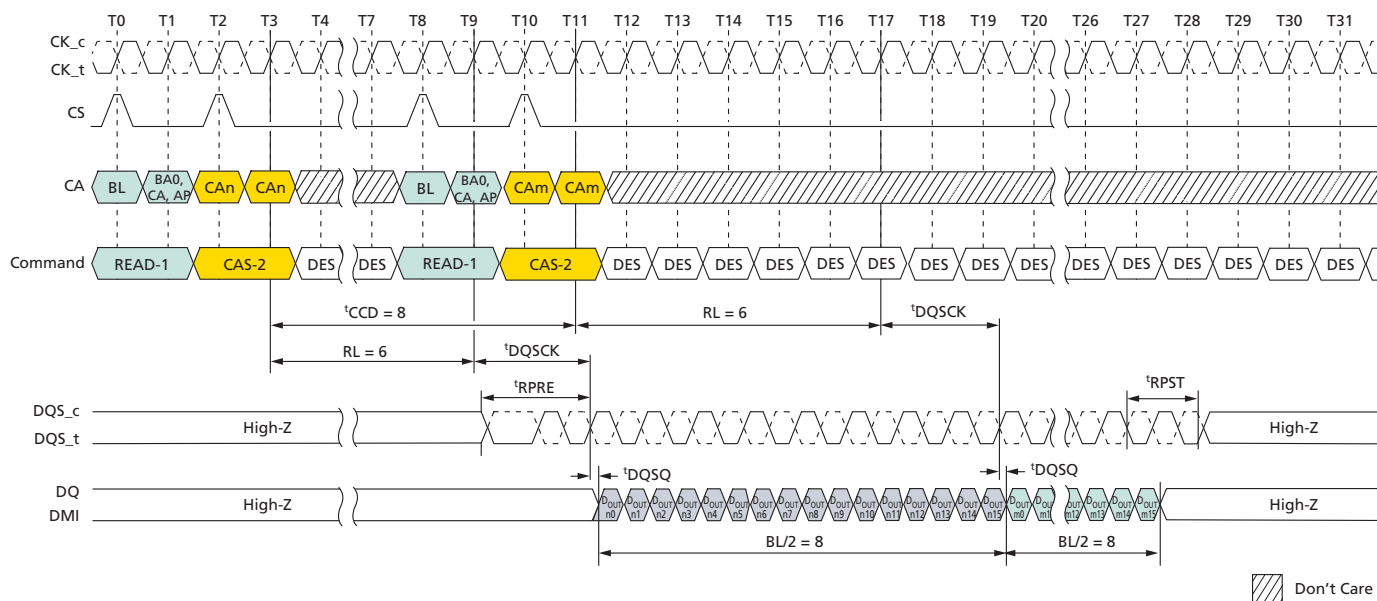
1. Data clocking edges will always be driven
2. Postamble
3. Preamble

Essentially the data clocking, preamble, and postamble will be ordered such that all edges will be driven.

Additional examples of seamless and borderline non-overlapping cases have been included for clarity.

### READ-to-READ Operations – Seamless

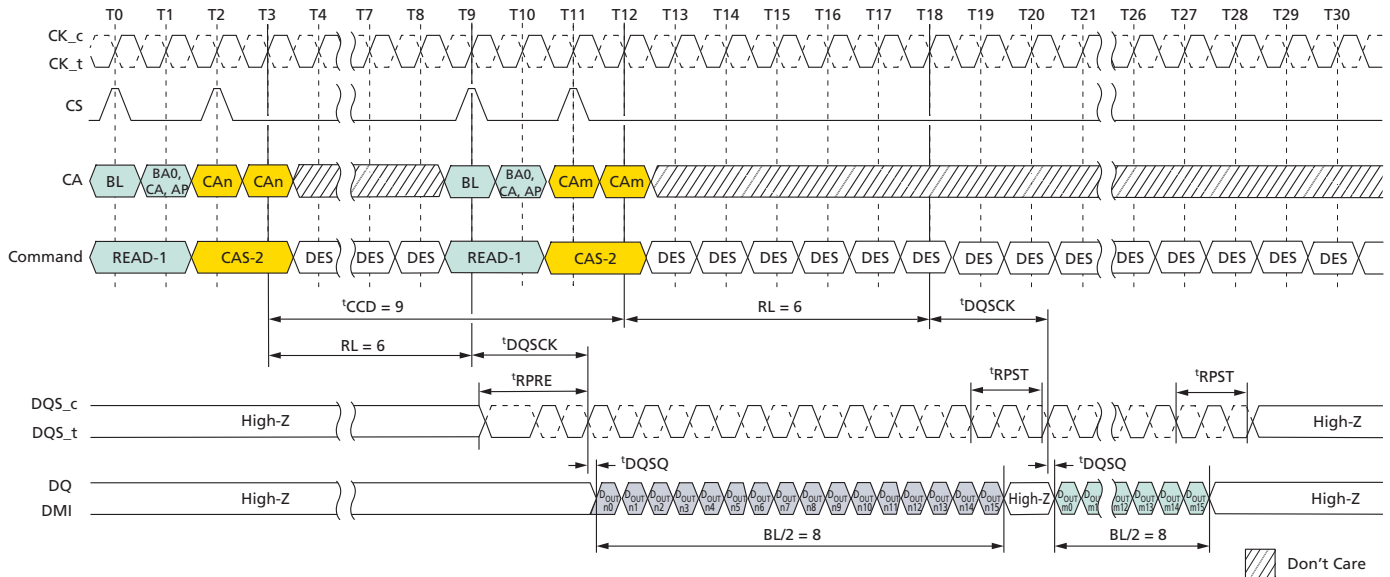
Figure 37: READ Operations:  $t_{CCD} = \text{MIN}$ , Preamble = Toggle, 1.5nCK Postamble



- Notes:
1. BL = 16 for column  $n$  and column  $m$ ; RL = 6; Preamble = Toggle; Postamble = 1.5nCK.
  2. D<sub>OUT</sub>  $n/m$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

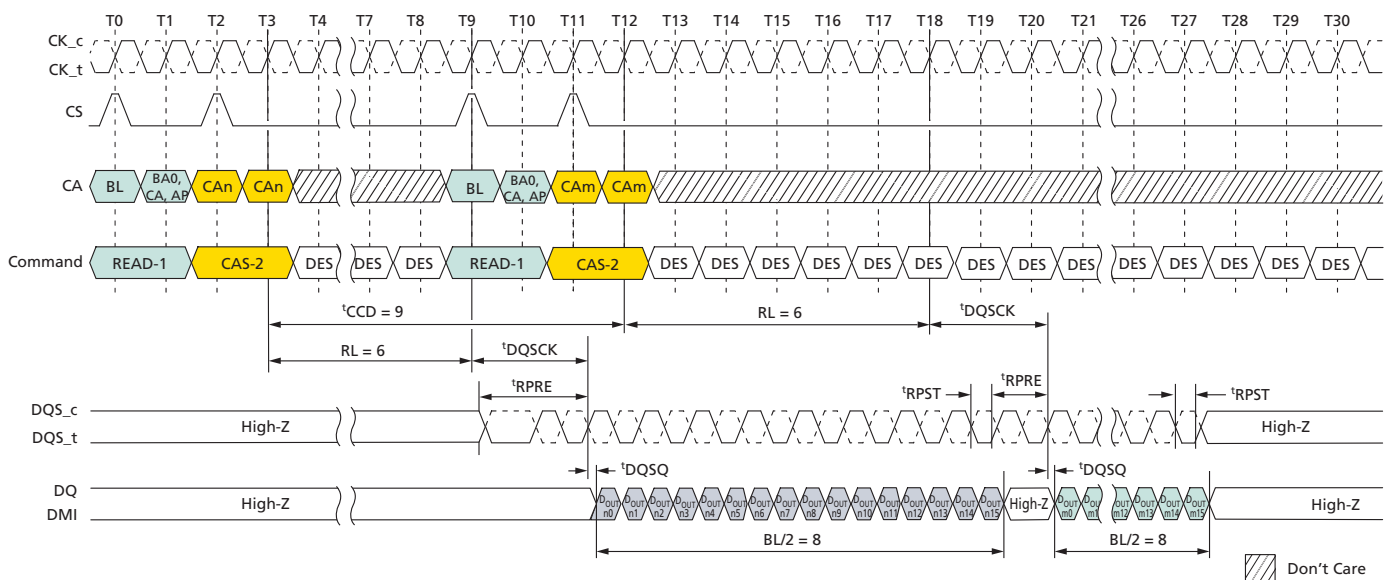
### READ-to-READ Operations – Consecutive

**Figure 38: Seamless READ:  $t_{CCD} = MIN + 1$ , Preamble = Toggle, 1.5nCK Postamble**



- Notes:
1. BL = 16 for column  $n$  and column  $m$ ; RL = 6; Preamble = Toggle; Postamble = 1.5nCK.
  2.  $D_{OUT} n/m$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

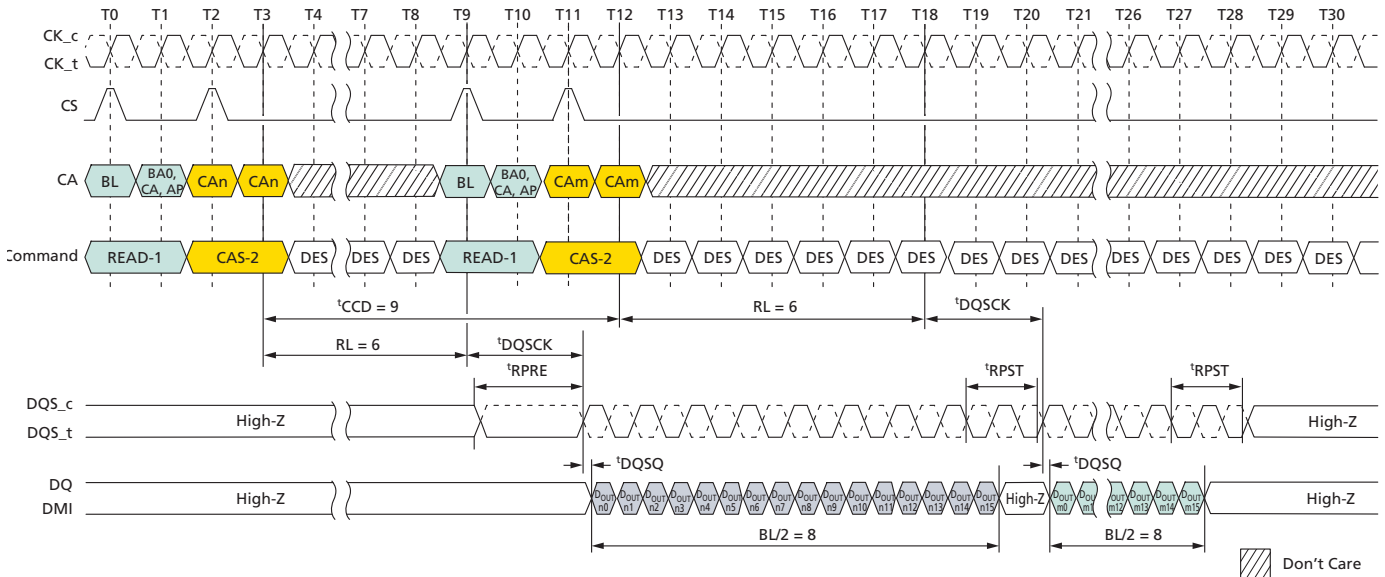
**Figure 39: Consecutive READ:  $t_{CCD} = MIN + 1$ , Preamble = Toggle, 0.5nCK Postamble**



- Notes:
1. BL = 16 for column  $n$  and column  $m$ ; RL = 6; Preamble = Toggle; Postamble = 0.5nCK.
  2.  $D_{OUT} n/m$  = data-out from column  $n$  and column  $m$ .

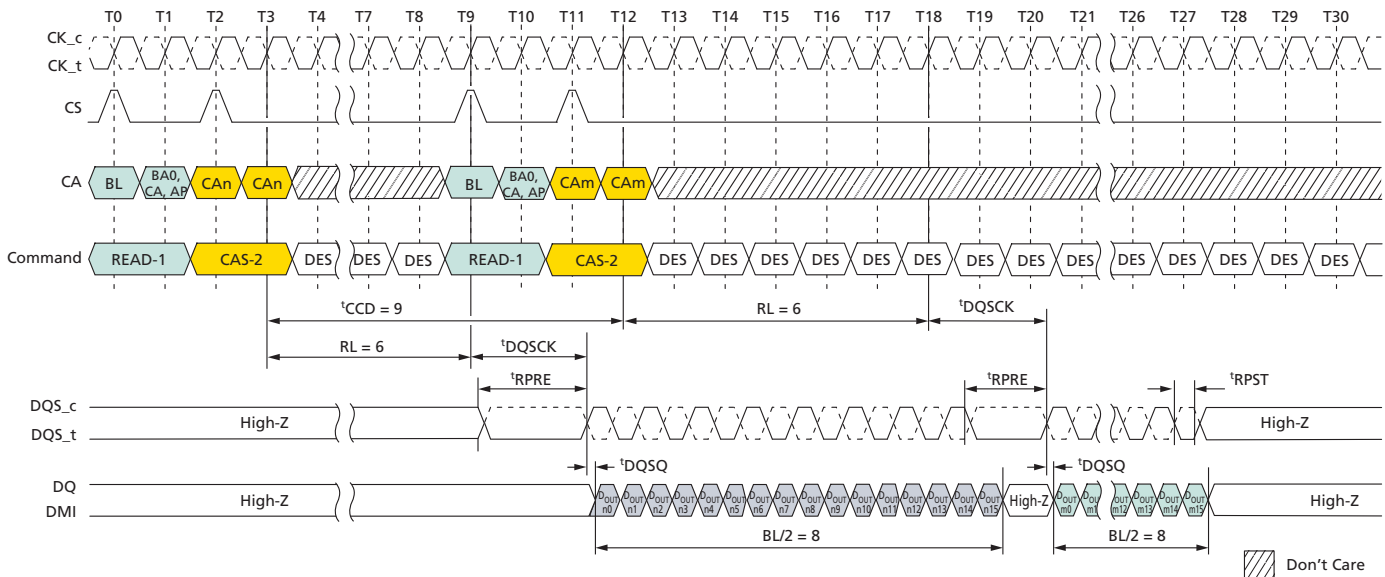
- DES commands are shown for ease of illustration; other commands may be valid at these times.

**Figure 40: Consecutive READ:  $t_{CCD} = MIN + 1$ , Preamble = Static,  $1.5nCK$  Postamble**



- Notes:
- BL = 16 for column  $n$  and column  $m$ ;  $RL = 6$ ; Preamble = Static; Postamble =  $1.5nCK$ .
  - $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  - DES commands are shown for ease of illustration; other commands may be valid at these times.

**Figure 41: Consecutive READ:  $t_{CCD} = MIN + 1$ , Preamble = Static,  $0.5nCK$  Postamble**

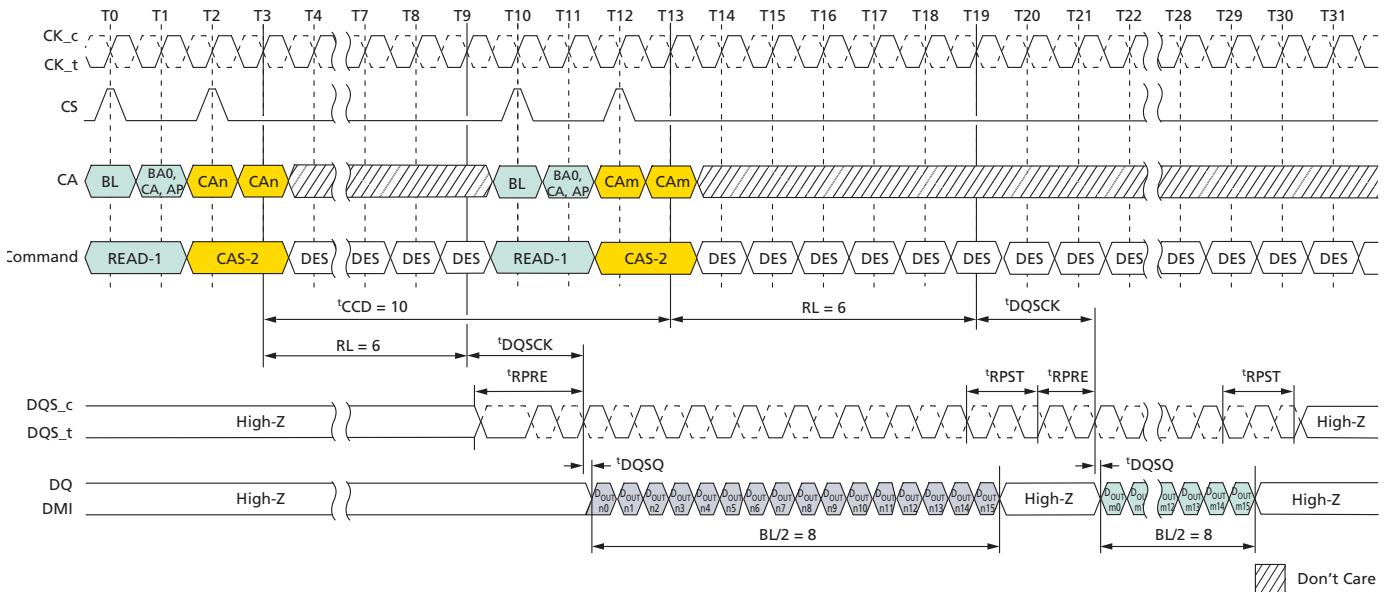


- Notes:
- BL = 16 for column  $n$  and column  $m$ ;  $RL = 6$ ; Preamble = Static; Postamble =  $0.5nCK$ .



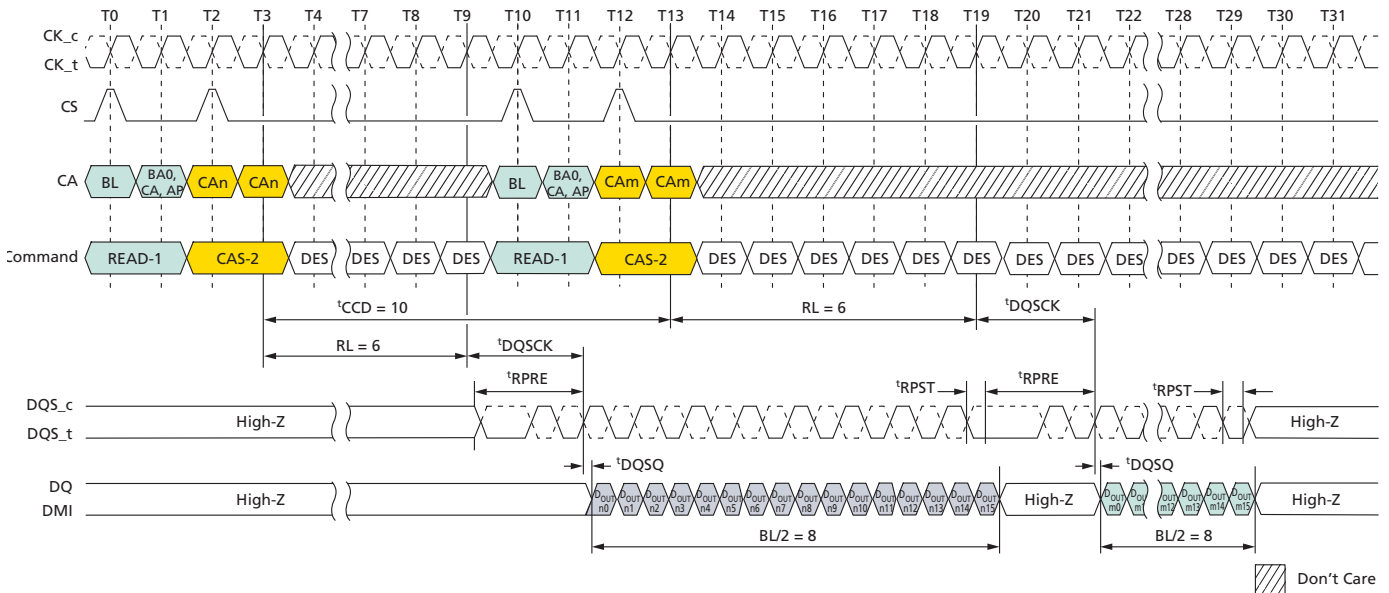
2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

**Figure 42: Consecutive READ:  $t_{CCD} = MIN + 2$ , Preamble = Toggle, 1.5nCK Postamble**



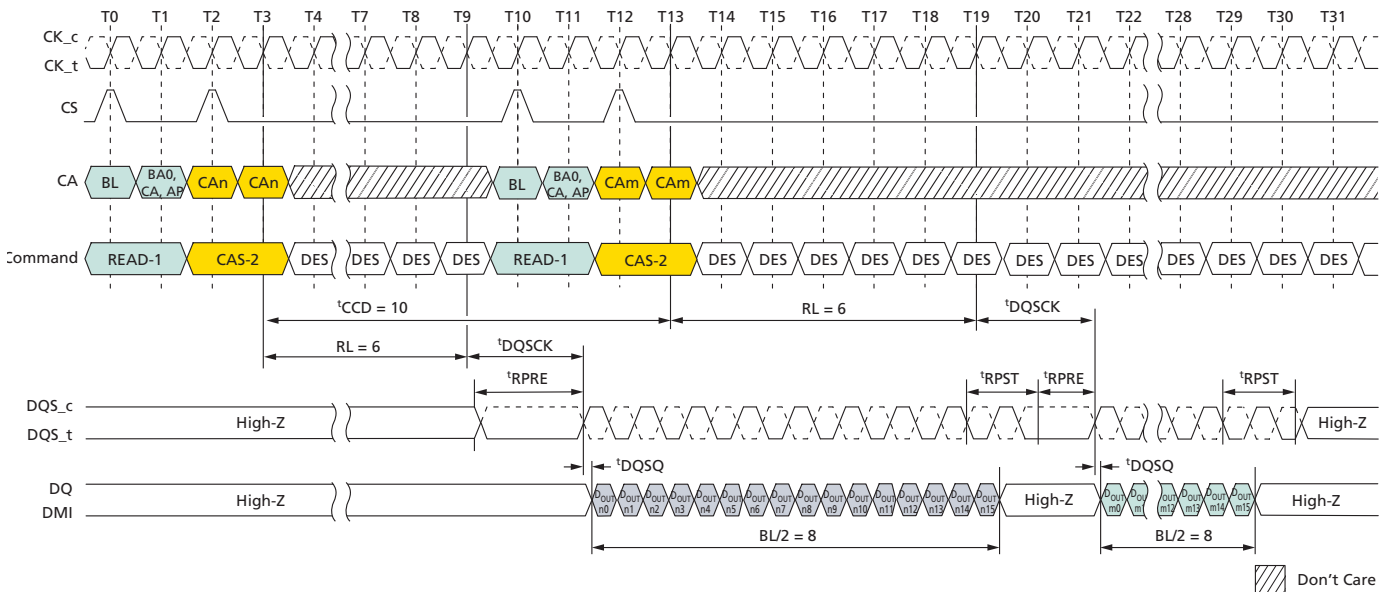
- Notes:
1.  $BL = 16$  for column  $n$  and column  $m$ ;  $RL = 6$ ; Preamble = Toggle; Postamble = 1.5nCK.
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 43: Consecutive READ:  $t_{CCD} = \text{MIN} + 2$ , Preamble = Toggle,  $0.5n\text{CK}$  Postamble



- Notes:
1. BL = 16 for column  $n$  and column  $m$ ; RL = 6; Preamble = Toggle; Postamble =  $0.5n\text{CK}$ .
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

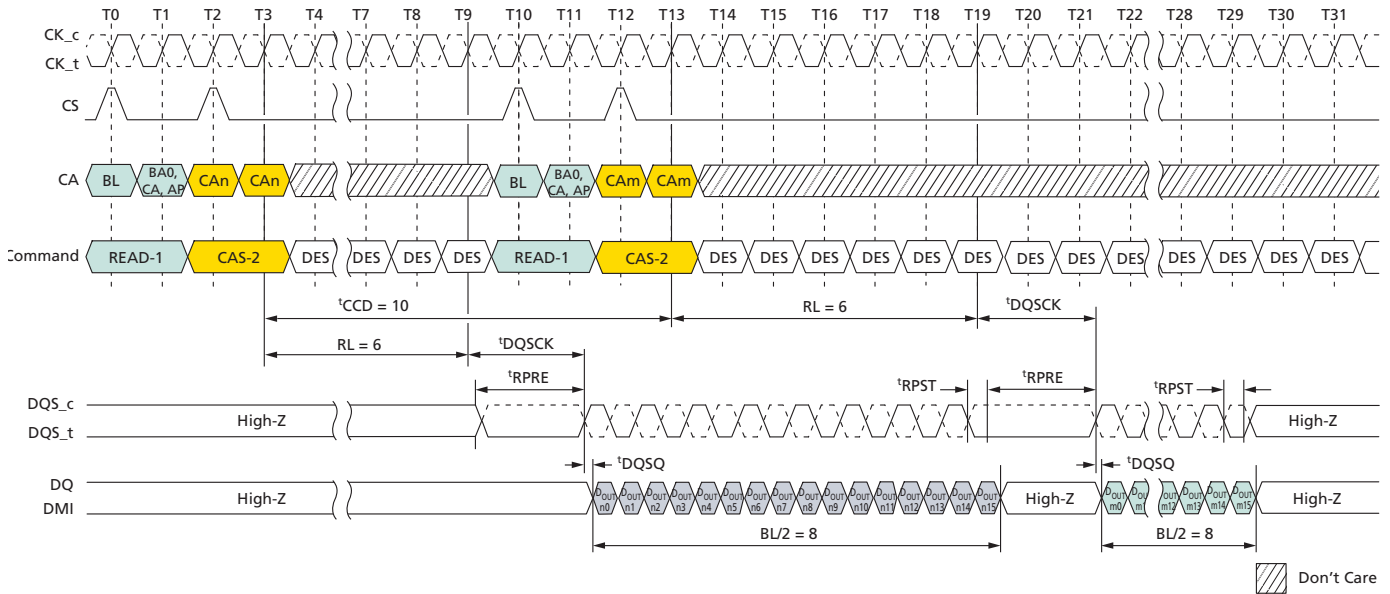
Figure 44: Consecutive READ:  $t_{CCD} = \text{MIN} + 2$ , Preamble = Static,  $1.5n\text{CK}$  Postamble



- Notes:
1. BL = 16 for column  $n$  and column  $m$ ; RL = 6; Preamble = Static; Postamble =  $1.5n\text{CK}$ .
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .

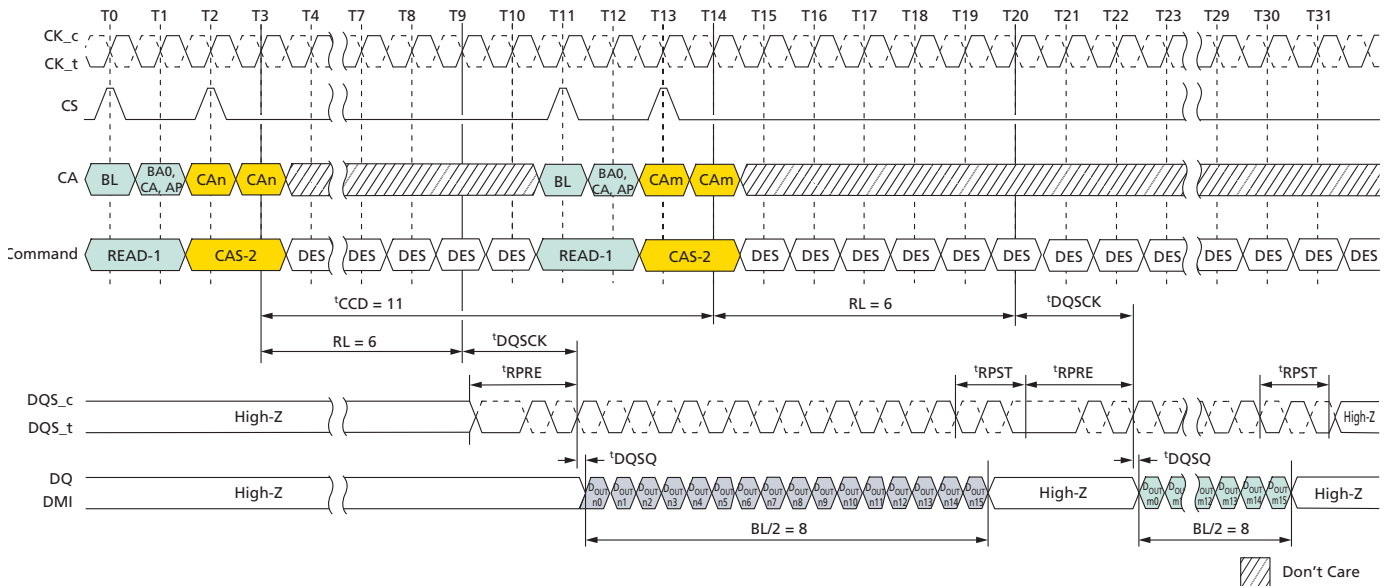
- DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 45: Consecutive READ:  $t_{CCD} = \text{MIN} + 2$ , Preamble = Static,  $0.5n\text{CK}$  Postamble



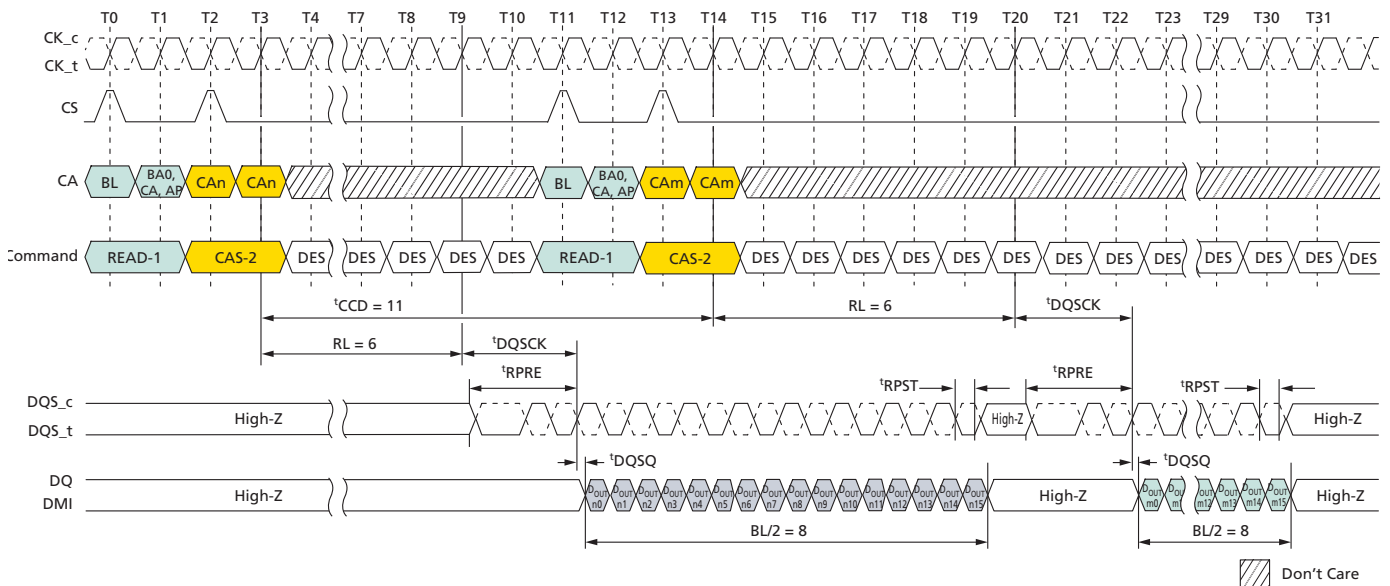
- Notes:
- BL = 16 for column  $n$  and column  $m$ ; RL = 6; Preamble = Static; Postamble =  $0.5n\text{CK}$ .
  - $D_{OUT} n/m$  = data-out from column  $n$  and column  $m$ .
  - DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 46: Consecutive READ:  $t_{CCD} = \text{MIN} + 3$ , Preamble = Toggle, 1.5nCK Postamble



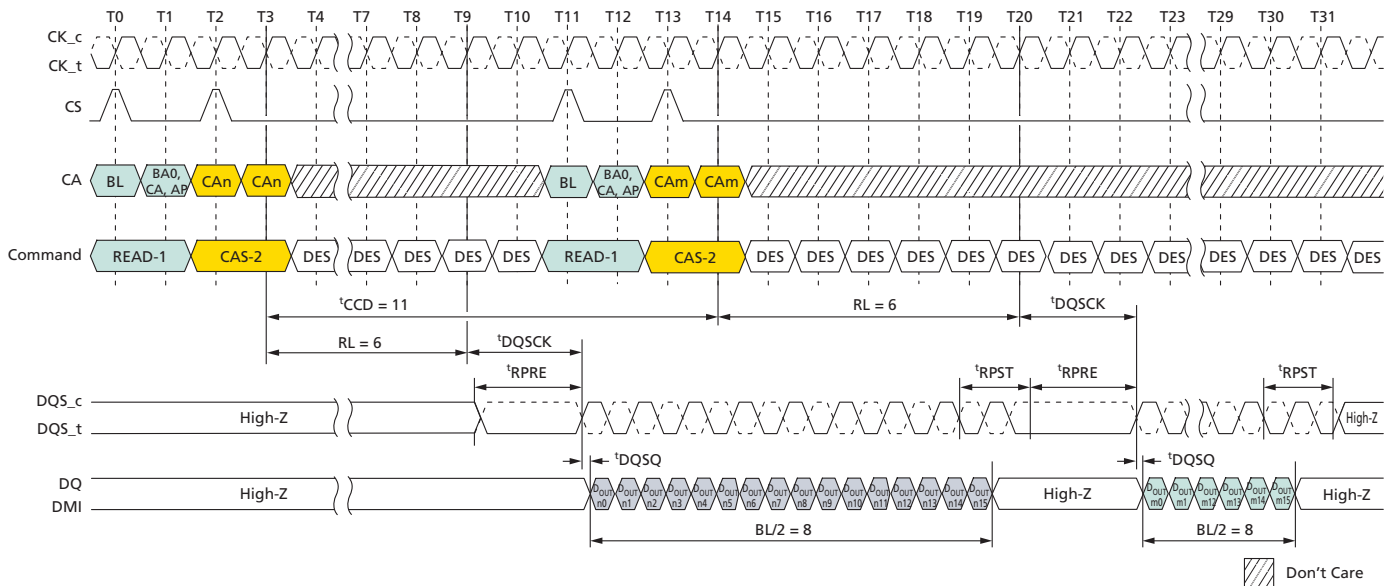
- Notes:
1.  $BL = 16$  for column  $n$  and column  $m$ ;  $RL = 6$ ; Preamble = Toggle; Postamble =  $1.5nCK$ .
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 47: Consecutive READ:  $t_{CCD} = \text{MIN} + 3$ , Preamble = Toggle, 0.5nCK Postamble



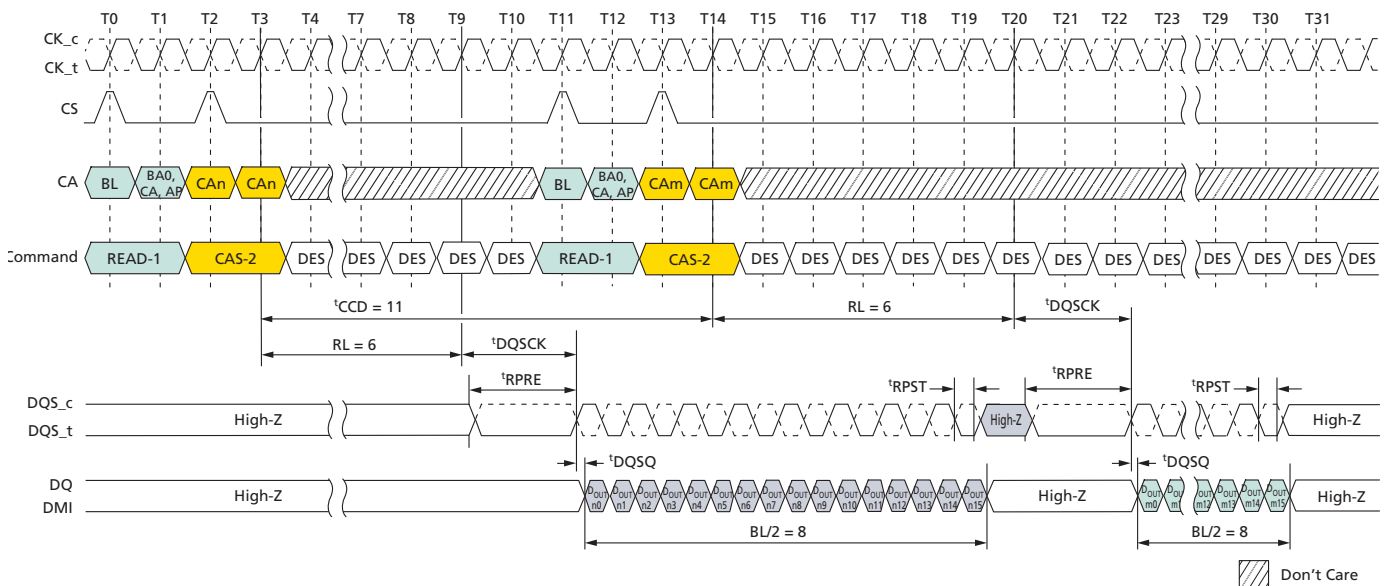
- Notes:
1.  $BL = 16$  for column  $n$  and column  $m$ ;  $RL = 6$ ; Preamble = Toggle; Postamble =  $0.5nCK$ .
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 48: Consecutive READ:  $t_{CCD} = \text{MIN} + 3$ , Preamble = Static,  $1.5n\text{CK}$  Postamble



- Notes:
1.  $BL = 16$  for column  $n$  and column  $m$ ;  $RL = 6$ ; Preamble = Static; Postamble =  $1.5n\text{CK}$ .
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

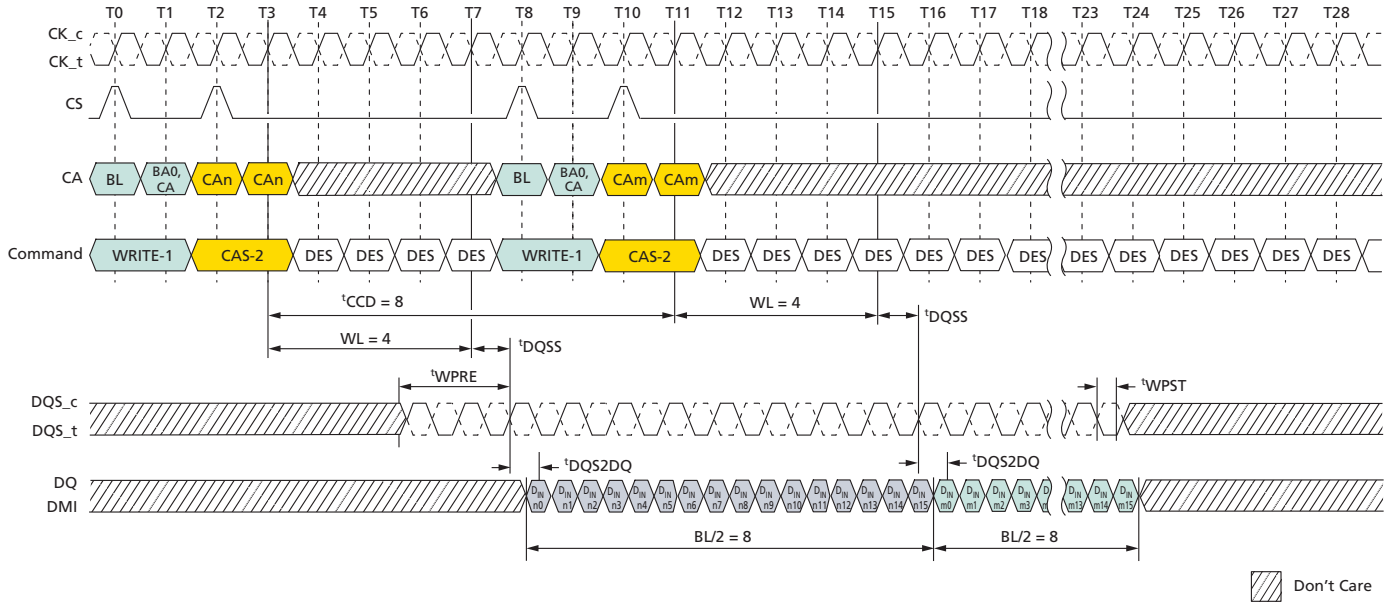
Figure 49: Consecutive READ:  $t_{CCD} = \text{MIN} + 3$ , Preamble = Static,  $0.5n\text{CK}$  Postamble



- Notes:
1.  $BL = 16$  for column  $n$  and column  $m$ ;  $RL = 6$ , Preamble = Static; Postamble =  $0.5n\text{CK}$
  2.  $D_{OUT\ n/m}$  = data-out from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

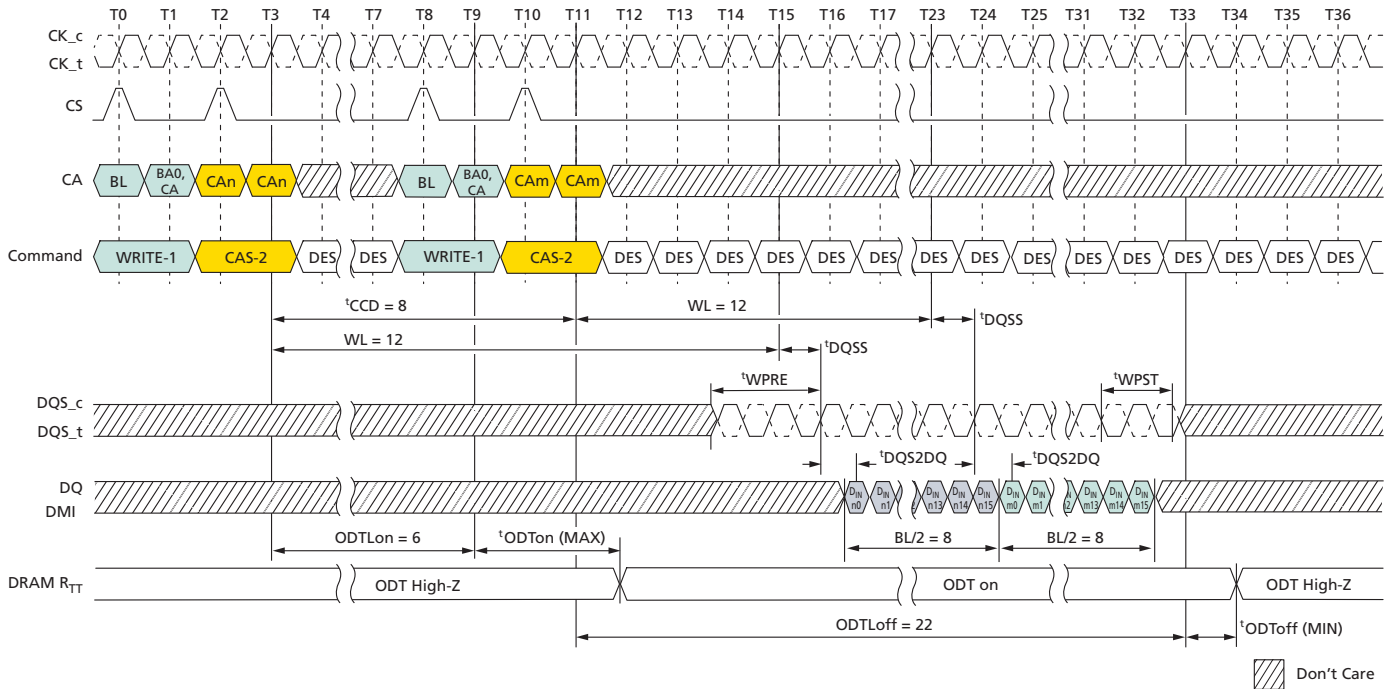
WRITE-to-WRITE Operations – Seamless

Figure 50: Seamless WRITE:  $t_{CCD} = \text{MIN}, 0.5n\text{CK}$  Postamble



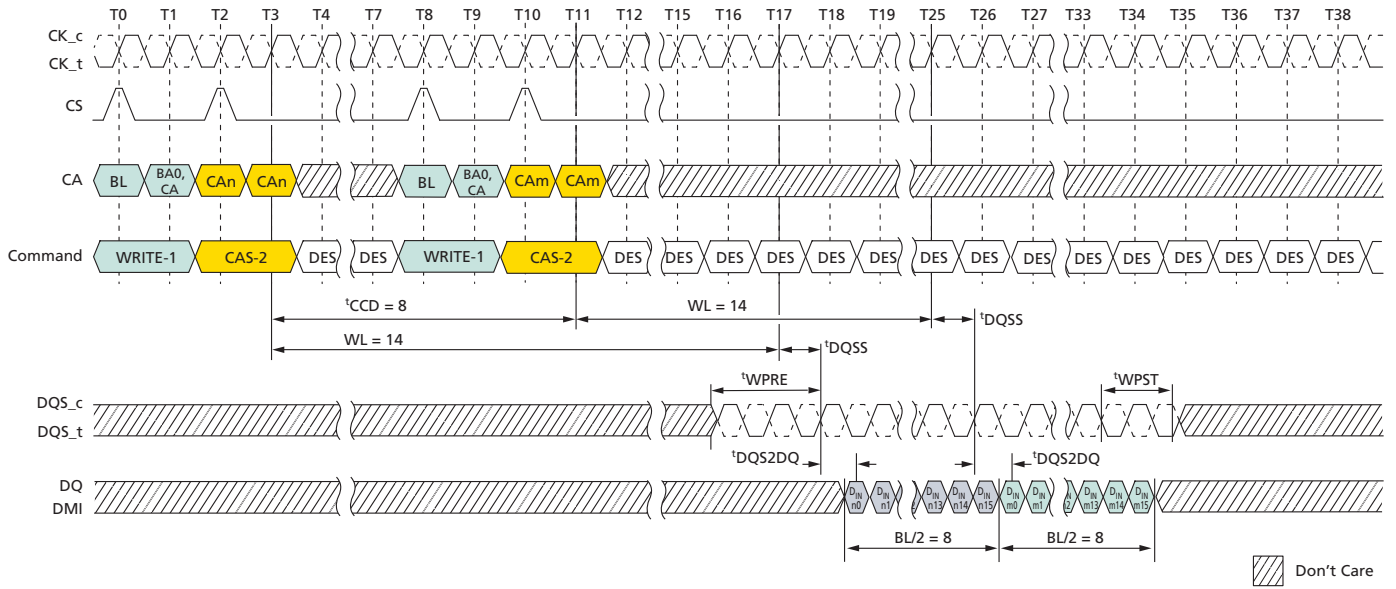
- Notes:
1. BL = 16, Write postamble =  $0.5n\text{CK}$ .
  2.  $D_{IN\ n/m}$  = data-in from column  $n$  and column  $m$ .
  3. The minimum number of clock cycles from the burst WRITE command to the burst WRITE command for any bank is BL/2.
  4. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 51: Seamless WRITE:  $t_{CCD} = \text{MIN}$ ,  $1.5n\text{CK}$  Postamble,  $533 \text{ MHz} < \text{Clock Frequency} \leq 800 \text{ MHz}$ , ODT Worst Timing Case



- Notes:
1. Clock frequency = 800 MHz,  $t_{CK(AVG)} = 1.25\text{ns}$ .
  2. BL = 16, Write postamble =  $1.5n\text{CK}$ .
  3.  $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .
  4. The minimum number of clock cycles from the burst WRITE command to the burst WRITE command for any bank is BL/2.
  5. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 52: Seamless WRITE:  $t_{CCD} = \text{MIN}, 1.5n\text{CK}$  Postamble

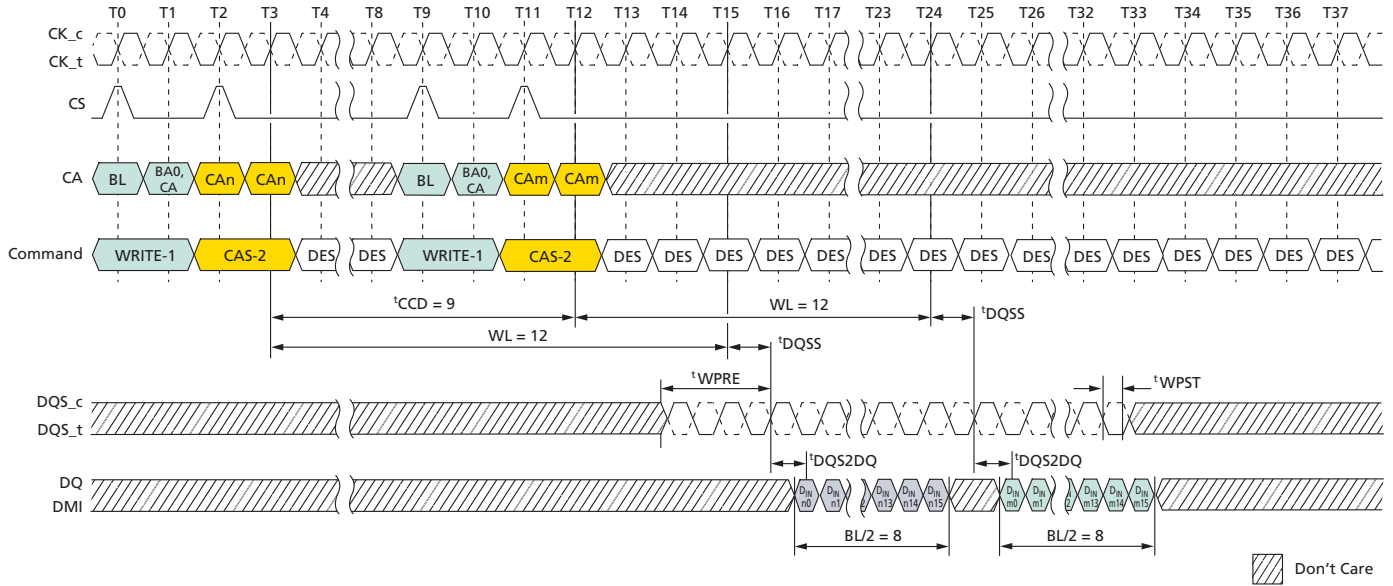


- Notes:
1.  $BL = 16$ , Write postamble =  $1.5n\text{CK}$ .
  2.  $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .
  3. The minimum number of clock cycles from the burst WRITE command to the burst WRITE command for any bank is  $BL/2$ .
  4. DES commands are shown for ease of illustration; other commands may be valid at these times.



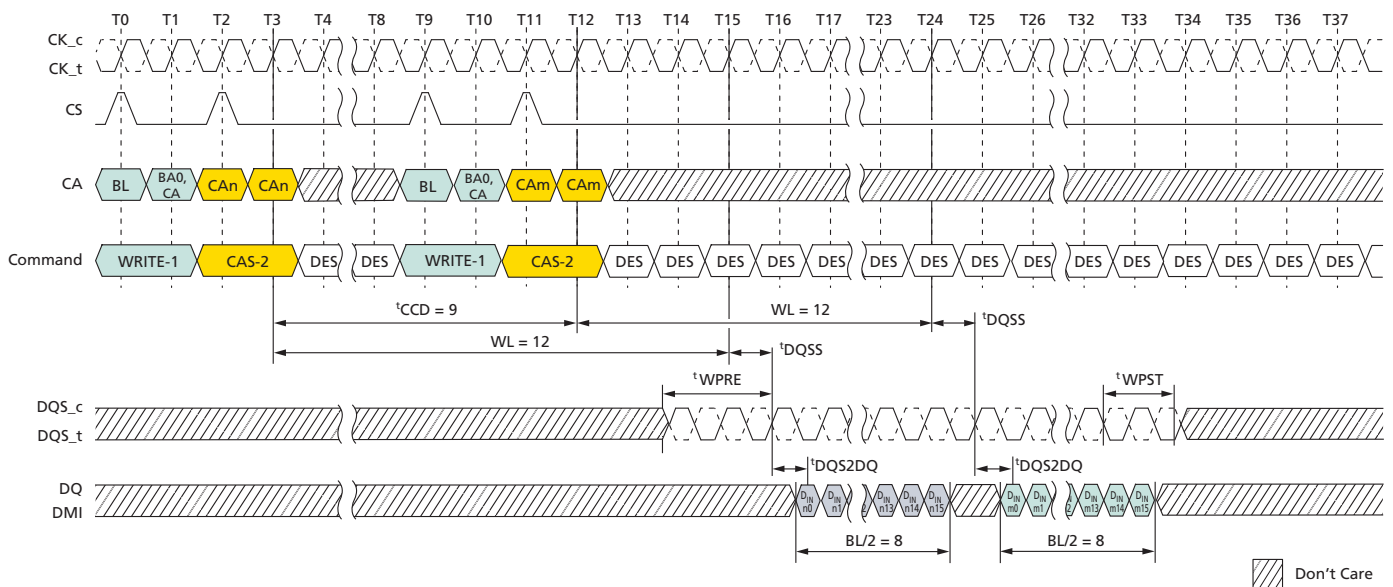
WRITE-to-WRITE Operations – Consecutive

Figure 53: Consecutive WRITE:  $t_{CCD} = \text{MIN} + 1, 0.5n\text{CK}$  Postamble



- Notes:
1. BL = 16, Write postamble =  $0.5n\text{CK}$ .
  2.  $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

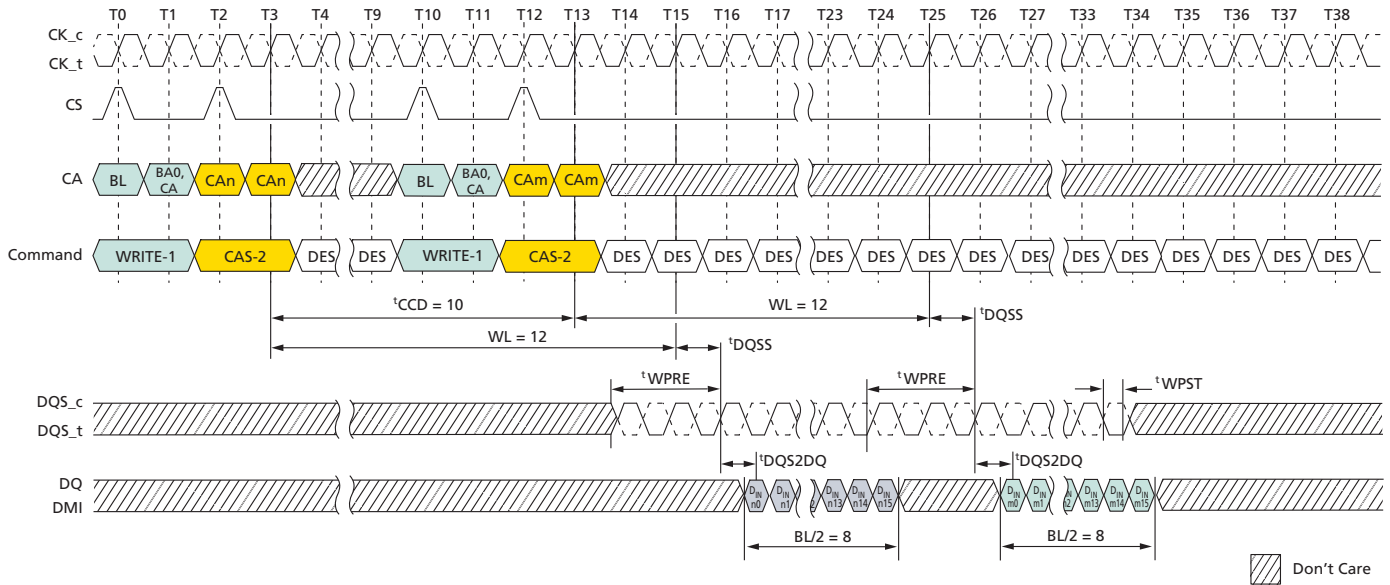
Figure 54: Consecutive WRITE:  $t_{CCD} = \text{MIN} + 1, 1.5n\text{CK}$  Postamble



- Notes:
1. BL = 16, Write postamble =  $1.5n\text{CK}$ .
  2.  $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .

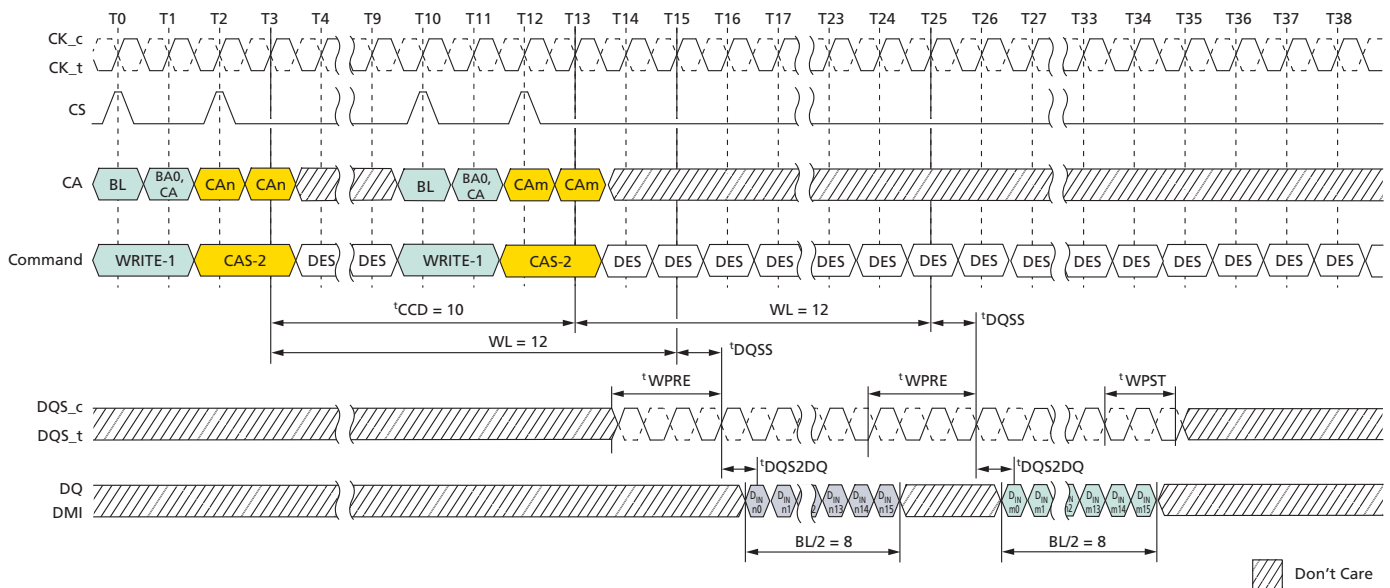
- DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 55: Consecutive WRITE:  $t_{CCD} = \text{MIN} + 2, 0.5n\text{CK}$  Postamble



- Notes:
- BL = 16, Write postamble =  $0.5n\text{CK}$ .
  - $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .
  - DES commands are shown for ease of illustration; other commands may be valid at these times.

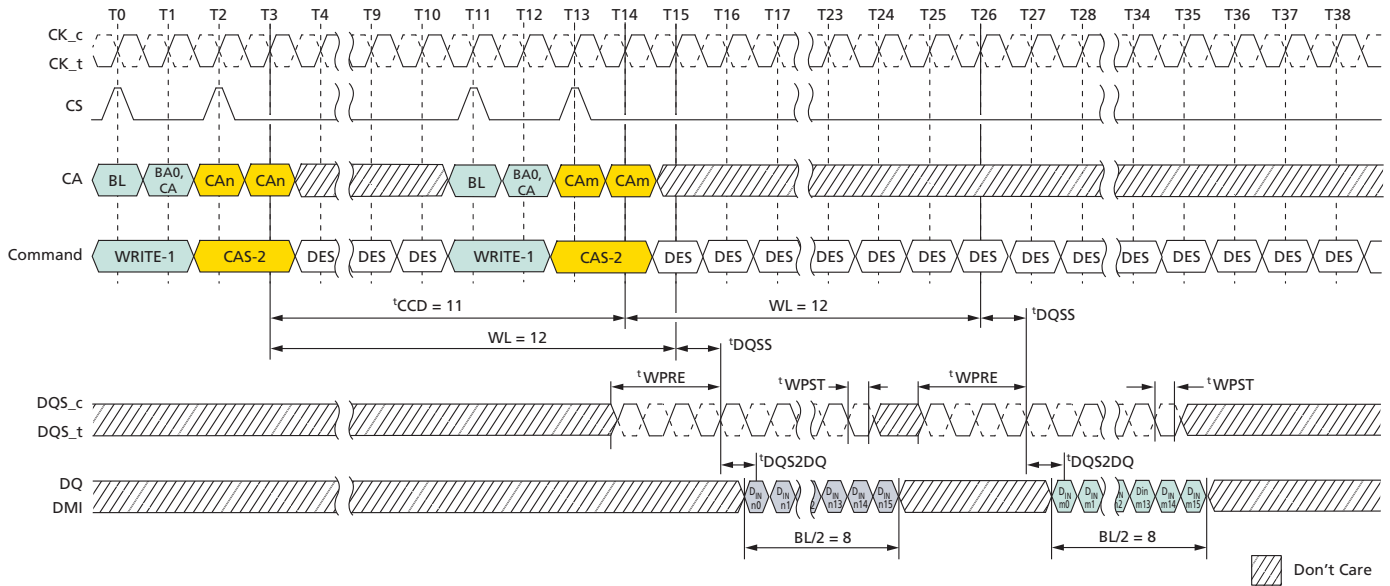
Figure 56: Consecutive WRITE:  $t_{CCD} = \text{MIN} + 2, 1.5n\text{CK}$  Postamble



- Notes:
- BL = 16, Write postamble =  $1.5n\text{CK}$ .

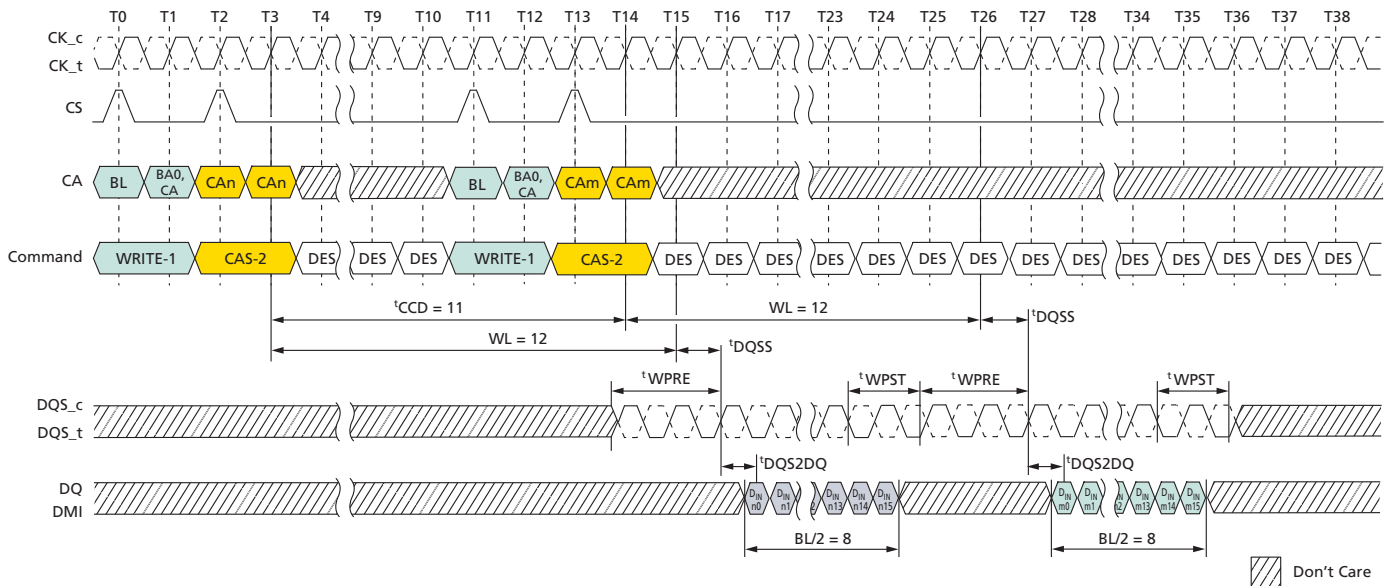
2.  $D_{IN\ n/m}$  = data-in from column  $n$  and column  $m$ .
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

**Figure 57: Consecutive WRITE:  $t_{CCD} = MIN + 3, 0.5nCK$  Postamble**



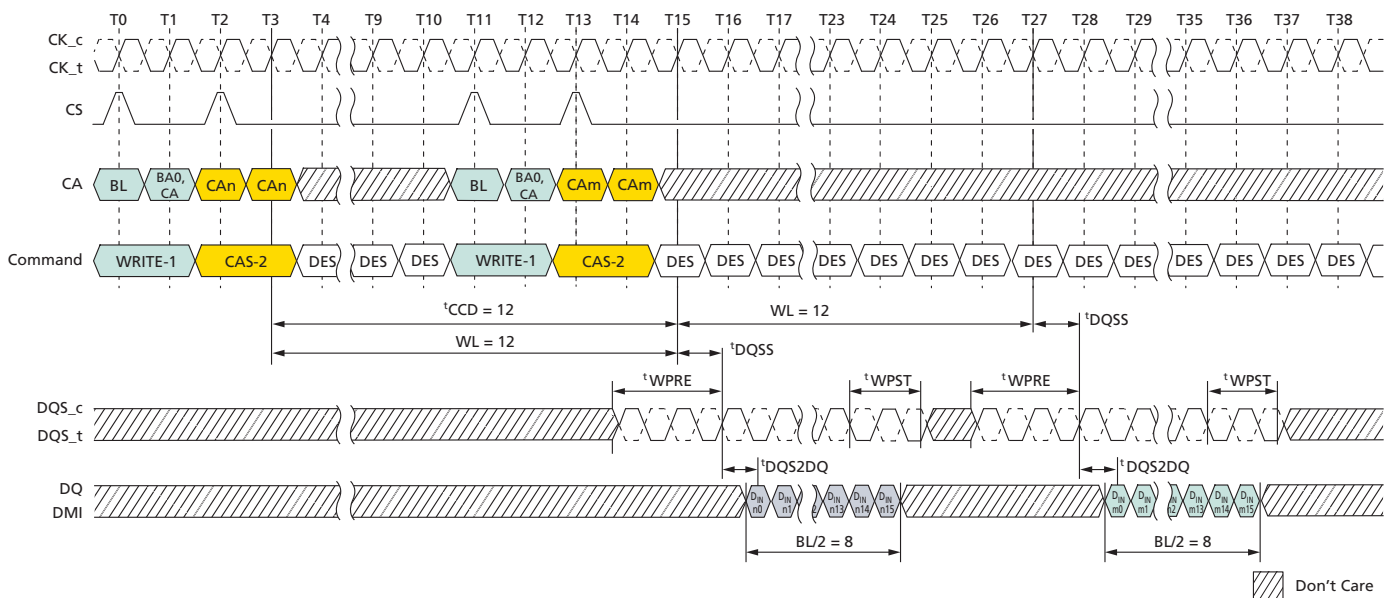
- Notes:
1.  $BL = 16$ , Write postamble =  $0.5nCK$ .
  2.  $D_{IN\ n/m}$  = data-in from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 58: Consecutive WRITE:  $t_{CCD} = \text{MIN} + 3, 1.5n\text{CK}$  Postamble



- Notes:
1. BL = 16, Write postamble =  $1.5n\text{CK}$ .
  2.  $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 59: Consecutive WRITE:  $t_{CCD} = \text{MIN} + 4, 1.5n\text{CK}$  Postamble



- Notes:
1. BL = 16, Write postamble =  $1.5n\text{CK}$ .
  2.  $D_{IN} n/m$  = data-in from column  $n$  and column  $m$ .
  3. DES commands are shown for ease of illustration; other commands may be valid at these times.

## PRECHARGE Operation

The PRECHARGE command is used to precharge or close a bank that has been activated. The PRECHARGE command is initiated with CKE, CS, and CA[5:0] in the proper state (see Command Truth Table). The PRECHARGE command can be used to precharge each bank independently or all banks simultaneously. The all banks (AB) flag and the bank address bit are used to determine which bank(s) to precharge. The precharged bank(s) will be available for subsequent row access  $t_{RPab}$  after an all-bank PRECHARGE command is issued, or  $t_{RPpb}$  after a single-bank PRECHARGE command is issued.

To ensure that the device can meet the instantaneous current demands, the row precharge time for an all-bank PRECHARGE ( $t_{RPab}$ ) is longer than the per-bank precharge time ( $t_{RPpb}$ ).

**Table 94: Precharge Bank Selection**

AB (CA[5], R1)	BA2 (CA[2], R2)	BA1 (CA[1], R2)	BA0 (CA[0], R2)	Precharged Bank
0	0	0	0	Bank 0 only
0	0	0	1	Bank 1 only
0	0	1	0	Bank 2 only
0	0	1	1	Bank 3 only
0	1	0	0	Bank 4 only
0	1	0	1	Bank 5 only
0	1	1	0	Bank 6 only
0	1	1	1	Bank 7 only
1	Don't Care	Don't Care	Don't Care	All banks

### Burst READ Operation Followed by Precharge

The PRECHARGE command can be issued as early as BL/2 clock cycles after a READ command, but the PRECHARGE command cannot be issued until after  $t_{RAS}$  is satisfied. A new bank ACTIVATE command can be issued to the same bank after the row precharge time ( $t_{RP}$ ) has elapsed. The minimum read-to-precharge time must also satisfy a minimum analog time from the second rising clock edge of the CAS-2 command.  $t_{RTP}$  begins BL/2 - 8 clock cycles after the READ command.

Figure 60: Burst READ Followed by Precharge – BL16, Toggling Preamble, 0.5nCK Postamble

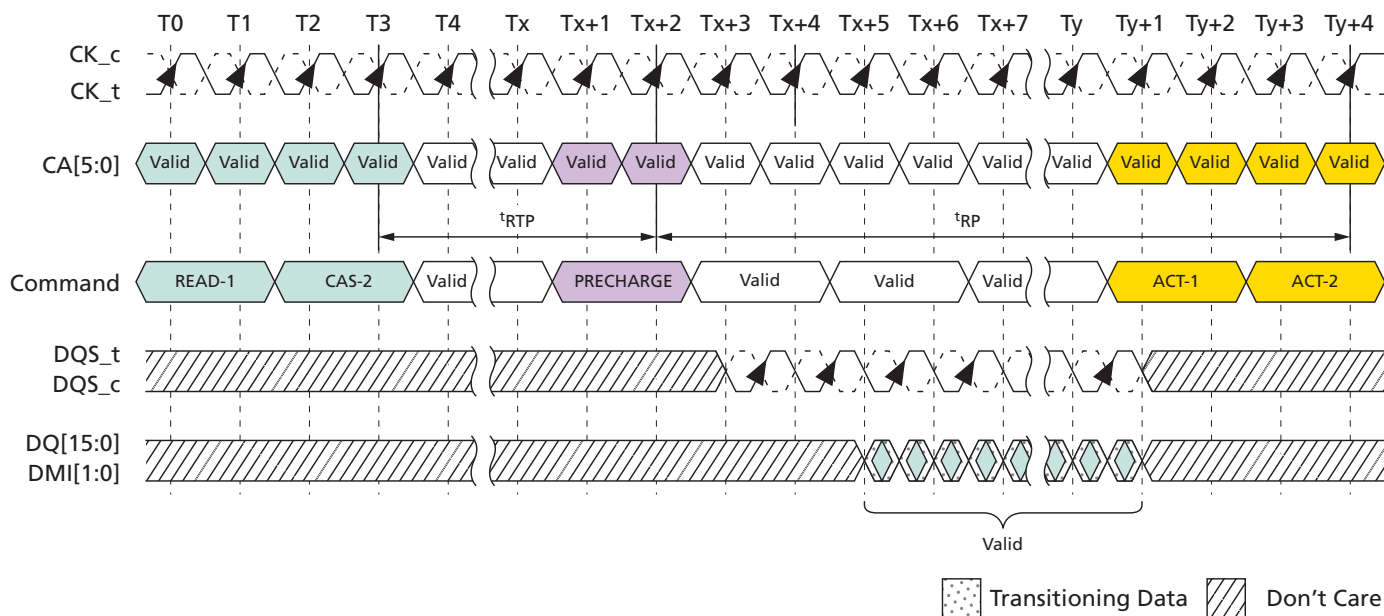
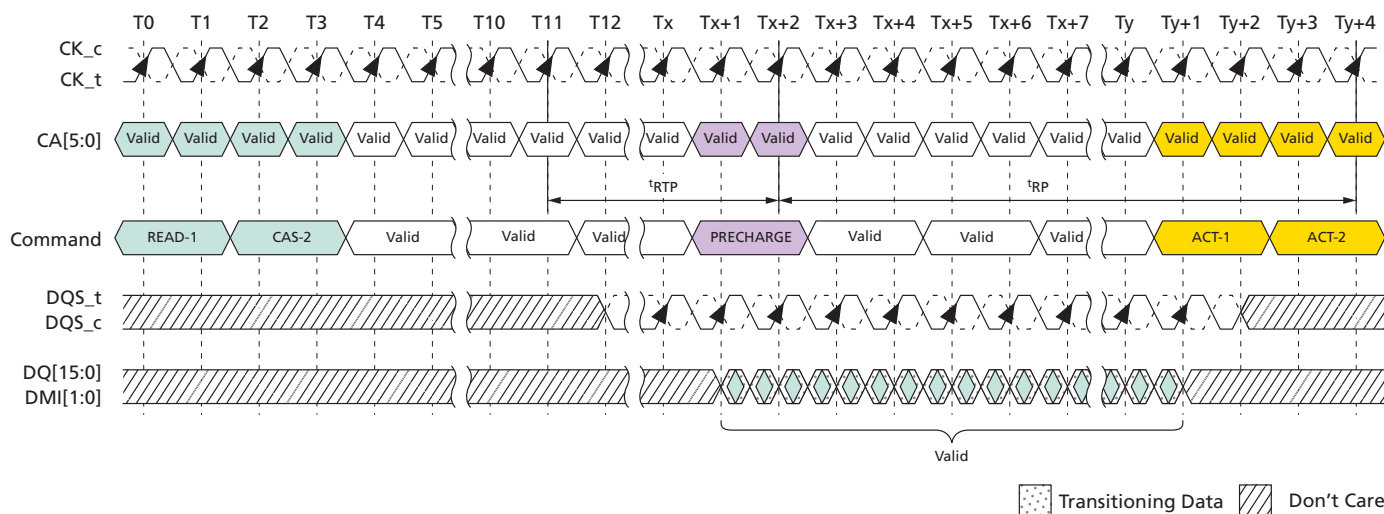


Figure 61: Burst READ Followed by Precharge – BL32, 2<sup>t</sup>CK, 0.5nCK Postamble

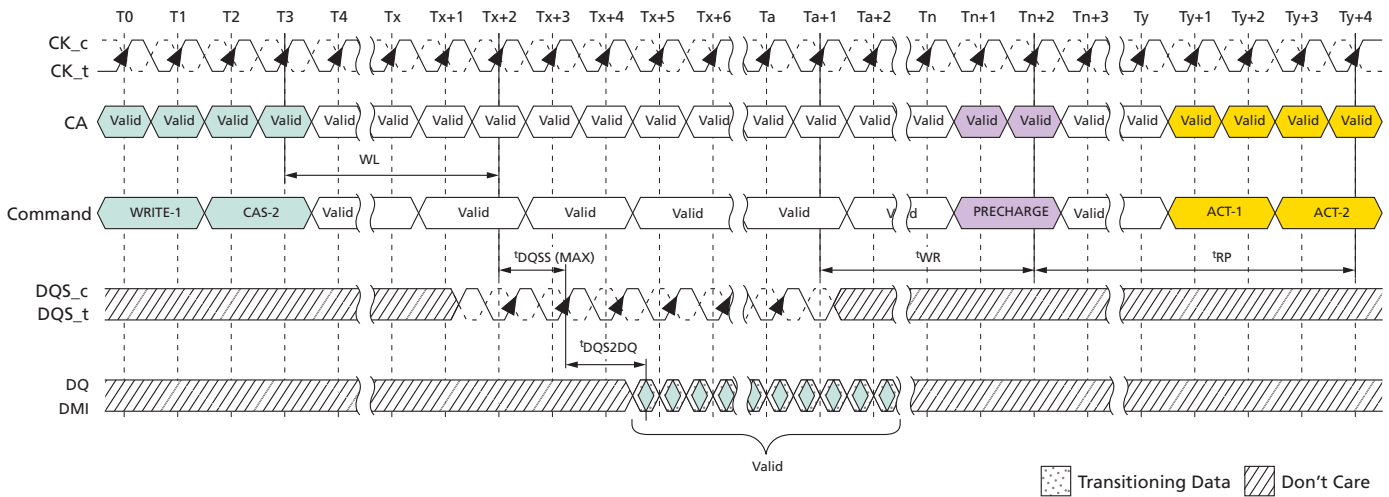


### Burst WRITE Followed by Precharge

A write recovery time ( $t^w_{WR}$ ) must be provided before a PRECHARGE command may be issued. This delay is referenced from the next rising edge of CK after the last valid DQS clock of the burst.

Devices write data to the memory array in prefetch multiples (prefetch = 16). An internal WRITE operation can only begin after a prefetch group has been clocked; therefore,  $t^w_{WR}$  starts at the prefetch boundaries. The minimum write-to-precharge time for commands to the same bank is  $WL + BL/2 + 1 + RU(t^w_{WR} / t^w_{CK})$  clock cycles.

Figure 62: Burst WRITE Followed by PRECHARGE – BL16, 2nCK Preamble, 0.5nCK Postamble



## Auto Precharge

Before a new row can be opened in an active bank, the active bank must be precharged using either the PRECHARGE command or the auto precharge (AP) function. When a READ or a WRITE command is issued to the device, the AP bit (CA5) can be set to enable the active bank to automatically begin precharge at the earliest possible moment during the burst READ or WRITE cycle.

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

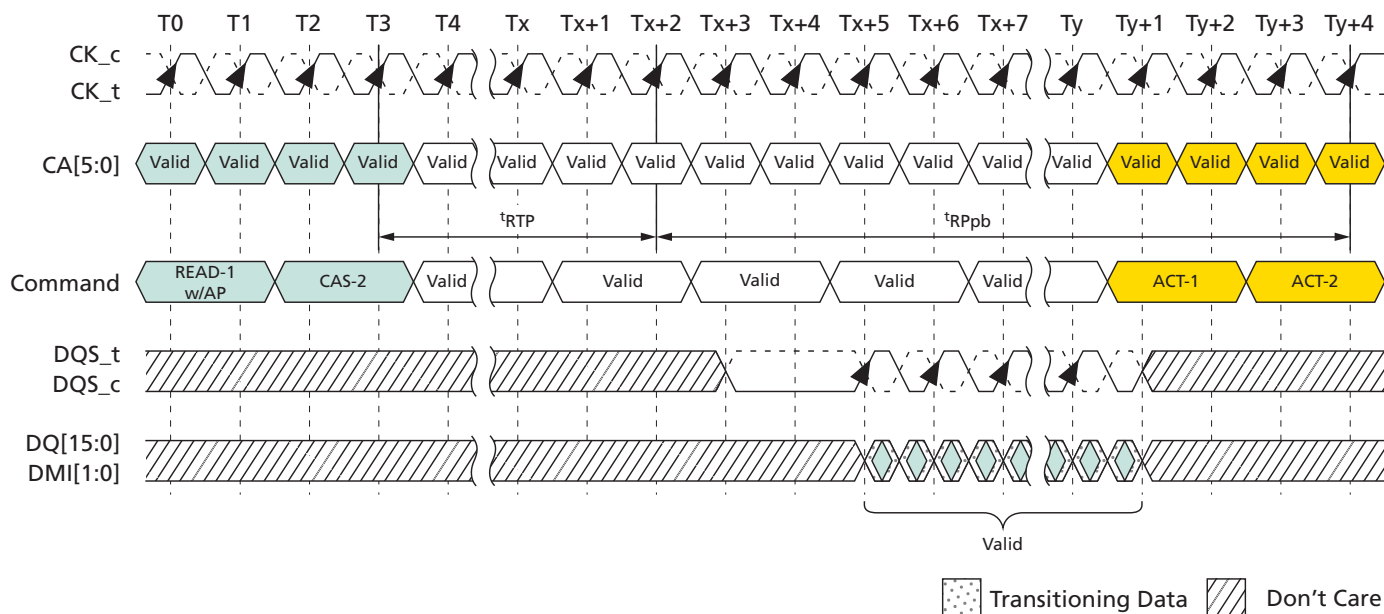
If AP is HIGH when the READ or WRITE command is issued, the auto PRECHARGE function is engaged. This feature enables the PRECHARGE operation to be partially or completely hidden during burst READ cycles (dependent upon READ or WRITE latency), thus improving system performance for random data access.

## Burst READ With Auto Precharge

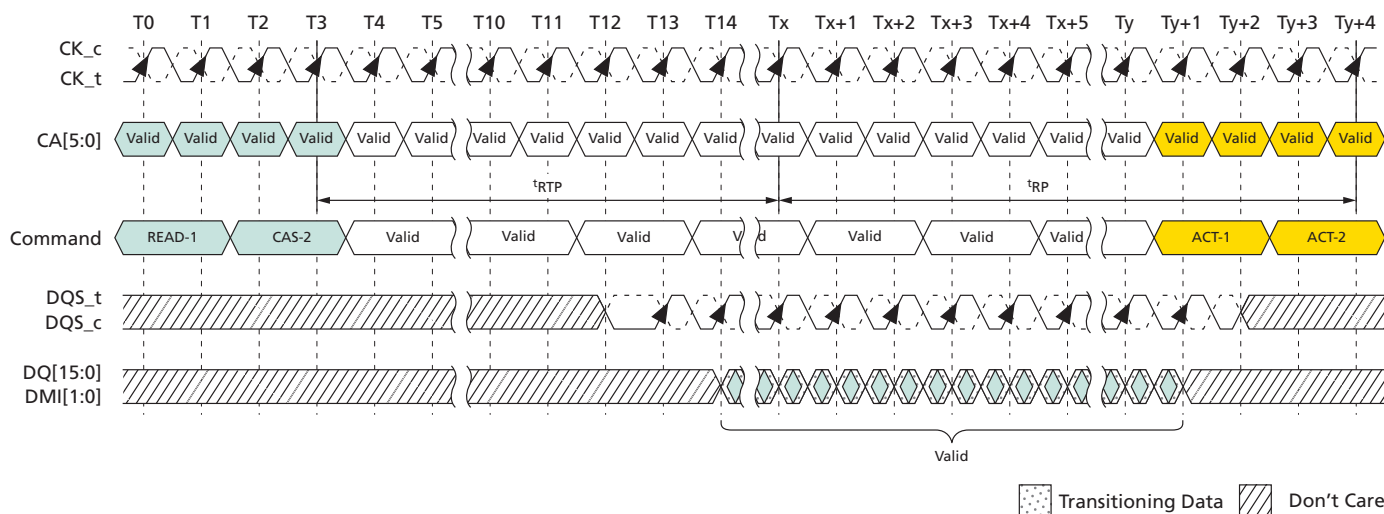
If AP is HIGH when a READ command is issued, the READ with AUTO PRECHARGE function is engaged. The devices start an AUTO PRECHARGE operation on the rising edge of the clock at  $BL/2$  after the second beat of the READ w/AP command, or  $BL/4 - 4 + RU$  ( $tRTP/tCK$ ) clock cycles after the second beat of the READ w/AP command, whichever is greater. Following an AUTO PRECHARGE operation, an ACTIVATE command can be issued to the same bank if the following two conditions are both satisfied:

1. The RAS precharge time ( $tRP$ ) has been satisfied from the clock at which the auto precharge began, and
2. The RAS cycle time ( $tRC$ ) from the previous bank activation has been satisfied.

**Figure 63: Burst READ With Auto Precharge – BL16, Non-Toggling Preamble, 0.5nCK Postamble**



**Figure 64: Burst READ With Auto Precharge – BL32, Toggling Preamble, 1.5nCK Postamble**



### Burst WRITE With Auto Precharge

If AP is HIGH when a WRITE command is issued, the WRITE with AUTO PRECHARGE function is engaged. The device starts an auto precharge on the rising edge  $t_{WR}$  cycles after the completion of the burst WRITE.

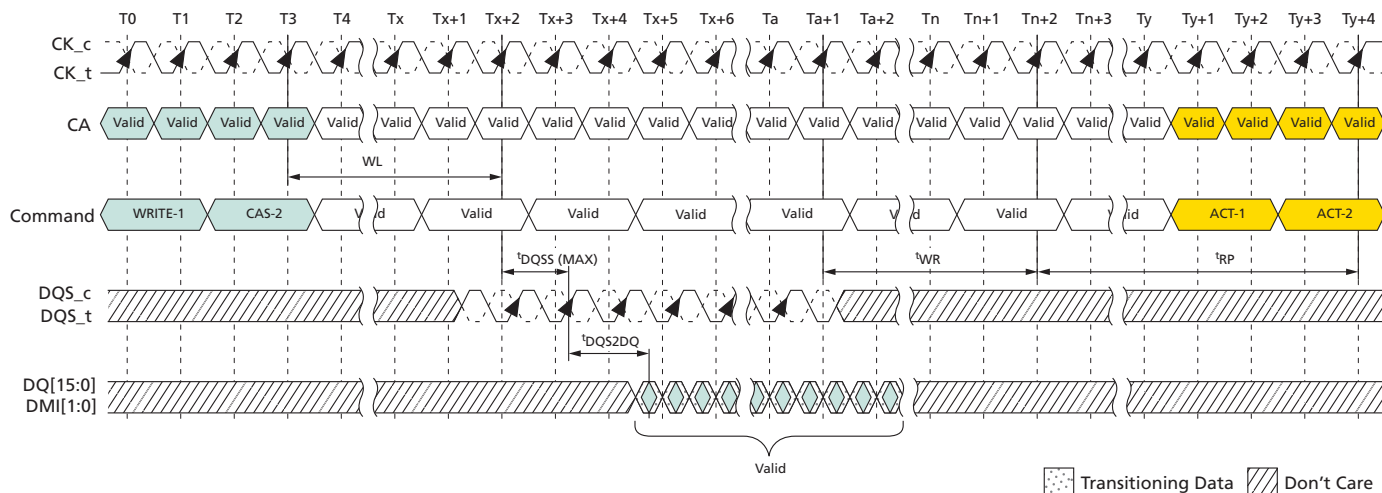
Following a WRITE with AUTO PRECHARGE, an ACTIVATE command can be issued to the same bank if the following conditions are met:

1. The RAS precharge time ( $t_{RP}$ ) has been satisfied from the clock at which the auto precharge began, and



2. The RAS cycle time ( $t_{RC}$ ) from the previous bank activation has been satisfied.

**Figure 65: Burst WRITE With Auto Precharge – BL16, 2nCK Preamble, 0.5nCK Postamble**



**Table 95: Timing Between Commands (PRECHARGE and AUTO PRECHARGE): DQ ODT is Disable**

From Command	To Command	Minimum Delay Between "From Command" and "To Command"	Unit	Notes
READ BL = 16	PRECHARGE (to same bank as READ)	$t_{RTP}$	$t_{CK}$	1, 6
	PRECHARGE ALL	$t_{RTP}$	$t_{CK}$	1, 6
READ BL = 32	PRECHARGE (to same bank as READ)	$8t_{CK} + t_{RTP}$	$t_{CK}$	1, 6
	PRECHARGE ALL	$8t_{CK} + t_{RTP}$	$t_{CK}$	1, 6
READ w/AP BL = 16	PRECHARGE (to same bank as READ w/AP)	$nRTP$	$t_{CK}$	1, 10
	PRECHARGE ALL	$nRTP$	$t_{CK}$	1, 10
	ACTIVATE (to same bank as READ w/AP)	$nRTP + t_{RPpb}$	$t_{CK}$	1, 8, 10
	WRITE or WRITE w/AP (same bank)	Illegal	–	
	MASK-WR or MASK-WR w/AP (same bank)	Illegal	–	
	WRITE or WRITE w/AP (different bank)	$RL + RU (t_{DQSCK MAX}/t_{CK}) + BL/2 + RD (t_{RPST}) - WL + t_{WPRE}$	$t_{CK}$	3, 4, 5
	MASK-WR or MASK-WR w/AP (different bank)	$RL + RU (t_{DQSCK MAX}/t_{CK}) + BL/2 + RD (t_{RPST}) - WL + t_{WPRE}$	$t_{CK}$	3, 4, 5
	READ or READ w/AP (same bank)	Illegal	–	
READ or READ w/AP (different bank)	BL/2	$t_{CK}$	3	

**Table 95: Timing Between Commands (PRECHARGE and AUTO PRECHARGE): DQ ODT is Disable (Continued)**

From Command	To Command	Minimum Delay Between "From Command" and "To Command"	Unit	Notes
READ w/AP BL = 32	PRECHARGE (to same bank as READ w/AP)	$8^t\text{CK} + n\text{RTP}$	$^t\text{CK}$	1, 10
	PRECHARGE ALL	$8^t\text{CK} + n\text{RTP}$	$^t\text{CK}$	1, 10
	ACTIVATE (to same bank as READ w/AP)	$8^t\text{CK} + n\text{RTP} + ^t\text{RPpb}$	$^t\text{CK}$	1, 8, 10
	WRITE or WRITE w/AP (same bank)	Illegal	-	
	MASK-WR or MASK-WR w/AP (same bank)	Illegal	-	
	WRITE or WRITE w/AP (different bank)	$\text{RL} + \text{RU} (^t\text{DQSCK MAX}/^t\text{CK}) + \text{BL}/2 + \text{RD} (^t\text{RPST}) - \text{WL} + ^t\text{WPRE}$	$^t\text{CK}$	3, 4, 5
	MASK-WR or MASK-WR w/AP (different bank)	$\text{RL} + \text{RU} (^t\text{DQSCK MAX}/^t\text{CK}) + \text{BL}/2 + \text{RD} (^t\text{RPST}) - \text{WL} + ^t\text{WPRE}$	$^t\text{CK}$	3, 4, 5
	READ or READ w/AP (same bank)	Illegal	-	
	READ or READ w/AP (different bank)	$\text{BL}/2$	$^t\text{CK}$	3
WRITE BL = 16 and 32	PRECHARGE (to same bank as WRITE)	$\text{WL} + \text{BL}/2 + ^t\text{WR} + 1$	$^t\text{CK}$	1, 7
	PRECHARGE ALL	$\text{WL} + \text{BL}/2 + ^t\text{WR} + 1$	$^t\text{CK}$	1, 7
MASK-WR BL = 16	PRECHARGE (to same bank as MASK-WR)	$\text{WL} + \text{BL}/2 + ^t\text{WR} + 1$	$^t\text{CK}$	1, 7
	PRECHARGE ALL	$\text{WL} + \text{BL}/2 + ^t\text{WR} + 1$	$^t\text{CK}$	1, 7
WRITE w/AP BL = 16 and 32	PRECHARGE (to same bank as WRITE w/AP)	$\text{WL} + \text{BL}/2 + n\text{WR} + 1$	$^t\text{CK}$	1, 11
	PRECHARGE ALL	$\text{WL} + \text{BL}/2 + n\text{WR} + 1$	$^t\text{CK}$	1, 11
	ACTIVATE (to same bank as WRITE w/AP)	$\text{WL} + \text{BL}/2 + n\text{WR} + 1 + ^t\text{RPpb}$	$^t\text{CK}$	1, 8, 11
	WRITE or WRITE w/AP (same bank)	Illegal	-	
	READ or READ w/AP (same bank)	Illegal	-	
	WRITE or WRITE w/AP (different bank)	$\text{BL}/2$	$^t\text{CK}$	3
	MASK-WR or MASK-WR w/AP (different bank)	$\text{BL}/2$	$^t\text{CK}$	3
	READ or READ w/AP (different bank)	$\text{WL} + \text{BL}/2 + ^t\text{WTR} + 1$	$^t\text{CK}$	3, 9

**Table 95: Timing Between Commands (PRECHARGE and AUTO PRECHARGE): DQ ODT is Disable (Continued)**

From Command	To Command	Minimum Delay Between "From Command" and "To Command"	Unit	Notes
MASK-WR w/AP BL = 16	PRECHARGE (to same bank as MASK-WR w/AP)	$WL + BL/2 + nWR + 1$	$t_{CK}$	1, 11
	PRECHARGE ALL	$WL + BL/2 + nWR + 1$	$t_{CK}$	1, 11
	ACTIVATE (to same bank as MASK-WR w/AP)	$WL + BL/2 + nWR + 1 + t_{RPpb}$	$t_{CK}$	1, 8, 11
	WRITE or WRITE w/AP (same bank)	Illegal	–	3
	MASK-WR or MASK-WR w/AP (same bank)	Illegal	–	3
	WRITE or WRITE w/AP (different bank)	BL/2	$t_{CK}$	3
	MASK-WR or MASK-WR w/AP (different bank)	BL/2	$t_{CK}$	3
	READ or READ w/AP (same bank)	Illegal	–	3
	READ or READ w/AP (different bank)	$WL + BL/2 + t_{WTR} + 1$	$t_{CK}$	3, 9
PRECHARGE	PRECHARGE (to same bank as PRECHARGE)	4	$t_{CK}$	1
	PRECHARGE ALL	4	$t_{CK}$	1
PRECHARGE ALL	PRECHARGE	4	$t_{CK}$	1
	PRECHARGE ALL	4	$t_{CK}$	1

- Notes:
1. For a given bank, the precharge period should be counted from the latest PRECHARGE command, whether per-bank or all-bank, issued to that bank. The precharge period is satisfied  $t_{RP}$  after that latest PRECHARGE command.
  2. Any command issued during the minimum delay time as specified in the table above is illegal.
  3. After READ w/AP, seamless READ operations to different banks are supported. After WRITE w/AP or MASK-WR w/AP, seamless WRITE operations to different banks are supported. READ, WRITE, and MASK-WR operations may not be truncated or interrupted.
  4.  $t_{RPST}$  values depend on MR1 OP[7] respectively.
  5.  $t_{WPRE}$  values depend on MR1 OP[2] respectively.
  6. Minimum delay between "from command" and "to command" in clock cycle is calculated by dividing  $t_{RTP}$  (in ns) by  $t_{CK}$  (in ns) and rounding up to the next integer: Minimum delay [cycles] = roundup ( $t_{RTP}$  [ns]/ $t_{CK}$  [ns]).
  7. Minimum delay between "from command" and "to command" in clock cycle is calculated by dividing  $t_{WR}$  (in ns) by  $t_{CK}$  (in ns) and rounding up to the next integer: Minimum delay [cycles] = roundup ( $t_{WR}$  [ns]/ $t_{CK}$  [ns]).

8. Minimum delay between "from command" and "to command" in clock cycle is calculated by dividing  $t_{RPpb}$  (in ns) by  $t_{CK}$  (in ns) and rounding up to the next integer: Minimum delay [cycles] = roundup ( $t_{RPpb}$  [ns]/ $t_{CK}$  [ns]).
9. Minimum delay between "from command" and "to command" in clock cycle is calculated by dividing  $t_{WTR}$  (in ns) by  $t_{CK}$  (in ns) and rounding up to the next integer: Minimum delay [cycles] = roundup ( $t_{WTR}$  [ns]/ $t_{CK}$  [ns]).
10. For READ w/AP the value is  $nRTP$ , which is defined in mode register 2.
11. For WRITE w/AP the value is  $nWR$ , which is defined in mode register 1.

**Table 96: Timing Between Commands (PRECHARGE and AUTO PRECHARGE): DQ ODT is Enable**

From Command	To Command	Minimum Delay Between "From Command" and "To Command"	Unit	Notes
READ w/AP BL = 16	WRITE or WRITE w/AP (different bank)	$RL + RU (t_{DQSCK} MAX/t_{CK}) + BL/2 + RD (t_{RPST}) - ODT_{Lon} - RD (t_{ODTon} MIN/t_{CK}) + 1$	$t_{CK}$	2, 3
	MASK-WR or MASK-WR w/AP (different bank)	$RL + RU (t_{DQSCK} MAX/t_{CK}) + BL/2 + RD (t_{RPST}) - ODT_{Lon} - RD (t_{ODTon} MIN/t_{CK}) + 1$	$t_{CK}$	2, 3
READ w/AP BL = 32	WRITE or WRITE w/AP (different bank)	$RL + RU (t_{DQSCK} MAX/t_{CK}) + BL/2 + RD (t_{RPST}) - ODT_{Lon} - RD (t_{ODTon} MIN/t_{CK}) + 1$	$t_{CK}$	2, 3
	MASK-WR or MASK-WR w/AP (different bank)	$RL + RU (t_{DQSCK} MAX/t_{CK}) + BL/2 + RD (t_{RPST}) - ODT_{Lon} - RD (t_{ODTon} MIN/t_{CK}) + 1$	$t_{CK}$	2, 3

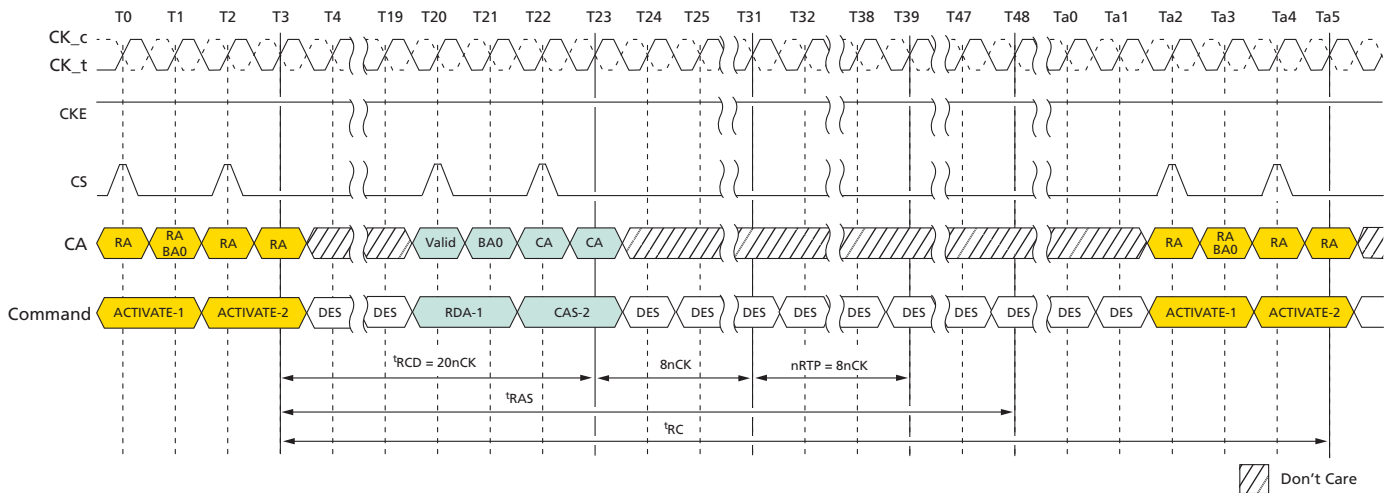
- Notes:
1. The rest of the timing about PRECHARGE and AUTO PRECHARGE is same as DQ ODT is disable case.
  2. After READ w/AP, seamless read operations to different banks are supported. READ, WRITE, and MASK-WR operations may not be truncated or interrupted.
  3.  $t_{RPST}$  values depend on MR1 OP[7] respectively.

## RAS Lock Function

READ with AUTO PRECHARGE or WRITE/MASK WRITE with AUTO PRECHARGE commands may be issued after  $t_{RCD}$  has been satisfied. The LPDDR4 SDRAM RAS lockout feature will schedule the internal precharge to assure that  $t_{RAS}$  is satisfied.  $t_{RC}$  needs to be satisfied prior to issuing subsequent ACTIVATE commands to the same bank.

The figure below shows example of RAS lock function.

Figure 66: Command Input Timing with RAS Lock

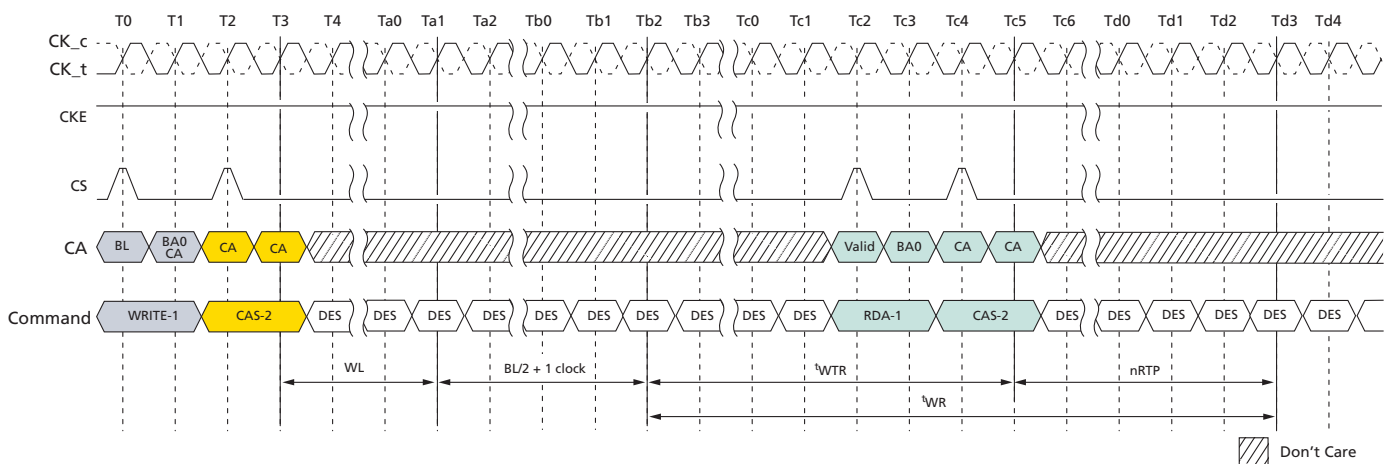


- Notes:
- $t_{CK} (AVG) = 0.938ns$ , Data rate = 2133 Mbps,  $t_{RCD} (MIN) = MAX(18ns, 4nCK)$ ,  $t_{RAS} (MIN) = MAX(42ns, 3nCK)$ ,  $nRTP = 8nCK$ , BL = 32.
  - $t_{RCD} = 20nCK$  comes from roundup ( $18ns/0.938ns$ ).
  - DES commands are shown for ease of illustration; other commands may be valid at these times.

### Delay Time From WRITE-to-READ with Auto Precharge

In the case of WRITE command followed by READ with AUTO PRECHARGE, controller must satisfy  $t_{WR}$  for the WRITE command before initiating the device internal auto-precharge. It means that  $(t_{WTR} + nRTP)$  should be equal or longer than  $(t_{WR})$  when BL setting is 16, as well as  $(t_{WTR} + nRTP + 8nCK)$  should be equal or longer than  $(t_{WR})$  when BL setting is 32. Refer to the following figure for details.

Figure 67: Delay Time From WRITE-to-READ with Auto Precharge



- Notes:
- Burst length at read = 16.

- DES commands are shown for ease of illustration; other commands may be valid at these times.

## REFRESH Command

The REFRESH command is initiated with CS HIGH, CA0 LOW, CA1 LOW, CA2 LOW, CA3 HIGH and CA4 LOW at the first rising edge of clock. Per bank REFRESH is initiated with CA5 LOW at the first rising edge of the clock. The all-bank REFRESH is initiated with CA5 HIGH at the first rising edge of clock.

A per bank REFRESH command (REFpb) is performed to the bank address as transferred on CA0, CA1, and CA2 on the second rising edge of the clock. Bank address BA0 is transferred on CA0, bank address BA1 is transferred on CA1, and bank address BA2 is transferred on CA2. A per bank REFRESH command (REFpb) to the eight banks can be issued in any order. For example, REFpb commands may be issued in the following order: 1-3-0-2-4-7-5-6. After the eight banks have been refreshed using the per bank REFRESH command, the controller can send another set of per bank REFRESH commands in the same order or a different order. One possible order can be a sequential round robin: 0-1-2-3-4-5-6-7. It is illegal to send a per bank REFRESH command to the same bank unless all eight banks have been refreshed using the per bank REFRESH command. The count of eight REFpb commands starts with the first REFpb command after a synchronization event.

The bank count is synchronized between the controller and the device by resetting the bank count to zero. Synchronization can occur upon reset procedure or at every exit from self refresh. The REFab command also synchronizes the counter between the controller and the device to zero. The device can be placed in self refresh, or a REFab command can be issued at any time without cycling through all eight banks using per bank REFRESH command. After the bank count is synchronized to zero, the controller can issue per bank REFRESH commands in any order, as described above.

A REFab command issued when the bank counter is not zero will reset the bank counter to zero and the device will perform refreshes to all banks as indicated by the row counter. If another REFRESH command (REFab or REFpb) is issued after the REFab command then it uses an incremented value of the row counter.

The table below shows examples of both bank and refresh counter increment behavior.

**Table 97: Bank and Refresh Counter Increment Behavior**

#	Command	BA0	BA1	BA2	Refresh Bank #	Bank Counter #	Ref. Conter # (Row Address #)
0	Reset, SRX, or REFab					To 0	–
1	REFpb	0	0	0	0	0 to 1	n
2	REFpb	0	0	1	1	1 to 2	
3	REFpb	0	1	0	2	2 to 3	
4	REFpb	0	1	1	3	3 to 4	
5	REFpb	1	0	0	4	4 to 5	
6	REFpb	1	0	1	5	5 to 6	
7	REFpb	1	1	0	6	6 to 7	
8	REFpb	1	1	1	7	7 to 0	

**Table 97: Bank and Refresh Counter Increment Behavior (Continued)**

#	Command	BA0	BA1	BA2	Refresh Bank #	Bank Counter #	Ref. Conter # (Row Address #)	
9	REFpb	1	1	0	6	0 to 1	n + 1	
10	REFpb	1	1	1	7	1 to 2		
11	REFpb	0	0	1	1	2 to 3		
12	REFpb	0	1	1	3	3 to 4		
13	REFpb	1	0	1	5	4 to 5		
14	REFpb	0	1	0	2	5 to 6		
15	REFpb	0	0	0	0	6 to 7		
16	REFpb	1	0	0	4	7 to 0		
17	REFpb	0	0	0	0	0 to 1		n + 2
18	REFpb	0	0	1	1	1 to 2		
19	REFpb	0	1	0	2	2 to 3		
<b>20</b>	<b>REFab</b>	<b>V</b>	<b>V</b>	<b>V</b>	<b>0 to 7</b>	<b>To 0</b>	<b>n + 2</b>	
21	REFpb	1	1	0	6	0 to 1	n + 3	
22	REFpb	1	1	1	7	1 to 2		
Snip								

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

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

- $t_{RfCab}$  has been satisfied after the prior REFab command
- $t_{RfCpb}$  has been satisfied after the prior REFpb command
- $t_{RP}$  has been satisfied after the prior PRECHARGE command to that bank
- $t_{RRD}$  has been satisfied after the prior ACTIVATE command (for example, after activating a row in a different bank than the one affected by the REFpb command)

The target bank is inaccessible during per bank REFRESH cycle time ( $t_{RfCpb}$ ). However, other banks within the device are accessible and can be addressed during the cycle. During the REFpb operation, any of the banks other than the one being refreshed can be maintained in an active state or accessed by a READ or a WRITE command. When the per bank REFRESH cycle has completed, the affected bank will be in the idle state.

After issuing REFpb, the following conditions must be met:

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

An all-bank REFRESH command (REFab) issues a REFRESH command to every bank in a channel. All banks must be idle when REFab is issued (for example, by issuing a PRECHARGE ALL command prior to issuing an all-bank REFRESH command). The REFab

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

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

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

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

**Table 98: REFRESH Command Timing Constraints**

Symbol	Minimum Delay From...	To	Notes
$t_{RFCab}$	REFab	REFab	
		ACTIVATE command to any bank	
		REFpb	
$t_{RFCpb}$	REFpb	REFab	
		ACTIVATE command to same bank as REFpb	
		REFpb	
$t_{RRD}$	REFpb	ACTIVATE command to a different bank than REFpb	
	ACTIVATE	REFpb	1
		ACTIVATE command to a different bank than the prior ACTIVATE command	

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

**Figure 68: All-Bank REFRESH Operation**

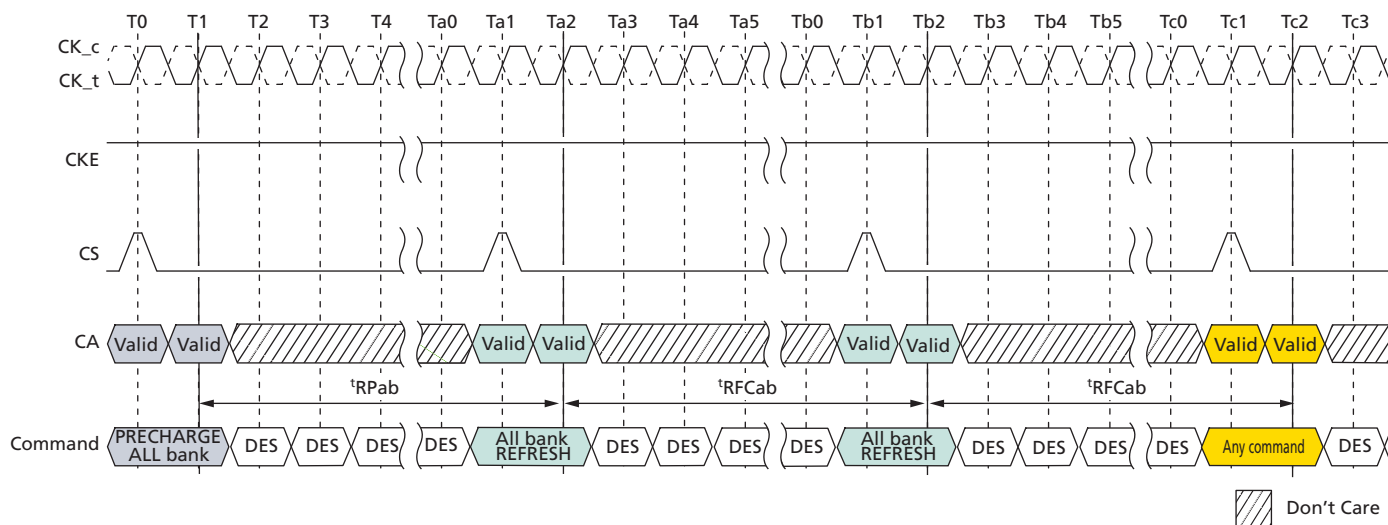
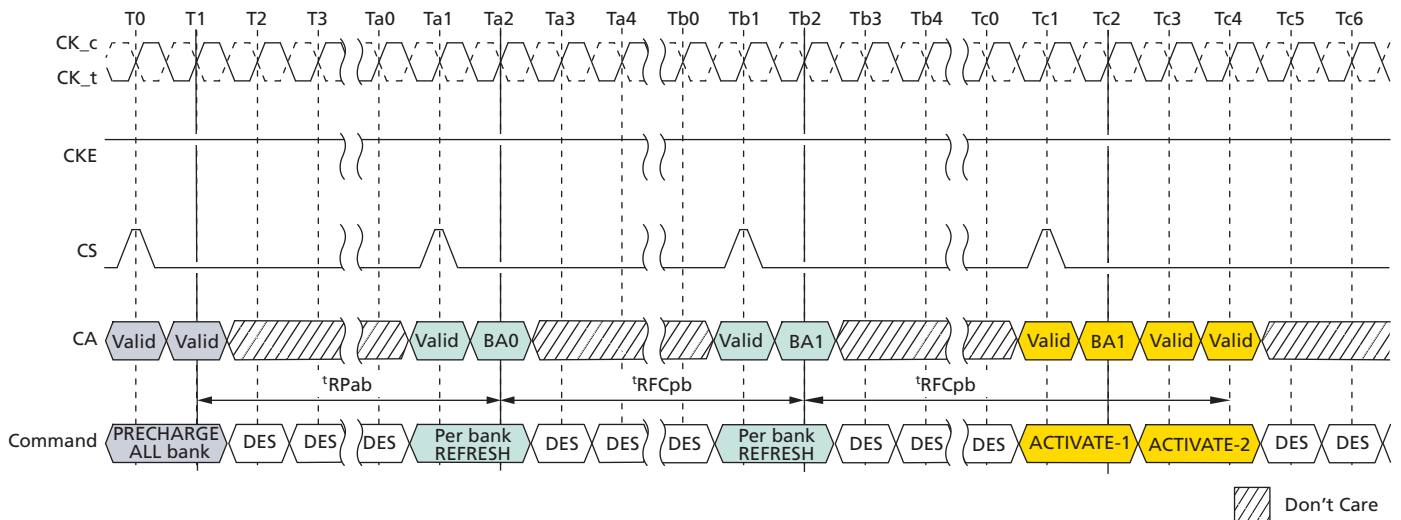




Figure 69: Per Bank REFRESH Operation



- Notes:
1. In the beginning of this example, the REFpb bank is pointing to bank 0.
  2. Operations to banks other than the bank being refreshed are supported during the  ${}^t\text{RFCpb}$  period.

In general, a REFRESH command needs to be issued to the device regularly every  ${}^t\text{REFI}$  interval. To allow for improved efficiency in scheduling and switching between tasks, some flexibility in the absolute refresh interval is provided. A maximum of eight REFRESH commands can be postponed during operation of the device, but at no point in time are more than a total of eight REFRESH commands allowed to be postponed. And a maximum number of pulled-in or postponed REF command is dependent on refresh rate. It is described in the table below. In the case where eight REFRESH commands are postponed in a row, the resulting maximum interval between the surrounding REFRESH commands is limited to  $9 \times {}^t\text{REFI}$ . A maximum of eight additional REFRESH commands can be issued in advance (pulled in), with each one reducing the number of regular REFRESH commands required later by one. Note that pulling in more than eight REFRESH commands in advance does not reduce the number of regular REFRESH commands required later; therefore, the resulting maximum interval between two surrounding REFRESH commands is limited to  $9 \times {}^t\text{REFI}$ . At any given time, a maximum of 16 REFRESH commands can be issued within  $2 \times {}^t\text{REFI}$ .

Self refresh mode may be entered with a maximum of eight REFRESH commands being postponed. After exiting self refresh mode with one or more REFRESH commands postponed, additional REFRESH commands may be postponed to the extent that the total number of postponed REFRESH commands (before and after self refresh) will never exceed eight. During self refresh mode, the number of postponed or pulled-in REFRESH commands does not change.

And for per bank refresh, a maximum of  $8 \times 8$  per bank REFRESH commands can be postponed or pulled in for scheduling efficiency. At any given time, a maximum of  $2 \times 8 \times 8$  per bank REFRESH commands can be issued within  $2 \times {}^t\text{REFI}$ .

**Table 99: Legacy REFRESH Command Timing Constraints**

MR4 OP[2:0]	Refresh Rate	Max. No. of pulled-in or postponed REFab	Max. Interval between Two REFab	Max. No. of REFab <sup>1</sup>	Per Bank Refresh
000b	Low Temp. Limit	N/A	N/A	N/A	N/A
001b	$4 \times t_{REFI}$	8	$9 \times 4 \times t_{REFI}$	16	1/8 of REFab
010b	$2 \times t_{REFI}$	8	$9 \times 2 \times t_{REFI}$	16	1/8 of REFab
011b	$1 \times t_{REFI}$	8	$9 \times t_{REFI}$	16	1/8 of REFab
100b	$0.5 \times t_{REFI}$	8	$9 \times 0.5 \times t_{REFI}$	16	1/8 of REFab
101b	$0.25 \times t_{REFI}$	8	$9 \times 0.25 \times t_{REFI}$	16	1/8 of REFab
110b	$0.25 \times t_{REFI}$	8	$9 \times 0.25 \times t_{REFI}$	16	1/8 of REFab
111b	High Temp. Limit	N/A	N/A	N/A	N/A

Note: 1. Maximum number of REFab within  $\text{MAX}(2 \times t_{REFI} \times \text{refresh rate multiplier}, 16 \times t_{RFC})$ .

**Table 100: Modified REFRESH Command Timing Constraints**

MR4 OP[2:0]	Refresh Rate	Max. No. of pulled-in or postponed REFab	Max. Interval between Two REFab	Max. No. of REFab <sup>1</sup>	Per Bank Refresh
000B	LOW Temp. Limit	N/A	N/A	N/A	N/A
001B	$4 \times t_{REFI}$	2	$3 \times 4 \times t_{REFI}$	4	1/8 of REFab
010B	$2 \times t_{REFI}$	4	$5 \times 2 \times t_{REFI}$	8	1/8 of REFab
011B	$1 \times t_{REFI}$	8	$9 \times t_{REFI}$	16	1/8 of REFab
100B	$0.5 \times t_{REFI}$	8	$9 \times 0.5 \times t_{REFI}$	16	1/8 of REFab
101B	$0.25 \times t_{REFI}$	8	$9 \times 0.25 \times t_{REFI}$	16	1/8 of REFab
110B	$0.25 \times t_{REFI}$	8	$9 \times 0.25 \times t_{REFI}$	16	1/8 of REFab
111B	HIGH Temp. Limit	N/A	N/A	N/A	N/A

- Notes:
- For any thermal transition phase where refresh mode is transitioned to either  $2 \times t_{REFI}$  or  $4 \times t_{REFI}$ , LPDDR4 devices will support the previous postponed refresh requirement provided the number of postponed refreshes is monotonically reduced to meet the new requirement. However, the pulled-in REFRESH commands in previous thermal phase are not applied in new thermal phase. Entering new thermal phase the controller must count the number of pulled-in REFRESH commands as zero, regardless of remaining pulled-in REFRESH commands in previous thermal phase.
  - LPDDR4 devices are refreshed properly if memory controller issues REFRESH commands with same or shorter refresh period than reported by MR4 OP[2:0]. If shorter refresh period is applied, the corresponding requirements from Table apply. For example, when MR4 OP[2:0] = 001b, controller can be in any refresh rate from  $4 \times t_{REFI}$  to  $0.25 \times t_{REFI}$ . When MR4 OP[2:0] = 010b, the only prohibited refresh rate is  $4 \times t_{REFI}$ .

Figure 70: Postponing REFRESH Commands (Example)

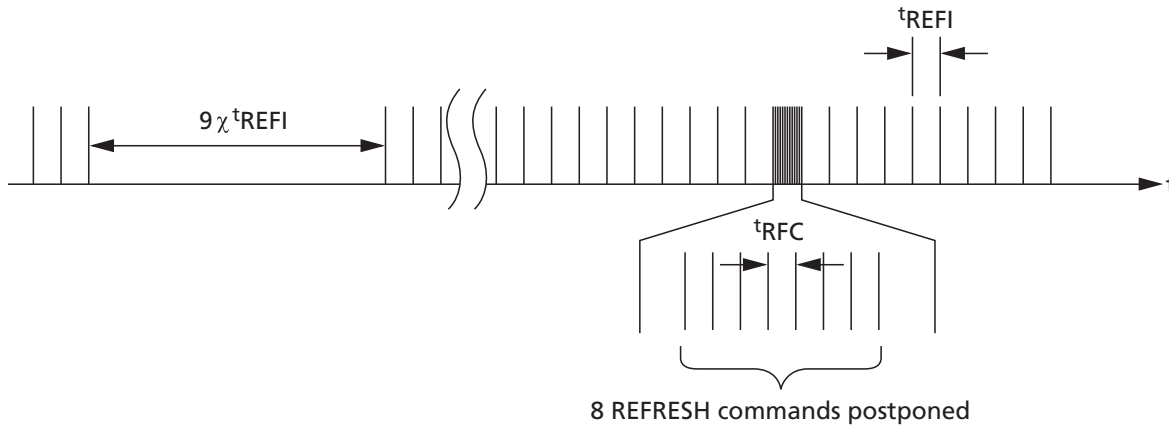
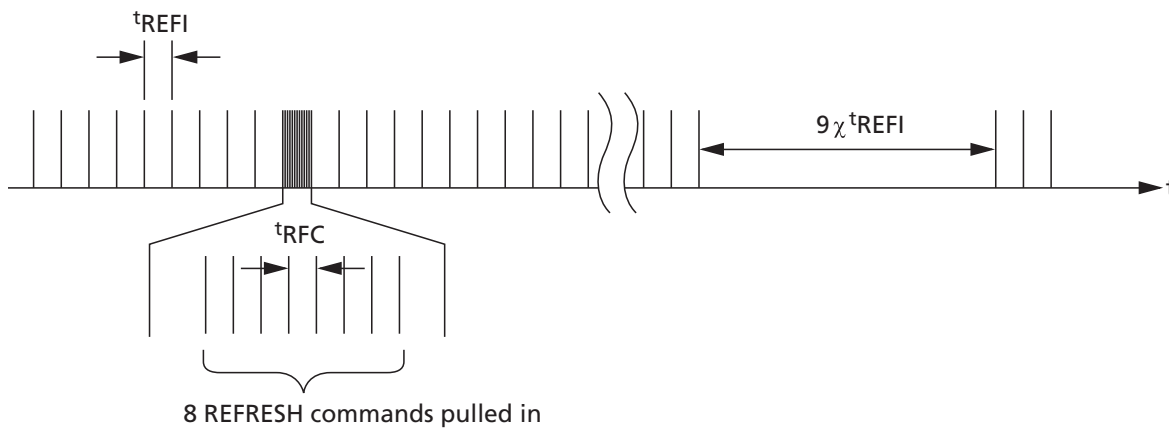


Figure 71: Pulling In REFRESH Commands (Example)



## Refresh Requirement

Between the SRX command and SRE command, at least one extra REFRESH command is required. After the SELF REFRESH EXIT command, in addition to the normal REFRESH command at  $t_{REFI}$  interval, the device requires a minimum of one extra REFRESH command prior to the SELF REFRESH ENTRY command.

Table 101: Refresh Requirement Parameters

Parameter	Symbol	Density (per channel)						Unit	
		2Gb	3Gb	4Gb	6Gb	8Gb	12Gb		16Gb
Number of banks per channel	–			8			TBD	TBD	–
Refresh window ( $t_{REFW}$ ): $T_{CASE} \leq 85^{\circ}C$	$t_{REFW}$			32			TBD	TBD	ms
Refresh window ( $t_{REFW}$ ): 1/2 rate refresh	$t_{REFW}$			16			TBD	TBD	ms

**Table 101: Refresh Requirement Parameters (Continued)**

Parameter	Symbol	Density (per channel)						Unit		
		2Gb	3Gb	4Gb	6Gb	8Gb	12Gb		16Gb	
Refresh window ( $t_{REFW}$ ): 1/4 rate refresh	$t_{REFW}$	8						TBD	TBD	ms
Required number of REFRESH commands in $t_{REFW}$ window	R	8192						TBD	TBD	–
Average refresh interval	REFab	$t_{REFI}$						TBD	TBD	$\mu$ s
	REFpb	$t_{REFIpb}$						TBD	TBD	ns
REFRESH cycle time (all banks)	$t_{RFCab}$	130	180	280		TBD	TBD	ns		
REFRESH cycle time (per bank)	$t_{RFCpb}$	60	90	140		TBD	TBD	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. Self refresh abort feature is available for higher density devices starting with 6Gb density per channel device and  $t_{XSR\_abort}(min)$  is defined as  $t_{RFCpb} + 17.5ns$ .

## SELF REFRESH Operation

### Self Refresh Entry and Exit

The SELF REFRESH command can be used to retain data in the device without external REFRESH commands. The device has a built-in timer to accommodate SELF REFRESH operation. Self refresh is entered by the SELF REFRESH ENTRY command defined by having CS HIGH, CA0 LOW, CA1 LOW, CA2 LOW, CA3 HIGH, CA4 HIGH, and CA5 valid (valid meaning that it is at a logic level HIGH or LOW) for the first rising edge, and CS LOW, CA0 valid, CA1 valid, CA2 valid, CA3 valid, CA4 valid, and CA5 valid at the second rising edge of clock. The SELF REFRESH command is only allowed when READ DATA burst is completed and the device is in the idle state.

During self refresh mode, external clock input is needed and all input pins of the device are activated. The device can accept the following commands: MRR-1, CAS-2, DES, SRX, MPC, MRW-1, and MRW-2, except PASR bank/segment setting.

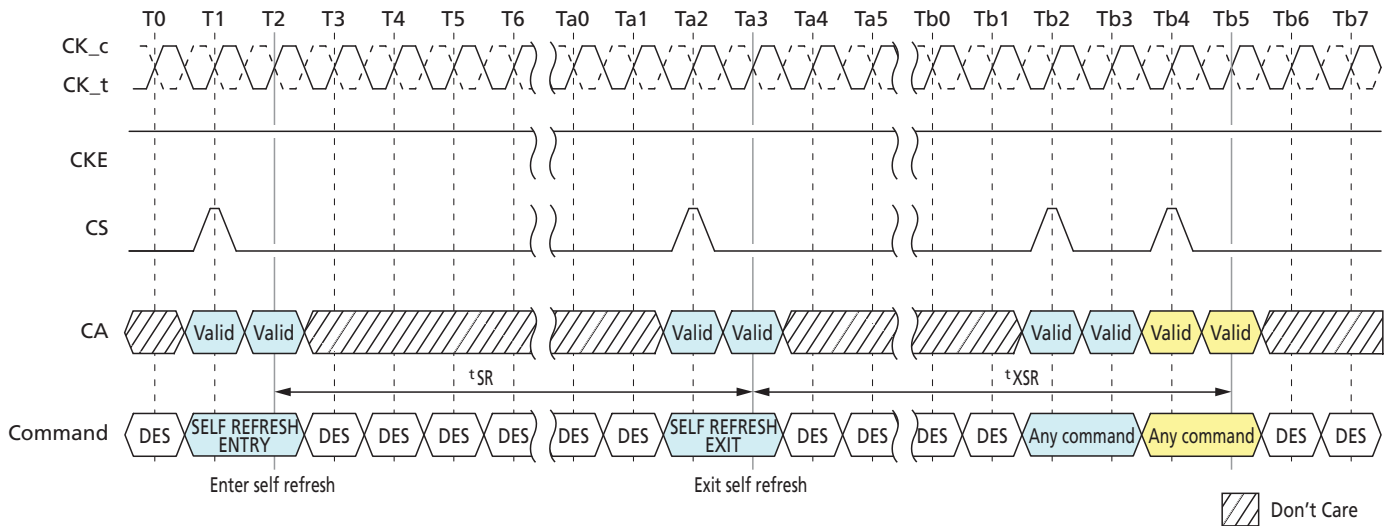
The device can operate in self refresh mode within the standard and elevated temperature ranges. It also manages self refresh power consumption when the operating temperature changes: lower at low temperatures and higher at high temperatures.

For proper SELF REFRESH operation, power supply pins ( $V_{DD1}$ ,  $V_{DD2}$ , and  $V_{DDQ}$ ) must be at valid levels.  $V_{DDQ}$  can be turned off during self refresh with power-down after  $t_{CKELCK}$  is satisfied. (Refer to the Self Refresh Entry/Exit Timing with Power-Down Entry/Exit figure.) Prior to exiting self refresh with power-down,  $V_{DDQ}$  must be within specified limits. The minimum time that the device must remain in self refresh mode is  $t_{SR}(MIN)$ . After self refresh exit is registered, only MRR-1, CAS-2, DES, MPC, MRW-1, and MRW-2 except PASR bank/segment setting are allowed until  $t_{XSR}$  is satisfied.

The use of self refresh mode introduces the possibility that an internally timed refresh event can be missed when self refresh exit is registered. Upon exit from self refresh, it is

required that at least one REFRESH command (8 per-bank or 1 all-bank) is issued before entry into a subsequent self refresh. This REFRESH command is not included in the count of regular REFRESH commands required by the  $t_{REFI}$  interval, and does not modify the postponed or pulled-in refresh counts; the REFRESH command does count toward the maximum refreshes permitted within  $2 \times t_{REFI}$ .

**Figure 72: Self Refresh Entry/Exit Timing**

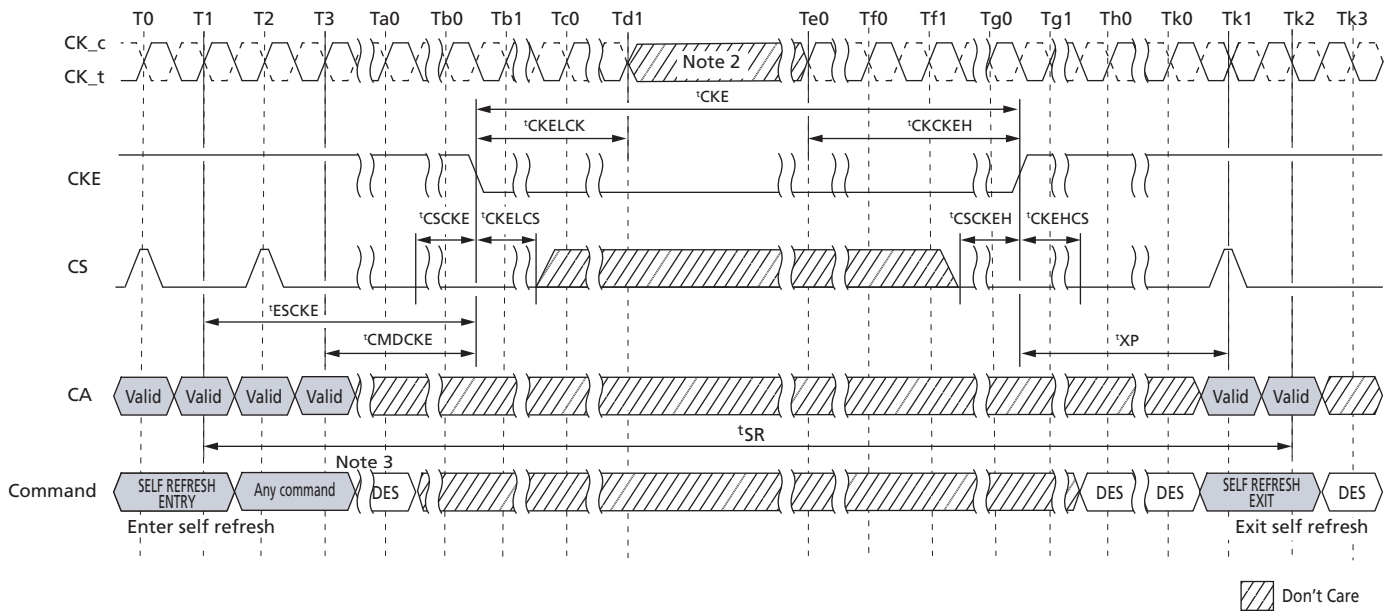


- Notes:
1. MRR-1, CAS-2, DES, SRX, MPC, MRW-1, and MRW-2 commands (except PASR bank/segment setting) are allowed during self refresh.
  2. DES commands are shown for ease of illustration; other commands may be valid at these times.

### Power-Down Entry and Exit During Self Refresh

Entering/exiting power-down mode is allowed during self refresh mode. The related timing parameters between self refresh entry/exit and power-down entry/exit are shown below.

Figure 73: Self Refresh Entry/Exit Timing with Power-Down Entry/Exit

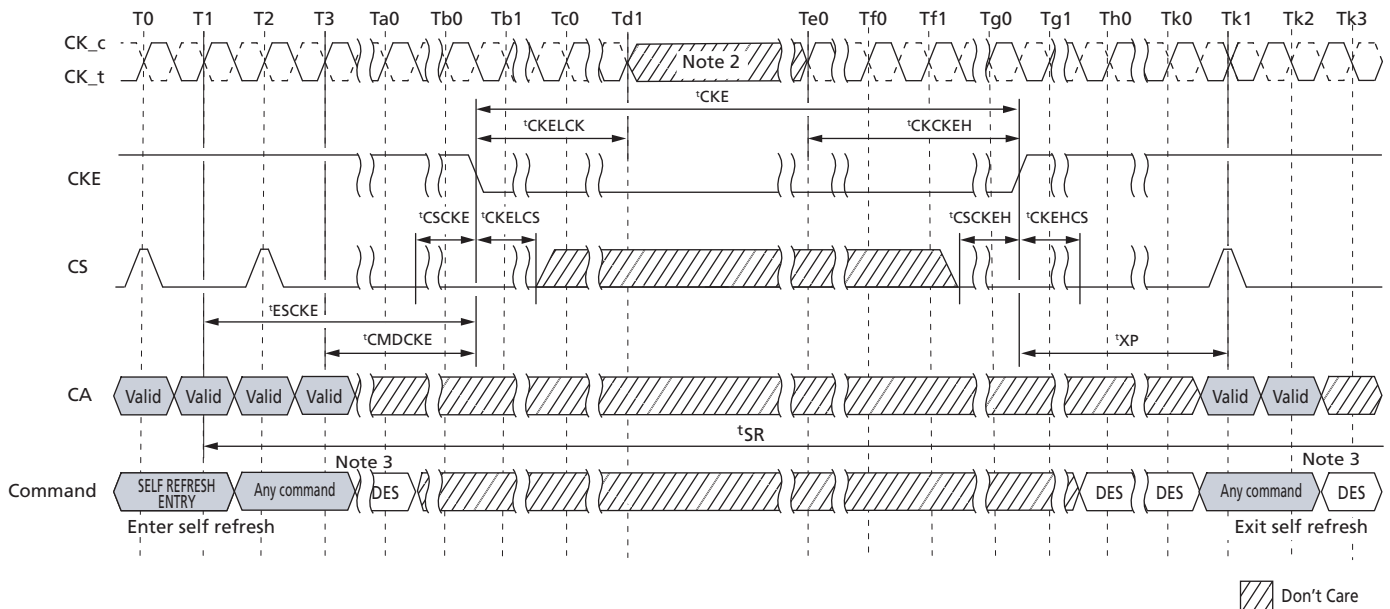


- Notes:
1. MRR-1, CAS-2, DES, SRX, MPC, MRW-1, and MRW-2 commands (except PASR bank/segment setting) are allowed during self refresh.
  2. Input clock frequency can be changed, or the input clock can be stopped, or floated after  $t_{CKELCK}$  satisfied and during power-down, provided that upon exiting power-down, the clock is stable and within specified limits for a minimum of  $t_{CKCKEH}$  of stable clock prior to power-down exit and the clock frequency is between the minimum and maximum specified frequency for the speed grade in use.
  3. Two clock command for example.

### Command Input Timing After Power-Down Exit

Command input timings after power-down exit during self refresh mode are shown below.

Figure 74: Command Input Timings after Power-Down Exit During Self Refresh



- Notes:
1. MRR-1, CAS-2, DES, SRX, MPC, MRW-1, and MRW-2 commands (except PASR bank/segment setting) are allowed during self refresh.
  2. Input clock frequency can be changed or the input clock can be stopped or floated after  $t_{CKELCK}$  satisfied and during power-down, provided that upon exiting power-down, the clock is stable and within specified limits for a minimum of  $t_{CKCKEH}$  of stable clock prior to power-down exit and the clock frequency is between the minimum and maximum specified frequency for the speed grade in use.
  3. Two clock command for example.

### Self Refresh Abort

If MR4 OP[3] is enabled, the device aborts any ongoing refresh during self refresh exit and does not increment the internal refresh counter. The controller can issue a valid command after a delay of  $t_{XSR\_abort}$  instead of  $t_{XSR}$ .

The value of  $t_{XSR\_abort}$  (MIN) is defined as  $t_{RFCpb} + 17.5ns$ .

Upon exit from self refresh mode, the device requires a minimum of one extra refresh (eight per bank or one for the entire bank) before entering a subsequent self refresh mode. This requirement remains the same irrespective of the setting of the MR bit for self refresh abort.

Self refresh abort feature is valid for 6Gb density per channel and larger densities only.

### MRR, MRW, MPC Commands During $t_{XSR}$ , $t_{RFC}$

MODE REGISTER READ (MRR) command, MODE REGISTER WRITE (MRW) command and MULTI PURPOSE command (MPC) can be issued during  $t_{XSR}$  period.

Figure 75: MRR, MRW, and MPC Commands Issuing Timing During  $t^{\text{XSR}}$

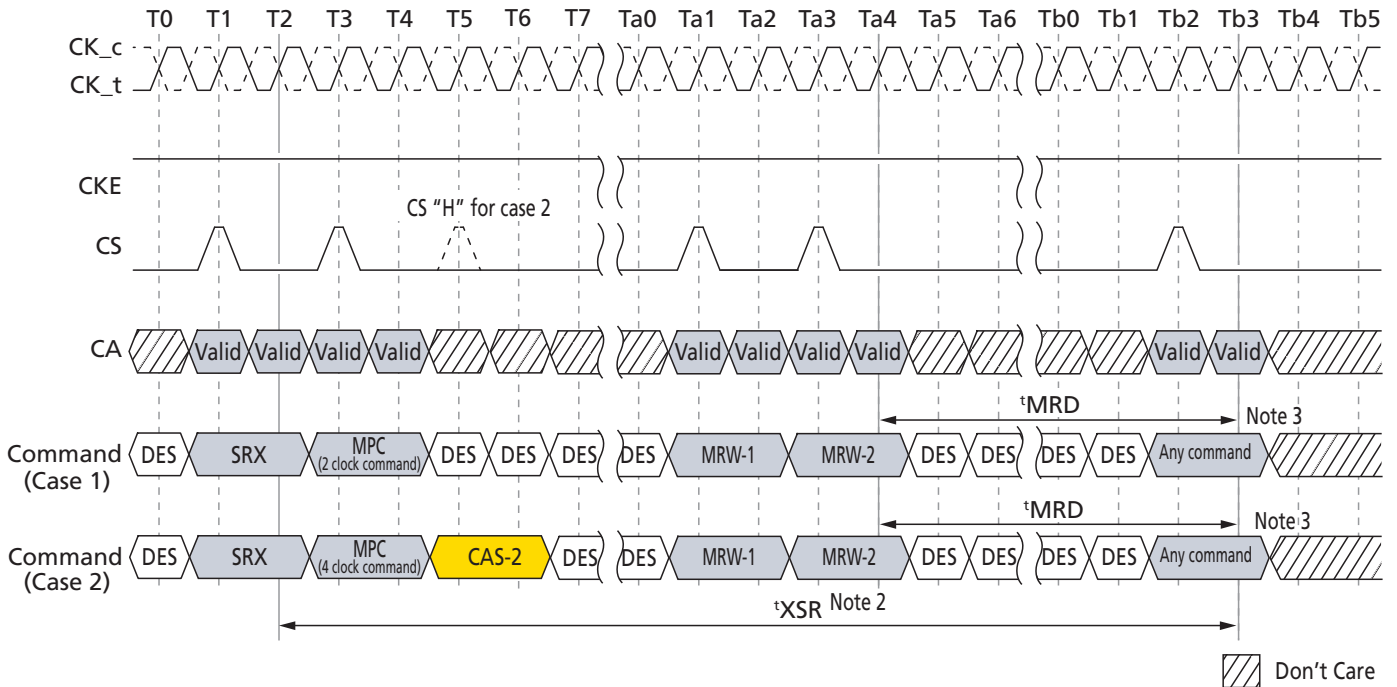
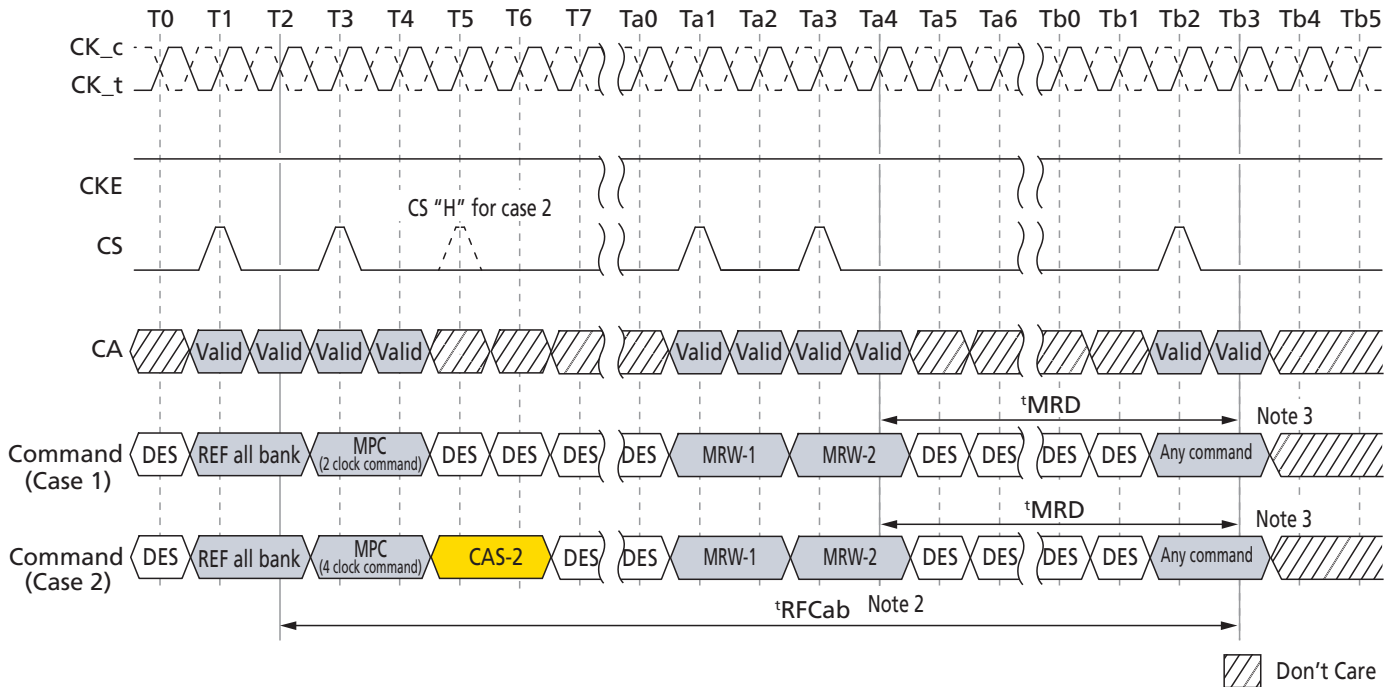




Figure 76: MRR, MRW, and MPC Commands Issuing Timing During  $t_{RFC}$



- Notes:
1. MPC and MRW commands are shown. Any combination of MRR, MRW, and MPC is allowed during  $t_{RFCab}$  or  $t_{RFCpb}$  period.
  2. REFRESH cycle time depends on REFRESH command. In the case of per bank REFRESH command issued, REFRESH cycle time will be  $t_{RFCpb}$ .
  3. "Any command" includes MRR, MRW, and all MPC commands.

## Power-Down Mode

### Power-Down Entry and Exit

Power-down is asynchronously entered when CKE is driven LOW. CKE must not go LOW while the following operations are in progress:

- Mode register read
- Mode register write
- Read
- Write
- $V_{REF(CA)}$  range and value setting via MRW
- $V_{REF(DQ)}$  range and value setting via MRW
- Command bus training mode entering/exiting via MRW
- VRCG HIGH current mode entering/exiting via MRW

CKE can go LOW while any other operations such as row activation, precharge, auto precharge, or refresh are in progress. The power-down  $I_{DD}$  specification will not be applied until such operations are complete. Power-down entry and exit are shown below.

Entering power-down deactivates the input and output buffers, excluding CKE and RESET\_n. To ensure that there is enough time to account for internal delay on the CKE signal path, CS input is required stable LOW level and CA input level is "Don't Care" after CKE is driven LOW, this timing period is defined as  $t_{CKELCS}$ . Clock input is required after CKE is driven LOW, this timing period is defined as  $t_{CKELCK}$ . CKE LOW will result in deactivation of all input receivers except RESET\_n after  $t_{CKELCK}$  has expired. In power-down mode, CKE must be held LOW; all other input signals except RESET\_n are "Don't Care." CKE LOW must be maintained until  $t_{CKE(MIN)}$  is satisfied.

$V_{DDQ}$  can be turned off during power-down after  $t_{CKELCK}$  is satisfied. Prior to exiting power-down,  $V_{DDQ}$  must be within its minimum/maximum operating range. No REFRESH operations are performed in power-down mode except self refresh power-down. The maximum duration in non-self-refresh power-down mode is only limited by the refresh requirements outlined in the REFRESH command section.

The power-down state is asynchronously exited when CKE is driven HIGH. CKE HIGH must be maintained until  $t_{CKE(MIN)}$  is satisfied. A valid, executable command can be applied with power-down exit latency  $t_{XP}$  after CKE goes HIGH. Power-down exit latency is defined in the AC timing parameter table.

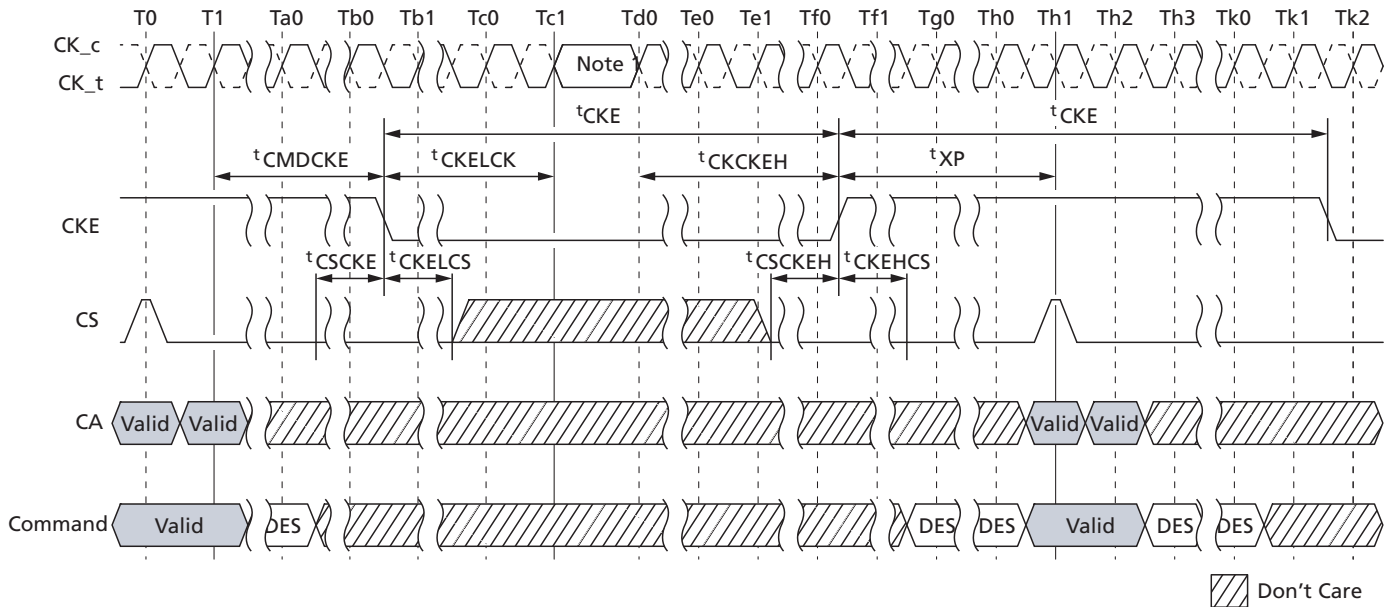
Clock frequency change or clock stop is inhibited during  $t_{CMDCKE}$ ,  $t_{CKELCK}$ ,  $t_{CKCKEH}$ ,  $t_{XP}$ ,  $t_{MRWCKEL}$ , and  $t_{ZQCKE}$  periods.

If power-down occurs when all banks are idle, this mode is referred to as idle power-down. If power-down occurs when there is a row active in any bank, this mode is referred to as active power-down. And if power-down occurs when self refresh is in progress, this mode is referred to as self refresh power-down in which the internal refresh is continuing in the same way as self refresh mode.

When CA, CK, and/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 power-down when  $V_{DDQ}$  is stable and within its minimum/maximum operating range.

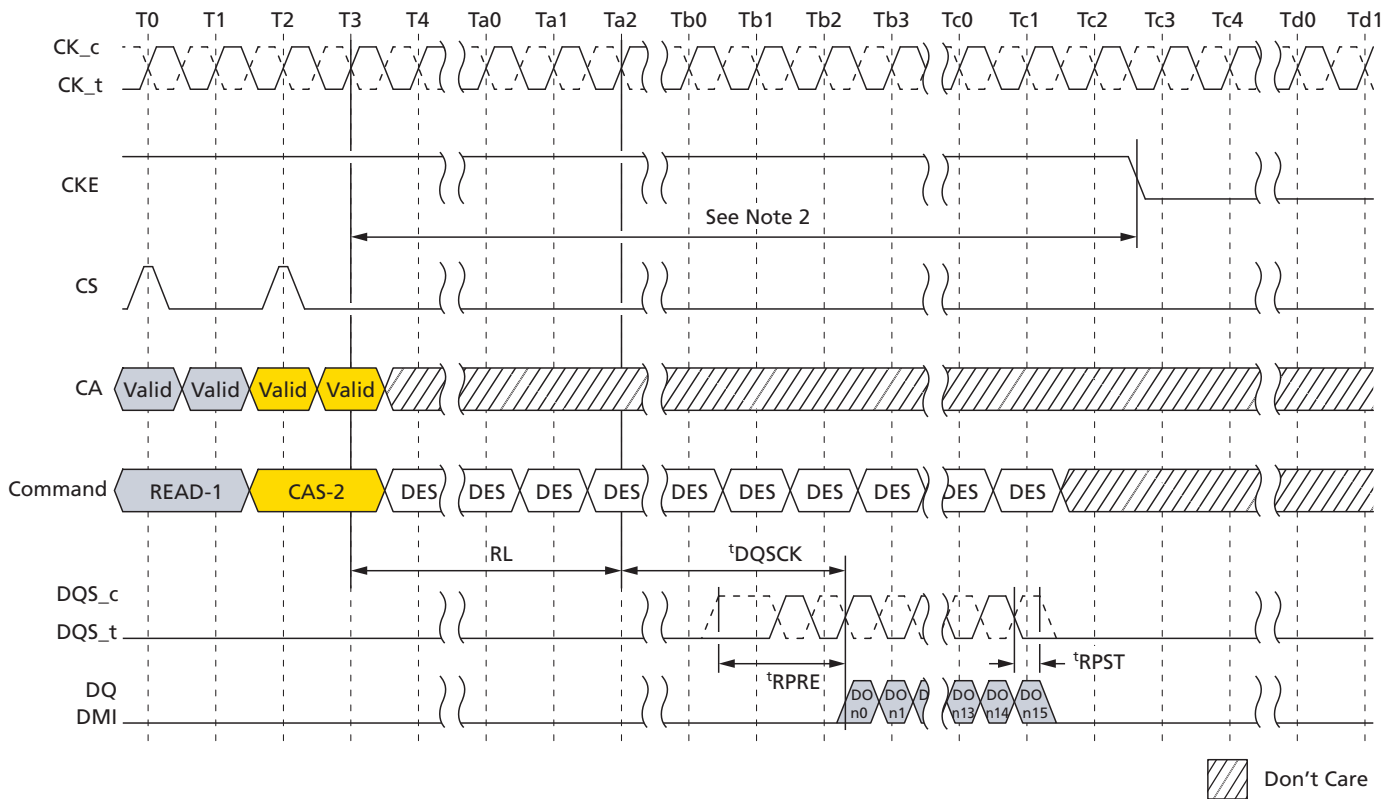
The LPDDR4 DRAM cannot be placed in power-down state during start DQS interval oscillator operation.

Figure 77: Basic Power-Down Entry and Exit Timing



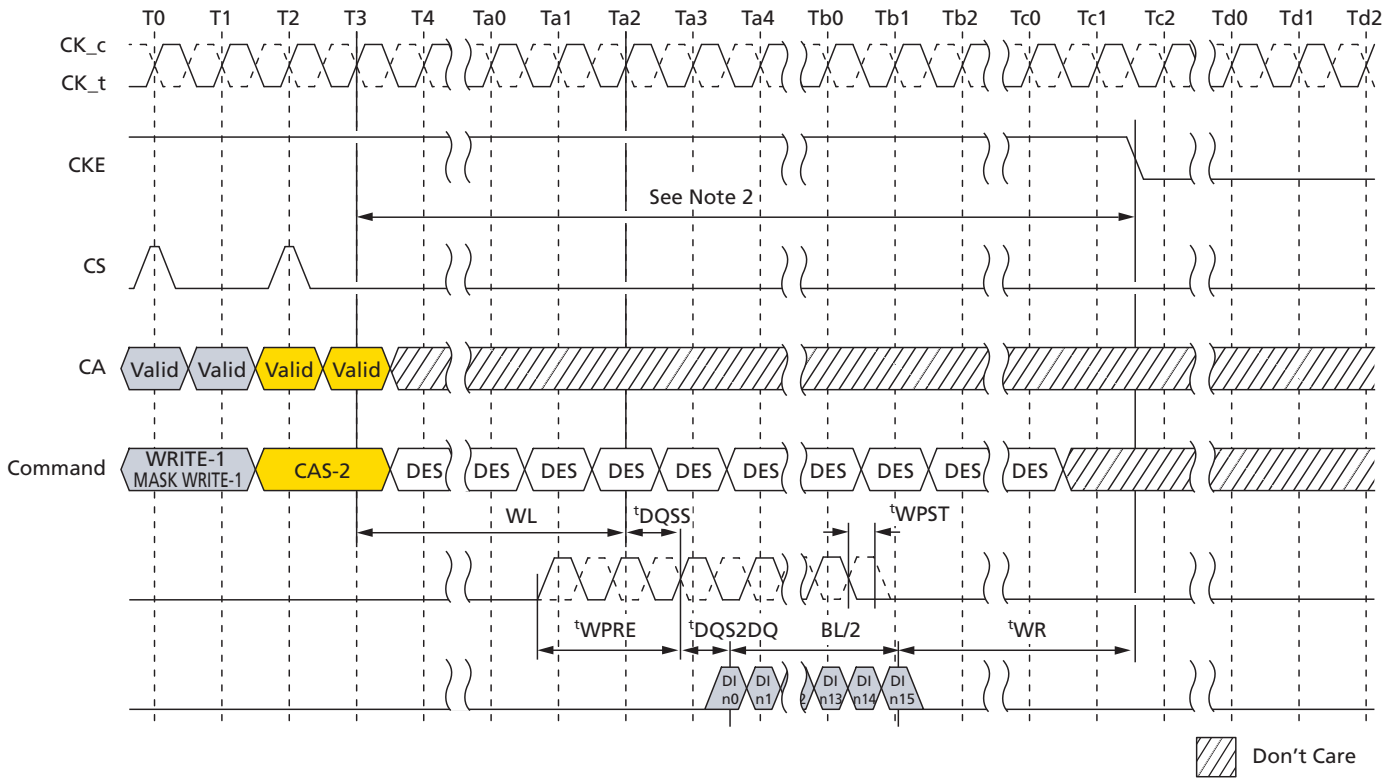
Note: 1. Input clock frequency can be changed or the input clock can be stopped or floated during power-down, provided that upon exiting power-down, the clock is stable and within specified limits for a minimum of  $t_{CKCKEH}$  of stable clock prior to power-down exit and the clock frequency is between the minimum and maximum specified frequency for the speed grade in use.

Figure 78: Read and Read with Auto Precharge to Power-Down Entry



- Notes:
1. CKE must be held HIGH until the end of the burst operation.
  2. Minimum delay time from READ command or READ with AUTO PRECHARGE command to falling edge of CKE signal is as follows:
    - When read postamble =  $0.5nCK$  (MR1 OP[7] = [0]),  
 $(RL \times tCK) + tDQSCK(MAX) + ((BL/2) \times tCK) + 1tCK$
    - When read postamble =  $1.5nCK$  (MR1 OP[7] = [1]),  
 $(RL \times tCK) + tDQSCK(MAX) + ((BL/2) \times tCK) + 2tCK$

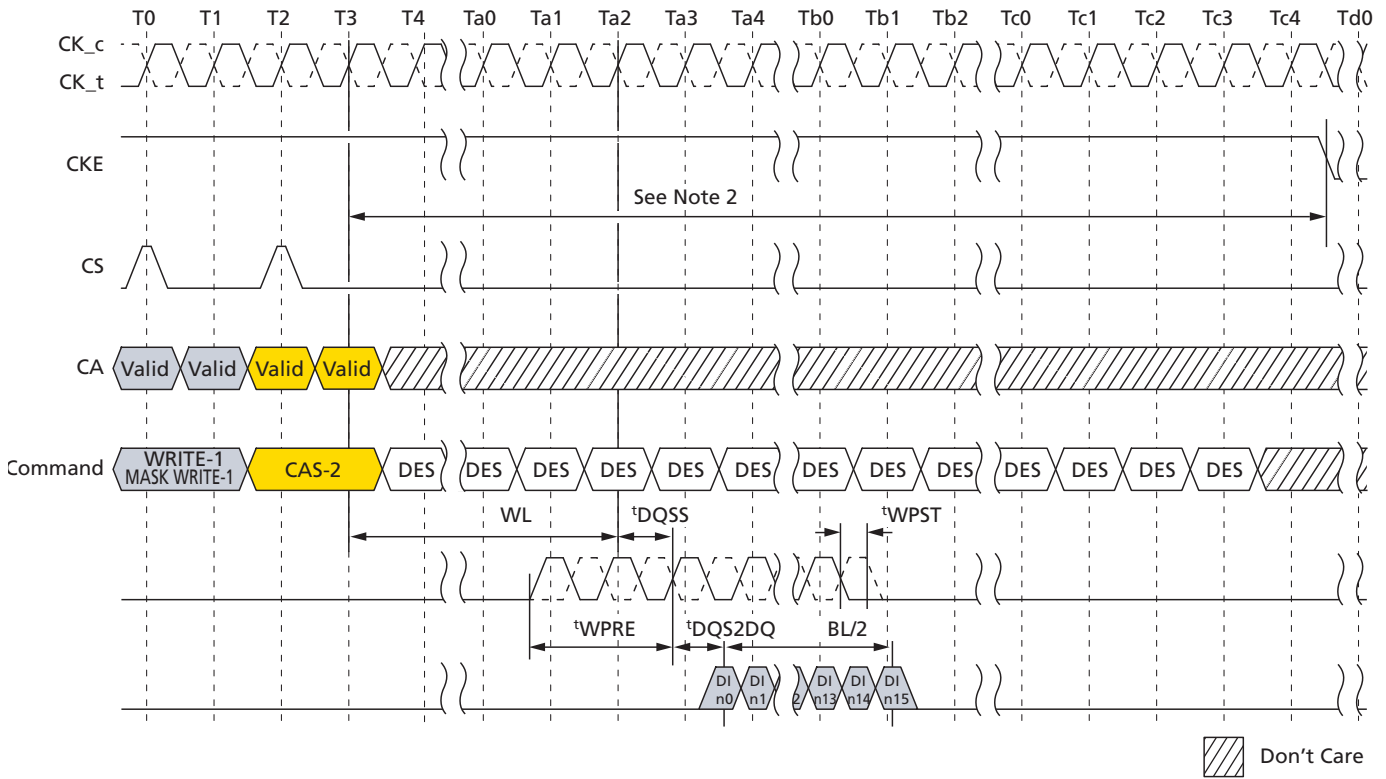
Figure 79: Write and Mask Write to Power-Down Entry



- Notes:
1. CKE must be held HIGH until the end of the burst operation.
  2. Minimum delay time from WRITE command or MASK WRITE command to falling edge of CKE signal is as follows:  

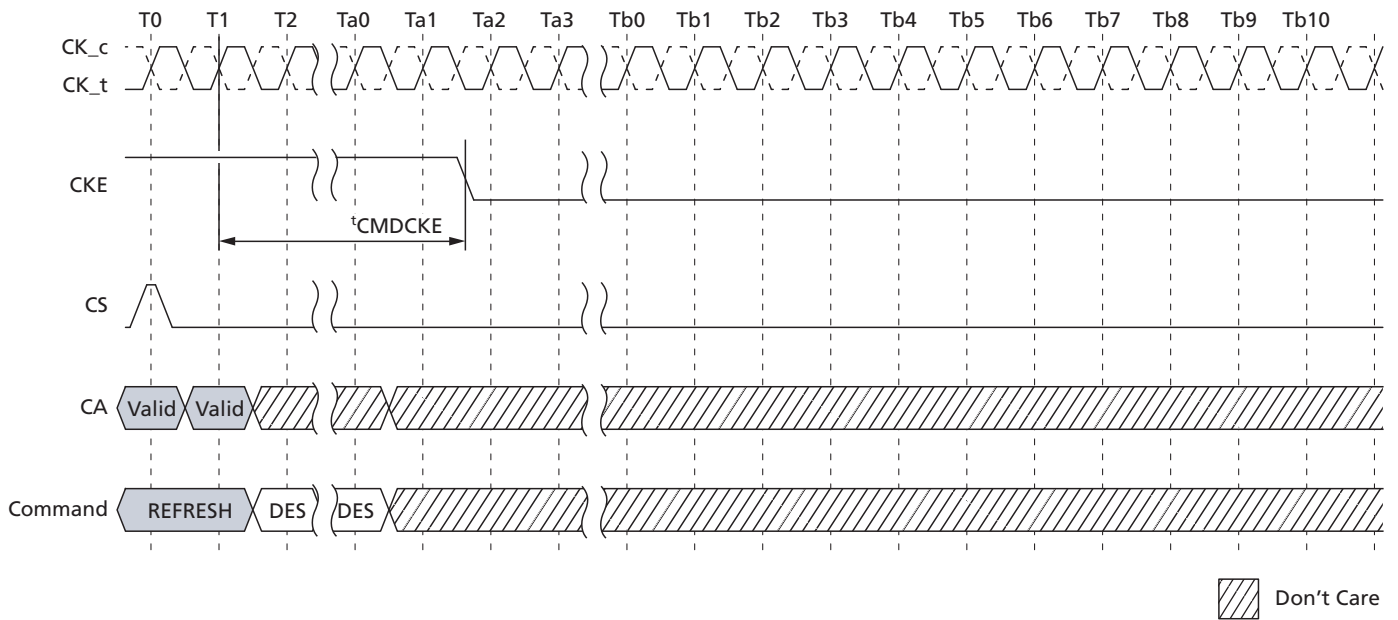
$$(WL \times t_{CK}) + t_{DQSS(MAX)} + t_{DQS2DQ(MAX)} + ((BL/2) \times t_{CK}) + t_{WR}$$
  3. This timing is applied regardless of DQ ODT disable/enable setting: MR11 OP[2:0].
  4. This timing diagram only applies to the WRITE and MASK WRITE commands without auto precharge.

Figure 80: Write With Auto Precharge and Mask Write With Auto Precharge to Power-Down Entry



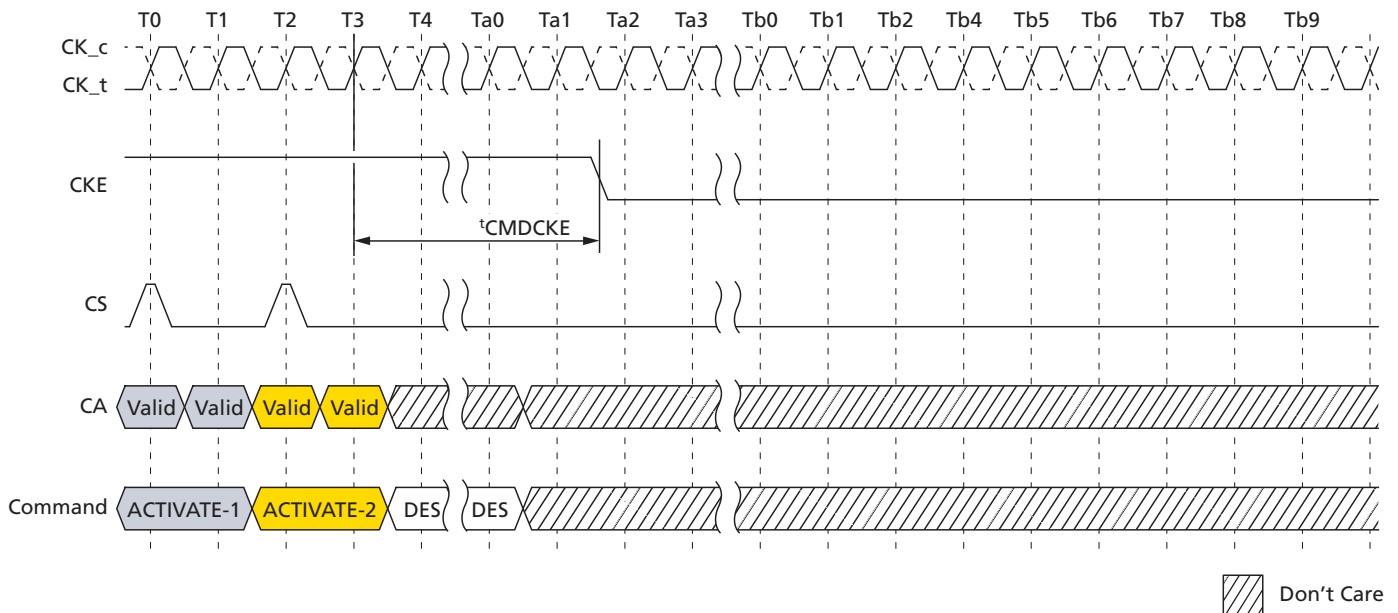
- Notes:
1. CKE must be held HIGH until the end of the burst operation.
  2. Delay time from WRITE with AUTO PRECHARGE command or MASK WRITE with AUTO PRECHARGE command to falling edge of CKE signal is more than  $(WL \times t_{CK}) + t_{DQSS(MAX)} + t_{DQS2DQ(MAX)} + ((BL/2) \times t_{CK}) + (n_{WR} \times t_{CK}) + (2 \times t_{CK})$
  3. This timing is applied regardless of DQ ODT disable/enable setting: MR11 OP[2:0].

**Figure 81: Refresh Entry to Power-Down Entry**



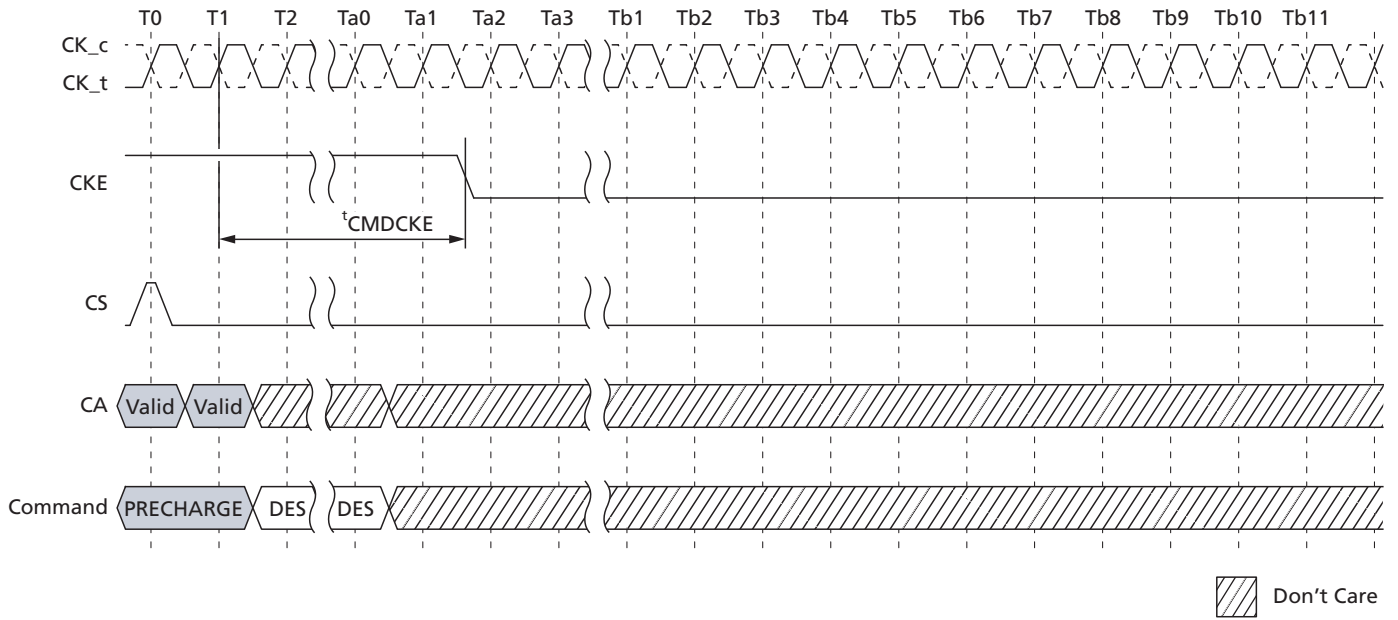
Note: 1. CKE must be held HIGH until t<sub>CMDCKE</sub> is satisfied.

**Figure 82: ACTIVATE Command to Power-Down Entry**



Note: 1. CKE must be held HIGH until t<sub>CMDCKE</sub> is satisfied.

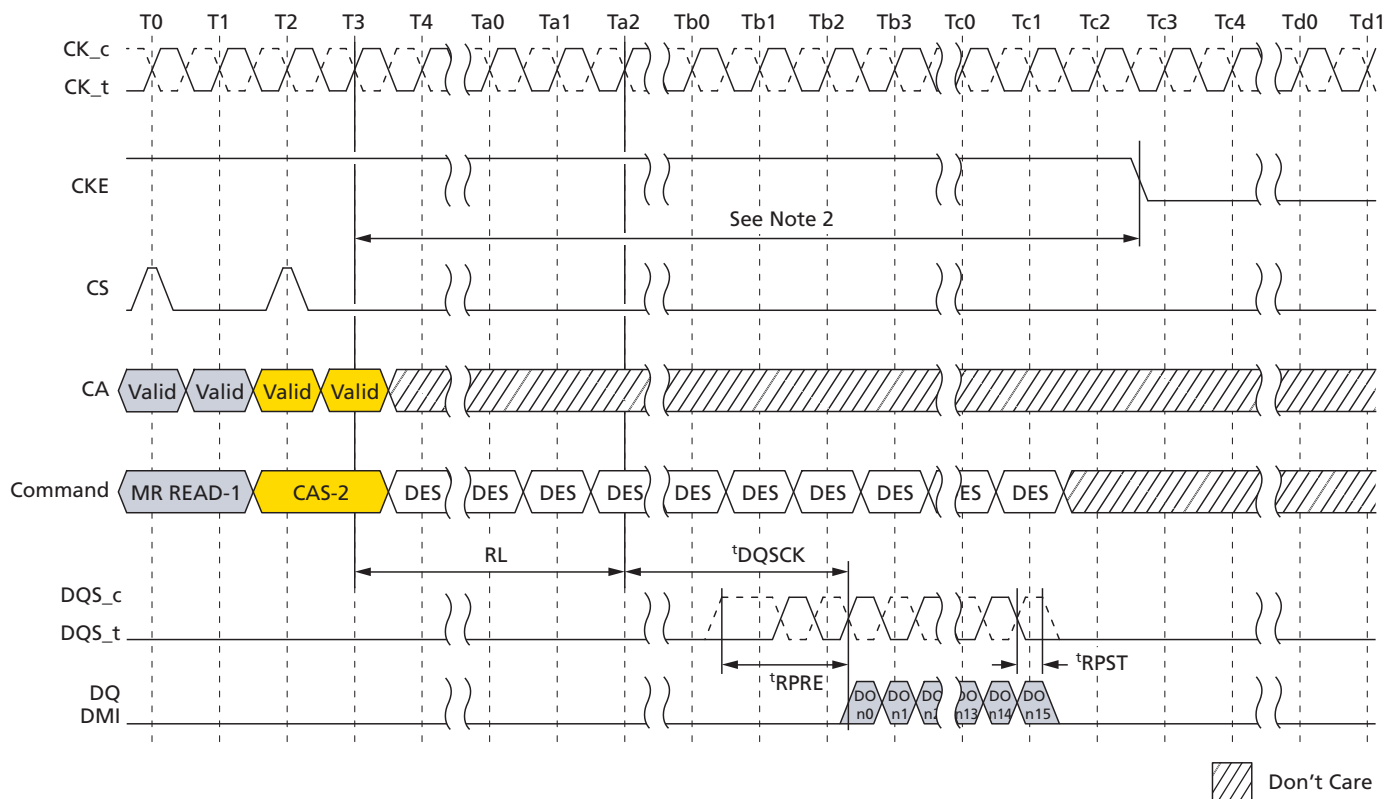
Figure 83: PRECHARGE Command to Power-Down Entry



Note: 1. CKE must be held HIGH until  $t_{CMDCKE}$  is satisfied.



Figure 84: Mode Register Read to Power-Down Entry



- Notes: 1. CKE must be held HIGH until the end of the burst operation.  
2. Minimum delay time from MODE REGISTER READ command to falling edge of CKE signal is as follows:

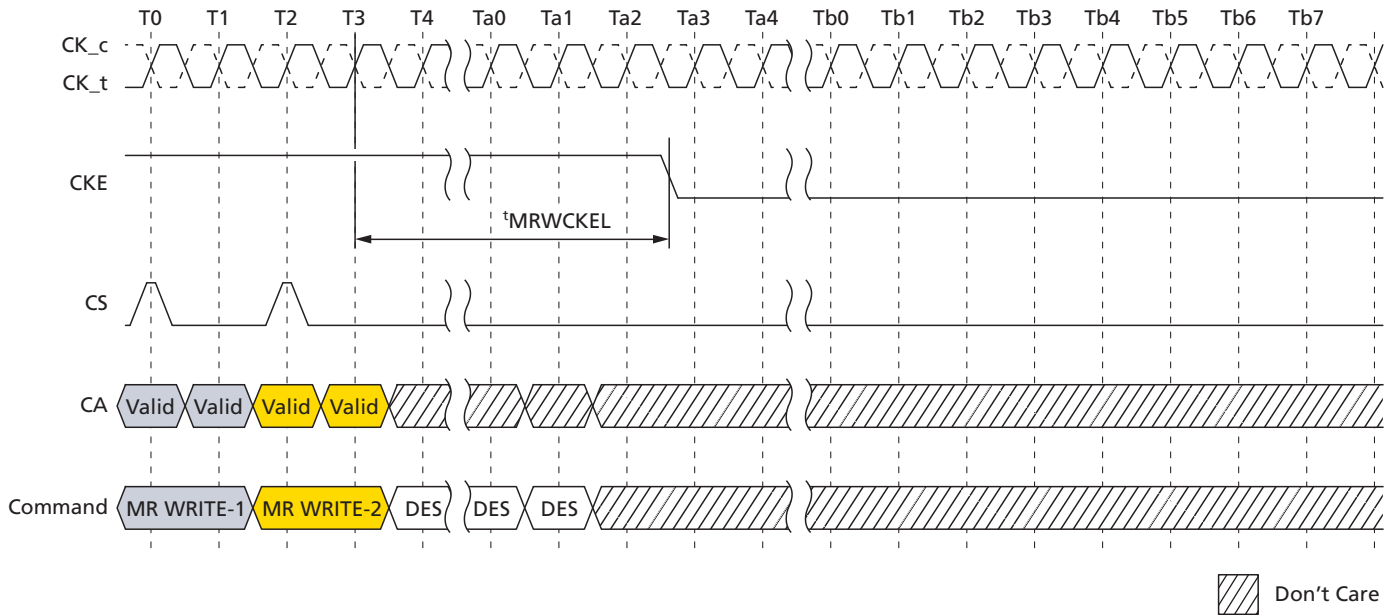
When read postamble = 0.5nCK ( MR1 OP[7] = [0]),

$$(RL \times tCK) + tDQSCK(MAX) + ((BL/2) \times tCK) + 1tCK$$

When read postamble = 1.5nCK (MR1 OP[7] = [1]),

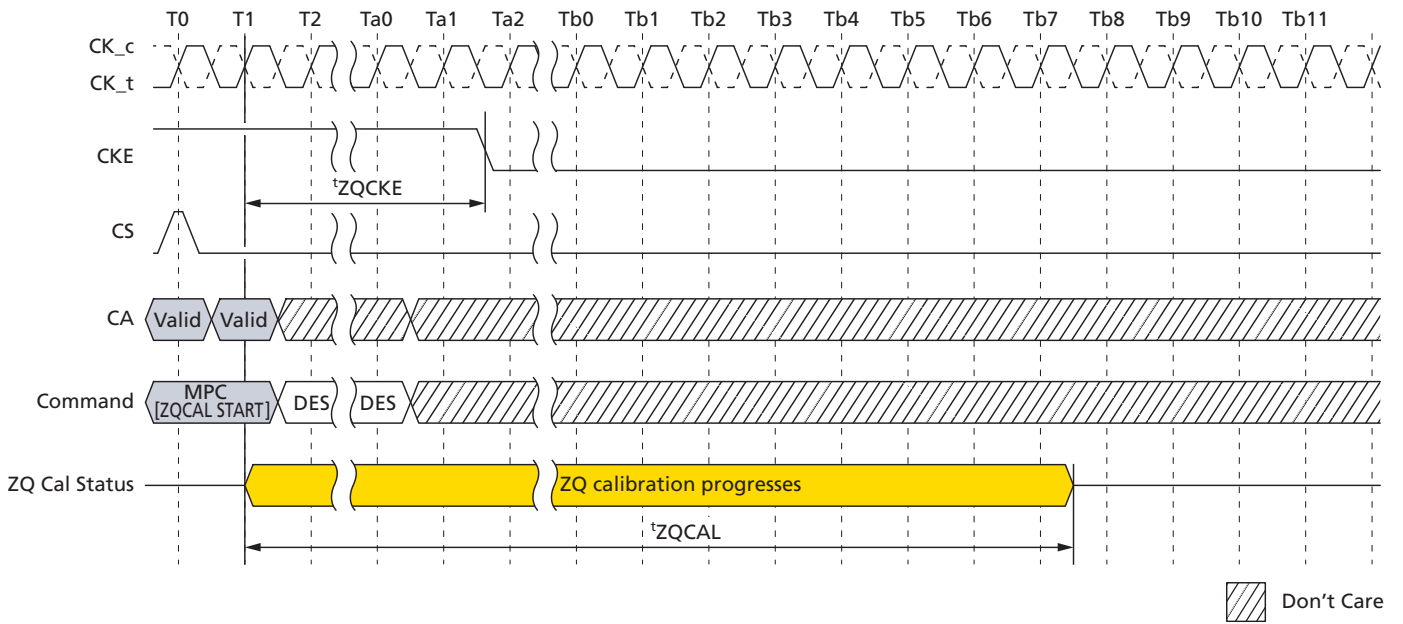
$$(RL \times tCK) + tDQSCK(MAX) + ((BL/2) \times tCK) + 2tCK$$

Figure 85: Mode Register Write to Power-Down Entry



- Notes:
1. CKE must be held HIGH until  $t^{\text{MRWCKEL}}$  is satisfied.
  2. This timing is the general definition for power-down entry after MODE REGISTER WRITE command. When a MODE REGISTER WRITE command changes a parameter or starts an operation that requires special timing longer than  $t^{\text{MRWCKEL}}$ , that timing must be satisfied before CKE is driven LOW. Changing the  $V_{\text{REF(DQ)}}$  value is one example, in this case the appropriate  $t^{\text{VREF-SHORT/MIDDLE/LONG}}$  must be satisfied.

Figure 86: MULTI PURPOSE Command for ZQCAL Start to Power-Down Entry



Note: 1. ZQ calibration continues if CKE goes LOW after t<sub>ZQCKE</sub> is satisfied.

## Input Clock Stop and Frequency Change

### Clock Frequency Change – CKE LOW

During CKE LOW, the device supports input clock frequency changes under the following conditions:

- $t_{CK(ABS)}$  (MIN) is met for each clock cycle
- Refresh requirements apply during clock frequency change
- During clock frequency change, only REFab or REFpb commands may be executing
- Any ACTIVATE or PRECHARGE commands have completed prior to changing the frequency
- Related timing conditions,  $t_{RCD}$  and  $t_{RP}$ , have been met prior to changing the frequency
- The initial clock frequency must be maintained for a minimum of  $t_{CKELCK}$  after CKE goes LOW
- The clock satisfies  $t_{CH(ABS)}$  and  $t_{CL(ABS)}$  for a minimum of  $t_{CKCKEH}$  prior to CKE going HIGH

After the input clock frequency changes and CKE is held HIGH, additional MRW commands may be required to set the WR, RL, and so forth. These settings may require adjustment to meet minimum timing requirements at the target clock frequency.

### Clock Stop – CKE LOW

During CKE LOW, the device supports clock stop under the following conditions:

- CK\_t and CK\_c are don't care during clock stop
- Refresh requirements apply during clock stop
- During clock stop, only REFab or REFpb commands may be executing
- Any ACTIVATE or PRECHARGE commands have completed prior to stopping the clock
- Related timing conditions,  $t_{RCD}$  and  $t_{RP}$ , have been met prior to stopping the clock
- The initial clock frequency must be maintained for a minimum of  $t_{CKELCK}$  after CKE goes LOW
- The clock satisfies  $t_{CH(ABS)}$  and  $t_{CL(ABS)}$  for a minimum of  $t_{CKCKEH}$  prior to CKE going HIGH

### Clock Frequency Change – CKE HIGH

During CKE HIGH, the device supports input clock frequency change under the following conditions:

- $t_{CK(ABS)}$  (MIN) is met for each clock cycle
- Refresh requirements apply during clock frequency change
- During clock frequency change, only REFab or REFpb commands may be executing
- Any ACTIVATE, READ, WRITE, PRECHARGE, MODE REGISTER WRITE, or MODE REGISTER READ commands (and any associated data bursts) have completed prior to changing the frequency
- Related timing conditions ( $t_{RCD}$ ,  $t_{WR}$ ,  $t_{RP}$ ,  $t_{MRW}$ , and  $t_{MRR}$ ) have been met prior to changing the frequency

- During clock frequency change, CS is held LOW
- The device is ready for normal operation after the clock satisfies  $t_{CH}(abs)$  and  $t_{CL}(abs)$  for a minimum of  $2 \times t_{CK} + t_{XP}$

After the input clock frequency is changed, additional MRW commands may be required to set the WR, RL, and so forth. These settings may need to be adjusted to meet minimum timing requirements at the target clock frequency.

### **Clock Stop – CKE HIGH**

During CKE HIGH, the device supports clock stop under the following conditions:

- CK<sub>t</sub> is held LOW and CK<sub>c</sub> is held HIGH during clock stop
- During clock stop, CS is held LOW
- Refresh requirements apply during clock stop
- During clock stop, only REFab or REFpb commands may be executing
- Any ACTIVATE, READ, WRITE, MPC (WRITE-FIFO, READ-FIFO, READ DQ CALIBRATION), PRECHARGE, MODE REGISTER WRITE, or MODE REGISTER READ commands have completed, including any associated data bursts and extra 4 clock cycles must be provided prior to stopping the clock
- Related timing conditions ( $t_{RCD}$ ,  $t_{WR}$ ,  $t_{RP}$ ,  $t_{MRW}$ ,  $t_{MRR}$ ,  $t_{ZQLAT}$ , and so forth) have been met prior to stopping the clock
- READ with AUTO PRECHARGE and WRITE with AUTO PRECHARGE commands need extra 4 clock cycles in addition to the related timing constraints, nWR and nRTP, to complete the operations
- REFab, REFpb, SRE, SRX, and MPC[ZQCAL START] commands are required to have extra 4 clock cycles prior to stopping the clock
- The device is ready for normal operation after the clock is restarted and satisfies  $t_{CH}(abs)$  and  $t_{CL}(abs)$  for a minimum of  $2 \times t_{CK} + t_{XP}$

## MODE REGISTER READ Operation

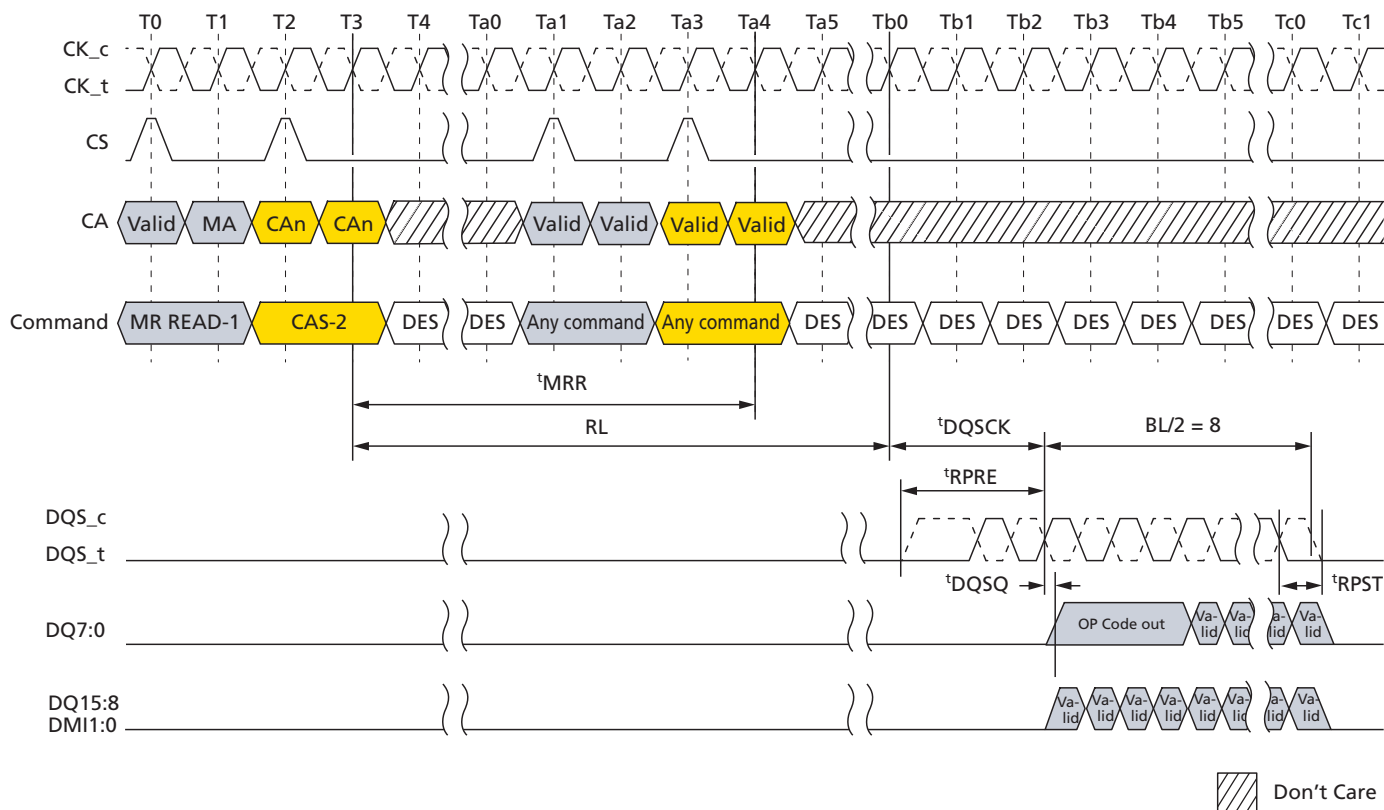
The MODE REGISTER READ (MRR) command is used to read configuration and status data from the device registers. The MRR command is initiated with CS and CA[5:0] in the proper state as defined by the Command Truth Table. The mode register address operands (MA[5:0]) enable the user to select one of 64 registers. The mode register contents are available on the first four UI data bits of DQ[7:0] after  $RL \times {}^tCK + {}^tDQSCK + {}^tDQSQ$  following the MRR command. Subsequent data bits contain valid but undefined content. DQS is toggled for the duration of the MODE REGISTER READ burst. The MRR has a command burst length of 16. MRR operation must not be interrupted.

**Table 102: MRR**

UI	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DQ0	OP0										V					
DQ1	OP1										V					
DQ2	OP2										V					
DQ3	OP3										V					
DQ4	OP4										V					
DQ5	OP5										V					
DQ6	OP6										V					
DQ7	OP7										V					
DQ8– DQ15									V							
DMI0– DMI1									V							

- Notes:
1. MRR data are extended to the first 4 UIs, allowing the LPDRAM controller to sample data easily.
  2. DBI may apply or may not apply during normal MRR. It's vendor-specific. If read DBI is enable with MRS and vendor cannot support the DBI during MRR, DMI pin status should be LOW.
  3. The read preamble and postamble of MRR are the same as for a normal read.

**Figure 87: MODE REGISTER READ Operation**

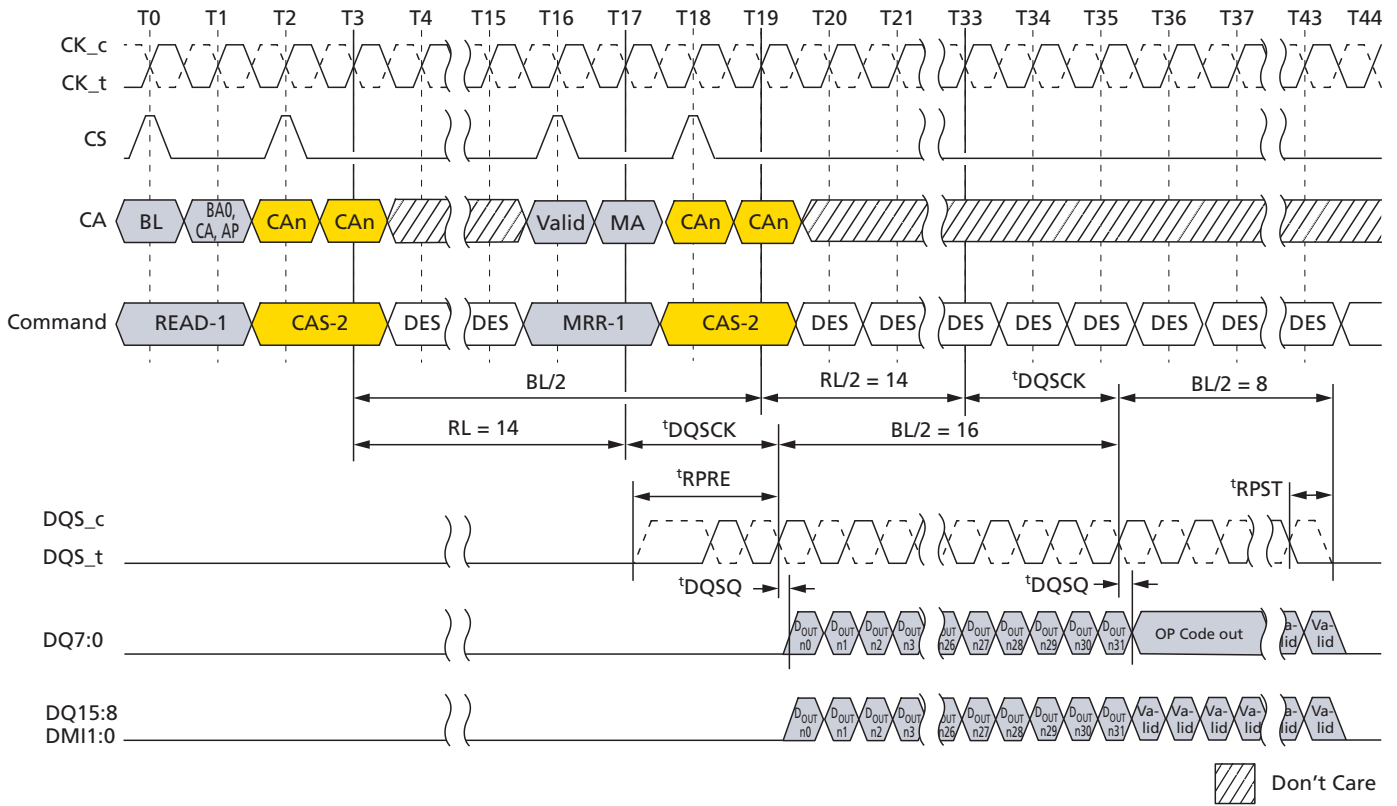


- Notes:
1. Only BL = 16 is supported.
  2. Only DESELECT is allowed during  $t_{MRR}$  period.
  3. There are some exceptions about issuing commands after  $t_{MRR}$ . Refer to MRR/MRW Timing Constraints Table for detail.
  4. DBI is disable mode.
  5. DES commands except  $t_{MRR}$  period are shown for ease of illustration; other commands may be valid at these times.
  6. DQ/DQS:  $V_{SSQ}$  termination

**MRR After a READ and WRITE Command**

After a prior READ command, the MRR command must not be issued earlier than BL/2 clock cycles, in a similar way  $WL + BL/2 + 1 + RU$  ( $t_{WTR}/t_{CK}$ ) clock cycles after a PRIOR WRITE, WRITE with AP, MASK WRITE, MASK WRITE with AP, and MPC[WRITE-FIFO] command in order to avoid the collision of READ and WRITE burst data on device internal data bus.

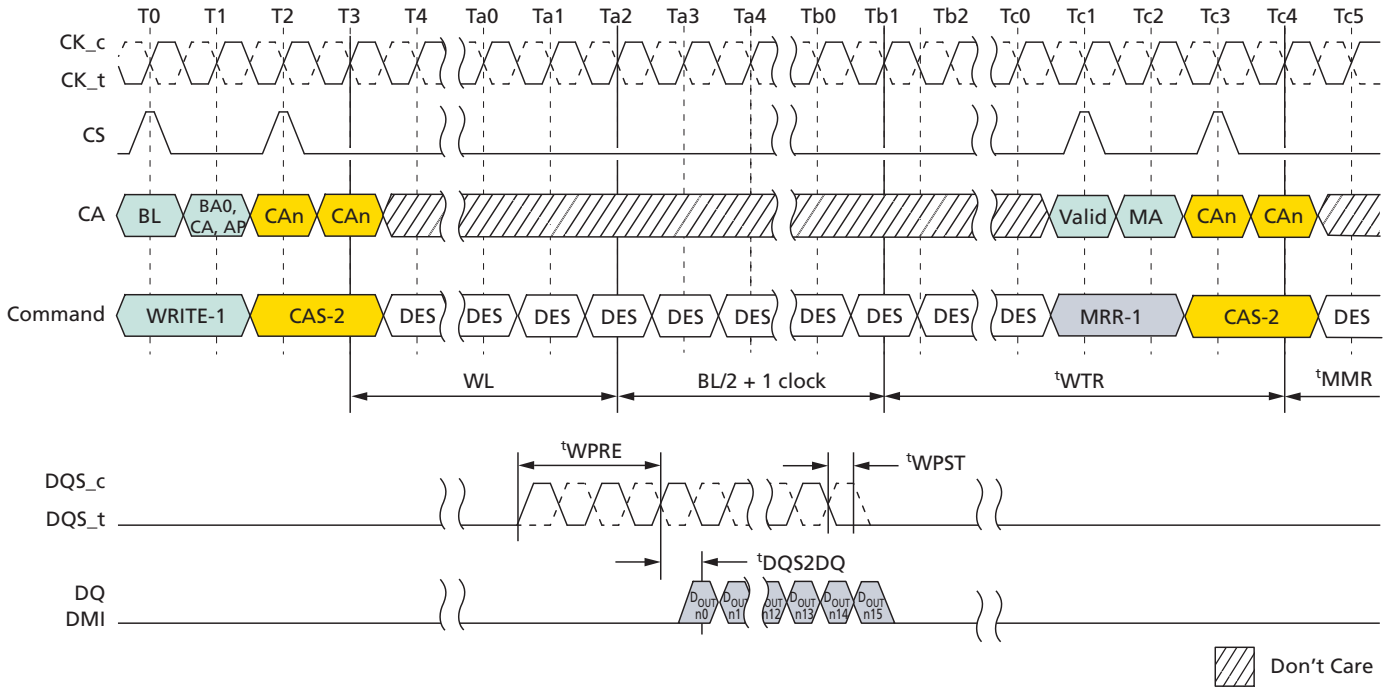
Figure 88: READ-to-MRR Timing



- Notes:
1. The minimum number of clock cycles from the burst READ command to the MRR command is  $BL/2$ .
  2. Read  $BL = 32$ , MRR  $BL = 16$ ,  $RL = 14$ , Preamble = Toggle, Postamble =  $0.5nCK$ , DBI = Disable,  $DQ/DQS: V_{SSQ}$  termination.
  3.  $D_{OUT} n =$  data-out to column  $n$ .
  4. DES commands except  $tMRR$  period are shown for ease of illustration; other commands may be valid at these times.



Figure 89: WRITE-to-MRR Timing

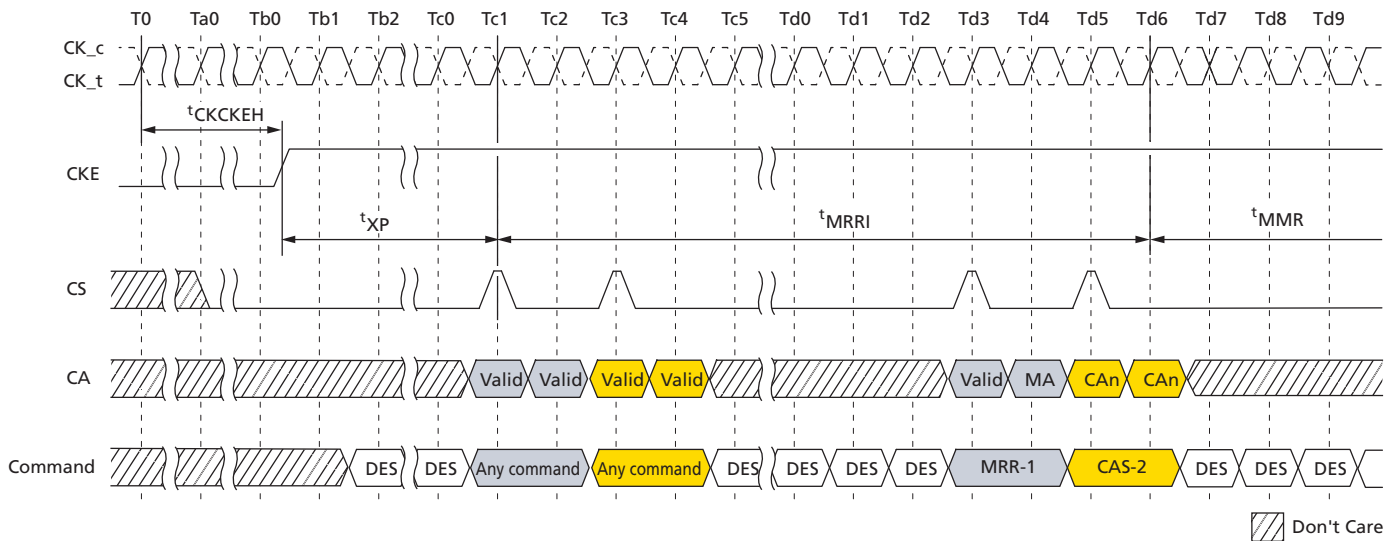


- Notes:
1. Write BL=16, Write postamble = 0.5nCK, DQ/DQS: V<sub>SSQ</sub> termination.
  2. Only DES is allowed during t<sub>MRR</sub> period.
  3. D<sub>OUT</sub> n = data-out to column n.
  4. The minimum number of clock cycles from the BURST WRITE command to MRR command is WL + BL/2 + 1 + RU(t<sub>WTR</sub>/t<sub>CK</sub>).
  5. t<sub>WTR</sub> starts at the rising edge of CK after the last latching edge of DQS.
  6. DES commands except t<sub>MRR</sub> period are shown for ease of illustration; other commands may be valid at these times.

### MRR After Power-Down Exit

Following the power-down state, an additional time, t<sub>MRRI</sub>, is required prior to issuing the MODE REGISTER READ (MRR) command. This additional time (equivalent to t<sub>RCD</sub>) is required in order to maximize power-down current savings by allowing more power-up time for the MRR data path after exit from power-down mode.

Figure 90: MRR Following Power-Down

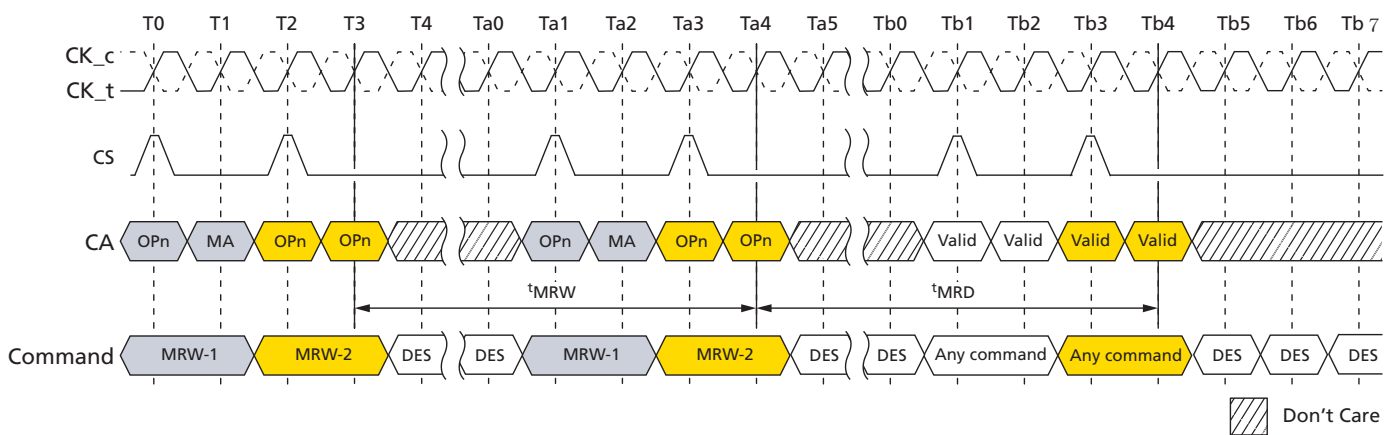


- Notes:
1. Only DES is allowed during  $t_{MRR}$  period.
  2. DES commands except  $t_{MRR}$  period are shown for ease of illustration; other commands may be valid at these times.

## MODE REGISTER WRITE

The MODE REGISTER WRITE (MRW) writes configuration data to the mode registers. The MRW command is initiated with CKE, CS, and CA[5:0] to valid levels at the rising edge of the clock. The mode register address and the data written to it is contained in CA[5:0] according to the Command Truth Table. The MRW command period is defined by  $t_{MRW}$ . Mode register WRITES to read-only registers have no impact on the functionality of the device.

Figure 91: MODE REGISTER WRITE Timing



## Mode Register Write States

MRW can be issued from either a bank-idle or a bank-active state. Certain restrictions may apply for MRW from an active state.

**Table 103: Truth Table for MRR and MRW**

Current State	Command	Intermediate State	Next State
All banks idle	MRR	Reading mode register, all banks idle	All banks idle
	MRW	Writing mode register, all banks idle	All banks idle
Bank(s) active	MRR	Reading mode register	Bank(s) active
	MRW	Writing mode register	Bank(s) active

**Table 104: MRR/MRW Timing Constraints: DQ ODT is Disable**

From Command	To Command	Minimum Delay Between "From Command" and "To Command"	Unit	Notes
MRR	MRR	$t^{\text{MRR}}$	–	
	RD/RDA	$t^{\text{MRR}}$	–	
	WR/WRA/MWR/MWRA	$RL + RU(t^{\text{DQSC}}(\text{MAX})/t^{\text{CK}}) + BL/2 - WL + t^{\text{WPRE}} + RD(t^{\text{RPST}})$	$n\text{CK}$	
	MRW	$RL + RU(t^{\text{DQSC}}(\text{MAX})/t^{\text{CK}}) + BL/2 + 3$	$n\text{CK}$	
RD/RDA	MRR	$BL/2$	$n\text{CK}$	
WR/WRA/MWR/MWRA		$WL + 1 + BL/2 + RU(t^{\text{WTR}}/t^{\text{CK}})$	$n\text{CK}$	
MRW		$t^{\text{MRD}}$	–	
POWER-DOWN EXIT		$t^{\text{XP}} + t^{\text{MRRI}}$	–	
MRW	RD/RDA	$t^{\text{MRD}}$	–	
	WR/WRA/MWR/MWRA	$t^{\text{MRD}}$	–	
	MRW	$t^{\text{MRW}}$	–	
RD/ RD-FIFO/ READ DQ CAL	MRW	$RL + BL/2 + RU(t^{\text{DQSC}}(\text{MAX})/t^{\text{CK}}) + RD(t^{\text{RPST}}) + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK})$	$n\text{CK}$	
RD with AUTO PRECHARGE		$RL + BL/2 + RU(t^{\text{DQSC}}(\text{MAX})/t^{\text{CK}}) + RD(t^{\text{RPST}}) + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK}) + n\text{RTP} - 8$	$n\text{CK}$	
WR/ MWR/ WR-FIFO		$WL + 1 + BL/2 + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK})$	$n\text{CK}$	
WR/MWR with AUTO PRE-CHARGE		$WL + 1 + BL/2 + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK}) + n\text{WR}$	$n\text{CK}$	

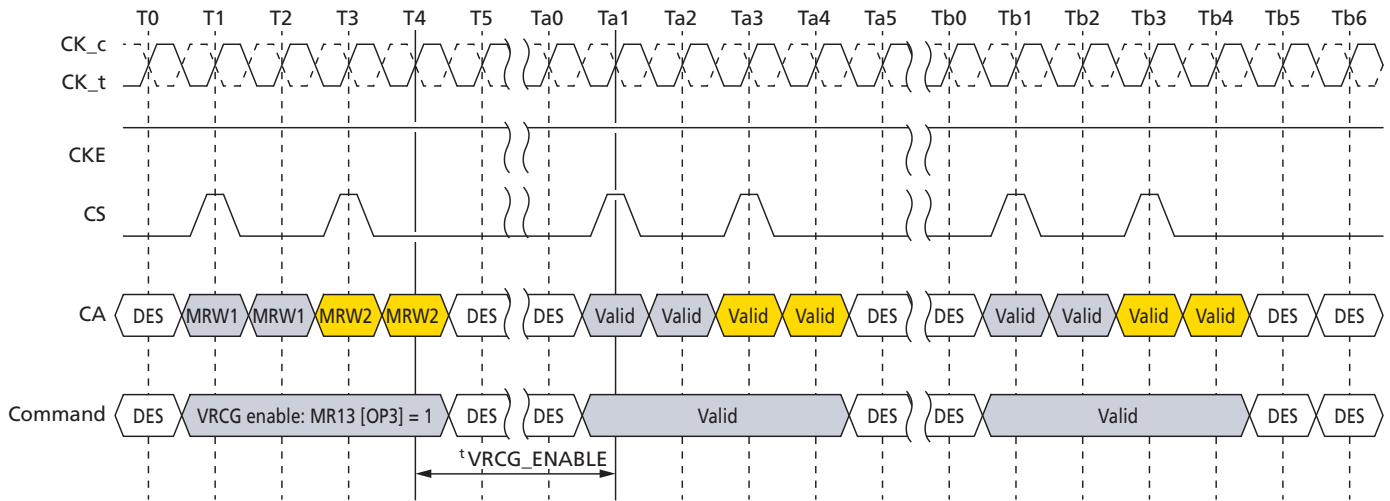
**Table 105: MRR/MRW Timing Constraints: DQ ODT is Enable**

From Command	To Command	Minimum Delay Between "From Command" and "To Command"	Unit	Notes
MRR	MRR	$t^{\text{MRR}}$	–	
	RD/RDA	$t^{\text{MRR}}$	–	
	WR/WRA/MWR/MWRA	$RL + RU(t^{\text{DQ}}SCK(\text{MAX})/t^{\text{CK}}) + BL/2 - ODT_{\text{Lon}} - RD(t^{\text{ODT}}_{\text{on}}(\text{MIN})/t^{\text{CK}}) + RD(t^{\text{RPST}}) + 1$	nCK	
	MRW	$RL + RU(t^{\text{DQ}}SCK(\text{MAX})/t^{\text{CK}}) + BL/2 + 3$	nCK	
RD/RDA	MRR	$BL/2$	nCK	
WR/WRA/MWR/MWRA		$WL + 1 + BL/2 + RU(t^{\text{WTR}}/t^{\text{CK}})$	nCK	
MRW		$t^{\text{MRD}}$	–	
POWER-DOWN EXIT		$t^{\text{XP}} + t^{\text{MRR1}}$	–	
MRW	RD/RDA	$t^{\text{MRD}}$	–	
	WR/WRA/MWR/MWRA	$t^{\text{MRD}}$	–	
	MRW	$t^{\text{MRW}}$	–	
RD/ RD-FIFO/ READ DQ CAL	MRW	$RL + BL/2 + RU(t^{\text{DQ}}SCK(\text{max})/t^{\text{CK}}) + RD(t^{\text{RPST}}) + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK})$	nCK	
RD with AUTO PRECHARGE		$RL + BL/2 + RU(t^{\text{DQ}}SCK(\text{MAX})/t^{\text{CK}}) + RD(t^{\text{RPST}}) + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK}) + n\text{RTP} - 8$	nCK	
WR/ MWR/ WR-FIFO		$WL + 1 + BL/2 + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK})$	nCK	
WR/MWR with AUTO PRE-CHARGE		$WL + 1 + BL/2 + \text{MAX}(RU(7.5\text{ns}/t^{\text{CK}}), 8n\text{CK}) + n\text{WR}$	nCK	

## V<sub>REF</sub> Current Generator (VRCG)

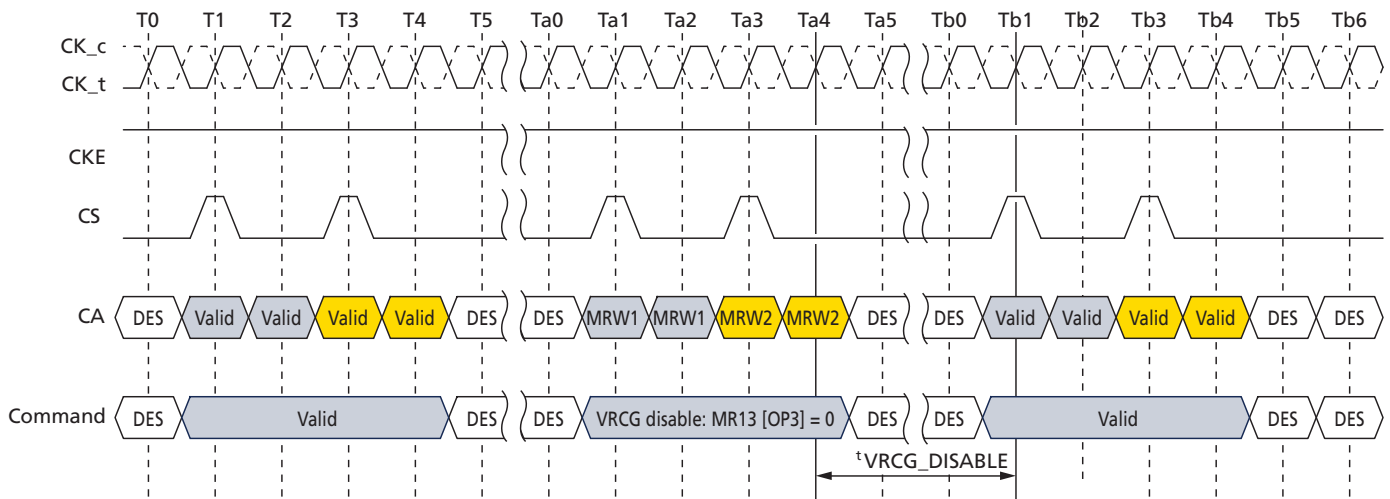
LPDDR4 SDRAM V<sub>REF</sub> current generators (VRCG) incorporate a high current mode to reduce the settling time of the internal V<sub>REF(DQ)</sub> and V<sub>REF(CA)</sub> levels during training and when changing frequency set points during operation. The high current mode is enabled by setting MR13[OP3] = 1. Only DESELECT commands may be issued until  $t^{\text{VRCG\_ENABLE}}$  is satisfied.  $t^{\text{VRCG\_ENABLE}}$  timing is shown below.

Figure 92: VRCG Enable Timing



VRCG high current mode is disabled by setting MR13[OP3] = 0. Only DESELECT commands may be issued until  $t_{VRCG\_DISABLE}$  is satisfied.  $t_{VRCG\_DISABLE}$  timing is shown below.

Figure 93: VRCG Disable Timing



Note that LPDDR4 SDRAM devices support  $V_{FER(CA)}$  and  $V_{REF(DQ)}$  range and value changes without enabling VRCG high current mode.

Table 106: VRCG Enable/Disable Timing

Parameter	Symbol	Min	Max	Unit
$V_{REF}$ high current mode enable time	$t_{VRCG\_ENABLE}$	–	200	ns
$V_{REF}$ high current mode disable time	$t_{VRCG\_DISABLE}$	–	100	ns

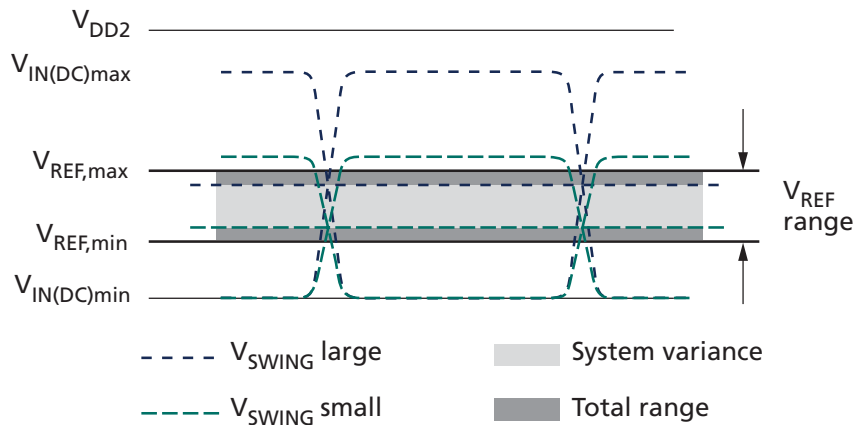
## V<sub>REF</sub> Training

### V<sub>REF(CA)</sub> Training

The device's internal V<sub>REF(CA)</sub> specification parameters are operating voltage range, step size, V<sub>REF</sub> step time, V<sub>REF</sub> full-range step time, and V<sub>REF</sub> valid level.

The voltage operating range specifies the minimum required V<sub>REF</sub> setting range for LPDDR4 devices. The minimum range is defined by V<sub>REF,max</sub> and V<sub>REF,min</sub>.

**Figure 94: V<sub>REF</sub> Operating Range (V<sub>REF,max</sub>, V<sub>REF,min</sub>)**

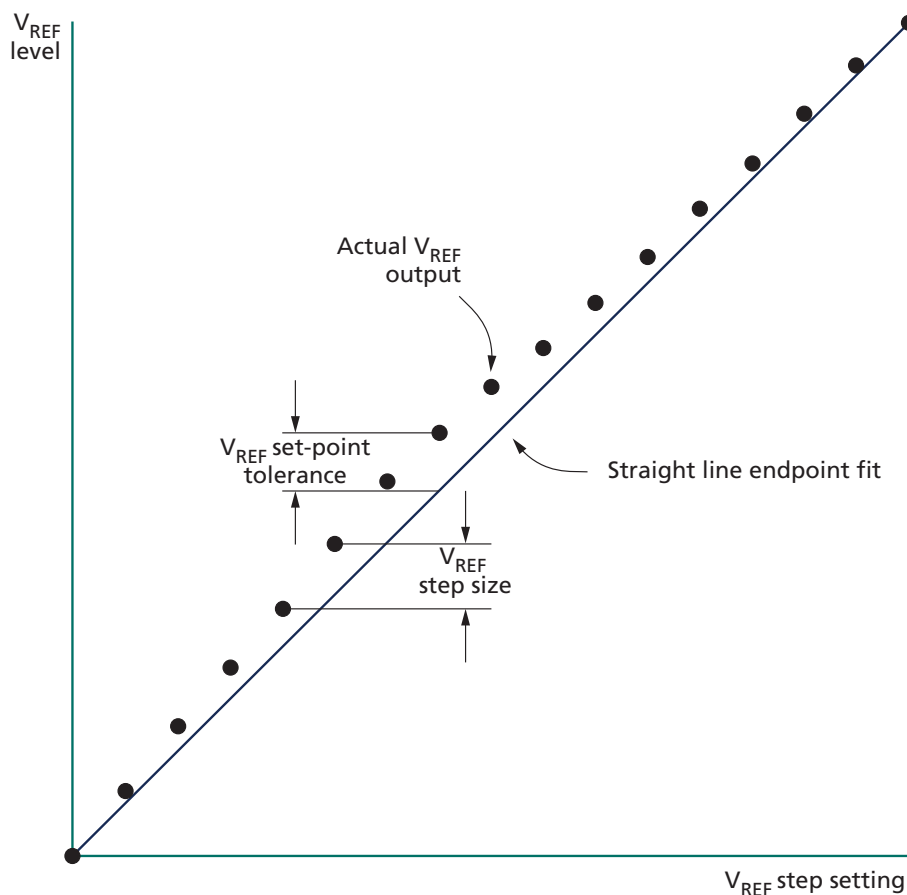


The V<sub>REF</sub> step size is defined as the step size between adjacent steps. However, for a given design, the device has one value for V<sub>REF</sub> step size that falls within the given range.

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

The V<sub>REF</sub> set tolerance is measured with respect to the ideal line that is based on the two endpoints, where the endpoints are at the minimum and maximum V<sub>REF</sub> values for a specified range.

Figure 95: V<sub>REF</sub> Set-Point Tolerance and Step Size



The V<sub>REF</sub> increment/decrement step times are defined by <sup>t</sup>V<sub>REF</sub>\_TIME-SHORT, <sup>t</sup>V<sub>REF</sub>\_TIME-MIDDLE, and <sup>t</sup>V<sub>REF</sub>\_TIME-LONG. The parameters are defined from TS to TE as shown below, where TE is referenced to when the V<sub>REF</sub> voltage is at the final DC level within the V<sub>REF</sub> valid tolerance (V<sub>REF, val\_tol</sub>).

The V<sub>REF</sub> valid level is defined by V<sub>REF, val\_tol</sub> to qualify the step time TE (see the following figures). This parameter is used to ensure an adequate RC time constant behavior of the voltage level change after any V<sub>REF</sub> increment/decrement adjustment. This parameter is only applicable for LPDDR4 component level validation/characterization.

<sup>t</sup>V<sub>REF</sub>\_TIME-SHORT is for a single step size increment/decrement change in the V<sub>REF</sub> voltage.

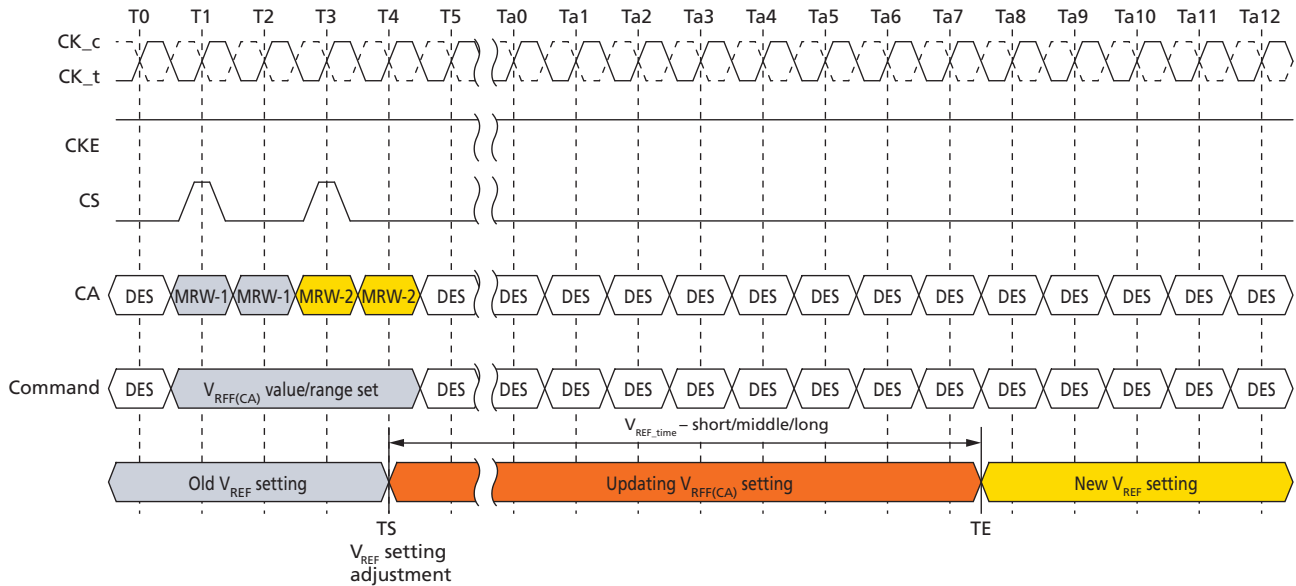
<sup>t</sup>V<sub>REF</sub>\_TIME-MIDDLE is at least two stepsizes increment/decrement change within the same V<sub>REF(CA)</sub> range in V<sub>REF</sub> voltage.

<sup>t</sup>V<sub>REF</sub>\_TIME-LONG is the time including up to V<sub>REF, min</sub> to V<sub>REF, max</sub> or V<sub>REF, max</sub> to V<sub>REF, min</sub> change across the V<sub>REF(CA)</sub> range in V<sub>REF</sub> voltage.

TS is referenced to MRW command clock.

TE is referenced to V<sub>REF, val\_tol</sub>.

Figure 96:  $t_{V_{ref}}$  for Short, Middle, and Long Timing Diagram



The MRW command to the mode register bits are as follows;

MR12 OP[5:0] : V<sub>REF(CA)</sub> Setting

MR12 OP[6] : V<sub>REF(CA)</sub> Range

The minimum time required between two V<sub>REF</sub> MRW commands is  $t_{V_{REF\_TIME\_SHORT}}$  for a single step and  $t_{V_{REF\_TIME\_MIDDLE}}$  for a full voltage range step.

Figure 97: V<sub>REF(CA)</sub> Single-Step Increment

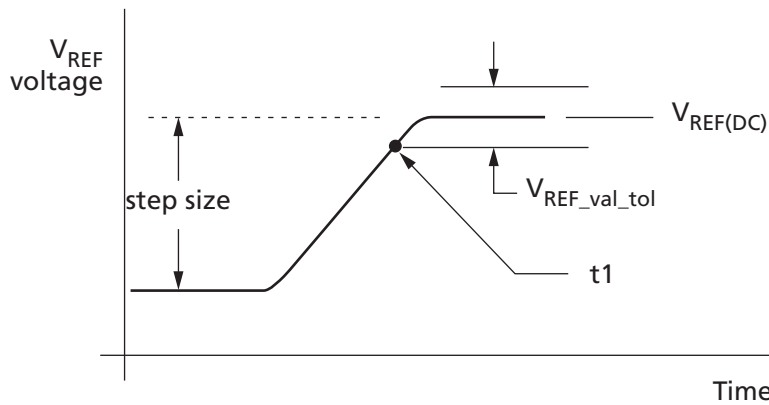




Figure 98: V<sub>REF(CA)</sub> Single-Step Decrement

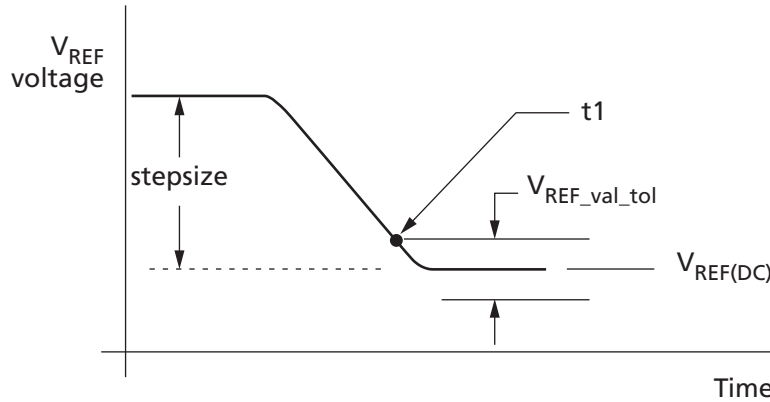


Figure 99: V<sub>REF(CA)</sub> Full Step from V<sub>REF,min</sub> to V<sub>REF,max</sub>

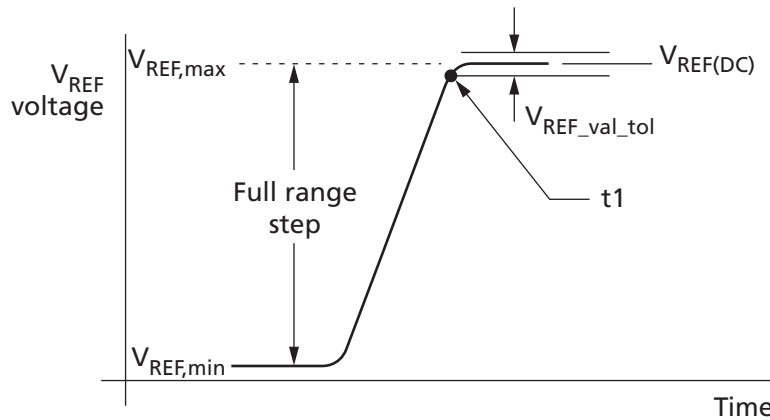
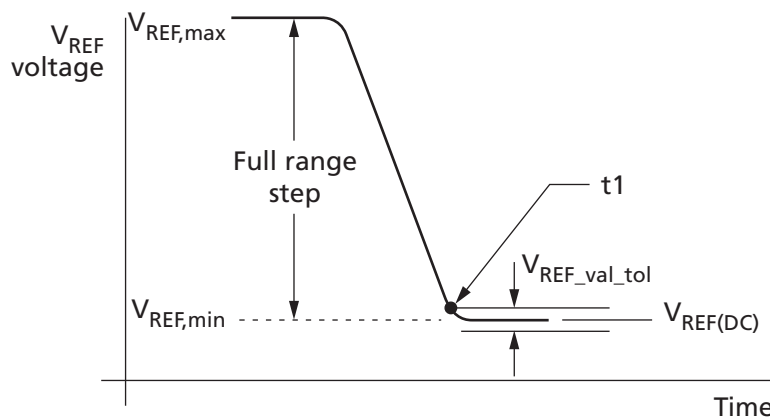


Figure 100: V<sub>REF(CA)</sub> Full Step from V<sub>REF,max</sub> to V<sub>REF,min</sub>



The following table contains the CA internal V<sub>REF</sub> specification that will be characterized at the component level for compliance.

**Table 107: Internal V<sub>REF(CA)</sub> Specifications**

Symbol	Parameter	Min	Typ	Max	Unit	Notes
V <sub>REF(CA),max_r0</sub>	V <sub>REF(CA)</sub> range-0 MAX operating point	–	–	30%	V <sub>DD2</sub>	1, 11
V <sub>REF(CA),min_r0</sub>	V <sub>REF(CA)</sub> range-0 MIN operating point	10%	–	–	V <sub>DD2</sub>	1, 11
V <sub>REF(CA),max_r1</sub>	V <sub>REF(CA)</sub> range-1 MAX operating point	–	–	42%	V <sub>DD2</sub>	1, 11
V <sub>REF(CA),min_r1</sub>	V <sub>REF(CA)</sub> range-1 MIN operating point	22%	–	–	V <sub>DD2</sub>	1, 11
V <sub>REF(CA),step</sub>	V <sub>REF(CA)</sub> step size	0.30%	0.40%	0.50%	V <sub>DD2</sub>	2
V <sub>REF(CA),set_tol</sub>	V <sub>REF(CA)</sub> set tolerance	–1.00%	0.00%	1.00%	V <sub>DD2</sub>	3, 4, 6
		–0.10%	0.00%	0.10%	V <sub>DD2</sub>	3, 5, 7
t <sub>VREF_TIME-SHORT</sub>	V <sub>REF(CA)</sub> step time	–	–	100	ns	8
t <sub>VREF_TIME-MIDDLE</sub>		–	–	200	ns	12
t <sub>VREF_TIME-LONG</sub>		–	–	250	ns	9
t <sub>VREF_time_weak</sub>		–	–	1	ms	13, 14
V <sub>REF(CA)_val_tol</sub>	V <sub>REF(CA)</sub> valid tolerance	–0.10%	0.00%	0.10%	V <sub>DD2</sub>	10

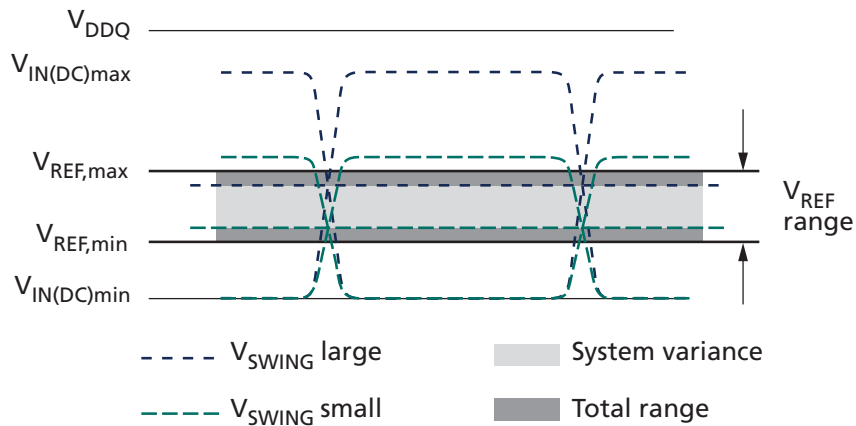
- Notes:
1. V<sub>REF(CA)</sub> DC voltage referenced to V<sub>DD2(DC)</sub>.
  2. V<sub>REF(CA)</sub> step size increment/decrement range. V<sub>REF(CA)</sub> at DC level.
  3.  $V_{REF(CA),new} = V_{REF(CA),old} + n \times V_{REF(CA),step}$ ; n = number of steps; if increment, use "+"; if decrement, use "-".
  4. The minimum value of V<sub>REF(CA)</sub> setting tolerance =  $V_{REF(CA),new} - 1.0\% \times V_{DD2}$ . The maximum value of V<sub>REF(CA)</sub> setting tolerance =  $V_{REF(CA),new} + 1.0\% \times V_{DD2}$ . For n > 4.
  5. The minimum value of V<sub>REF(CA)</sub> setting tolerance =  $V_{REF(CA),new} - 0.10\% \times V_{DD2}$ . The maximum value of V<sub>REF(CA)</sub> setting tolerance =  $V_{REF(CA),new} + 0.10\% \times V_{DD2}$ . For n < 4.
  6. Measured by recording the minimum and maximum values of the V<sub>REF(CA)</sub> output over the range, drawing a straight line between those points and comparing all other V<sub>REF(CA)</sub> output settings to that line.
  7. Measured by recording the minimum and maximum values of the V<sub>REF(CA)</sub> output across four consecutive steps (n = 4), drawing a straight line between those points and comparing all other V<sub>REF(CA)</sub> output settings to that line.
  8. Time from MRW command to increment or decrement one step size for V<sub>REF(CA)</sub>.
  9. Time from MRW command to increment or decrement V<sub>REF,min</sub> to V<sub>REF,max</sub> or V<sub>REF,max</sub> to V<sub>REF,min</sub> change across the V<sub>REF(CA)</sub> range in V<sub>REF</sub> voltage.
  10. Only applicable for DRAM component level test/characterization purposes. Not applicable for normal mode of operation. V<sub>REF</sub> valid is to qualify the step times which will be characterized at the component level.
  11. DRAM range-0 or range-1 set by MR12 OP[6].
  12. Time from MRW command to increment or decrement more than one step size up to a full range of V<sub>REF</sub> voltage within the same V<sub>REF(CA)</sub> range.
  13. Applies when VRCG high current mode is not enabled, specified by MR13 [OP3] = 0b.
  14. t<sub>VREF\_time\_weak</sub> covers all V<sub>REF(CA)</sub> range and value change conditions are applied to t<sub>VREF\_TIME-SHORT/MIDDLE/LONG</sub>.

### V<sub>REF(DQ)</sub> Training

The device's internal V<sub>REF(DQ)</sub> specification parameters are operating voltage range, step size, V<sub>REF</sub> step tolerance, V<sub>REF</sub> step time and V<sub>REF</sub> valid level.

The voltage operating range specifies the minimum required V<sub>REF</sub> setting range for LPDDR4 devices. The minimum range is defined by V<sub>REF,max</sub> and V<sub>REF,min</sub>.

**Figure 101: V<sub>REF</sub> Operating Range (V<sub>REF,max</sub>, V<sub>REF,min</sub>)**

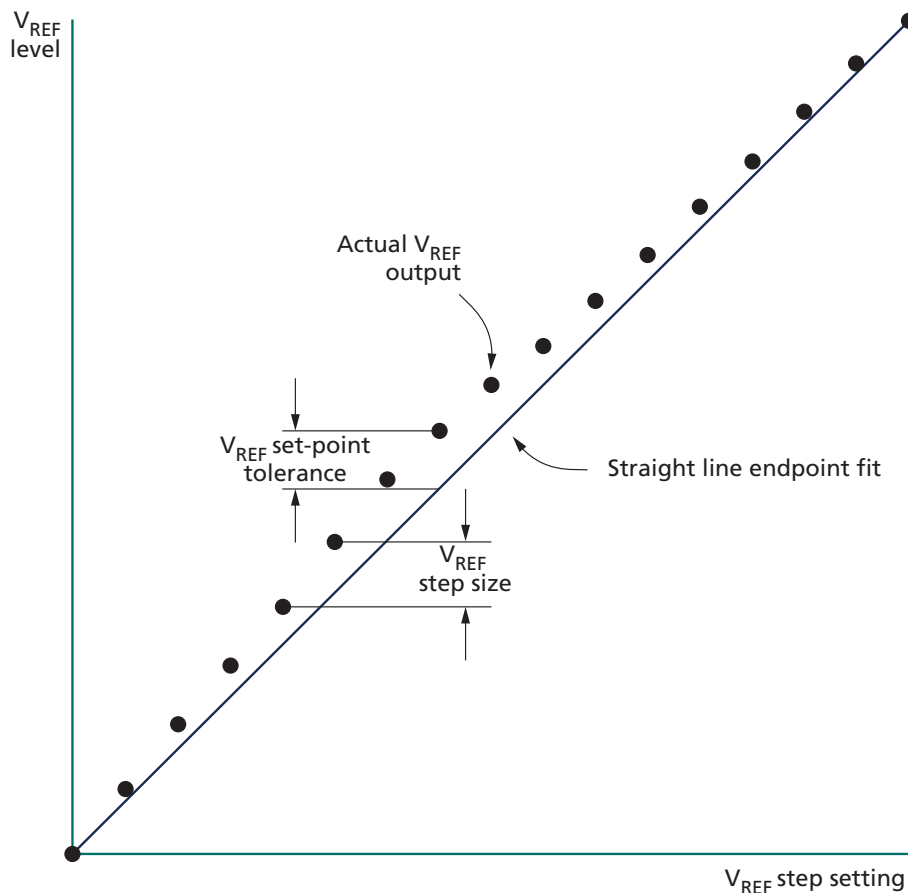


The V<sub>REF</sub> step size is defined as the step size between adjacent steps. However, for a given design, the device has one value for V<sub>REF</sub> step size that falls within the given range.

The V<sub>REF</sub> set tolerance is the variation in the V<sub>REF</sub> voltage from the ideal setting. This accounts for accumulated error over multiple steps. There are two ranges for V<sub>REF</sub> set tolerance uncertainty. The range of V<sub>REF</sub> set tolerance uncertainty is a function of the number of steps *n*.

The V<sub>REF</sub> set tolerance is measured with respect to the ideal line that is based on the two endpoints, where the endpoints are at the minimum and maximum V<sub>REF</sub> values for a specified range.

Figure 102: V<sub>REF</sub> Set Tolerance and Step Size



The V<sub>REF</sub> increment/decrement step times are defined by  $t_{V_{REF\_TIME\_SHORT}}$ ,  $t_{V_{REF\_TIME\_MIDDLE}}$  and  $t_{V_{REF\_TIME\_LONG}}$ . The  $t_{V_{REF\_TIME\_SHORT}}$ ,  $t_{V_{REF\_TIME\_MIDDLE}}$  and  $t_{V_{REF\_TIME\_LONG}}$  times are defined from TS to TE in the following figure where TE is referenced to when the V<sub>REF</sub> voltage is at the final DC level within the V<sub>REF</sub> valid tolerance ( $V_{REFVAL\_TOL}$ ).

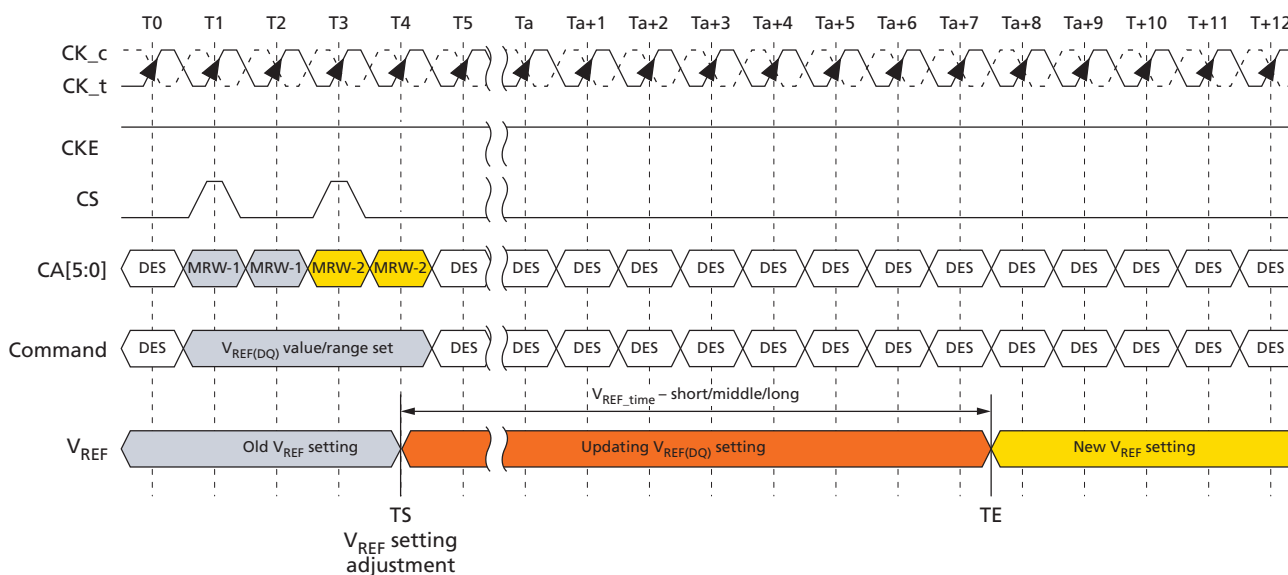
The V<sub>REF</sub> valid level is defined by  $V_{REFVAL\_TOL}$  to qualify the step time TE (see the figure below). This parameter is used to ensure an adequate RC time constant behavior of the voltage level change after any V<sub>REF</sub> increment/decrement adjustment. This parameter is only applicable for DRAM component level validation/characterization.

$t_{V_{REF\_TIME\_SHORT}}$  is for a single step size increment/decrement change in the V<sub>REF</sub> voltage.

$t_{V_{REF\_TIME\_MIDDLE}}$  is at least two step sizes of increment/decrement change in the V<sub>REF(DQ)</sub> range in the V<sub>REF</sub> voltage.

$t_{V_{REF\_TIME\_LONG}}$  is the time including and up to the full range of V<sub>REF</sub> (MIN to MAX or MAX to MIN) across the V<sub>REF(DQ)</sub> range in V<sub>REF</sub> voltage.

**Figure 103: V<sub>REF(DQ)</sub> Transition Time for Short, Middle, or Long Changes**



- Notes: 1. TS is referenced to MRW command clock.  
2. TE is referenced to V<sub>REF,VAL\_TOL</sub>.

The MRW command to the mode register bits are defined as:

MR14 OP[5:0]: V<sub>REF(DQ)</sub> setting

MR14 OP[6]: V<sub>REF(DQ)</sub> range

The minimum time required between two V<sub>REF</sub> MRW commands is t<sub>VREF\_TIME-SHORT</sub> for a single step and t<sub>VREF\_TIME-MIDDLE</sub> for a full voltage range step.

**Figure 104: V<sub>REF(DQ)</sub> Single-Step Size Increment**

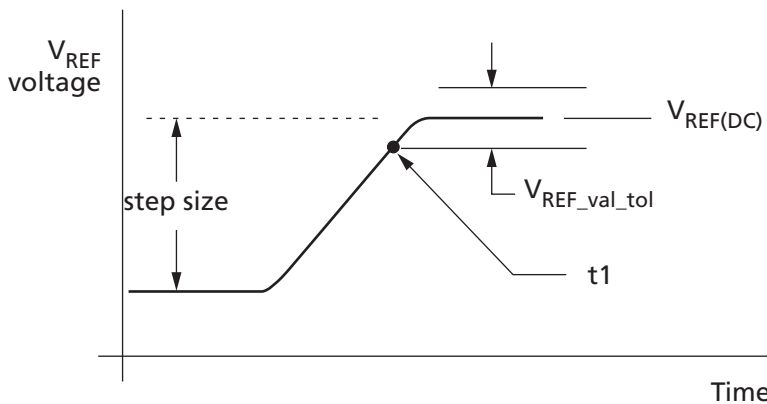


Figure 105: V<sub>REF(DQ)</sub> Single-Step Size Decrement

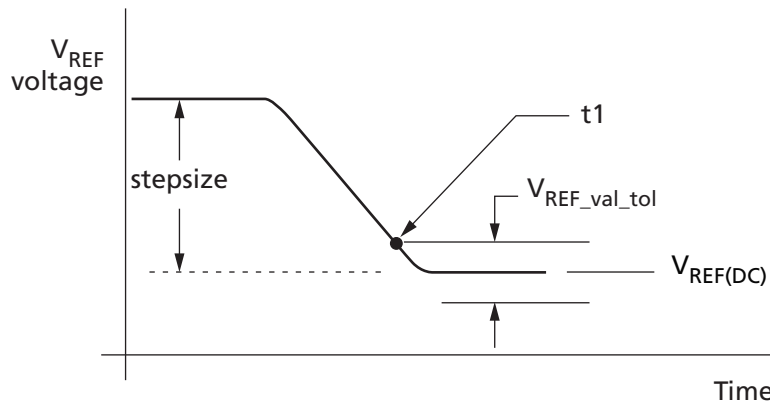


Figure 106: V<sub>REF(DQ)</sub> Full Step from V<sub>REF,min</sub> to V<sub>REF,max</sub>

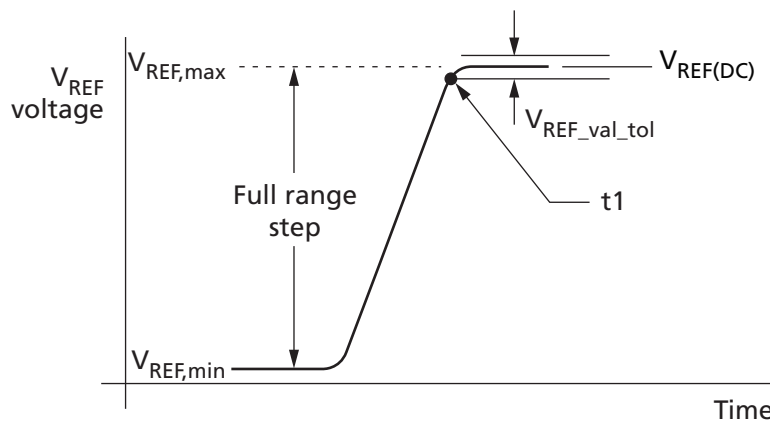
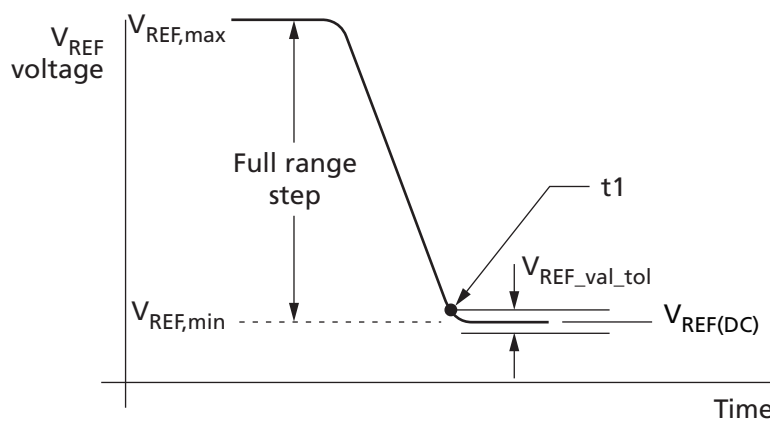


Figure 107: V<sub>REF(DQ)</sub> Full Step from V<sub>REF,max</sub> to V<sub>REF,min</sub>



The following table contains the DQ internal V<sub>REF</sub> specification that will be characterized at the component level for compliance.

**Table 108: Internal V<sub>REF(DQ)</sub> Specifications**

Symbol	Parameter	Min	Typ	Max	Unit	Notes
V <sub>REF(DQ),max_r0</sub>	V <sub>REF</sub> MAX operating point Range-0	–	–	30%	V <sub>DDQ</sub>	1, 11
V <sub>REF(DQ),min_r0</sub>	V <sub>REF</sub> MIN operating point Range-0	10%	–	–	V <sub>DDQ</sub>	1, 11
V <sub>REF(DQ),max_r1</sub>	V <sub>REF</sub> MAX operating point Range-1	–	–	42%	V <sub>DDQ</sub>	1, 11
V <sub>REF(DQ),min_r1</sub>	V <sub>REF</sub> MIN operating point Range-1	22%	–	–	V <sub>DDQ</sub>	1, 11
V <sub>REF(DQ),step</sub>	V <sub>REF(DQ)</sub> step size	0.30%	0.40%	0.50%	V <sub>DDQ</sub>	2
V <sub>REF(DQ),set_tol</sub>	V <sub>REF(DQ)</sub> set tolerance	–1.00%	0.00%	1.00%	V <sub>DDQ</sub>	3, 4, 6
		–0.10%	0.00%	0.10%	V <sub>DDQ</sub>	3, 5, 7
t <sub>VREF_TIME-SHORT</sub>	V <sub>REF(DQ)</sub> step time	–	–	100	ns	8
t <sub>VREF_TIME-MIDDLE</sub>		–	–	200	ns	12
t <sub>VREF_TIME-LONG</sub>		–	–	250	ns	9
t <sub>VREF_time_weak</sub>		–	–	1	ms	13, 14
V <sub>REF(DQ),val_tol</sub>	V <sub>REF(DQ)</sub> valid tolerance	–0.10%	0.00%	0.10%	V <sub>DDQ</sub>	10

- Notes:
1. V<sub>REF(DQ)</sub> DC voltage referenced to V<sub>DDQ(DC)</sub>.
  2. V<sub>REF(DQ)</sub> step size increment/decrement range. V<sub>REF(DQ)</sub> at DC level.
  3.  $V_{REF(DQ),new} = V_{REF(DQ),old} + n \times V_{REF(DQ),step}$ ; n = number of steps; if increment, use "+"; if decrement, use "-".
  4. The minimum value of V<sub>REF(DQ)</sub> setting tolerance =  $V_{REF(DQ),new} - 1.0\% \times V_{DDQ}$ . The maximum value of V<sub>REF(DQ)</sub> setting tolerance =  $V_{REF(DQ),new} + 1.0\% \times V_{DDQ}$ . For n > 4.
  5. The minimum value of V<sub>REF(DQ)</sub> setting tolerance =  $V_{REF(DQ),new} - 0.10\% \times V_{DDQ}$ . The maximum value of V<sub>REF(DQ)</sub> setting tolerance =  $V_{REF(DQ),new} + 0.10\% \times V_{DDQ}$ . For n < 4.
  6. Measured by recording the minimum and maximum values of the V<sub>REF(DQ)</sub> output over the range, drawing a straight line between those points and comparing all other V<sub>REF(DQ)</sub> output settings to that line.
  7. Measured by recording the minimum and maximum values of the V<sub>REF(DQ)</sub> output across four consecutive steps (n = 4), drawing a straight line between those points and comparing all other V<sub>REF(DQ)</sub> output settings to that line.
  8. Time from MRW command to increment or decrement one step size for V<sub>REF(DQ)</sub>.
  9. Time from MRW command to increment or decrement V<sub>REF,min</sub> to V<sub>REF,max</sub> or V<sub>REF,max</sub> to V<sub>REF,min</sub> change across the V<sub>REF(DQ)</sub> Range in V<sub>REF(DQ)</sub> Voltage.
  10. Only applicable for DRAM component level test/characterization purposes. Not applicable for normal mode of operation. V<sub>REF</sub> valid is to qualify the step times which will be characterized at the component level.
  11. DRAM range-0 or range-1 set by MR14 OP[6].
  12. Time from MRW command to increment or decrement more than one step size up to a full range of V<sub>REF</sub> voltage within the same V<sub>REF(DQ)</sub> range.
  13. Applies when VRCG high current mode is not enabled, specified by MR13 [OP3] = 0.
  14. t<sub>VREF\_time\_weak</sub> covers all V<sub>REF(DQ)</sub> Range and Value change conditions are applied to t<sub>VREF\_TIME-SHOR/MIDDLE/LONG</sub>.

## Command Bus Training

### Command Bus Training Mode

The command bus must be trained before enabling termination for high-frequency operation. The device provides an internal  $V_{REF(CA)}$  that defaults to a level suitable for un-terminated, low-frequency operation, but the  $V_{REF(CA)}$  must be trained to achieve suitable receiver voltage margin for terminated, high-frequency operation.

The training mode described here centers the internal  $V_{REF(CA)}$  in the CA data eye and at the same time allows for timing adjustments of the CS and CA signals to meet setup/hold requirements. Because it can be difficult to capture commands prior to training the CA inputs, the training mode described here uses a minimum of external commands to enter, train, and exit the CA bus training mode.

The die has a bond-pad (ODT\_CA) to control the command bus termination for multi-rank operation. Other mode register bits are provided to fine tune termination control in a variety of system configuration. See On-Die Termination for more information.

The device uses frequency set points to enable multiple operating settings for the die. The device defaults to FSP-OP[0] at power-up, which has the default settings to operate in un-terminated, low-frequency environments. Prior to training, the termination should be enabled for one die in each channel by setting MR13 OP[6] = 1b (FSP-WR[1]) and setting all other mode register bits for FSP-OP[1] to the desired settings for high-frequency operation. Upon training entry, the device will automatically switch to FSP-OP[1] and use the high-frequency settings during training (See the Command Bus Training Entry Timing figure for more information on FSP-OP register sets). Upon training exit, the device will automatically switch back to FSP-OP[0], returning to a "known-good" state for un-terminated, low-frequency operation.

To enter command bus training mode, issue a MRW-1 command followed by a MRW-2 command to set MR13 OP[0] = 1b (command bus training mode enabled).

After time  $t_{MRD}$ , CKE may be set LOW, causing the device to switch to FSP-OP[1], and completing the entry into command bus training mode.

A status DQS\_t, DQS\_c, DQ, and DMI are as noted below; the DQ ODT state will be followed by FREQUENCY SET POINT function except in the case of output pins.

- DQS\_t[0], DQS\_c[0] become input pins for capturing DQ[6:0] levels by toggling.
- DQ[5:0] become input pins for setting  $V_{REF(CA)}$  level.
- DQ[6] becomes an input pin for setting  $V_{REF(CA)}$  range.
- DQ[7] and DMI[0] become input pins, and their input level is valid or floating.
- DQ[13:8] become output pins to feedback, capturing value via the command bus using the CS signal.
- DQS\_t[1], DQS\_c[1], DMI[1], and DQ[15:14] become output pins or are disabled, meaning the device may be driven to a valid level or may be left floating.

At time  $t_{CAENT}$  later, the device may change its  $V_{REF(CA)}$  range and value using input signals DQS\_t[0], DQS\_c[0], and DQ[6:0] from existing value that is set via MR12 OP[6:0]. The mapping between MR12 OP code and DQs is shown below. At least one  $V_{REF(CA)}$  setting is required before proceeding to the next training step.



**Table 109: Mapping MR12 Op Code and DQ Numbers**

	Mapping						
MR12 OP code	OP6	OP5	OP4	OP3	OP2	OP1	OP0
DQ number	DQ6	DQ5	DQ4	DQ3	DQ2	DQ1	DQ0

The new  $V_{REF(CA)}$  value must "settle" for time  $t_{VREFCA\_Long}$  before attempting to latch CA information.

**Note:** If DQ ODT is enabled in MR11-OP[2:0], then the SDRAM will terminate the DQ lanes during command bus training when entering  $V_{REF(CA)}$  range and values on DQ[6:0].

To verify that the receiver has the correct  $V_{REF(CA)}$  setting, and to further train the CA eye relative to clock (CK), values latched at the receiver on the CA bus are asynchronously output to the DQ bus.

To exit command bus training mode, drive CKE HIGH, and after time  $t_{VREFCA\_Long}$ , issue the MRW-1 command followed by the MRW-2 command to set MR13 OP[0] = 0b. After time  $t_{MRW}$ , the device is ready for normal operation. After training exit, the device will automatically switch back to the FSP-OP registers that were in use prior to training.

Command bus training (CBT) may be executed from the idle or self refresh state. When executing CBT within the self refresh state, the device must not be in a power-down state (for example, CKE must be HIGH prior to training entry). CBT entry and exit is the same, regardless of the state from which CBT is initiated.

## Training Sequence for Single-Rank Systems

The sequence example shown here assumes an initial low-frequency, non-terminating operating point training a high-frequency, terminating operating point. The **bold text** shows high-frequency instructions. Any operating point may be trained from any known good operating point.

1. Set MR13 OP[6] = 1b to enable writing to frequency set point 1 (FSP-WR[1]) (or FSP-OP[0]).
2. Write FSP-WR[1] (or FSP-WR[0]) registers for all channels to set up high-frequency operating parameters.
3. Issue MRW-1 and MRW-2 commands to enter command bus training mode.
4. Drive CKE LOW, **and change CK frequency to the high-frequency operating point.**
5. **Perform command bus training ( $V_{REF(CA)}$ , CS, and CA).**
6. **Exit training by driving CKE HIGH**, change CK frequency to the low-frequency operating point, and issue MRW-1 and MRW-2 commands. When CKE is driven HIGH, the device will automatically switch back to the FSP-OP registers that were in use prior to training (trained values are not retained).
7. Write the trained values to FSP-WR[1] (or FSP-WR[0]) by issuing MRW-1 and MRW-2 commands to the SDRAM and setting all applicable mode register parameters.
8. Issue MRW-1 and MRW-2 commands to switch the terminating rank to FSP-OP[1] (or FSP-OP[0]), to turn on termination, **and change CK frequency to the high-frequency operating point. At this point the command bus is trained and you may proceed to other training or normal operation.**

## Training Sequence for Multiple-Rank Systems

The sequence example shown here is assuming an initial low-frequency operating point, training a high-frequency operating point. The **bold text** shows high-frequency instructions. Any operating point may be trained from any known good operating point.

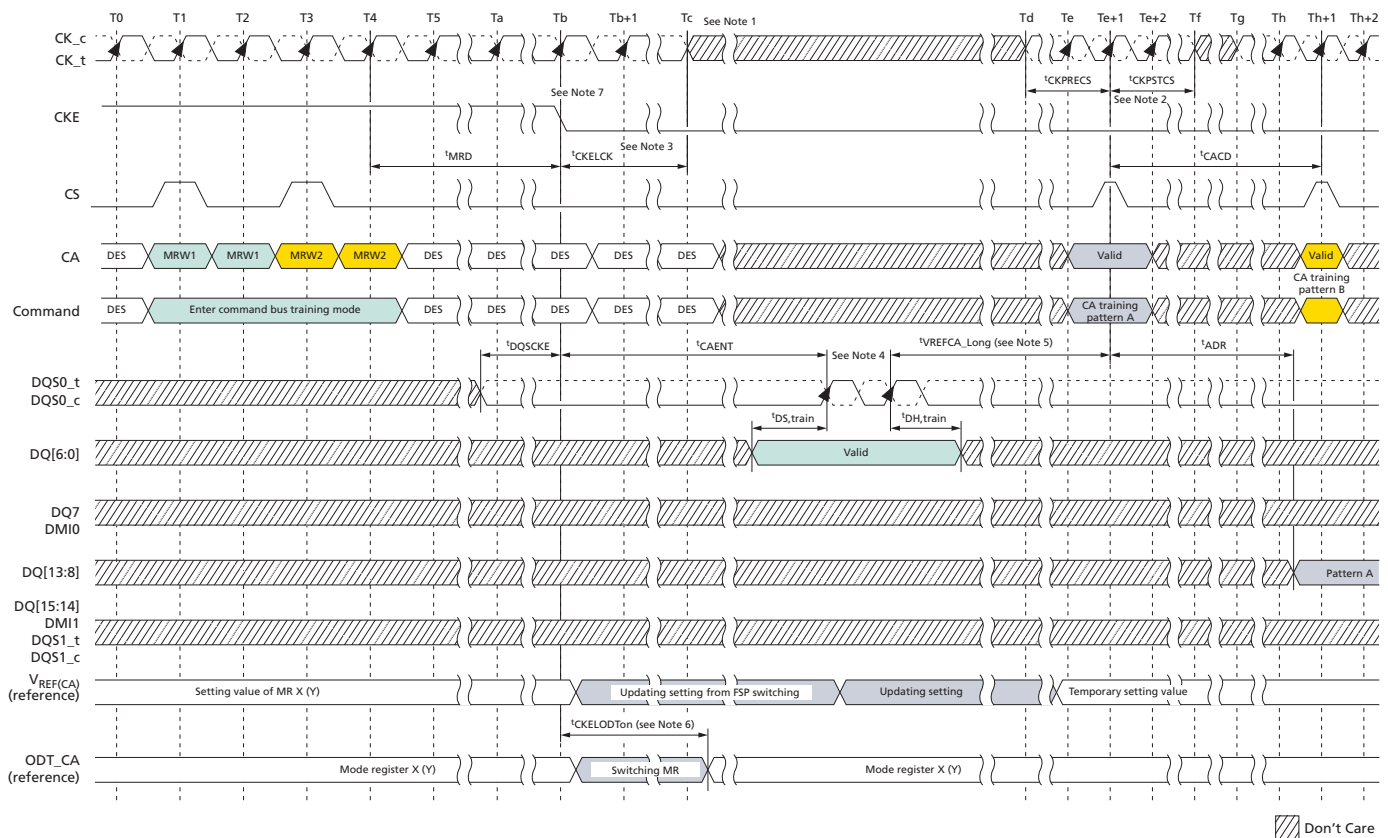
1. Set MR13 OP[6] = 1b to enable writing to frequency set point 1 (FSP-WR[1]) (or FSP-WR[0]).
2. Write FSP-WR[1] (or FSP-WR[0]) registers for all channels and ranks to set up high-frequency operating parameters.
3. Read MR0 OP[7] on all channels and ranks to determine which die are terminating, signified by MR0 OP[7] = 1b.
4. Issue MRW-1 and MRW-2 commands to enter command bus training mode on the terminating rank.
5. Drive CKE LOW on the terminating rank (or all ranks), **and change CK frequency to the high-frequency operating point.**
6. **Perform command bus training on the terminating rank ( $V_{REF(CA)}$ , CS, and CA).**
7. **Exit training by driving CKE HIGH**, change CK frequency to the low-frequency operating point, and issue MRW-1 and MRW-2 commands to write the trained values to FSP-WR[1] (or FSP-WR[0]). When CKE is driven HIGH, the SDRAM will automatically switch back to the FSP-OP registers that were in use prior to training (trained values are not retained by the device).
8. Issue MRW-1 and MRW-2 commands to enter training mode on the non-terminating rank (but keep CKE HIGH).
9. Issue MRW-1 and MRW-2 commands to switch the terminating rank to FSP-OP[1] (or FSP-OP[0]), to turn on termination, **and change CK frequency to the high-frequency operating point.**
10. **Drive CKE LOW on the non-terminating (or all) ranks. The non-terminating rank(s) will now be using FSP-OP[1] (or FSP-OP[0]).**
11. **Perform command bus training on the non-terminating rank ( $V_{REF(CA)}$ , CS, and CA).**
12. **Issue MRW-1 and MRW-2 commands to switch the terminating rank to FSP-OP[0] (or FSP-OP[1]) to turn off termination.**
13. **Exit training by driving CKE HIGH on the non-terminating rank**, change CK frequency to the low-frequency operating point, and issue MRW-1 and MRW-2 commands. When CKE is driven HIGH, the device will automatically switch back to the FSP-OP registers that were in use prior to training (that is, trained values are not retained by the device).
14. Write the trained values to FSP-WR[1] (or FSP-WR[0]) by issuing MRW-1 and MRW-2 commands and setting all applicable mode register parameters.
15. Issue MRW-1 and MRW-2 commands to switch the terminating rank to FSP-OP[1] (or FSP-OP[0]), to turn on termination, **and change CK frequency to the high-frequency operating point. At this point the command bus is trained for both ranks and the user may proceed to other training or normal operation.**

## Relation Between CA Input Pin and DQ Output Pin

Table 110: Mapping of CA Input Pin and DQ Output Pin

	Mapping					
CA number	CA5	CA4	CA3	CA2	CA1	CA0
DQ number	DQ13	DQ12	DQ11	DQ10	DQ9	DQ8

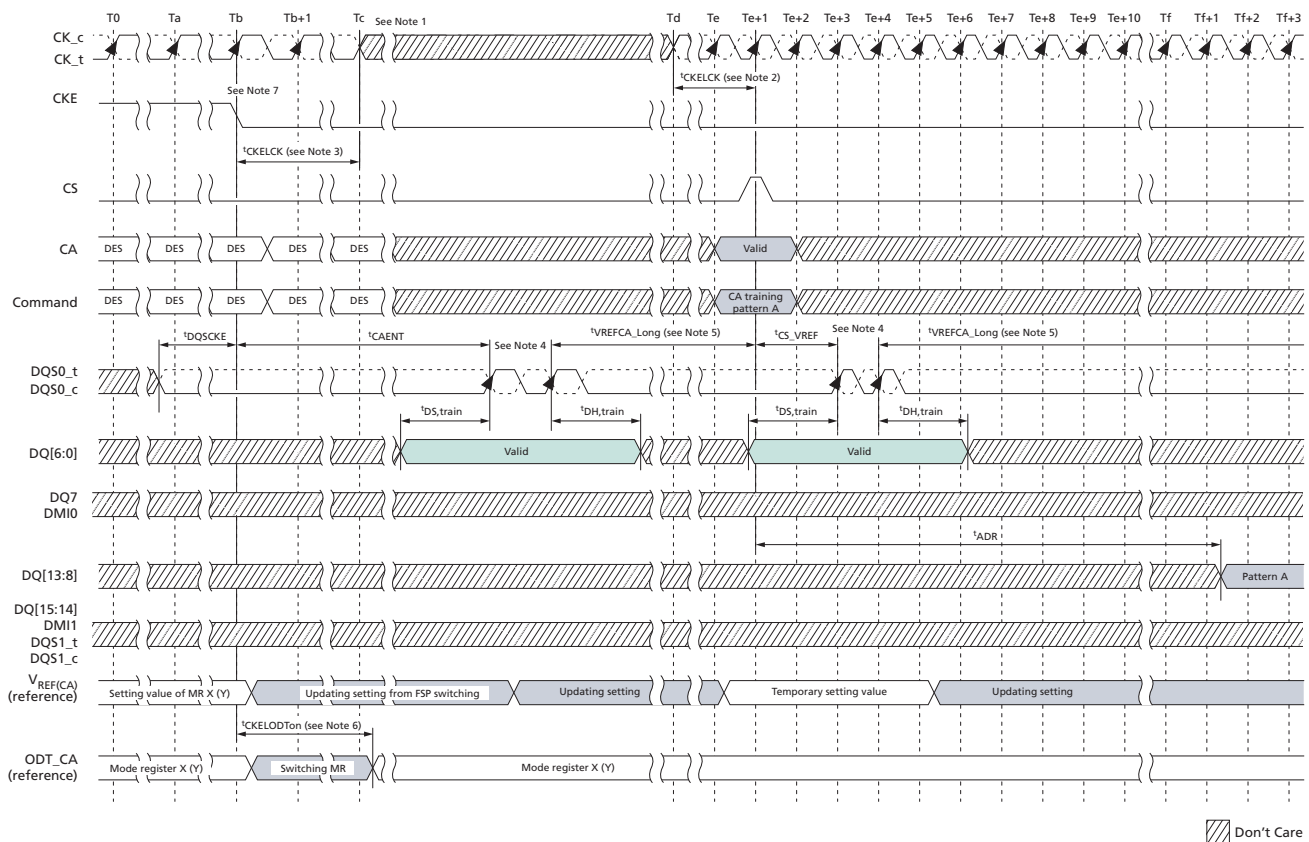
Figure 108: Command Bus Training Mode Entry – CA Training Pattern I/O with  $V_{REF(CA)}$  Value Update



- Notes:
1. After  $t_{CKELCK}$ , the clock can be stopped or the frequency changed any time.
  2. The input clock condition should be satisfied  $t_{CKPRECS}$  and  $t_{CKPSTCS}$ .
  3. Continue to drive CK, and hold CA and CS LOW, until  $t_{CKELCK}$  after CKE is LOW (which disables command decoding).
  4. The device may or may not capture the first rising edge of DQS<sub>t</sub>/DQS<sub>c</sub> due to an unstable first rising edge. Therefore, at least two consecutive pulses of DQS signal input is required every for DQS input signal while capturing DQ[6:0] signals. The captured value of the DQ[6:0] signal level by each DQS edge may be overwritten at any time and the device will temporarily update the  $V_{REF(CA)}$  setting of MR12 after time  $t_{VREFCA\_Long}$ .
  5.  $t_{VREFCA\_Long}$  may be reduced to  $t_{VREFCA\_Short}$  if the following conditions are met: 1) The new  $V_{REF}$  setting is a single step above or below the old  $V_{REF}$  setting; 2) The DQS pulses a single time, or the new  $V_{REF}$  setting value on DQ[6:0] is static and meets  $t_{DS,train}/t_{DH,train}$  for every DQS pulse applied.

- When CKE is driven LOW, the device will switch its FSP-OP registers to use the alternate (non-active) set. For example, if the device is currently using FSP-OP[0], then it will switch to FSP-OP[1] when CKE is driven LOW. All operating parameters should be written to the alternate mode registers before entering command bus training to ensure that ODT settings, RL/WL/nWR setting, and so forth, are set to the correct values. If the alternate FSP-OP has ODT\_CA disabled, then termination will not be enabled in command bus training mode. If the ODT\_CA pad is bonded to  $V_{SS}$  or floating, ODT\_CA termination will never enable for that die.
- When CKE is driven LOW in command bus training mode, the device will change operation to the alternate FSP, that is, the inverse of the FSP programmed in the FSP-OP mode register.

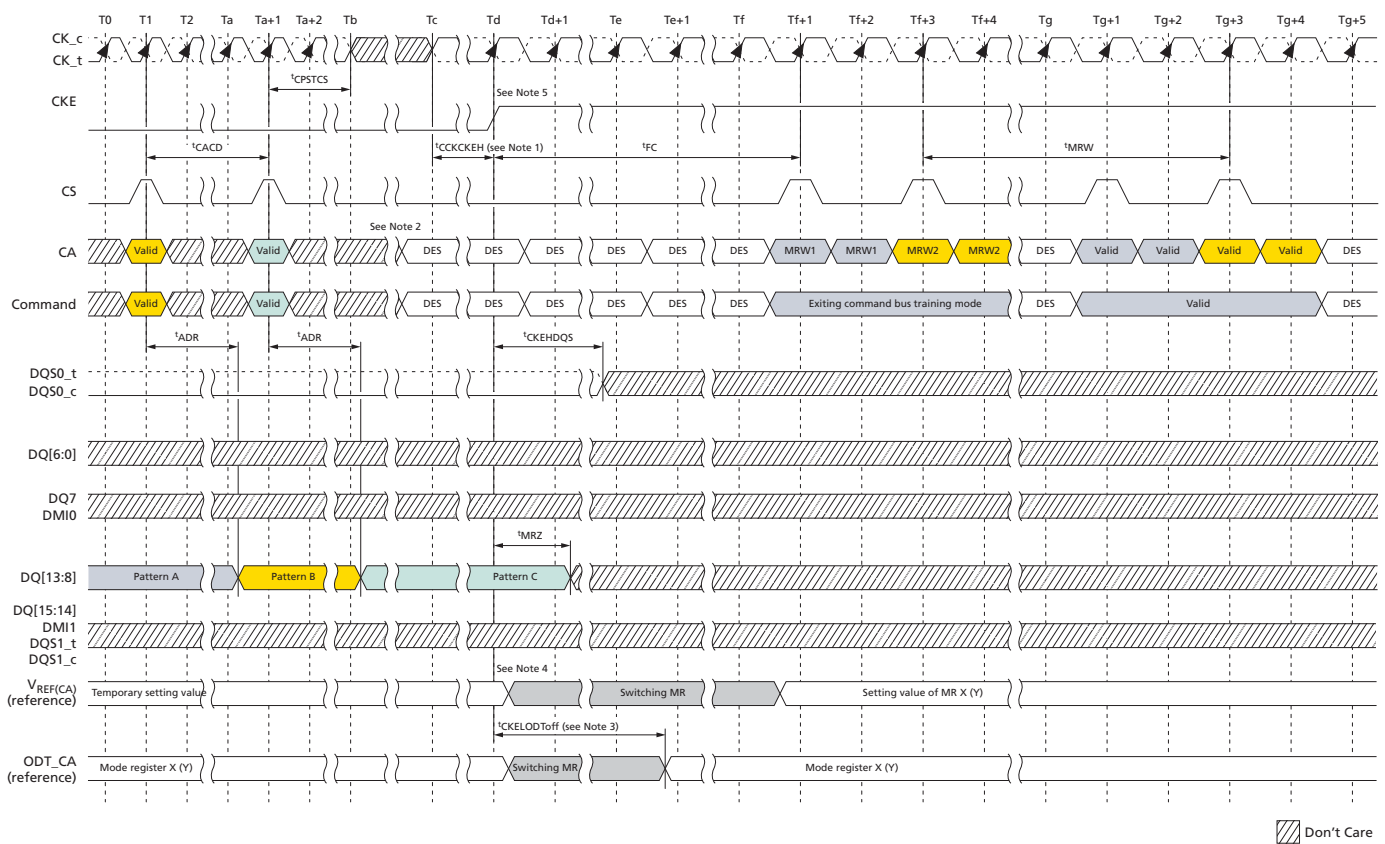
**Figure 109: Consecutive  $V_{REF(CA)}$  Value Update**



- Notes:
- After  $t_{CKELCK}$ , the clock can be stopped or the frequency changed any time.
  - The input clock condition should be satisfied  $t_{CKPRECS}$  and  $t_{CKPSTCS}$ .
  - Continue to drive CK, and hold CA and CS LOW, until  $t_{CKELCK}$  after CKE is LOW (which disables command decoding).
  - The device may or may not capture the first rising edge of DQS<sub>t</sub>/DQS<sub>c</sub> due to an unstable first rising edge. Therefore, at least two consecutive pulses of DQS signal input is required every for DQS input signal while capturing DQ[6:0] signals. The captured value of the DQ[6:0] signal level by each DQS edge may be overwritten at any time and the device will temporarily update the  $V_{REF(CA)}$  setting of MR12 after time  $t_{VREFCA\_Long}$ .
  - $t_{VREFCA\_Long}$  may be reduced to  $t_{VREFCA\_Short}$  if the following conditions are met: 1) The new  $V_{REF}$  setting is a single step above or below the old  $V_{REF}$  setting; 2) The DQS

- pulses a single time, or the new  $V_{REF}$  setting value on DQ[6:0] is static and meets  $t_{DS,train} / t_{DH,train}$  for every DQS pulse applied.
- When CKE is driven LOW, the device will switch its FSP-OP registers to use the alternate (non-active) set. For example, if the device is currently using FSP-OP[0], then it will switch to FSP-OP[1] when CKE is driven LOW. All operating parameters should be written to the alternate mode registers before entering command bus training to ensure that ODT settings, RL/WL/nWR setting, and so forth, are set to the correct values. If the alternate FSP-OP has ODT\_CA disabled, then termination will not be enabled in command bus training mode. If the ODT\_CA pad is bonded to  $V_{SS}$  or floating, ODT\_CA termination will never enable for that die.
  - When CKE is driven LOW in command bus training mode, the device will change operation to the alternate FSP, that is, the inverse of the FSP programmed in the FSP-OP mode register.

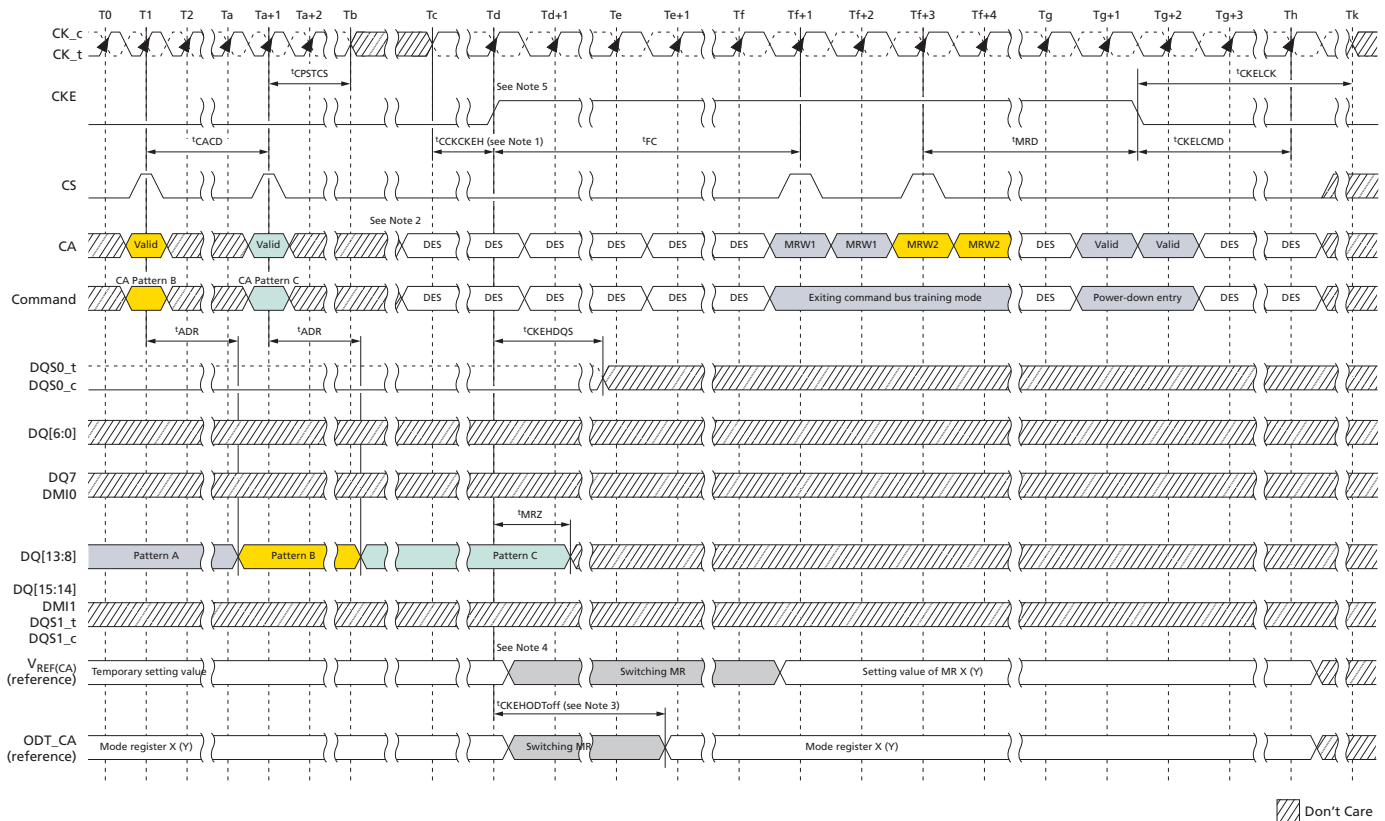
**Figure 110: Command Bus Training Mode Exit with Valid Command**



- Notes:
- The clock can be stopped or the frequency changed any time before  $t_{CKCKEH}$ . CK must meet  $t_{CKCKEH}$  before CKE is driven HIGH. When CKE is driven HIGH, the clock frequency must be returned to the original frequency (that is, the frequency corresponding to the FSP at command bus training mode entry).
  - CS and CA[5:0] must be deselected (LOW)  $t_{CKCKEH}$  before CKE is driven HIGH.
  - When CKE is driven HIGH, ODT\_CA will revert to the state/value defined by FSP-OP prior to command bus training mode entry, that is, the original frequency set point (FSP-OP, MR13-OP[7]). For example, if the device was using FSP-OP[1] for training, then it will switch to FSP-OP[0] when CKE is driven HIGH.

4. Training values are not retained by the device and must be written to the FSP-OP register set before returning to operation at the trained frequency. For example,  $V_{REF(CA)}$  will return to the value programmed in the original set point.
5. When CKE is driven HIGH, the device will revert to the FSP in operation at command bus training mode entry.

**Figure 111: Command Bus Training Mode Exit with Power-Down Entry**



- Notes:
1. The clock can be stopped or the frequency changed any time before  $t_{CKCKEH}$ . CK must meet  $t_{CKCKEH}$  before CKE is driven HIGH. When CKE is driven HIGH, the clock frequency must be returned to the original frequency (that is, the frequency corresponding to the FSP at command bus training mode entry).
  2. CS and CA[5:0] must be deselected (LOW)  $t_{CKCKEH}$  before CKE is driven HIGH.
  3. When CKE is driven HIGH, ODT\_CA will revert to the state/value defined by FSP-OP prior to command bus training mode entry, that is, the original frequency set point (FSP-OP, MR13-OP[7]). For example, if the device was using FSP-OP[1] for training, then it will switch to FSP-OP[0] when CKE is driven HIGH.
  4. Training values are not retained by the device and must be written to the FSP-OP register set before returning to operation at the trained frequency. For example,  $V_{REF(CA)}$  will return to the value programmed in the original set point.
  5. When CKE is driven HIGH, the device will revert to the FSP in operation at command bus training mode entry.

## Write Leveling

### Mode Register Write-WR Leveling Mode

To improve signal-integrity performance, the device provides a write leveling feature to compensate for CK-to-DQS timing skew, affecting timing parameters such as  $t_{DQSS}$ ,  $t_{DSS}$ , and  $t_{DSH}$ . The memory controller uses the write leveling feature to receive feedback from the device, enabling it to adjust the clock-to-data strobe signal relationship for each DQS<sub>t</sub>/DQS<sub>c</sub> signal pair. The device samples the clock state with the rising edge of DQS signals and asynchronously feeds back to the memory controller. The memory controller references this feedback to adjust the clock-to-data strobe signal relationship for each DQS<sub>t</sub>/DQS<sub>c</sub> signal pair.

All data bits (DQ[7:0] for DQS[0] and DQ[15:8] for DQS[1]) carry the training feedback to the controller. Both DQS signals in each channel must be leveled independently. Write leveling entry/exit is independent between channels for dual channel devices.

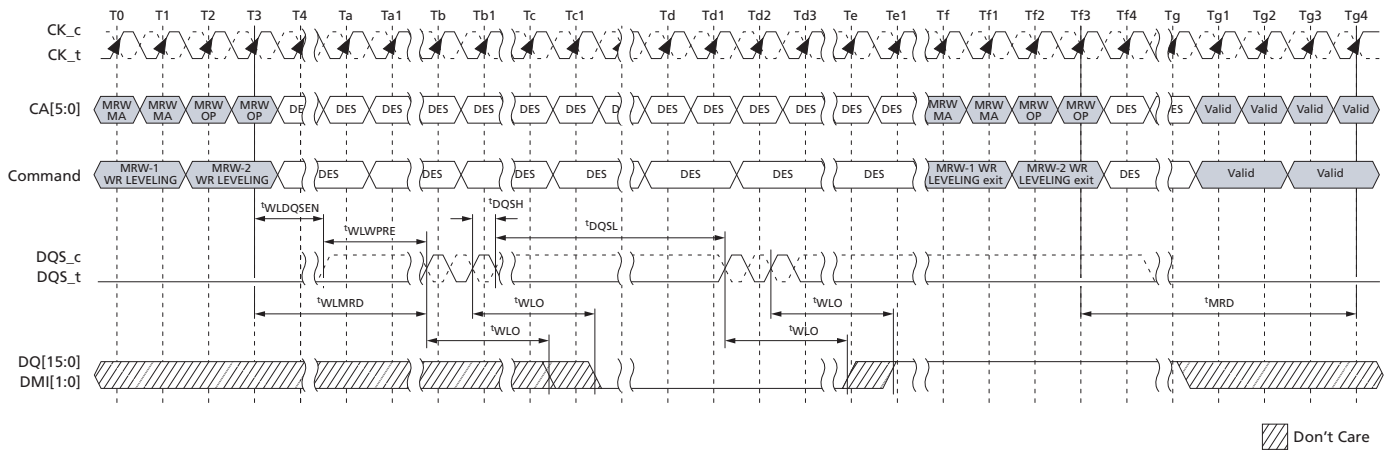
The device enters write leveling mode when mode register MR2-OP[7] is set HIGH. When entering write leveling mode, the state of the DQ pins is undefined. During write leveling mode, only DESELECT commands, or a MRW command to exit the WRITE LEVELING operation, are allowed. Depending on the absolute values of  $t_{QSL}$  and  $t_{QSH}$  in the application, the value of  $t_{DQSS}$  may have to be better than the limits provided in the AC Timing Parameters section in order to satisfy the  $t_{DSS}$  and  $t_{DSH}$  specifications. Upon completion of the WRITE LEVELING operation, the device exits write leveling mode when MR2-OP[7] is reset LOW.

Write leveling should be performed before write training (DQS2DQ training).

### Write Leveling Procedure

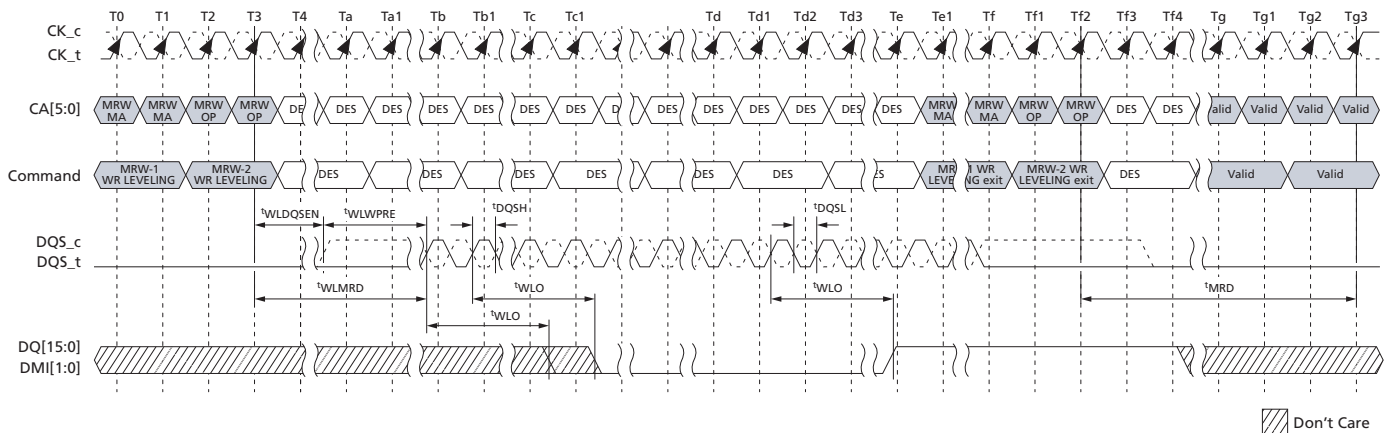
1. Enter write leveling mode by setting MR2-OP[7]=1.
2. Once in write leveling mode, DQS<sub>t</sub> must be driven LOW and DQS<sub>c</sub> HIGH after a delay of  $t_{WLDQSEN}$ .
3. Wait for a time  $t_{WLDQSEN}$  before providing the first DQS signal input. The delay time  $t_{WLMRD}(MAX)$  is controller-dependent.
4. The device may or may not capture the first rising edge of DQS<sub>t</sub> due to an unstable first rising edge; therefore, at least two consecutive pulses of DQS signal input is required for every DQS input signal during write training mode. The captured clock level for each DQS edge is overwritten, and the device provides asynchronous feedback on all DQ bits after time  $t_{WLO}$ .
5. The feedback provided by the device is referenced by the controller to increment or decrement the DQS<sub>t</sub> and/or DQS<sub>c</sub> delay settings.
6. Repeat steps 4 and 5 until the proper DQS<sub>t</sub>/DQS<sub>c</sub> delay is established.
7. Exit write leveling mode by setting MR2-OP[7] = 0.

Figure 112: Write Leveling Timing –  $t_{DQSL}$  (MAX)



Note: 1. Clock can be stopped except during DQS toggle period ( $CK_t = \text{LOW}$ ,  $CK_c = \text{HIGH}$ ).  
However, a stable clock prior to sampling is required to ensure timing accuracy.

Figure 113: Write Leveling Timing –  $t_{DQSL}$  (MIN)



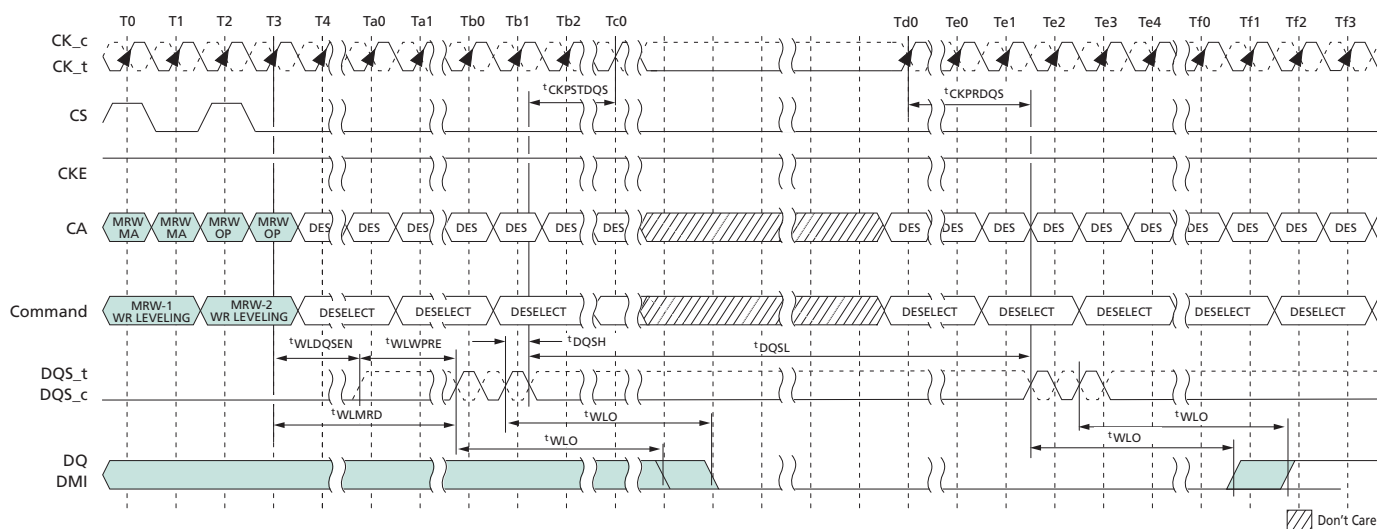
Note: 1. Clock can be stopped except during DQS toggle period ( $CK_t = \text{LOW}$ ,  $CK_c = \text{HIGH}$ ).  
However, a stable clock prior to sampling is required to ensure timing accuracy.

### Input Clock Frequency Stop and Change

The input clock frequency can be stopped or changed from one stable clock rate to another stable clock rate during write leveling mode. The frequency stop or change timing is shown below.



Figure 114: Clock Stop and Timing During Write Leveling



- Notes: 1. CK\_t is held LOW and CK\_c is held HIGH during clock stop.  
2. CS will be held LOW during clock stop.

Table 111: Write Leveling Timing Parameters

Parameter	Symbol	Min/Max	Value	Units
DQS_t/DQS_c delay after write leveling mode is programmed	tWLDQSEN	MIN	20	tCK
		MAX	–	
Write preamble for write leveling	tWLWPRE	MIN	20	tCK
		MAX	–	
First DQS_t/DQS_c edge after write leveling mode is programmed	tWLMRD	MIN	40	tCK
		MAX	–	
Write leveling output delay	tWLO	MIN	0	ns
		MAX	20	
MODE REGISTER SET command delay	tMRD	MIN	MAX (14ns, 10nCK)	ns
		MAX	–	
Valid clock requirement before DQS toggle	tCKPRDQS	MIN	MAX (7.5ns, 4nCK)	–
		MAX	–	
Valid clock requirement after DQS toggle	tCKPSTDQS	MIN	MAX (7.5ns, 4nCK)	–
		MAX	–	

Table 112: Write Leveling Setup and Hold Timing

Parameter	Symbol	Min/Max	Data Rate					Unit
			1600	2400	3200	3733	4267	
Write leveling hold time	tWLH	MIN	150	100	75	62.5	50	ps

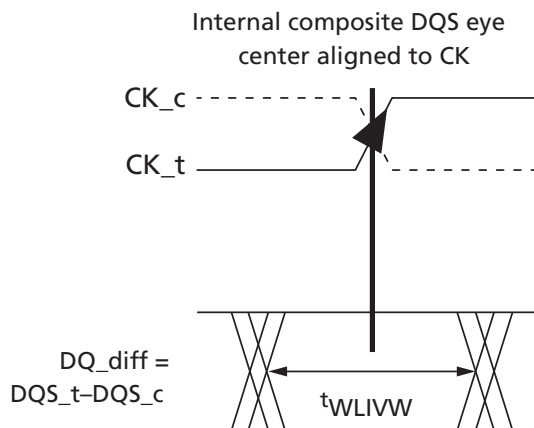
**Table 112: Write Leveling Setup and Hold Timing (Continued)**

Parameter	Symbol	Min/Max	Data Rate					Unit
			1600	2400	3200	3733	4267	
Write leveling setup time	$t^{\text{WLS}}$	MIN	150	100	75	62.5	50	ps
Write leveling input valid window	$t^{\text{WLIVW}}$	MIN	240	160	120	105	90	ps

- Notes:
1. In addition to the traditional setup and hold time specifications, there is value in a invalid window-based specification for write leveling training. As the training is based on each device, worst case process skews for setup and hold do not make sense to close timing between CK and DQS.
  2.  $t^{\text{WLIVW}}$  is defined in a similar manner to  $TdIVW_{\text{total}}$ , except that here it is a DQS invalid window with respect to CK. This would need to account for all voltage and temperature (VT) drift terms between CK and DQS within the device that affect the write leveling invalid window.

The figure below shows the DQS input mask for timing with respect to CK. The “total” mask ( $t^{\text{WLIVW}}$ ) defines the time the input signal must not encroach in order for the DQS input to be successfully captured by CK. The mask is a receiver property and it is not the valid data-eye.

**Figure 115: DQS\_t/DQS\_c to CK\_t/CK\_c Timings at the Pins Referenced from the Internal Latch**



## MULTIPURPOSE Operation

The device uses the MULTIPURPOSE command to issue a NO OPERATION (NOP) command 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 SDRAM. OP[6] is a special bit that is decoded on the first rising CK edge of the MPC command. When OP[6] = 0, the device executes a NOP command, and when OP[6] = 1, the device further decodes one of several training commands.



When OP[6] = 1 and 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, 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 a typical 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 commands do not require a CAS-2 command, including the following:

- NOP
- START DQS OSCILLATOR
- STOP DQS OSCILLATOR
- ZQCAL START
- ZQCAL LATCH

**Table 113: MPC Command Definition**

SDR Command	SDR Command Pins		SDR CA Pins							CK_t Edge	Notes
	CKE		CS	CA0	CA1	CA2	CA3	CA4	CA5		
	CK_t (n-1)	CK_t(n)									
MPC (Train, NOP)	H	H	H	L	L	L	L	L	OP6		1, 2
			L	OP0	OP1	OP2	OP3	OP4	OP5		

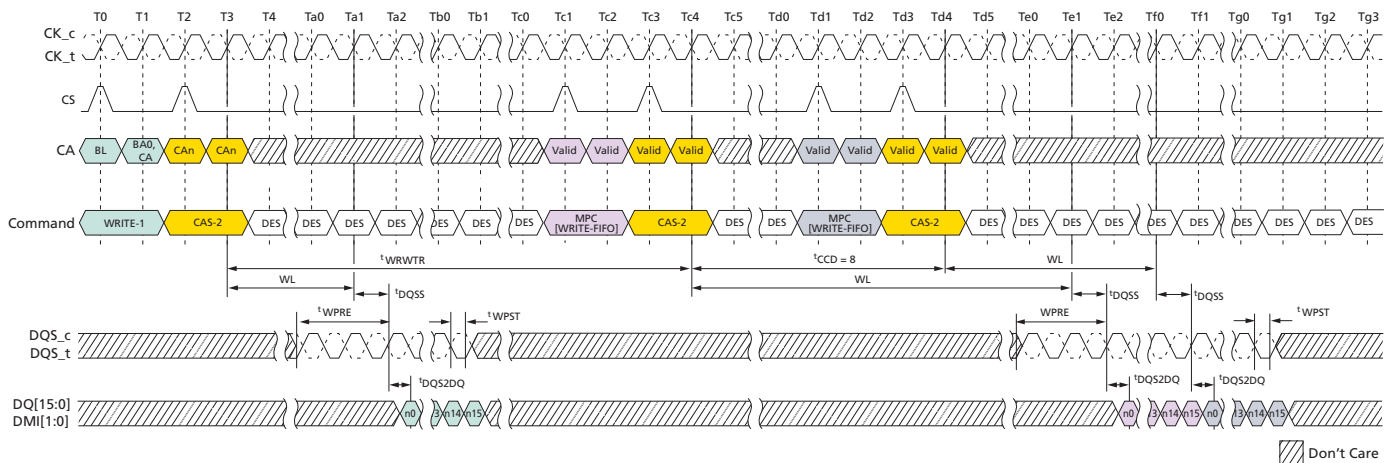
- Notes:
1. See the Command Truth Table for more information.
  2. MPC commands for READ or WRITE TRAINING operations must be immediately followed by the CAS-2 command, consecutively, without any other commands in between. The MPC command must be issued before issuing the CAS-2 command.

**Table 114: MPC Commands**

Function	Operand	Data
Training Modes	OP[6:0]	<b>0XXXXXXb:</b> NOP <b>1000001b:</b> READ-FIFO: READ-FIFO supports only BL16 operation <b>1000011b:</b> READ DQ CALIBRATION (MR32/MR40) <b>100101b:</b> RFU <b>100111b:</b> WRITE-FIFO: WRITE-FIFO supports only BL16 operation <b>1001001b:</b> RFU <b>1001011b:</b> START DQS OSCILLATOR <b>1001101b:</b> STOP DQS OSCILLATOR <b>1001111b:</b> ZQCAL START <b>1010001b:</b> ZQCAL LATCH <b>All Others:</b> Reserved

- 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].

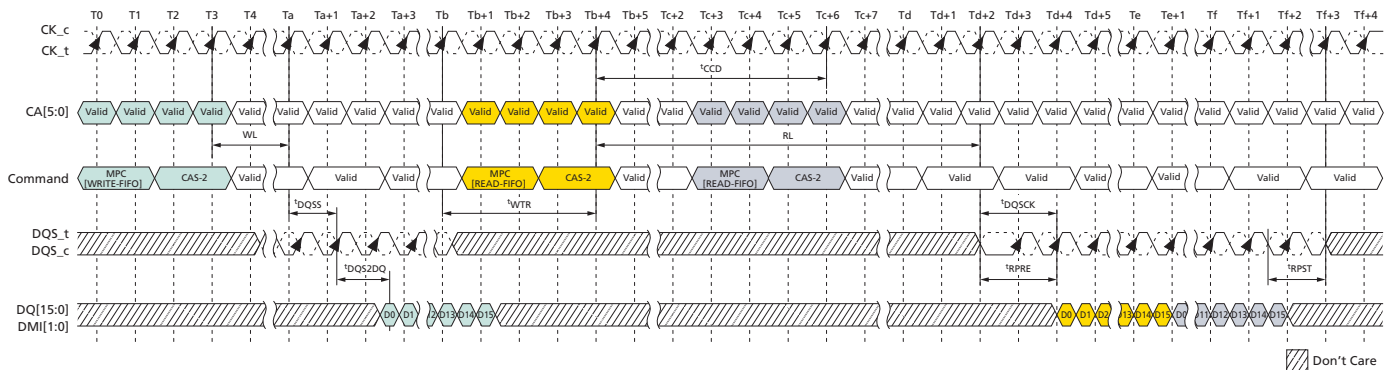
**Figure 116: WRITE-FIFO –  $t_{WRPRE} = 2nCK$ ,  $t_{WPST} = 0.5nCK$**



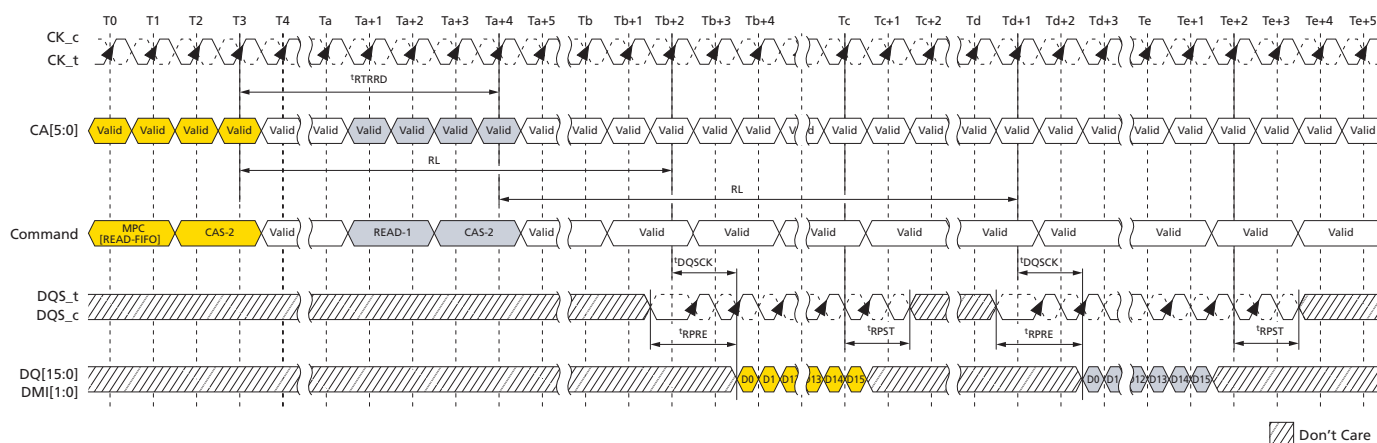
- Notes:
1. MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active, during refresh or during self refresh, with CKE HIGH.
  2. Write-1 to MPC is shown as an example of command-to-command timing for MPC. Timing from Write-1 to MPC[WRITE-FIFO] is  $t_{WRWTR}$ .
  3. Seamless MPC[WRITE-FIFO] commands may be executed by repeating the command every  $t_{CCD}$  time.
  4. MPC[WRITE-FIFO] uses the same command-to-data timing relationship ( $WL$ ,  $t_{DQSS}$ ,  $t_{DQS2DQ}$ ) as a WRITE-1 command.
  5. A maximum of five MPC[WRITE-FIFO] commands may be executed consecutively without corrupting FIFO data. The sixth MPC[WRITE-FIFO] command will overwrite the FIFO data.

- from the first command. If fewer than five MPC[WRITE-FIFO] commands are executed, then the remaining FIFO locations will contain undefined data.
- For the CAS-2 command following an MPC command, the CAS-2 operands must be driven LOW.
  - To avoid corrupting the FIFO contents, MPC[READ-FIFO] must immediately follow MPC[WRITE-FIFO]/CAS-2 without any other commands in-between. See Write Training section for more information on FIFO pointer behavior.

**Figure 117: READ-FIFO –  $t_{WPRE} = 2nCK$ ,  $t_{WPST} = 0.5nCK$ ,  $t_{RPRE} = \text{Toggle}$ ,  $t_{RPST} = 1.5nCK$**



- Notes:
- MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active, during refresh or during self refresh with CKE HIGH.
  - Seamless MPC[READ-FIFO] commands may be executed by repeating the command every  $t_{CCD}$  time.
  - MPC[READ-FIFO] uses the same command-to-data timing relationship (RL,  $t_{DQSK}$ ) as a READ-1 command.
  - Data may be continuously read from the FIFO without any data corruption. After five MPC[READ-FIFO] commands, the FIFO pointer will wrap back to the first FIFO and continue advancing. If fewer than five MPC[WRITE-FIFO] commands were executed, then the MPC[READ-FIFO] commands to those FIFO locations will return undefined data. See Write Training for more information on the FIFO pointer behavior.
  - For the CAS-2 command immediately following an MPC command, the CAS-2 operands must be driven LOW.
  - DMI[1:0] signals will be driven if WR-DBI, RD-DBI, or DM is enabled in the mode registers. See Write Training for more information on DMI behavior.

**Figure 118: READ-FIFO –  $t_{RPRE} = \text{Toggle}$ ,  $t_{RPST} = 1.5nCK$** 


- Notes:
1. MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active, during refresh or during self refresh with CKE HIGH.
  2. MPC[READ-FIFO] to READ-1 operation is shown as an example of command-to-command timing for MPC. Timing from MPC[READ-FIFO] command to read is  $t_{RTRRD}$ .
  3. Seamless MPC[READ-FIFO] commands may be executed by repeating the command every  $t_{CCD}$  time.
  4. MPC[READ-FIFO] uses the same command-to-data timing relationship (RL,  $t_{DQSCK}$ ) as a READ-1 command.
  5. Data may be continuously read from the FIFO without any data corruption. After five MPC[READ-FIFO] commands, the FIFO pointer will wrap back to the first FIFO and continue advancing. If fewer than five MPC[WRITE-FIFO] commands are executed, then the MPC[READ-FIFO] commands to those FIFO locations will return undefined data. See Write Training for more information on the FIFO pointer behavior.
  6. For the CAS-2 command immediately following an MPC command, the CAS-2 operands must be driven LOW.
  7. DMI[1:0] signals will be driven if WR-DBI, RD-DBI, or DM is enabled in the mode registers. See Write Training for more information on DMI behavior.

**Table 115: Timing Constraints for Training Commands**

Previous Command	Next Command	Minimum Delay	Unit	Notes
WR/MWR	MPC[WRITE-FIFO]	$t_{WRWTR}$	nCK	1
	MPC[READ-FIFO]	Not allowed	–	2
	MPC[READ DQ CALIBRATION]	$WL + RU(t_{DQSS}(\text{MAX})/t_{CK}) + BL/2 + RU(t_{WTR}/t_{CK})$	nCK	
RD/MRR	MPC[WRITE-FIFO]	$t_{RTW}$	nCK	4
	MPC[READ-FIFO]	Not allowed	–	2
	MPC[READ DQ CALIBRATION]	$t_{RTRRD}$	nCK	3

**Table 115: Timing Constraints for Training Commands (Continued)**

Previous Command	Next Command	Minimum Delay	Unit	Notes
MPC[WRITE-FIFO]	WR/MWR	Not allowed	–	2
	MPC[WRITE-FIFO]	$t_{CCD}$	nCK	
	RD/MRR	Not allowed	–	2
	MPC[READ-FIFO]	$WL + RU(t_{DQSS(MAX)}/t_{CK}) + BL/2 + RU(t_{WTR}/t_{CK})$	nCK	
	MPC[READ DQ CALIBRATION]	Not allowed	–	2
MPC[READ-FIFO]	WR/MWR	$t_{RTW}$	nCK	4
	MPC[WRITE-FIFO]	$t_{RTW}$	nCK	4
	RD/MRR	$t_{RTRRD}$	nCK	3
	MPC[READ-FIFO]	$t_{CCD}$	nCK	
	MPC[READ DQ CALIBRATION]	$t_{RTRRD}$	nCK	3
MPC[READ DQ CALIBRATION]	WR/MWR	$t_{RTW}$	nCK	4
	MPC[WRITE-FIFO]	$t_{RTW}$	nCK	4
	RD/MRR	$t_{RTRRD}$	nCK	3
	MPC[READ-FIFO]	Not allowed	–	2
	MPC[READ DQ CALIBRATION]	$t_{CCD}$	nCK	

- Notes:
- $t_{WRWTR} = WL + BL/2 + RU(t_{DQSS(MAX)}/t_{CK}) + \text{MAX}(RU(7.5ns/t_{CK}), 8nCK)$ .
  - No commands are allowed between MPC[WRITE-FIFO] and MPC[READ-FIFO] except the MRW commands related to training parameters.
  - $t_{RTRRD} = RL + RU(t_{DQSCK(MAX)}/t_{CK}) + BL/2 + t_{RPST} + 0.5 + \text{MAX}(RU(7.5ns/t_{CK}), 8nCK)$ .
  - In case of DQ ODT disable MR11 OP[2:0] = 000b,  
 $t_{RTW} = RL + RU(t_{DQSCK(MAX)}/t_{CK}) + BL/2 - WL + t_{WPRE} + RD(t_{RPST})$ .  
 In case of DQ ODT enable MR11 OP[2:0] ≠ 000b,  
 $t_{RTW} = RL + RU(t_{DQSCK(MAX)}/t_{CK}) + BL/2 + t_{RPST} - \text{ODTLon} - RD(t_{ODTon}(\text{Min})/t_{CK}) + 1$ .

## Read DQ Calibration Training

The READ DQ CALIBRATION TRAINING function outputs a 16-bit, user-defined pattern on the DQ pins. Read DQ calibration is initiated by issuing a MPC[READ DQ CALIBRATION] command followed by a CAS-2 command, which causes the device to drive the contents of MR32, followed by the contents of MR40 on each of DQ[15:0] and DMI[1:0]. The pattern can be inverted on selected DQ pins according to user-defined invert masks written to MR15 and MR20.

### Read DQ Calibration Training Procedure

1. Issue MRW commands to write MR32 (first eight bits), MR40 (second eight bits), MR15 (eight-bit invert mask for byte 0), and MR20 (eight-bit invert mask for byte 1).

In the alternative, this step could be replaced with the default pattern:

- MR32 default = 5Ah
- MR40 default = 3Ch
- MR15 default = 55h
- MR20 default = 55h

2. Issue an MPC command, followed immediately by a CAS-2 command.

- Each time an MPC command, followed by a CAS-2, is received by the device, a 16-bit data burst will drive the eight bits programmed in MR32 followed by the eight bits programmed in MR40 on all I/O pins after the currently set RL.
- The data pattern will be inverted for I/O pins with a 1 programmed in the corresponding invert mask mode register bit (see table below).
- The pattern is driven on the DMI pins, but no DATA BUS INVERSION function is enabled, even if read DBI is enabled in the mode register.
- The MPC command can be issued every <sup>t</sup>CCD seamlessly, and <sup>t</sup>RTRRD delay is required between ARRAY READ command and the MPC command as well the delay required between the MPC command and an ARRAY READ.
- The operands received with the CAS-2 command must be driven LOW.

3. DQ

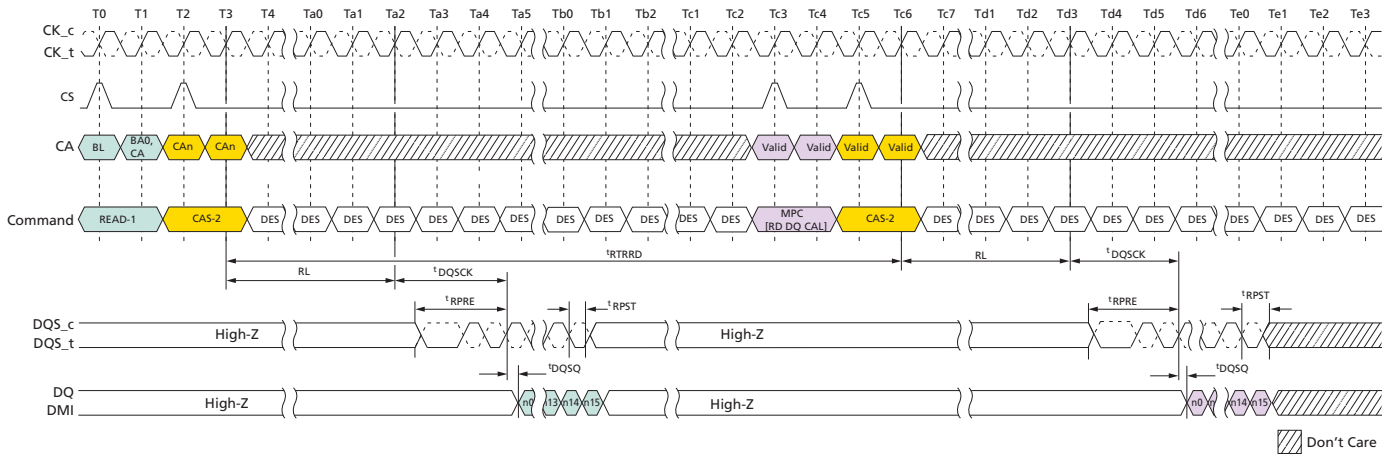
Read DQ calibration training can be performed with any or no banks active during refresh or during self refresh with CKE HIGH.

**Table 116: Invert Mask Assignments**

DQ pin	0	1	2	3	DMI0	4	5	6	7
MR15 bit	0	1	2	3	N/A	4	5	6	7
DQ pin	8	9	10	11	DMI1	12	13	14	15
MR20 bit	0	1	2	3	N/A	4	5	6	7

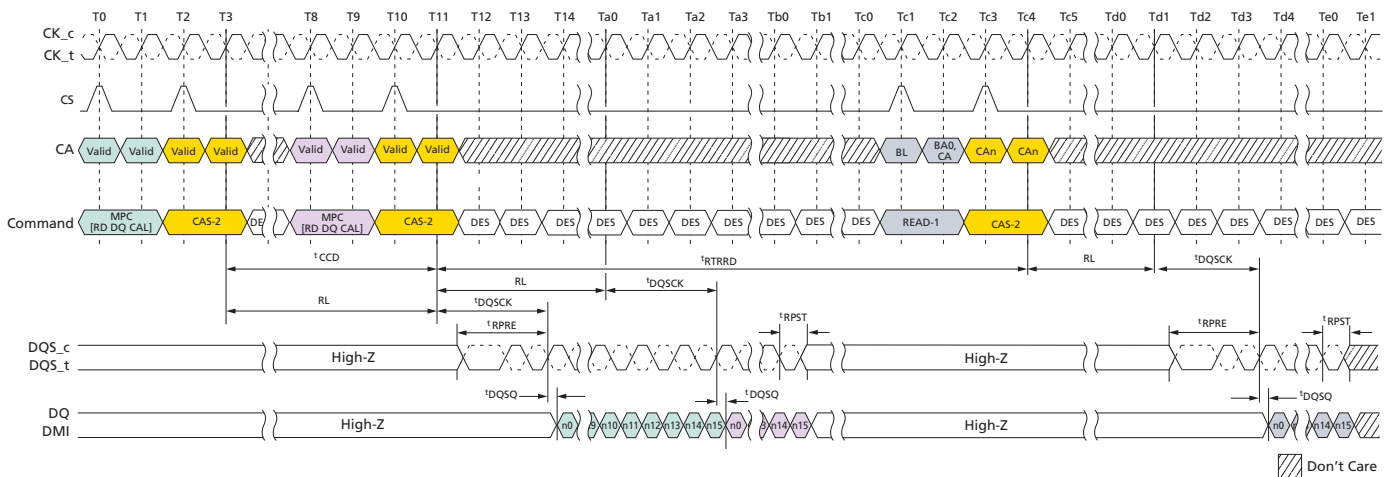


Figure 119: Read DQ Calibration Training Timing: Read-to-Read DQ Calibration



- Notes:
1. Read-1 to MPC operation is shown as an example of command-to-command timing. Timing from Read-1 to MPC command is  $t_{RTRRD}$ .
  2. MPC uses the same command-to-data timing relationship ( $RL$ ,  $t_{DQSK}$ ,  $t_{DQSQ}$ ) as a Read-1 command.
  3. BL = 16, Read preamble: Toggle, Read postamble: 0.5nCK.
  4. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 120: Read DQ Calibration Training Timing: RTRRD DQ Calibration to Read DQ Calibration/Read



- Notes:
1. MPC[READ DQ CALIBRATION] to MPC[READ DQ CALIBRATION] operation is shown as an example of command-to-command timing.
  2. MPC[READ DQ CALIBRATION] to READ-1 operation is shown as an example of command-to-command timing.
  3. MPC[READ DQ CALIBRATION] uses the same command-to-data timing relationship ( $RL$ ,  $t_{DQSK}$ ,  $t_{DQSQ}$ ) as a READ-1 command.
  4. Seamless MPC[READ DQ CALIBRATION] commands may be executed by repeating the command every  $t_{CCD}$  time.
  5. Timing from MPC[READ DQ CALIBRATION] command to READ-1 is  $t_{RTRRD}$ .

6. BL = 16, Read preamble: Toggle, Read postamble: 0.5nCK.
7. DES commands are shown for ease of illustration; other commands may be valid at these times.

### Read DQ Calibration Training Example

An example of read DQ calibration training output is shown in table below. This shows the 16-bit data pattern that will be driven on each DQ in byte 0 when one READ DQ CALIBRATION TRAINING command is executed. This output assumes the following mode register values are used:

- MR32 = 1CH
- MR40 = 59H
- MR15 = 55H
- MR20 = 55H

**Table 117: Read DQ Calibration Bit Ordering and Inversion Example**

Pin	Bit Sequence →																
	Invert	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DQ0	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ1	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ2	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ3	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DMI0	Never	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ4	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ5	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ6	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ7	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ8	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ9	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ10	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ11	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DMI1	Never	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ12	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ13	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0
DQ14	Yes	1	0	1	0	0	1	1	0	1	1	1	0	0	0	1	1
DQ15	No	0	1	0	1	1	0	0	1	0	0	0	1	1	1	0	0

- Notes:
1. The patterns contained in MR32 and MR40 are transmitted on DQ[15:0] and DMI[1:0] when read DQ calibration is initiated via a MPC[READ DQ CALIBRATION] 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 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 00100111 →.
  2. MR15 and MR20 may be used to invert the MR32/MR40 data pattern on the DQ pins. See MR15 and MR20 for more information. Data is never inverted on the DMI[1:0] pins.
  3. DMI [1:0] outputs status follows MR Setting vs. DMI Status table.

- No DATA BUS INVERSION (DBI) function is enacted during read DQ calibration, even if DBI is enabled in MR3-OP[6].

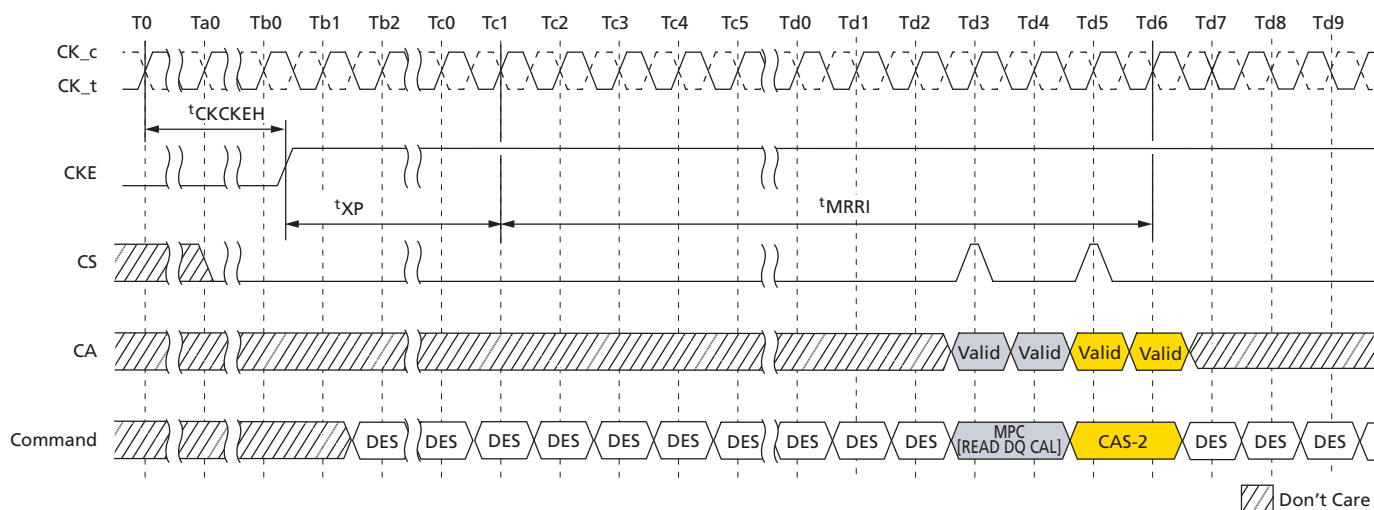
**Table 118: MR Setting vs. DMI Status**

DM Function MR13 OP[5]	WRITE DBI <sub>dc</sub> Function MR3 OP[7]	READ DBI <sub>dc</sub> Function MR3 OP[6] DMI	Status
1: Disable	0: Disable	0: Disable	High-Z
1: Disable	1: Enable	0: Disable	The data pattern is transmitted
1: Disable	0: Disable	1: Enable	The data pattern is transmitted
1: Disable	1: Enable	1: Enable	The data pattern is transmitted
0: Enable	0: Disable	0: Disable	The data pattern is transmitted
0: Enable	1: Enable	0: Disable	The data pattern is transmitted
0: Enable	0: Disable	1: Enable	The data pattern is transmitted
0: Enable	1: Enable	1: Enable	The data pattern is transmitted

### MPC[READ DQ CALIBRATION] After Power-Down Exit

Following the power-down state, an additional time,  $t_{MRRI}$ , is required prior to issuing the MPC[READ DQ CALIBRATION] command. This additional time (equivalent to  $t_{RCD}$ ) is required in order to be able to maximize power-down current savings by allowing more power-up time for the read DQ data in MR32 and MR40 data path after exit from standby, power-down mode.

**Figure 121: MPC[READ DQ CALIBRATION] Following Power-Down State**



## Write Training

The device uses an unmatched DQS-DQ path to enable high-speed performance and save power. As a result, the DQS strobe must be trained to arrive at the DQ latch center-aligned with the data eye. The DQ receiver is located at the DQ pad and has a shorter internal delay than the DQS signal. The DQ receiver will latch the data present on the

DQ bus when DQS reaches the latch, and training is accomplished by delaying the DQ signals relative to DQS such that the data eye arrives at the receiver latch centered on the DQS transition.

Two modes of training are available:

- Command-based FIFO WR/RD with user patterns
- An internal DQS clock-tree oscillator, which determines the need for, and the magnitude of, required training

The command-based FIFO WR/RD uses the MPC command with operands to enable this special mode of operation. When issuing the MPC command, if CA[5] is set LOW (OP[6] = 0), then the device will perform a NOP command. When CA[5] is set HIGH, the CA[4:0] pins enable training functions or are reserved for future use (RFU). MPC commands that initiate a read or write to the device must be followed immediately by a CAS-2 command. See the MPC Operation section for more information.

To perform write training, the controller can issue an MPC[WRITE-FIFO] command with OP[6:0] set, followed immediately by a CAS-2 command (CAS-2 operands should be driven LOW) to initiate a WRITE-FIFO. Timings for MPC[WRITE-FIFO] are identical to WRITE commands, with WL timed from the second rising clock edge of the CAS-2 command. Up to five consecutive MPC[WRITE-FIFO] commands with user-defined patterns may be issued to the device, which will store up to 80 values (BL16 × 5) per pin that can be read back via the MPC[READ-FIFO] command. (The WRITE/READ-FIFO POINTER operation is described in a different section.

After writing data with the MPC[WRITE-FIFO] command, the data can be read back with the MPC[READ-FIFO] command and results can be compared with "expected" data to determine whether further training (DQ delay) is needed. MPC[READ-FIFO] is initiated by issuing an MPC command, as described in the MPC Operation section, followed immediately by a CAS-2 command (CAS-2 operands must be driven LOW). Timings for the MPC[READ-FIFO] command are identical to READ commands, with RL timed from the second rising clock edge of the CAS-2 command.

READ-FIFO is nondestructive to the data captured in the FIFO; data may be read continuously until it is disturbed by another command, such as a READ, WRITE, or another MPC[WRITE-FIFO]. If fewer than five WRITE-FIFO commands are executed, unwritten registers will have undefined (but valid) data when read back.

For example: If five WRITE-FIFO commands are executed sequentially, then a series of READ-FIFO commands will read valid data from FIFO[0], FIFO[1]...FIFO[4] and then wrap back to FIFO[0] on the next READ-FIFO. However, if fewer than five WRITE-FIFO commands are executed sequentially (example = 3), then a series of READ-FIFO commands will return valid data for FIFO[0], FIFO[1], and FIFO[2], but the next two READ-FIFO commands will return undefined data for FIFO[3] and FIFO[4] before wrapping back to the valid data in FIFO[0].

The READ-FIFO pointer and WRITE-FIFO pointer are reset under the following conditions:

- Power-up initialization
- RESET\_n asserted
- Power-down entry
- Self refresh power-down entry

The MPC[WRITE-FIFO] command advances the WRITE-FIFO pointer, and the MPC[READ-FIFO] advances the READ-FIFO pointer. Also any normal (non-FIFO) READ operation (RD, RDA) advances both WRITE-FIFO pointer and READ-FIFO pointer. Issuing (non-FIFO) READ operation command is inhibited during write training period. To keep the pointers aligned, the SoC memory controller must adhere to the following restriction at the end of Write training period:

$$b = a + (n \times c)$$

Where:

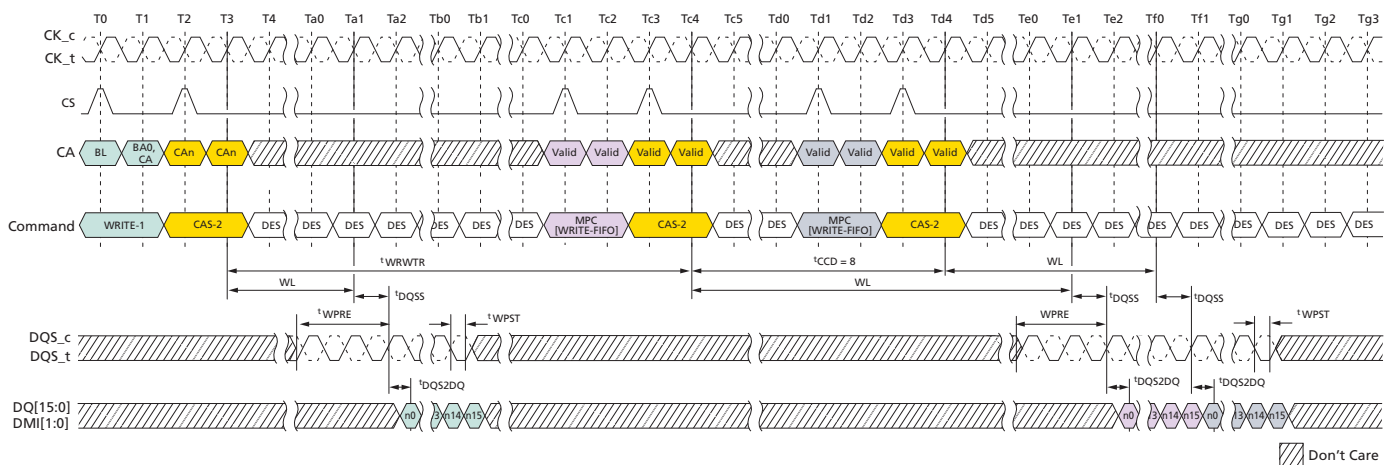
'a' is the number of MPC[WRITE-FIFO] commands

'b' is the number of MPC[READ-FIFO] commands

'c' is the FIFO depth (= 5 for LPDDR4)

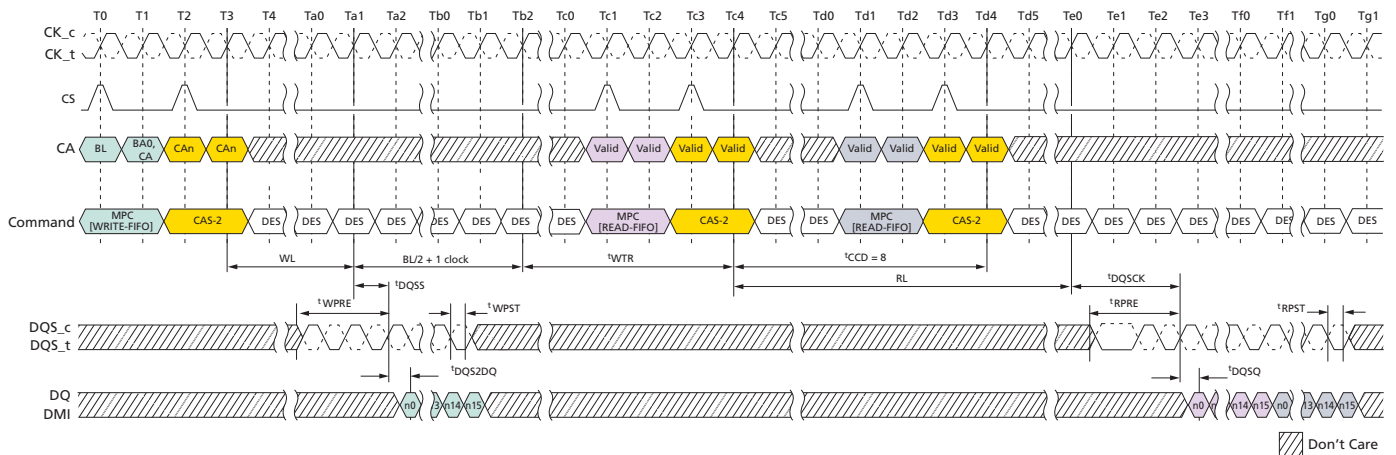
'n' is a positive integer,  $\geq 0$

**Figure 122: WRITE-to-MPC[WRITE-FIFO] Operation Timing**



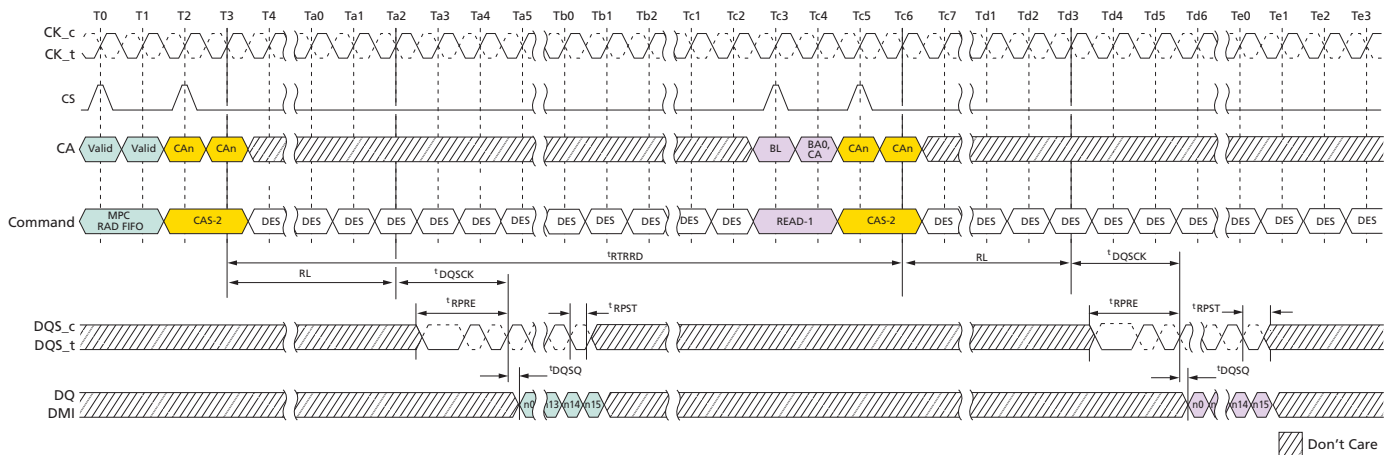
- Notes:
1. MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active during REFRESH or during SELF REFRESH with CKE HIGH.
  2. Write-1 to MPC is shown as an example of command-to-command timing for MPC. Timing from Write-1 to MPC[WRITE-FIFO] is  $t_{WRWTR}$ .
  3. Seamless MPC[WR-FIFO] commands may be executed by repeating the command every  $t_{CCD}$  time.
  4. MPC[WRITE-FIFO] uses the same command-to-data timing relationship ( $WL$ ,  $t_{DQSS}$ ,  $t_{DQS2DQ}$ ) as a WRITE-1 command.
  5. A maximum of five MPC[WRITE-FIFO] commands may be executed consecutively without corrupting FIFO data. The sixth MPC[WRITE-FIFO] command will overwrite the FIFO data from the first command. If fewer than five MPC[WRITE-FIFO] commands are executed, then the remaining FIFO locations will contain undefined data.
  6. For the CAS-2 command following an MPC command, the CAS-2 operands must be driven LOW.
  7. To avoid corrupting the FIFO contents, MPC[READ-FIFO] must immediately follow MPC[WRITE-FIFO]/CAS-2 without any other commands disturbing FIFO pointers in between. FIFO pointers are disturbed by CKE LOW, WRITE, MASKED WRITE, READ, READ DQ CALIBRATION, and MRR.
  8. BL = 16, Write postamble =  $0.5nCK$ .
  9. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 123: MPC[WRITE-FIFO]-to-MPC[READ-FIFO] Timing



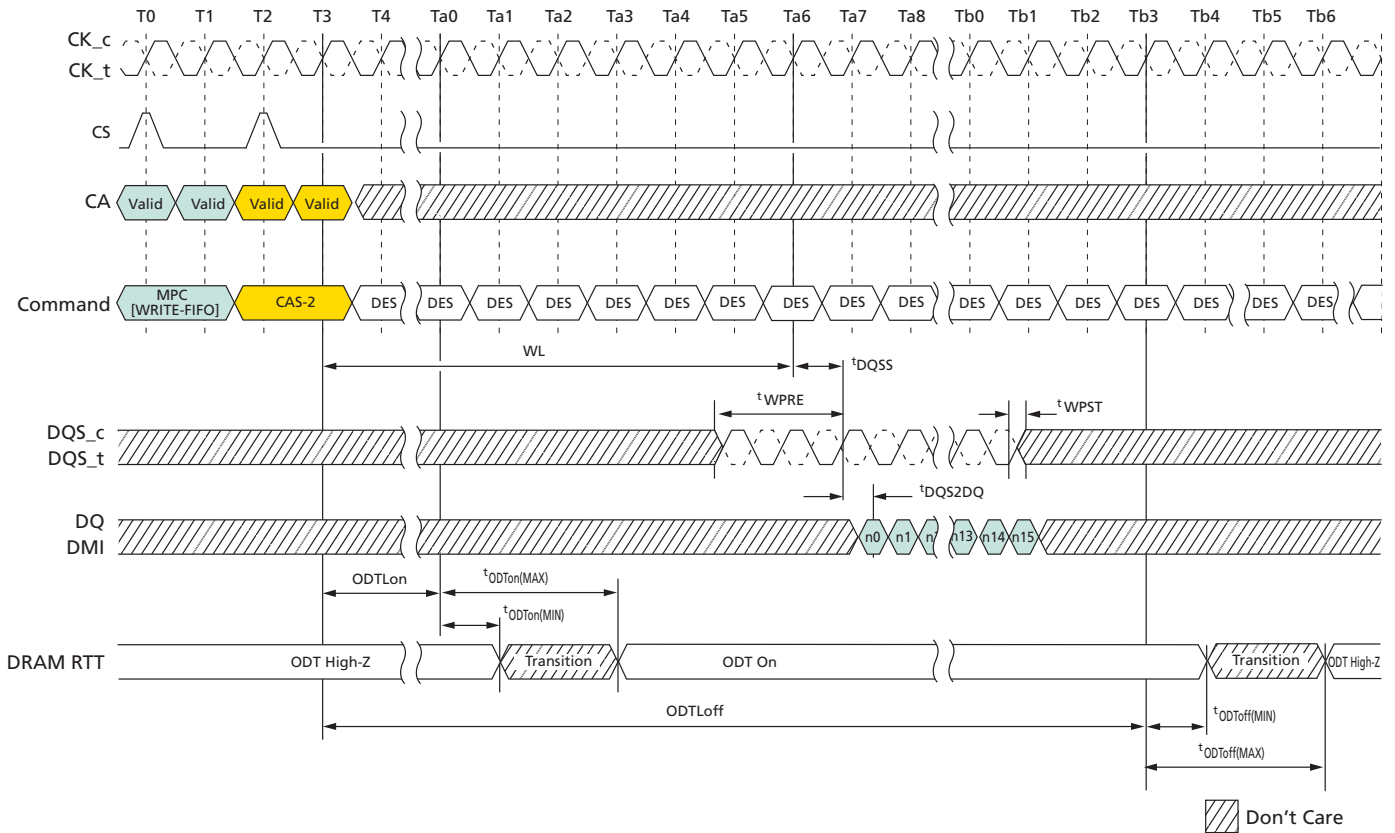
- Notes:
1. MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active during refresh or during self refresh with CKE HIGH.
  2. MPC[WRITE-FIFO] to MPC[READ-FIFO] is shown as an example of command-to-command timing for MPC. Timing from MPC[WRITE-FIFO] to MPC[READ-FIFO] is specified in the command-to-command timing table.
  3. Seamless MPC[READ-FIFO] commands may be executed by repeating the command every  $t_{CCD}$  time.
  4. MPC[READ-FIFO] uses the same command-to-data timing relationship (RL,  $t_{DQSK}$ ,  $t_{DQSQ}$ ) as a READ-1 command.
  5. Data may be continuously read from the FIFO without any data corruption. After five MPC[READ-FIFO] commands, the FIFO pointer will wrap back to the first FIFO and continue advancing. If fewer than five MPC[WRITE-FIFO] commands were executed, then the MPC[READ-FIFO] commands to those FIFO locations will return undefined data. See Write Training for more information on the FIFO pointer behavior.
  6. For the CAS-2 command immediately following an MPC command, the CAS-2 operands must be driven LOW.
  7. DMI[1:0] signals will be driven if WR-DBI, RD-DBI, or DM is enabled in the mode registers. See Write Training section for more information on DMI behavior.
  8. BL = 16, Write postamble =  $0.5nCK$ , Read preamble: Toggle, Read postamble:  $0.5nCK$ .
  9. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 124: MPC[READ-FIFO] to Read Timing



- Notes:
1. MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active during refresh or during self refresh with CKE HIGH.
  2. MPC[READ-FIFO] to READ-1 operation is shown as an example of command-to-command timing for MPC. Timing from MPC[READ-FIFO] command to READ is  $t_{RTRRD}$ .
  3. Seamless MPC[READ-FIFO] commands may be executed by repeating the command every  $t_{CCD}$  time.
  4. MPC[READ-FIFO] uses the same command-to-data timing relationship ( $RL$ ,  $t_{DQSCK}$ ,  $t_{DQSQ}$ ) as a READ-1 command.
  5. Data may be continuously read from the FIFO without any data corruption. After five MPC[READ-FIFO] commands, the FIFO pointer will wrap back to the first FIFO and continue advancing. If fewer than five MPC[WRITE-FIFO] commands were executed, then the MPC[READ-FIFO] commands to those FIFO locations will return undefined data. See Write Training for more information on the FIFO pointer behavior.
  6. For the CAS-2 command immediately following an MPC command, the CAS-2 operands must be driven LOW.
  7. DMI[1:0] signals will be driven if WR-DBI, RD-DBI, or DM is enabled in the mode registers. See Write Training for more information on DMI behavior.
  8. BL = 16, Read preamble: Toggle, Read postamble: 0.5nCK
  9. DES commands are shown for ease of illustration; other commands may be valid at these times.

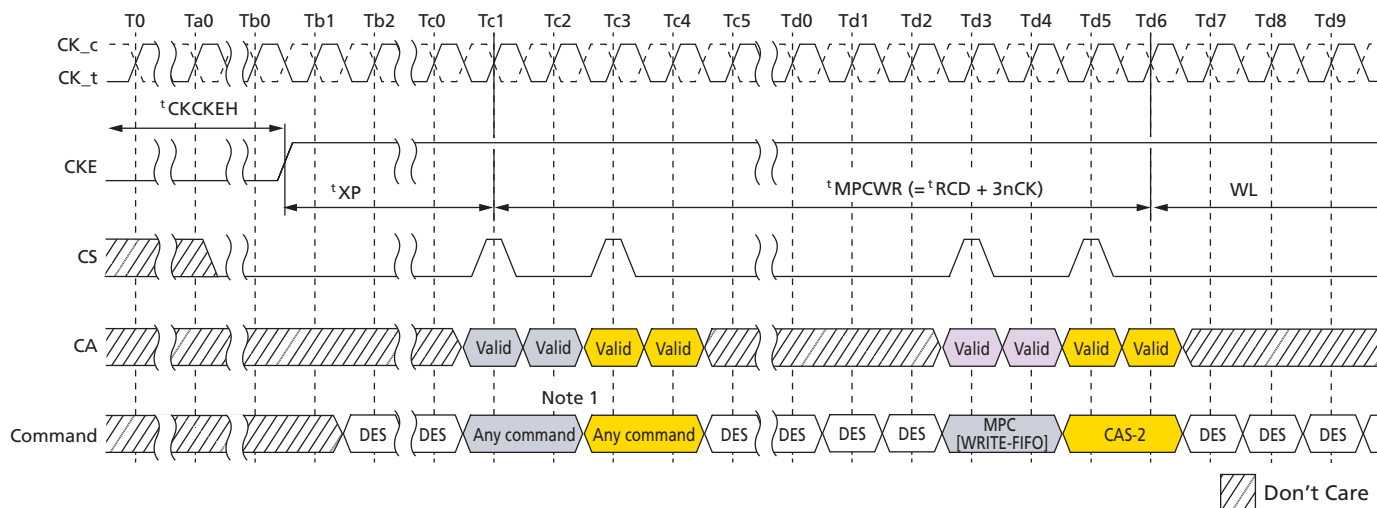
Figure 125: MPC[WRITE-FIFO] with DQ ODT Timing



- Notes:
1. MPC[WRITE-FIFO] can be executed with a single bank or multiple banks active during refresh or during self refresh with CKE HIGH.
  2. MPC[WRITE-FIFO] uses the same command-to-data/ODT timing relationship (RL,  $t_{DQSS}$ ,  $t_{DQS2DQ}$ , ODTLon, ODTLoff,  $t_{ODTon}$ ,  $t_{ODTOff}$ ) as a WRITE-1 command.
  3. For the CAS-2 command immediately following an MPC command, the CAS-2 operands must be driven LOW.
  4. BL = 16, Write postamble =  $0.5nCK$ .
  5. DES commands are shown for ease of illustration; other commands may be valid at these times.



Figure 126: Power-Down Exit to MPC[WRITE-FIFO] Timing



- Notes: 1. Any commands except MPC[WRITE-FIFO] and other exception commands defined other section in this document (for example, MPC[READ DQ CALIBRATION]).  
2. DES commands are shown for ease of illustration; other commands may be valid at these times.

Table 119: MPC[WRITE-FIFO] AC Timing

Parameter	Symbol	MIN/MAX	Value	Unit
Additional time after $t_{XP}$ has expired until MPC[WRITE-FIFO] command may be issued	$t_{MPCWR}$	MIN	$t_{RCD} + 3nCK$	–

### Internal Interval Timer

As voltage and temperature change on the device, the DQS clock-tree delay will shift, requiring retraining. The device includes an internal DQS clock-tree oscillator to measure the amount of delay over a given time interval (determined by the controller), allowing the controller to compare the trained delay value to the delay value seen at a later time. The DQS oscillator will provide the controller with important information regarding the need to retrain and the magnitude of potential error.

The DQS interval oscillator is started by issuing an MPC command with OP[5:0] = 101011b, which will start an internal ring oscillator that counts the number of time a signal propagates through a copy of the DQS clock tree.

The DQS oscillator may be stopped by issuing an MPC[STOP DQS OSCILLATOR] command with OP[6:0] set, as described in MPC Operation, or the controller may instruct the SDRAM to count for a specific number of clocks and then stop automatically (See MR23 for more information). If MR23 is set to automatically stop the DQS oscillator, then the MPC[STOP DQS OSCILLATOR] command should not be used (illegal). When the DQS oscillator is stopped by either method, the result of the oscillator counter is automatically stored in MR18 and MR19.

The controller may adjust the accuracy of the result by running the DQS interval oscillator for shorter (less accurate) or longer (more accurate) duration. The accuracy of the

result for a given temperature and voltage is determined by the following equation, where run time = total time between START and STOP commands and DQS delay = the value of the DQS clock tree delay (<sup>t</sup>DQS2DQ MIN/MAX):

$$\text{DQS oscillator granularity error} = \frac{2 \times (\text{DQS delay})}{\text{run time}}$$

Additional matching error must be included, which is the difference between DQS training circuit and the actual DQS clock tree across voltage and temperature. The matching error is vendor specific. Therefore, the total accuracy of the DQS oscillator counter is given by:

$$\text{DQS oscillator accuracy} = 1 - \text{granularity error} - \text{matching error}$$

For example, if the total time between START and STOP commands is 100ns, and the maximum DQS clock tree delay is 800ps (<sup>t</sup>DQS2DQ MAX), then the DQS oscillator granularity error is:

$$\text{DQS oscillator granularity error} = \frac{2 \times (0.8\text{ns})}{100\text{ns}} = 1.6\%$$

This equates to a granularity timing error of 12.8ps. Assuming a circuit matching error of 5.5ps across voltage and temperature, the accuracy is:

$$\text{DQS oscillator accuracy} = 1 - \frac{12.8 + 5.5}{800} = 97.7\%$$

For example, running the DQS oscillator for a longer period improves the accuracy. If the total time between START and STOP commands is 500ns, and the maximum DQS clock tree delay is 800ps (<sup>t</sup>DQS2DQ MAX), then the DQS oscillator granularity error is:

$$\text{DQS oscillator granularity error} = \frac{2 \times (0.8\text{ns})}{500\text{ns}} = 0.32\%$$

This equates to a granularity timing error or 2.56ps. Assuming a circuit matching error of 5.5ps across voltage and temperature, the accuracy is:

$$\text{DQS oscillator accuracy} = 1 - \frac{2.56 + 5.5}{800} = 99.0\%$$

The result of the DQS interval oscillator is defined as the number of DQS clock tree delays that can be counted within the run time, determined by the controller. The result is stored in MR18-OP[7:0] and MR19-OP[7:0].

MR18 contains the least significant bits (LSB) of the result, and MR19 contains the most significant bits (MSB) of the result. MR18 and MR19 are overwritten by the SDRAM when a MPC[STOP DQS OSCILLATOR] command is received.

The SDRAM counter will count to its maximum value (= 2<sup>16</sup>) and stop. If the maximum value is read from the mode registers, the memory controller must assume that the counter overflowed the register and therefore discard the result. The longest run time for the oscillator that will not overflow the counter registers can be calculated as follows:

$$\text{Longest runtime interval} = 2^{16} \times {}^t\text{DQS2DQ}(\text{MIN}) = 2^{16} \times 0.2\text{ns} = 13.1\mu\text{s}$$

### DQS Interval Oscillator Matching Error

The interval oscillator matching error is defined as the difference between the DQS training ckt (interval oscillator) and the actual DQS clock tree across voltage and temperature.

Parameters:

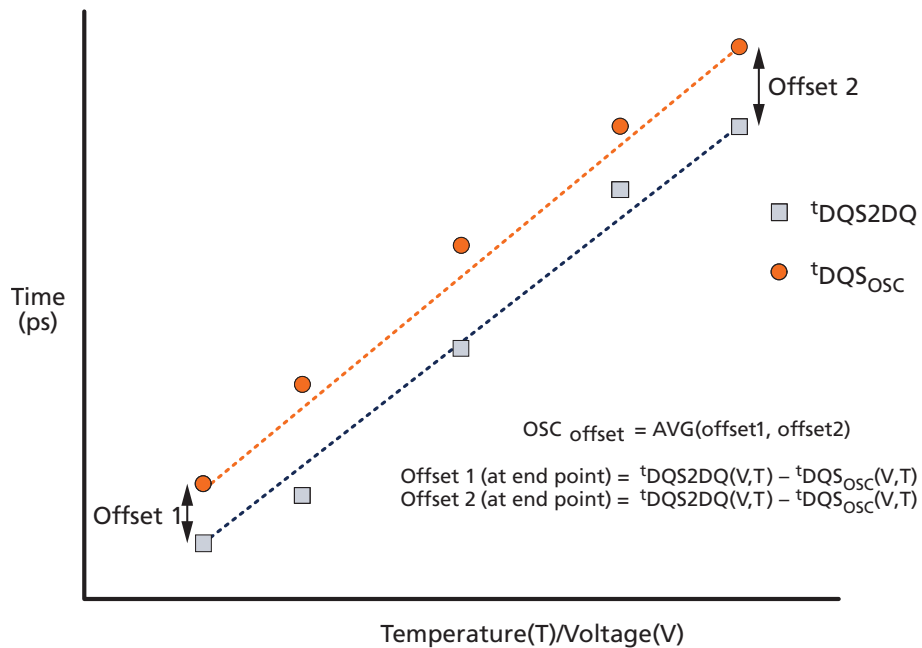
$t_{DQS2DQ}$ : Actual DQS clock tree delay

$t_{DQS_{OSC}}$ : Training ckt (interval oscillator) delay

$OSC_{Offset}$ : Average delay difference over voltage and temperature (shown below)

$OSC_{Match}$ : DQS oscillator matching error

**Figure 127: Interval Oscillator Offset –  $OSC_{Offset}$**



$OSC_{Match}$  :

$$OSC_{Match} = [ t_{DQS2DQ}(V,T) - t_{DQS_{OSC}}(V,T) - OSC_{offset} ]$$

$t_{DQS_{OSC}}$ :

$$t_{DQS_{OSC}}(V,T) = [ \frac{Runtime}{2 \times Count} ]$$

**Table 120: DQS Oscillator Matching Error Specification**

Parameter	Symbol	MIN	MAX	Unit	Notes
DQS oscillator matching error	$OSC_{Match}$	-20	20	ps	1, 2, 3, 4, 5, 6, 7, 8
DQS oscillator offset	$OSC_{offset}$	-100	100	ps	2, 4, 7

Notes: 1. The  $OSC_{Match}$  is the matching error per between the actual DQS and DQS interval oscillator over voltage and temperature.

2. This parameter will be characterized or guaranteed by design.
3. The  $OSC_{Match}$  is defined as the following:

$$OSC_{Match} = [ {}^tDQS2DQ(V, T) - {}^tDQS_{OSC}(V, T) - OSC_{offset} ]$$

Where  ${}^tDQS2DQ(V, T)$  and  ${}^tDQS_{OSC}(V, T)$  are determined over the same voltage and temperature conditions.

4. The runtime of the oscillator must be at least 200ns for determining  ${}^tDQS_{OSC}(V, T)$ .

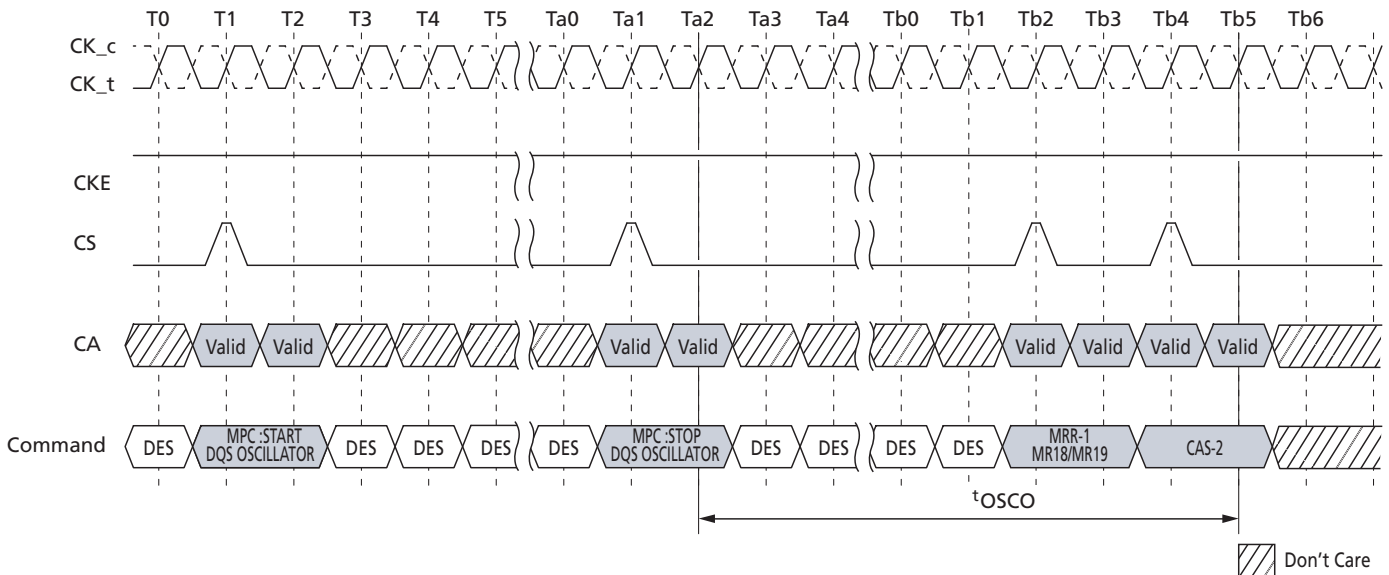
$${}^tDQS_{OSC}(V, T) = [ \frac{Runtime}{2 \times Count} ]$$

5. The input stimulus for  ${}^tDQS2DQ$  will be consistent over voltage and temperature conditions.
6. The  $OSC_{offset}$  is the average difference of the endpoints across voltage and temperature.
7. These parameters are defined per channel.
8.  ${}^tDQS2DQ(V, T)$  delay will be the average of DQS-to-DQ delay over the runtime period.

### OSC Count Readout Time

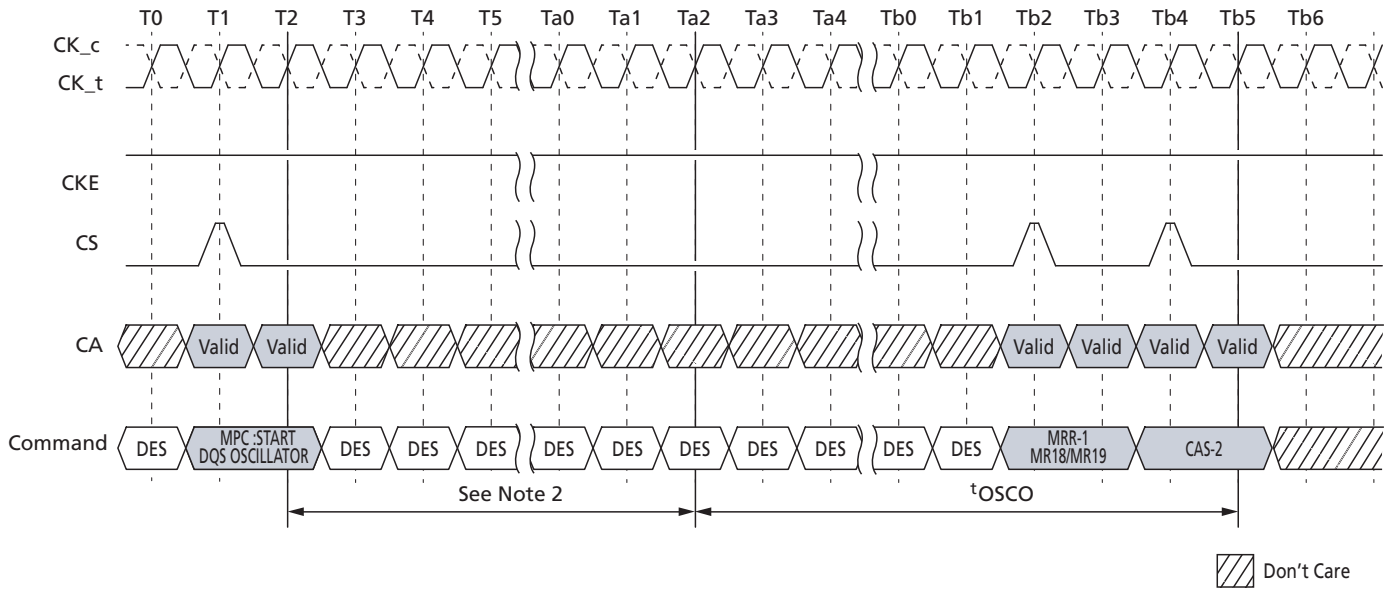
OSC Stop to its counting value readout timing is shown in following figures.

**Figure 128: In Case of DQS Interval Oscillator is Stopped by MPC Command**



Note: 1. DQS interval timer run time setting :MR23 OP[7:0] = 0000000b.

Figure 129: In Case of DQS Interval Oscillator is Stopped by DQS Interval Timer



- Notes: 1. DQS interval timer run time setting: MR23 OP[7:0] ≠ 00000000b.  
2. Setting counts of MR23.

Table 121: DQS Interval Oscillator AC Timing

Parameter	Symbol	MIN/MAX	Value	Unit
Delay time from OSC stop to mode register readout	$t_{OSCO}$	MIN	MAX (40ns, 8nCK)	ns

- Note: 1. START DQS OSCILLATOR command is prohibited until  $t_{OSCO}(\text{MIN})$  is satisfied.

## Thermal Offset

Because of tight thermal coupling, hot spots on an SOC can induce thermal gradients across the device. Because these hot spots may not be located near the thermal sensor, the temperature compensated self refresh (TCSR) circuit may not generate enough refresh cycles to guarantee memory retention. To address this shortcoming, the controller can provide a thermal offset that the memory can use to adjust its TCSR circuit to ensure reliable operation.

This thermal offset is provided through MR4 OP[6:5] to either or both channels (dual channel devices). This temperature offset may modify refresh behaviour for the channel to which the offset is provided. It will take a maximum of 200 $\mu$ s to have the change reflected in MR4 OP[2:0] for the channel to which the offset is provided. If the induced thermal gradient from the device temperature sensor location to the hot spot location of the controller is greater than 15°C, self refresh mode will not reliably maintain memory contents.

To accurately determine the temperature gradient between the memory thermal sensor and the induced hot spot, the memory thermal sensor location must be provided to the controller.

Support of the thermal offset function is optional. Please refer to the vendor data sheet to determine if this function is supported.

## Temperature Sensor

The device has a temperature sensor that can be read from MR4. This sensor can be used to determine the appropriate refresh rate, to determine whether AC timing de-rating is required at an elevated temperature range, and to monitor the operating temperature. Either the temperature sensor or the device  $T_{OPER}$  can be used to determine if operating temperature requirements are being met.

The device monitors device temperature and updates MR4 according to  $t_{TSI}$ . Upon exiting self refresh or power-down, the device temperature status bits shall be no older than  $t_{TSI}$ .

When using the temperature sensor, the actual device case temperature may be higher than the  $T_{OPER}$  specification that applies to standard or elevated temperature ranges. For example,  $T_{CASE}$  may be above 85°C when MR4[2:0] = b011. The device enables a 2°C temperature margin between the point when the device updates the MR4 value and the point when the controller reconfigures the system accordingly. When performing tight thermal coupling of the device to external hot spots, the maximum device temperature may be higher than indicated by MR4.

To ensure proper operation when using the temperature sensor, consider the following:

- TempGradient is the maximum temperature gradient experienced by the device at the temperature of interest over a range of 2°C.
- ReadInterval is the time period between MR4 reads from the system.
- TempSensorInterval ( $t_{TSI}$ ) is the maximum delay between the internal updates of MR4.
- SysRespDelay is the maximum time between a read of MR4 and a response from the system.

In order to determine the required frequency of polling MR4, the system uses the TempGradient and the maximum response time of the system in the following equation:

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

**Table 122: Temperature Sensor**

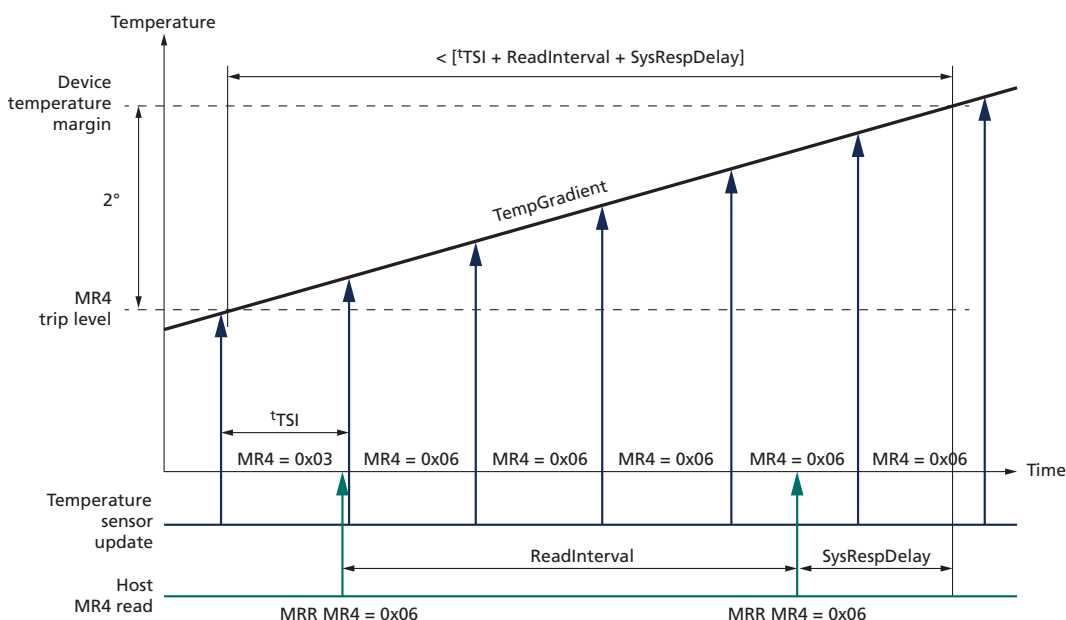
Parameter	Symbol	Max/Min	Value	Unit
System temperature gradient	TempGradient	MAX	System Dependent	°C/s
MR4 read interval	ReadInterval	MAX	System Dependent	ms
Temperature sensor interval	<sup>t</sup> TSI	MAX	32	ms
System response delay	SysRespDelay	MAX	System Dependent	ms
Device temperature margin	TempMargin	MAX	2	°C

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

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

In this case, ReadInterval shall be no greater than 167ms.

**Figure 130: Temperature Sensor Timing**



## ZQ Calibration

The MPC command is used to initiate ZQ calibration, which calibrates the output driver impedance and CA/DQ ODT impedance across process, temperature, and voltage. ZQ calibration occurs in the background of device operation and is designed to eliminate any need for coordination between channels (that is, it allows for channel independence). ZQ calibration is required each time that the PU-Cal value (MR3-OP[0]) is changed. Additional ZQ CALIBRATION commands may be required as the voltage and temperature change in the system environment. CA ODT values (MR11-OP[6:4]) and

DQ ODT values (MR11-OP[2:0]) may be changed without performing ZQ calibration, as long as the PU-Cal value doesn't change.

There are two ZQ calibration modes initiated with the MPC command: ZQCAL START and ZQCAL LATCH. ZQCAL START initiates the calibration procedure, and ZQCAL LATCH captures the result and loads it into the drivers.

A ZQCAL START command may be issued anytime the device is not in a power-down state. A ZQCAL LATCH command may be issued anytime outside of power-down after  $t^{\text{ZQCAL}}$  has expired and all DQ bus operations have completed. The CA bus must maintain a deselect state during  $t^{\text{ZQLAT}}$  to allow CA ODT calibration settings to be updated. The DQ calibration value will not be updated until ZQCAL LATCH is performed and  $t^{\text{ZQLAT}}$  has been met. The following mode register fields that modify I/O parameters cannot be changed following a ZQCAL START command and before  $t^{\text{ZQCAL}}$  has expired:

- PU-Cal (pull-up calibration  $V_{\text{OH}}$  point)
- PDDS (pull-down drive strength and Rx termination)
- DQ ODT (DQ ODT value)
- CA ODT (CA ODT value)

## ZQCAL Reset

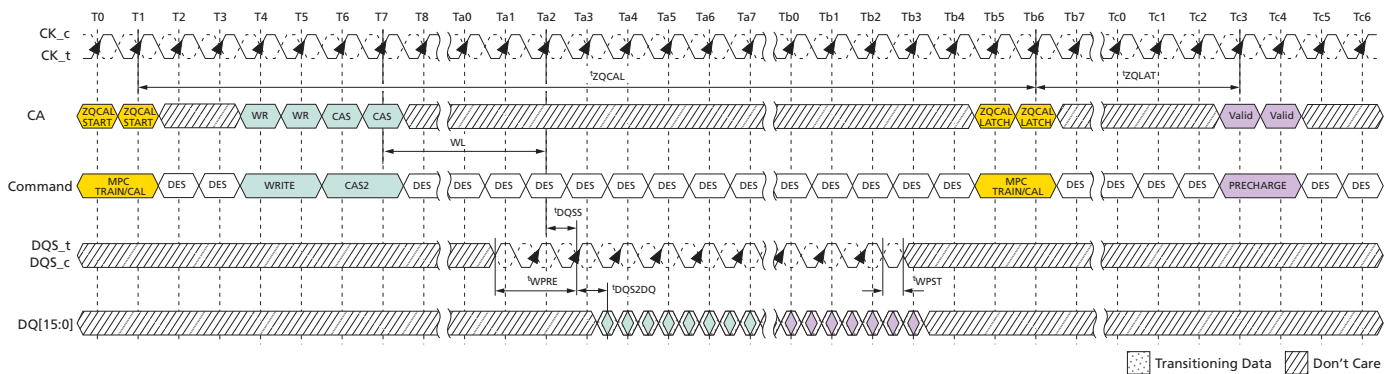
The ZQCAL RESET command resets the output impedance calibration to a default accuracy of  $\pm 30\%$  across process, voltage, and temperature. This command is used to ensure output impedance accuracy to  $\pm 30\%$  when ZQCAL START and ZQCAL LATCH commands are not used.

The ZQCAL RESET command is executed by writing MR10-OP[0] = 1B.

**Table 123: ZQ Calibration Parameters**

Parameter	Symbol	Min/Max	Value	Unit
ZQCAL START to ZQCAL LATCH command interval	$t^{\text{ZQCAL}}$	MIN	1	$\mu\text{s}$
ZQCAL LATCH to next valid command interval	$t^{\text{ZQLAT}}$	MIN	MAX (30ns, 8nCK)	ns
ZQCAL RESET to next valid command interval	$t^{\text{ZQRESET}}$	MIN	MAX (50ns, 3nCK)	ns



**Figure 131: ZQCAL Timing**


- Notes:
1. WRITE and PRECHARGE operations are shown for illustrative purposes. Any single or multiple valid commands may be executed within the  $t_{ZQCAL}$  time and prior to latching the results.
  2. Before the ZQCAL LATCH command can be executed, any prior commands that utilize the DQ bus must have completed. WRITE commands with DQ termination must be given enough time to turn off the DQ ODT before issuing the ZQCAL LATCH command. See the ODT section for ODT timing.

## Multichannel Considerations

The device includes a single ZQ pin and associated ZQ calibration circuitry. Calibration values from this circuit will be used by both channels according to the following protocol:

- The ZQCAL START command can be issued to either or both channels.
- The ZQCAL START command can be issued when either or both channels are executing other commands, and other commands can be issued during  $t_{ZQCAL}$ .
- The ZQCAL START command can be issued to both channels simultaneously.
- The ZQCAL START command will begin the calibration unless a previously requested ZQ calibration is in progress.
- If the ZQCAL START command is received while a ZQ calibration is in progress, the command will be ignored and the in-progress calibration will not be interrupted.
- The ZQCAL LATCH command is required for each channel.
- The ZQCAL LATCH command can be issued to both channels simultaneously.
- The ZQCAL LATCH command will latch results of the most recent ZQCAL START command provided  $t_{ZQCAL}$  has been met.
- ZQCAL LATCH commands that do not meet  $t_{ZQCAL}$  will latch the results of the most recently completed ZQ calibration.
- The ZQRESET MRW commands will only reset the calibration values for the channel issuing the command.

In compliance with complete channel independence, either channel may issue ZQCAL START and ZQCAL LATCH commands as needed without regard to the state of the other channel.

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

To use the ZQ CALIBRATION function, a 240 ohm,  $\pm 1\%$  tolerance external resistor must be connected between the ZQ pin and  $V_{DDQ}$ .

If the system configuration shares the CA bus to form a x32 (or wider) channel, the ZQ pin of each die's x16 channel must use a separate ZQCAL resistor.

If the system configuration has more than one rank, and if the ZQ pins of both ranks are attached to a single resistor, then the SDRAM controller must ensure that the ZQCAL's don't overlap.

The total capacitive loading on the ZQ pin must be limited to 25pF. For example, if a system configuration shares a CA bus between  $n$  channels to form an  $n$  x16 wide bus, and no means are available to control the ZQCAL separately for each channel (that is, separate CS, CKE, or CK), then each x16 channel must have a separate ZQCAL resistor. For a x32, two-rank system, each x16 channel must have its own ZQCAL resistor, but the ZQCAL resistor can be shared between ranks on each x16 channel. In this configuration, the CS signal can be used to ensure that the ZQCAL commands for Rank[0] and Rank[1] don't overlap.

## Frequency Set Points

Frequency set points enable the CA bus to be switched between two differing operating frequencies with changes in voltage swings and termination values, without ever being in an untrained state, which could result in a loss of communication to the device. This is accomplished by duplicating all CA bus mode register parameters, as well as other mode register parameters commonly changed with operating frequency.

These duplicated registers form two sets that use the same mode register addresses, with read/write access controlled by MR bit FSP-WR (frequency set point write/read) and the operating point controlled by MR bit FSP-OP (FREQUENCY SET POINT operation). Changing the FSP-WR bit enables MR parameters to be changed for an alternate frequency set-point without affecting the current operation.

Once all necessary parameters have been written to the alternate set point, changing the FSP-OP bit will switch operation to use all of the new parameters simultaneously (within  $t_{FC}$ ), eliminating the possibility of a loss of communication that could be caused by a partial configuration change.

Parameters which have two physical registers controlled by FSP-WR and FSP-OP include:

**Table 124: Mode Register Function with Two Physical Registers**

MR Number	Operand	Function	Notes
MR1	OP[1:0]	BL (Burst length)	
	OP[2]	WR-PRE (Write preamble length)	
	OP[3]	RD-PRE (Read preamble type)	
	OP[6:4]	$n$ WR (Write-recovery for AUTO PRECHARGE command)	
	OP[7]	RD-PST (Read postamble length)	
MR2	OP[2:0]	RL (READ latency)	
	OP[5:3]	WL (WRITE latency)	
	OP[6]	WLS (WRITE latency set)	
MR3	OP[0]	PU-CAL (Pull-up calibration point)	1
	OP[1]	WR-PST (Write postamble length)	
	OP[5:3]	PDDS (Pull-down drive strength)	
	OP[6]	DBI-RD (DBI-read enable)	
	OP[7]	DBI-WR (DBI-write enable)	
MR11	OP[2:0]	DQ ODT (DQ bus receiver on-die termination)	
	OP[6:4]	CA ODT (CA bus receiver on-die termination)	
MR12	OP[5:0]	$V_{REF(CA)}$ ( $V_{REF(CA)}$ setting)	
	OP[6]	$VR_{CA}$ ( $V_{REF(CA)}$ range)	
MR14	OP[5:0]	$V_{REF(DQ)}$ ( $V_{REF(DQ)}$ setting)	
	OP[6]	$VR_{DQ}$ ( $V_{REF(DQ)}$ range)	

**Table 124: Mode Register Function with Two Physical Registers (Continued)**

MR Number	Operand	Function	Notes
MR22	OP[2:0]	SOC ODT (Controller ODT value for V <sub>OH</sub> calibration)	
	OP[3]	ODTE-CK (CK ODT enabled for non-terminating rank)	
	OP[4]	ODTE-CS (CS ODT enable for non-terminating rank)	
	OP[5]	ODTD-CA (CA ODT termination disable)	

Note: 1. PU-CAL setting is required as the same value for both Ch. A and Ch. B before issuing ZQCAL START command. See Mode Register Definition section for more details.

Table below shows how the two mode registers for each of the parameters above can be modified by setting the appropriate FSP-WR value, and how device operation can be switched between operating points by setting the appropriate FSP-OP value. The FSP-WR and FSP-OP functions operate completely independently.

**Table 125: Relation Between MR Setting and DRAM Operation**

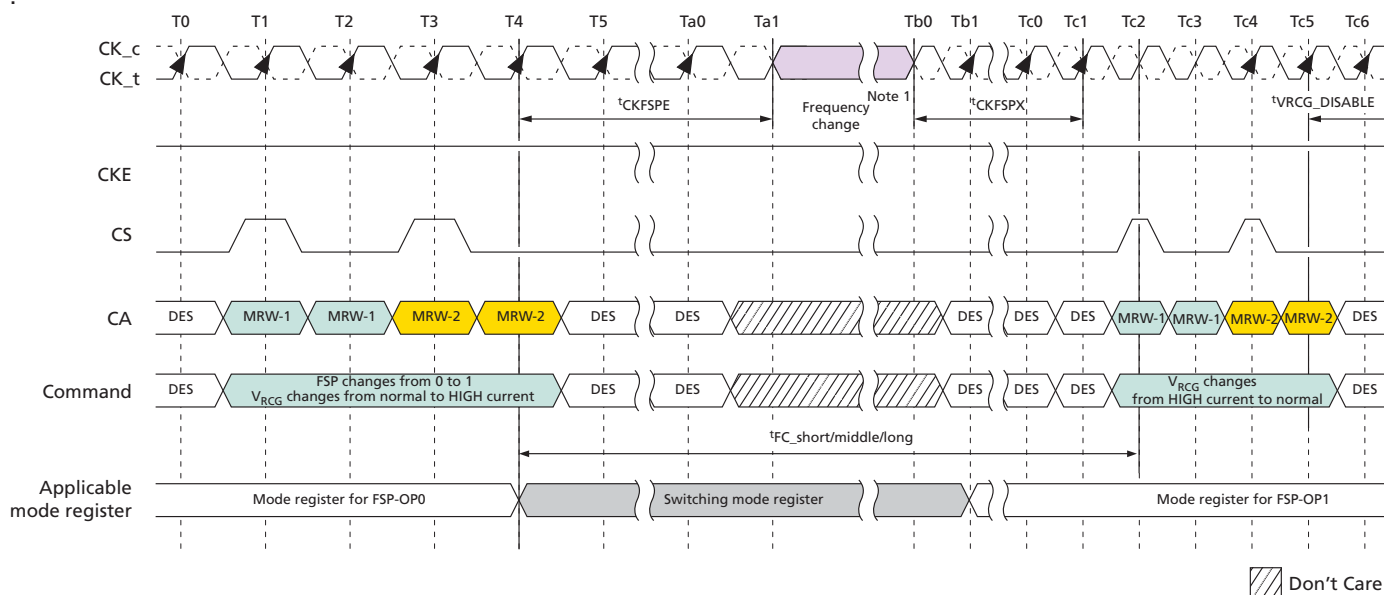
Function	MR# and Operand	Data	Operation	Notes
FSP-WR	MR13 OP[6]	0 (default)	Data write to mode register N for FSP-OP[0] by MRW command.	1
		1	Data write to mode register N for FSP-OP[1] by MRW command.	
FSP-OP	MR13 OP[7]	0 (default)	DRAM operates with mode register N for FSP-OP[0] setting.	2
		1	DRAM operates with mode register N for FSP-OP[1] setting.	

Notes: 1. FSP-WR stands for frequency set point write/read.  
2. FSP-OP stands for frequency set point operating point.

## Frequency Set Point Update Timing

The frequency set point update timing is shown below. When changing the frequency set point via MR13 OP[7], the V<sub>RCG</sub> setting: MR13 OP[3] have to be changed into V<sub>REF</sub> fast response (high current) mode at the same time. After frequency change time (<sup>t</sup>FC) is satisfied, V<sub>RCG</sub> can be changed into normal operation mode via MR13 OP[3].

Figure 132: Frequency Set Point Switching Timing



Note: 1. For frequency change during frequency set point switching, refer to input Clock Stop and Frequency Change section.

Table 126: Frequency Set Point AC Timing

Parameter	Symbol	Min/Max	Data Rate				Unit	Notes
			1600	3200	3733	4267		
Frequency set point switching time	t <sup>FC_short</sup>	MIN	200				ns	1
	t <sup>FC_middle</sup>	MIN	200				ns	
	t <sup>FC_long</sup>	MIN	250				ns	
Valid clock requirement after entering FSP change	t <sup>CKFSPE</sup>	MIN	MAX(7.5ns, 4nCK)				–	
Valid clock requirement before first valid command after FSP change	t <sup>CKFSPX</sup>	MIN	MAX(7.5ns, 4nCK)				–	

Note: 1. Frequency set point switching time depends on value of V<sub>REF(CA)</sub> setting: MR12 OP[5:0] and V<sub>REF(CA)</sub> range: MR12 OP[6] of FSP-OP 0 and 1. The details are shown in table below. Additionally change of frequency set point may affect V<sub>REF(DQ)</sub> setting. Settling time of V<sub>REF(DQ)</sub> level is the same as V<sub>REF(CA)</sub> level.

Table 127: t<sup>FC</sup> Value Mapping

Application	Step Size		Range	
	From FSP-OP0	To FSP-OP1	From FSP-OP0	To FSP-OP1
t <sup>FC_short</sup>	Base	A single step size increment/decrement	Base	No change

**Table 127:  $t_{FC}$  Value Mapping (Continued)**

Application	Step Size		Range	
	From FSP-OP0	To FSP-OP1	From FSP-OP0	To FSP-OP1
$t_{FC\_middle}$	Base	Two or more step size increment/decrement	Base	No change
$t_{FC\_long}$	–	–	Base	Change

Note: 1. As well as change from FSP-OP1 to FSP-OP0.

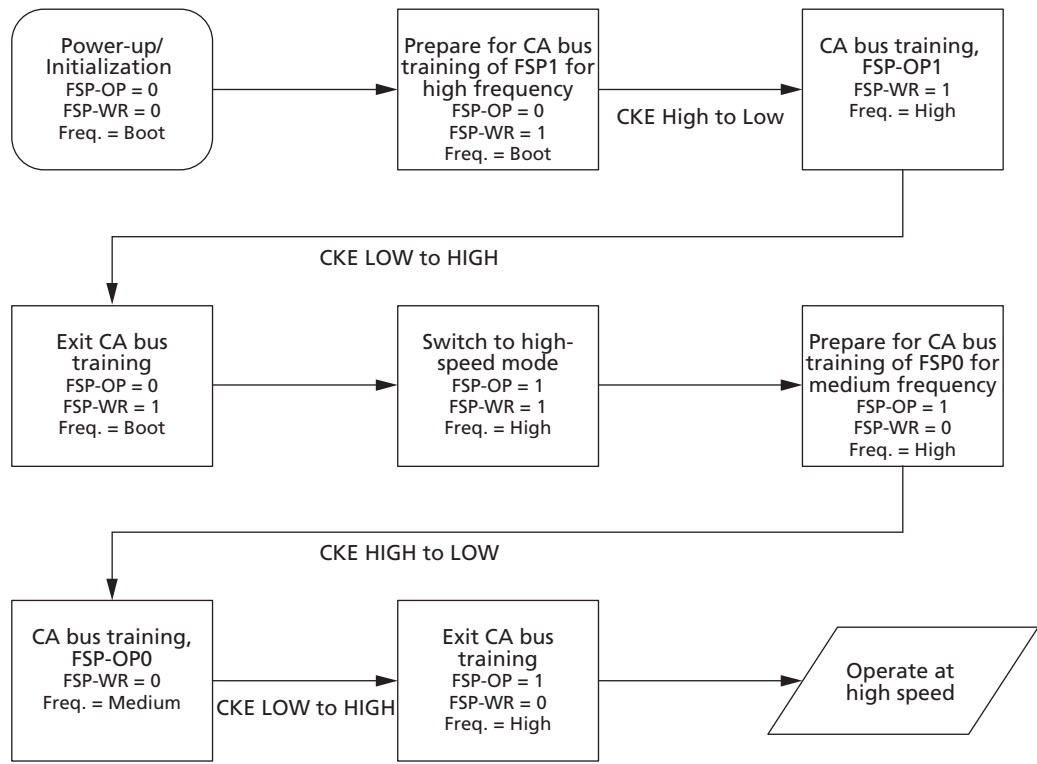
**Table 128:  $t_{FC}$  Value Mapping: Example**

Case	From/To	FSP-OP: MR13 OP[7]	$V_{REF(CA)}$ Setting: MR12: OP[5:0]	$V_{REF(CA)}$ Range: MR12 OP[6]	Application	Notes
1	From	0	001100	0	$t_{FC\_short}$	1
	To	1	001101	0		
2	From	0	001100	0	$t_{FC\_middle}$	2
	To	1	001110	0		
3	From	0	Don't Care	0	$t_{FC\_long}$	3
	To	1	Don't Care	1		

- Notes:
1. A single step size increment/decrement for  $V_{REF(CA)}$  setting value.
  2. Two or more step size increment/decrement for  $V_{REF(CA)}$  setting value.
  3.  $V_{REF(CA)}$  range is changed. In this case, changing  $V_{REF(CA)}$  setting doesn't affect  $t_{FC}$  value.

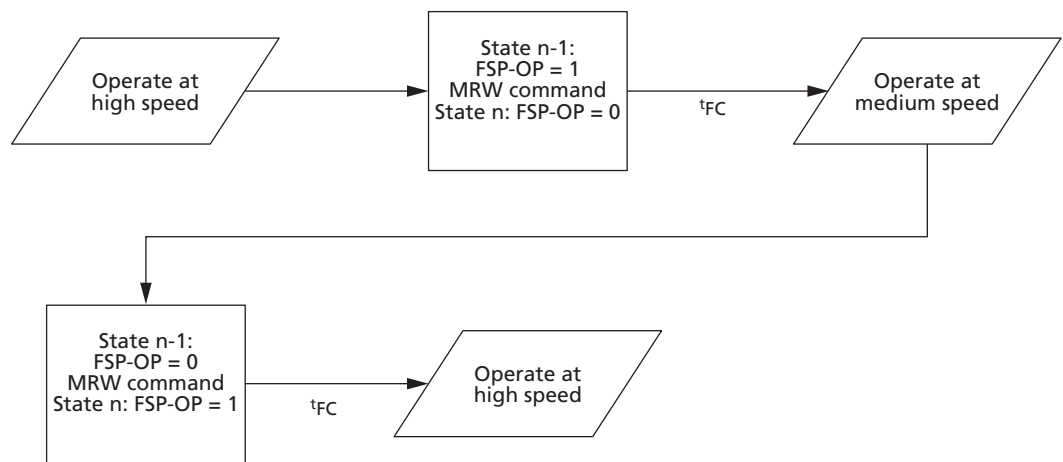
The LPDDR4 SDRAM defaults to FSP-OP[0] at power-up. Both set points default to settings needed to operate in un-terminated, low-frequency environments. To enable the device to operate at higher frequencies, Command bus training mode should be utilized to train the alternate frequency set point. See Command Bus Training section for more details on this training mode.

Figure 133: Training for Two Frequency Set Points



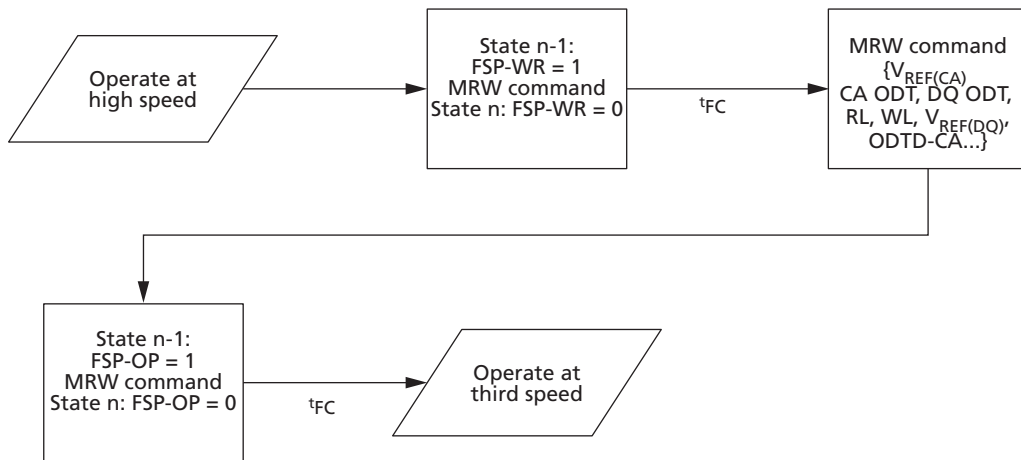
Once both of the frequency set points have been trained, switching between points can be performed with a single MRW followed by waiting for time  $t_{FC}$ .

Figure 134: Example of Switching Between Two Trained Frequency Set Points



Switching to a third (or more) set point can be accomplished if the memory controller has stored the previously-trained values (in particular the  $V_{REF(CA)}$  calibration value) and rewrites these to the alternate set point before switching FSP-OP.

Figure 135: Example of Switching to a Third Trained Frequency Set Point



## Pull-Up and Pull-Down Characteristics and Calibration

Table 129: Pull-Down Driver Characteristics – ZQ Calibration

$R_{ONPD,nom}$	Register	Min	Nom	Max	Unit
40 Ohm	$R_{ON40PD}$	0.90	1.0	1.10	$R_{ZQ}/6$
48 Ohm	$R_{ON48PD}$	0.90	1.0	1.10	$R_{ZQ}/5$
60 Ohm	$R_{ON60PD}$	0.90	1.0	1.10	$R_{ZQ}/4$
80 Ohm	$R_{ON80PD}$	0.90	1.0	1.10	$R_{ZQ}/3$
120 Ohm	$R_{ON120PD}$	0.90	1.0	1.10	$R_{ZQ}/2$
240 Ohm	$R_{ON240PD}$	0.90	1.0	1.10	$R_{ZQ}/1$

Note: 1. All value are after ZQ calibration. Without ZQ calibration,  $R_{ONPD}$  values are  $\pm 30\%$ .

Table 130: Pull-Up Characteristics – ZQ Calibration

$V_{OHPU,nom}$	$V_{OH,nom}$	Min	Nom	Max	Unit
$V_{DDQ}/2.5$	440	0.90	1.0	1.10	$V_{OH,nom}$
$V_{DDQ}/3$	367	0.90	1.0	1.10	$V_{OH,nom}$

Notes: 1. All value are after ZQ calibration. Without ZQ calibration,  $R_{ONPD}$  values are  $\pm 30\%$ .  
2.  $V_{OH,nom}$  (mV) values are based on a nominal  $V_{DDQ} = 1.1V$ .

Table 131: Valid Calibration Points

$V_{OHPU}$	ODT Value					
	240	120	80	60	48	40
$V_{DDQ}/2.5$	Valid	Valid	Valid	DNU	DNU	DNU



**Table 131: Valid Calibration Points (Continued)**

V <sub>OHPU</sub>	ODT Value					
	240	120	80	60	48	40
V <sub>DDQ</sub> /3	Valid	Valid	Valid	Valid	Valid	Valid

- Notes:
1. Once the output is calibrated for a given V<sub>OH(nom)</sub> calibration point, the ODT value may be changed without recalibration.
  2. If the V<sub>OH(nom)</sub> calibration point is changed, then recalibration is required.
  3. DNU = Do not use.

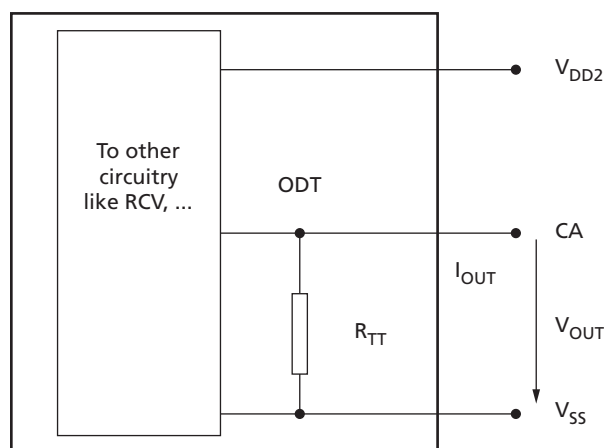
## On-Die Termination for the Command/Address Bus

The on-die termination (ODT) feature allows the device to turn on/off termination resistance for CK<sub>t</sub>, CK<sub>c</sub>, 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 the mode register setting.

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

**Figure 136: ODT for CA**

$$R_{TT} = \frac{V_{OUT}}{|I_{OUT}|}$$



### ODT Mode Register and ODT State Table

ODT termination values are set and enabled via MR11. The CA bus (CK<sub>t</sub>, CK<sub>c</sub>, 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<sub>t</sub>, CK<sub>c</sub>, CS, and CA 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 state.

The die has a bond pad (ODT\_CA) for multirank 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 multirank system, the terminating rank should be trained first, followed by the non-terminating rank(s).

**Table 132: Command Bus ODT State**

CA ODT MR11[6:4]	ODT_CA Bond Pad	ODTD-CA MR22 OP[5]	ODTE-CK MR22 OP[3]	ODTE-CS MR22 OP[4]	ODT State for CA	ODT State for CK	ODT State 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 = H or L (a defined logic level)
  3. Valid = 0 or 1.
  4. The state of ODT\_CA is not changed when the device enters power-down mode. This maintains termination for alternate ranks in multirank systems.

## ODT Mode Register and ODT Characteristics

**Table 133: ODT DC Electrical Characteristics – up to 3200 Mbps**

$R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[6:4]	$R_{TT}$	$V_{OUT}$	Min	Nom	Max	Unit	Notes
001b	240 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/1$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.2		
010b	120 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/2$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.2		
011b	80 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/3$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.2		
100b	60 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/4$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.2		

**Table 133: ODT DC Electrical Characteristics – up to 3200 Mbps (Continued)**

$R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[6:4]	$R_{TT}$	$V_{OUT}$	Min	Nom	Max	Unit	Notes
101b	48 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/5$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.2		
110b	40 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/6$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.2		
Mismatch, CA -CA within clock group		$0.33 \times V_{DD2}$	–	–	2	%	1, 2, 3

- Notes:
- The tolerance limits are specified after calibration with stable temperature and voltage. To understand the behavior of the tolerance limits when voltage or temperature changes after calibration, see the section on voltage and temperature sensitivity.
  - Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DD2}$ . Other calibration points may be required to achieve the linearity specification shown above, for example, calibration at  $0.5 \times V_{DD2}$  and  $0.1 \times V_{DD2}$ .
  - CA to CA mismatch within clock group variation for a given component including CK\_t, CK\_c, and CS (characterized).

$$\text{CA-to-CA mismatch} = \frac{R_{ODT}(\text{MAX}) - R_{ODT}(\text{MIN})}{R_{ODT}(\text{AVG})}$$

**Table 134: ODT DC Electrical Characteristics – Beyond 3200 Mbps**

$R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[6:4]	$R_{TT}$	$V_{OUT}$	Min	Nom	Max	Unit	Notes
001b	240 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/1$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.3		
010b	120 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/2$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.3		
011b	80 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/3$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.3		
100b	60 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/4$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.3		
101b	48 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/5$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.3		

**Table 134: ODT DC Electrical Characteristics – Beyond 3200 Mbps (Continued)**

$R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

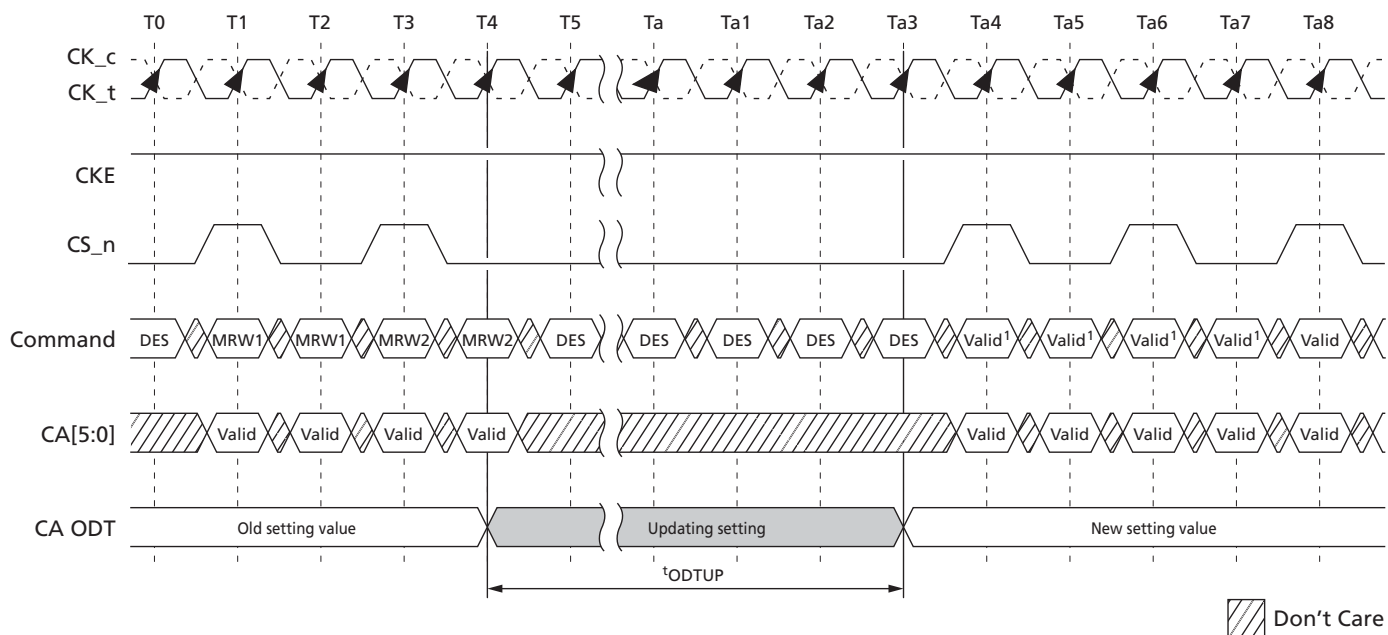
MR11 OP[6:4]	$R_{TT}$	$V_{OUT}$	Min	Nom	Max	Unit	Notes
110b	40 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DD2}$	0.8	1.0	1.1	$R_{ZQ}/6$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DD2}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DD2}$	0.9	1.0	1.3		
Mismatch, CA -CA within clock group		$0.33 \times V_{DD2}$	–	–	2	%	1, 2, 3

- Notes:
- The tolerance limits are specified after calibration with stable temperature and voltage. To understand the behavior of the tolerance limits when voltage or temperature changes after calibration, see the section on voltage and temperature sensitivity.
  - Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DD2}$ . Other calibration points may be required to achieve the linearity specification shown above, e.g. calibration at  $0.5 \times V_{DD2}$  and  $0.1 \times V_{DD2}$ .
  - CA to CA mismatch within clock group variation for a given component including CK\_t, CK\_c, and CS (characterized).

$$\text{CA-to-CA mismatch} = \frac{R_{ODT}(\text{MAX}) - R_{ODT}(\text{MIN})}{R_{ODT}(\text{AVG})}$$

### ODT for CA Update Time

**Figure 137: ODT for CA Setting Update Timing in 4-Clock Cycle Command**



## DQ On-Die Termination

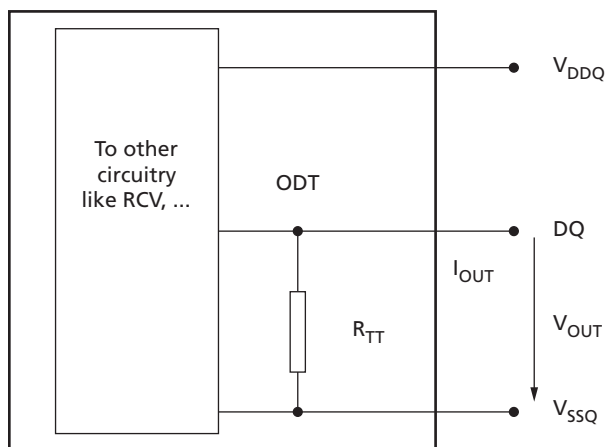
On-die termination (ODT) is a feature that allows the device to turn on/off termination resistance for each DQ, DQS, and DMI signal without the ODT control pin. The ODT feature is designed to improve signal integrity of the memory channel by allowing the DRAM controller to turn on and off termination 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.

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 MR bits.

$$R_{TT} = \frac{V_{OUT}}{|I_{OUT}|}$$

**Figure 138: Functional Representation of DQ ODT**



**Table 135: ODT DC Electrical Characteristics - up to 3200 Mbps**

$R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[2:0]	$R_{TT}$	$V_{OUT}$	Min	Nom	Max	Unit	Notes
001b	240 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	$R_{ZQ}/1$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.2		
010b	120 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	$R_{ZQ}/2$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.2		
011b	80 $\Omega$	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	$R_{ZQ}/3$	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.2		

**Table 135: ODT DC Electrical Characteristics – up to 3200 Mbps (Continued)**
 $R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[2:0]	R <sub>TT</sub>	V <sub>OUT</sub>	Min	Nom	Max	Unit	Notes
100b	60Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /4	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.2		
101b	48Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /5	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.2		
110b	40Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /6	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.2		
Mismatch error, DQ-to-DQ within a channel		$0.33 \times V_{DDQ}$	–	–	2	%	1, 2, 3

- Notes:
1. The ODT tolerance limits are specified after calibration with stable temperature and voltage. To understand the behavior of the tolerance limits when voltage or temperature changes after calibration, see the following section on voltage and temperature sensitivity.
  2. Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DDQ}$ . Other calibration points may be required to achieve the linearity specification shown above, (for example, calibration at  $0.5 \times V_{DDQ}$  and  $-0.1 \times V_{DDQ}$ ).
  3. DQ-to-DQ mismatch within byte variation for a given component, including DQS (characterized).

$$\text{DQ-to-DQ mismatch} = \frac{R_{ODT}(\text{MAX}) - R_{ODT}(\text{MIN})}{R_{ODT}(\text{AVG})}$$

**Table 136: ODT DC Electrical Characteristics – Beyond 3200 Mbps**
 $R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[2:0]	R <sub>TT</sub>	V <sub>OUT</sub>	Min	Nom	Max	Unit	Notes
001b	240Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /1	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.3		
010b	120Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /2	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.3		
011b	80Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /3	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.3		
100b	60Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /4	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.3		

**Table 136: ODT DC Electrical Characteristics – Beyond 3200 Mbps (Continued)**
 $R_{ZQ} = 240\Omega \pm 1\%$  over entire operating range after calibration

MR11 OP[2:0]	R <sub>TT</sub>	V <sub>OUT</sub>	Min	Nom	Max	Unit	Notes
101b	48Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /5	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.3		
110b	40Ω	$V_{OL(DC)} = 0.1 \times V_{DDQ}$	0.8	1.0	1.1	R <sub>ZQ</sub> /6	1, 2
		$V_{OM(DC)} = 0.33 \times V_{DDQ}$	0.9	1.0	1.1		
		$V_{OH(DC)} = 0.5 \times V_{DDQ}$	0.9	1.0	1.3		
Mismatch error, DQ-to-DQ within a channel		$0.33 \times V_{DDQ}$	–	–	2	%	1, 2, 3

- Notes:
- The ODT tolerance limits are specified after calibration with stable temperature and voltage. To understand the behavior of the tolerance limits when voltage or temperature changes after calibration, see the following section on voltage and temperature sensitivity.
  - Pull-down ODT resistors are recommended to be calibrated at  $0.33 \times V_{DDQ}$ . Other calibration points may be required to achieve the linearity specification shown above, for example, calibration at  $0.5 \times V_{DDQ}$  and  $-0.1 \times V_{DDQ}$ .
  - DQ-to-DQ mismatch within byte variation for a given component, including DQS (characterized).

$$\text{DQ-to-DQ mismatch} = \frac{R_{ODT}(\text{MAX}) - R_{ODT}(\text{MIN})}{R_{ODT}(\text{AVG})}$$

## Output Driver and Termination Register Temperature and Voltage Sensitivity

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

**Table 137: Output Driver and Termination Register Sensitivity Definition**

Resistor	Definition Point	Min	Max	Unit	Notes
R <sub>ONPD</sub>	$0.33 \times V_{DDQ}$	$90 - (dR_{ONdT} \cdot  \Delta T ) - (dR_{ONdV} \cdot  \Delta V )$	$110 + (dR_{ONdT} \cdot  \Delta T ) + (dR_{ONdV} \cdot  \Delta V )$	%	1, 2
V <sub>OHPU</sub>	$0.33 \times V_{DDQ}$	$90 - (dV_{OHdT} \cdot  \Delta T ) - (dV_{OHdV} \cdot  \Delta V )$	$110 + (dV_{OHdT} \cdot  \Delta T ) + (dV_{OHdV} \cdot  \Delta V )$		1, 2, 5
R <sub>TT(I/O)</sub>	$0.33 \times V_{DDQ}$	$90 - (dR_{ONdT} \cdot  \Delta T ) - (dR_{ONdV} \cdot  \Delta V )$	$110 + (dR_{ONdT} \cdot  \Delta T ) + (dR_{ONdV} \cdot  \Delta V )$		1, 2, 3
R <sub>TT(IN)</sub>	$0.33 \times V_{DD2}$	$90 - (dR_{ONdT} \cdot  \Delta T ) - (dR_{ONdV} \cdot  \Delta V )$	$110 + (dR_{ONdT} \cdot  \Delta T ) + (dR_{ONdV} \cdot  \Delta V )$		1, 2, 4

- Notes:
- $\Delta T = T - T(@\text{calibration})$ ,  $\Delta V = V - V(@\text{calibration})$
  - $dR_{ONdT}$ ,  $dR_{ONdV}$ ,  $dV_{OHdT}$ ,  $dV_{OHdV}$ ,  $dR_{TTdV}$ , and  $dR_{TTdT}$  are not subject to production test but are verified by design and characterization.
  - This parameter applies to input/output pin such as DQS, DQ, and DMI.
  - This parameter applies to input pin such as CK, CA, and CS.
  - Refer to Pull-up/Pull-down Driver Characteristics for V<sub>OHPU</sub>.

**Table 138: Output Driver and Termination Register Temperature and Voltage Sensitivity**

Symbol	Parameter	Min	Max	Unit
dR <sub>ONdT</sub>	R <sub>ON</sub> temperature sensitivity	0	0.75	%/°C
dR <sub>ONdV</sub>	R <sub>ON</sub> voltage sensitivity	0	0.20	%/mV
dV <sub>OHdT</sub>	V <sub>OH</sub> temperature sensitivity	0	0.75	%/°C
dV <sub>OHdV</sub>	V <sub>OH</sub> voltage sensitivity	0	0.35	%/mV
dR <sub>TTdT</sub>	R <sub>TT</sub> temperature sensitivity	0	0.75	%/°C
dR <sub>TTdV</sub>	R <sub>TT</sub> voltage sensitivity	0	0.20	%/mV

## ODT Mode Register

The ODT mode is enabled if MR11 OP[2:0] are non-zero. In this case, the value of R<sub>TT</sub> is determined by the settings of those bits. The ODT mode is disabled if MR11 OP[2:0] = 0.

## Asynchronous ODT

When ODT mode is enabled in MR11 OP[2:0], DRAM ODT is always High-Z. The DRAM ODT feature is automatically turned ON asynchronously after a WRITE-1, MASK WRITE-1, or MPC[WRITE-FIFO] command. After the burst write is complete, the DRAM ODT turns OFF asynchronously. The DQ bus ODT control is automatic and will turn the ODT resistance on/off if DQ ODT is enabled in the mode register.

The following timing parameters apply when the DQ bus ODT is enabled:

- ODTL<sub>on</sub>, t<sub>ODTon</sub> (MIN), t<sub>ODTon</sub> (MAX)
- ODTL<sub>off</sub>, t<sub>ODToff</sub> (MIN), t<sub>ODToff</sub> (MAX)

ODTL<sub>ON</sub> is a synchronous parameter and is the latency from a CAS-2 command to the t<sub>ODTon</sub> reference. ODTL<sub>ON</sub> latency is a fixed latency value for each speed bin. Each speed bin has a different ODTL<sub>ON</sub> latency.

Minimum R<sub>TT</sub> turn-on time (t<sub>ODTon</sub> (MIN)) is the point in time when the device termination circuit leaves High-Z and ODT resistance begins to turn on.

Maximum R<sub>TT</sub> turn on time (t<sub>ODTon</sub> (MAX)) is the point in time when the ODT resistance is fully on.

t<sub>ODTon</sub> (MIN) and t<sub>ODTon</sub> (MAX) are measured once ODTL<sub>on</sub> latency is satisfied from CAS-2 command.

ODTL<sub>OFF</sub> is a synchronous parameter and it is the latency from CAS-2 command to t<sub>ODToff</sub> reference. ODTL<sub>OFF</sub> latency is a fixed latency value for each speed bin. Each speed bin has a different ODTL<sub>OFF</sub> latency.

Minimum R<sub>TT</sub> turn-off time (t<sub>ODToff</sub> (MIN)) is the point in time when the device termination circuit starts to turn off the ODT resistance.

Maximum ODT turn off time (t<sub>ODToff</sub> (MAX)) is the point in time when the on-die termination has reached High-Z.

t<sub>ODToff</sub> (MIN) and t<sub>ODToff</sub> (MAX) are measured once ODTL<sub>off</sub> latency is satisfied from CAS-2 command.

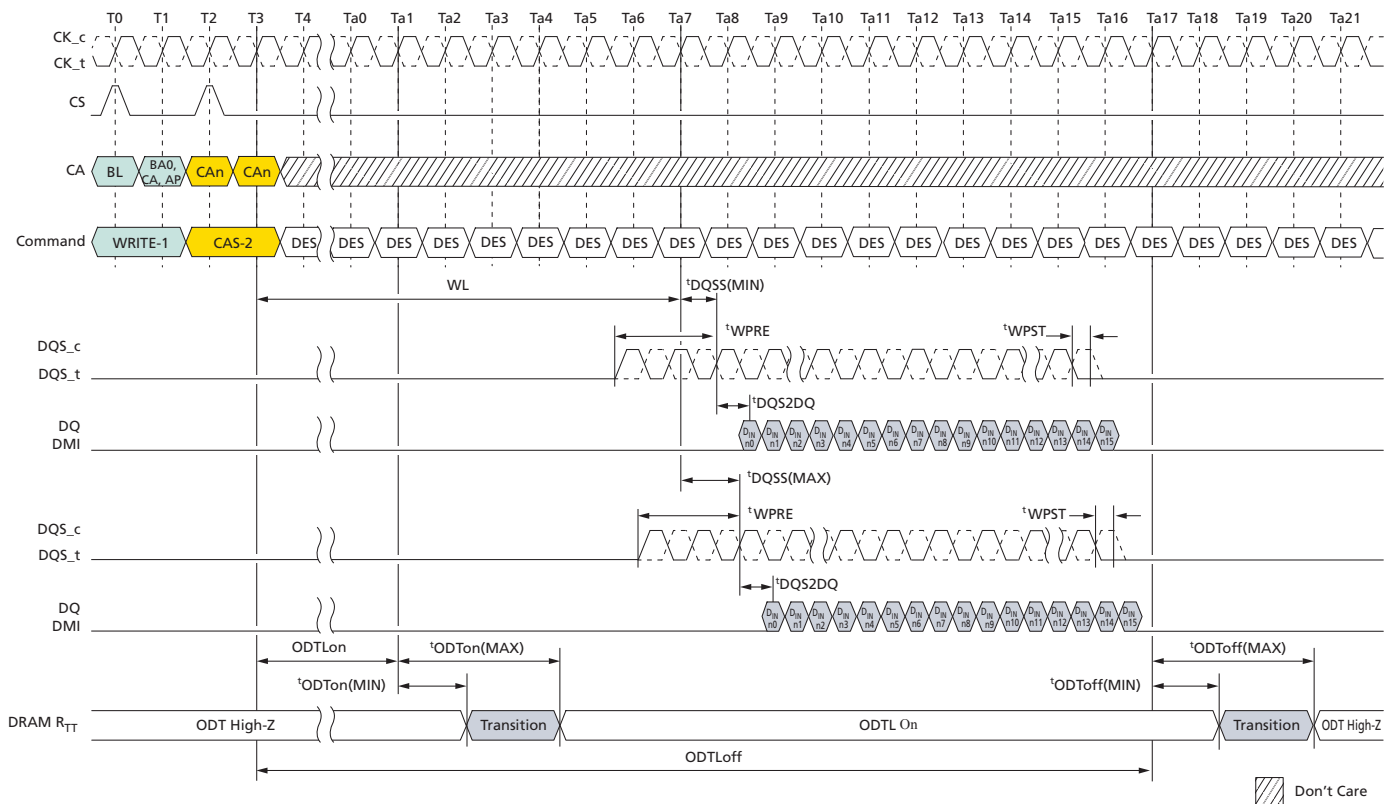


Table 139: ODT<sub>ON</sub> and ODT<sub>OFF</sub> Latency Values

ODT <sub>ON</sub> Latency <sup>1</sup>		ODT <sub>OFF</sub> Latency <sup>2</sup>		Lower Frequency Limit (>) (MHz)	Upper Frequency Limit (≤) (MHz)
t <sub>WPRE</sub> = 2 t <sub>CK</sub>					
WL Set A (nCK)	WL Set B (nCK)	WL Set A (nCK)	WL Set B (nCK)		
N/A	N/A	N/A	N/A	10	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

- Notes: 1. ODT<sub>ON</sub> is referenced from CAS-2 command.  
2. ODT<sub>OFF</sub> as shown in table assumes BL = 16. For BL32, 8 t<sub>CK</sub> should be added.

Figure 139: Asynchronous ODTon/ODToff Timing



- Notes: 1. BL = 16, Write postamble = 0.5nCK, DQ/DQS: V<sub>SSQ</sub> termination  
2. Din n = data-in to column n.

3. DES commands are shown for ease of illustration; other commands may be valid at these times.

### **DQ ODT During Power-Down and Self Refresh Modes**

DQ bus ODT will be disabled in power-down mode. In self refresh mode, the ODT will be turned off when CKE is LOW but will be enabled if CKE is HIGH and DQ ODT is enabled in the mode register.

### **ODT During Write Leveling Mode**

If ODT is enabled in MR11 OP[2:0] in write leveling mode, the device always provides the termination on DQS signals. DQ termination is always off in write leveling mode.

**Table 140: Termination State in Write Leveling Mode**

<b>ODT State in MR11 OP[2:0]</b>	<b>DQS Termination</b>	<b>DQ[15:0]/DMI[1:0] Termination</b>
Disabled	Off	Off
Enabled	On	Off

## Target Row Refresh Mode

The device limits the number of times that a given row can be accessed within a refresh period ( $t_{REFW} \times 2$ ) prior to requiring adjacent rows to be refreshed. The maximum activate count (MAC) is the maximum number of activates that a single row can sustain within a refresh period before the adjacent rows need to be refreshed. The row receiving the excessive activates is the target row (TRn), the adjacent rows to be refreshed are the victim rows. When the MAC limit is reached on TRn, either the device receives all ( $R \times 2$ ) REFRESH commands before another row activate is issued, or the device should be placed into targeted row refresh (TRR) mode. The TRR mode will refresh the rows adjacent to the TRn that encountered  $t_{MAC}$  limit.

If the device supports unlimited MAC value: MR24 OP[2:0] = 000 and MR24 OP[3] = 1, TARGET ROW REFRESH operation is not required. Even though the device allows to set MR24 OP[7] = 1: TRR mode enable, in this case the device behavior is vendor specific. For example, a certain device may ignore MRW command for entering/exiting TRR mode or a certain device may support commands related TRR mode. See vendor device datasheets for details about TRR mode definition at supporting unlimited MAC value case.

There could be a maximum of two target rows to a victim row in a bank. The cumulative value of the activates from the two target rows on a victim row in a bank should not exceed MAC value.

MR24 fields are required to support the new TRR settings. Setting MR24 OP[7] = 1 enables TRR mode and setting MR24 OP[7] = 0 disables TRR mode. MR24 OP[6:4] defines which bank (BAn) the target row is located in (refer to MR24 table for details).

The TRR mode must be disabled during initialization as well as any other device calibration modes. The TRR mode is entered from a DRAM idle state, once TRR mode has been entered, no other mode register commands are allowed until TRR mode is completed; however, setting MR24 OP[7] = 0 to interrupt and reissue the TRR mode is allowed.

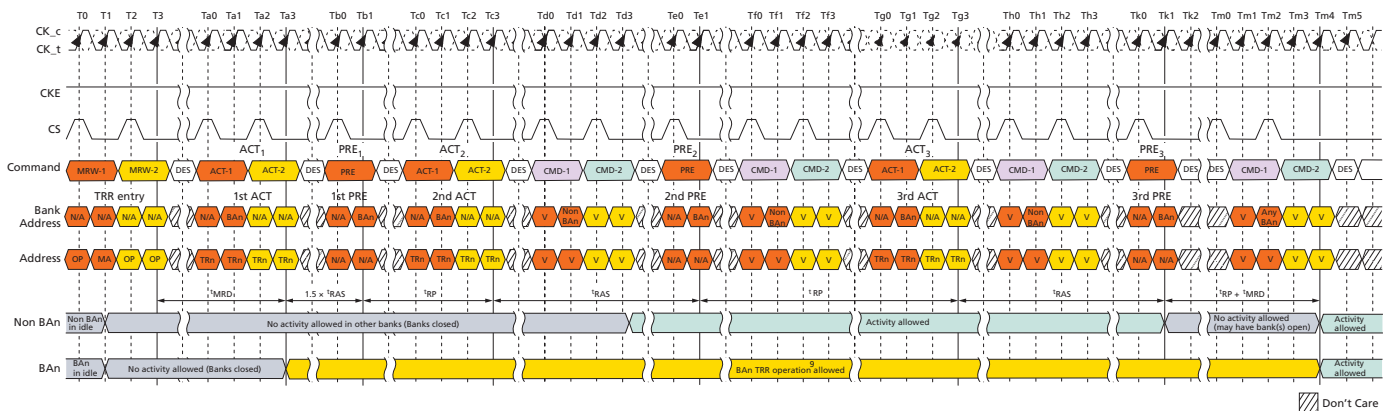
When enabled, TRR mode is self-clearing. the mode will be disabled automatically after the completion of defined TRR flow (after the third BAn precharge has completed plus  $t_{MRD}$ ). Optionally, the TRR mode can also be exited via another MRS command at the completion of TRR by setting MR24 OP[7] = 0. If the TRR is exited via another MRS command, the value written to MR24 OP[6:4] are "Don't Care."

## TRR Mode Operation

1. The timing diagram depicts TRR mode. The following steps must be performed when TRR mode is enabled. This mode requires all three ACT (ACT1, ACT2, and ACT3) and three corresponding PRE commands (PRE1, PRE2, and PRE3) to complete TRR mode. PRECHARGE All (PREA) commands issued while the device is in TRR mode will also perform precharge to BAn and counts towards PREn command.
2. Prior to issuing the MRW command to enter TRR mode, the device should be in the idle state. MRW command must be issued with MR24 OP[7] = 1 and MR24 OP[6:4] defining the bank in which the targeted row is located. All other MR24 bits should remain unchanged.
3. No activity is to occur with the device until  $t_{MRD}$  has been satisfied. When  $t_{MRD}$  has been satisfied, the only commands allowed BAn, until TRR mode has completed, are ACT and PRE.

4. The first ACT to the BA<sub>n</sub> with the TR<sub>n</sub> address can now be applied; no other command is allowed at this point. All other banks must remain inactive from when the first BA<sub>n</sub> ACT command is issued until  $[(1.5 \times t_{RAS}) + t_{RP}]$  is satisfied.
5. After the first ACT to the BA<sub>n</sub> with the TR<sub>n</sub> address is issued, PRE to BA<sub>n</sub> is to be issued  $(1.5 \times t_{RAS})$  later; and then followed  $t_{RP}$  later by the second ACT to the BA<sub>n</sub> with the TR<sub>n</sub> address.
6. After the second ACT to the BA<sub>n</sub> with the TR<sub>n</sub> address is issued, PRE to BA<sub>n</sub> is to be issued  $t_{RAS}$  later and then followed  $t_{RP}$  later by the third ACT to the BA<sub>n</sub> with the TR<sub>n</sub> address.
7. After the third ACT to the BA<sub>n</sub> with the TR<sub>n</sub> address is issued, PRE to BA<sub>n</sub> would be issued  $t_{RAS}$  later. TRR mode is completed once  $t_{RP}$  plus  $t_{MRD}$  is satisfied.
8. TRR mode must be completed as specified to guarantee that adjacent rows are refreshed. Anytime the TRR mode is interrupted and not completed, the interrupted TRR mode must be cleared and then subsequently performed again. To clear an interrupted TRR mode, MR24 change is required with setting MR24 OP[7] = 0, MR24 OP[6:4] are "Don't care," followed by three PRE to BA<sub>n</sub>, with  $t_{RP}$  time in between each PRE command. The complete TRR sequence (steps 2–7) must be then reissued and completed to guarantee that the adjacent rows are refreshed.
9. A REFRESH command to the device, or entering self refresh mode, is not allowed while the device is in TRR mode.

**Figure 140: Target Row Refresh Mode**



- Notes:
1. TR<sub>n</sub> is the targeted row.
  2. Bank BA<sub>n</sub> represents the bank in which the targeted row is located.
  3. TRR mode self-clears after  $t_{MRD} + t_{RP}$  measured from the third BA<sub>n</sub> precharge PRE<sub>3</sub> at clock edge Th<sub>4</sub>.
  4. TRR mode or any other activity can be re-engaged after  $t_{RP} + t_{MRD}$  from the third BA<sub>n</sub> precharge PRE<sub>3</sub>. PRE<sub>ALL</sub> also counts if it is issued instead of PRE<sub>n</sub>. TRR mode is cleared by the device after PRE<sub>3</sub> to the BA<sub>n</sub> bank.
  5. ACTIVATE commands to BA<sub>n</sub> during TRR mode do not provide refresh support (the refresh counter is unaffected).
  6. The device must restore the degraded row(s) caused by excessive activation of the targeted row (TR<sub>n</sub>) necessary to meet refresh requirements.
  7. A new TRR mode must wait  $t_{MRD} + t_{RP}$  time after the third precharge.
  8. BA<sub>n</sub> may not be used with any other command.
  9. ACT and PRE are the only allowed commands to BA<sub>n</sub> during TRR mode.
  10. REFRESH commands are not allowed during TRR mode.

11. All timings are to be met by DRAM during TRR mode, such as  $t_{FAW}$ . Issuing ACT1, ACT2, and ACT3 counts towards  $t_{FAW}$  budget.

## Post-Package Repair

The device has fail row address repair as an optional post-package repair (PPR) feature and it is readable through MR25 OP[7:0].

PPR provides simple and easy repair method in the system and fail row address can be repaired by the electrical programming of Electrical-fuse scheme. The device can correct one row per bank with PPR.

Electrical-fuse cannot be switched back to un-fused states once it is programmed. The controller should prevent unintended PPR mode entry and repair.

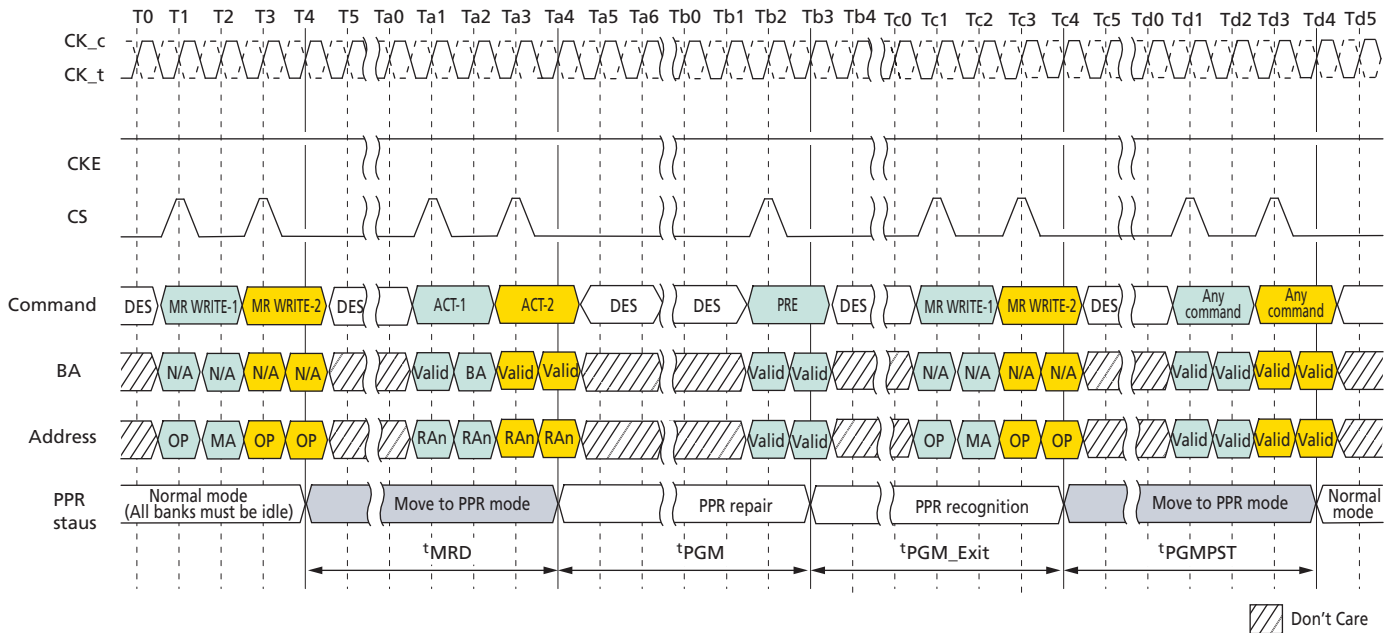
## Failed Row Address Repair

1. Before entering PPR mode, all banks must be precharged.
2. Enable PPR using MR4 OP[4] = 1 and wait  $t_{MRD}$ .
3. Issue ACT command with fail row address.
4. Wait  $t_{PGM}$  to allow the device repair target row address internally then issue PRECHARGE
5. Wait  $t_{PGM\_EXIT}$  after PRECHARGE, which allows the device to recognize repaired row address RAn.
6. Exit PPR mode with setting MR4 OP[4] = 0.
7. The device is ready for any valid command after  $t_{PGMPST}$ .
8. In more than one fail address repair case, repeat step 2 to 7.

Once PPR mode is exited, to confirm whether the target row has correctly repaired, the host can verify the repair by writing data into the target row and reading it back after PPR exit with MR4 OP[4] = 0 and  $t_{PGMPST}$ .

The following timing diagram shows PPR operation.

Figure 141: Post-Package Repair Timing



- Notes:
1. During  $t_{PGM}$ , any other commands (including refresh) are not allowed on each die.
  2. With one PPR command, only one row can be repaired at one time per die.
  3. When PPR procedure completes, reset procedure is required before normal operation.
  4. During PPR, memory contents are not refreshed and may be lost.

Table 141: Post-Package Repair Timing Parameters

Parameter	Symbol	Min	Max	Units
PPR programming time	$t_{PGM}$	1000	–	ms
PPR exit time	$t_{PGM\_EXIT}$	15	–	ns
New address setting time	$t_{PGMPST}$	50	–	$\mu$ s

## Read Preamble Training

Read preamble training is supported through the MPC function.

This mode can be used to train or read level the DQS receivers. After read preamble training is enabled by MR13 OP[1] = 1, the device will drive DQS\_t LOW and DQS\_c HIGH within  $t_{SDO}$  and remain at these levels until an MPC[READ DQ CALIBRATION] command is issued.

During read preamble training, the DQS preamble provided during normal operation will not be driven by the device. After the MPC[READ DQ CALIBRATION] command is issued, the device will drive DQS\_t/DQS\_c and DQ like a normal READ burst after RL and  $t_{DQSCK}$ . Prior to the MPC[READ DQ CALIBRATION] command, the device may or may not drive DQ[15:0] in this mode.

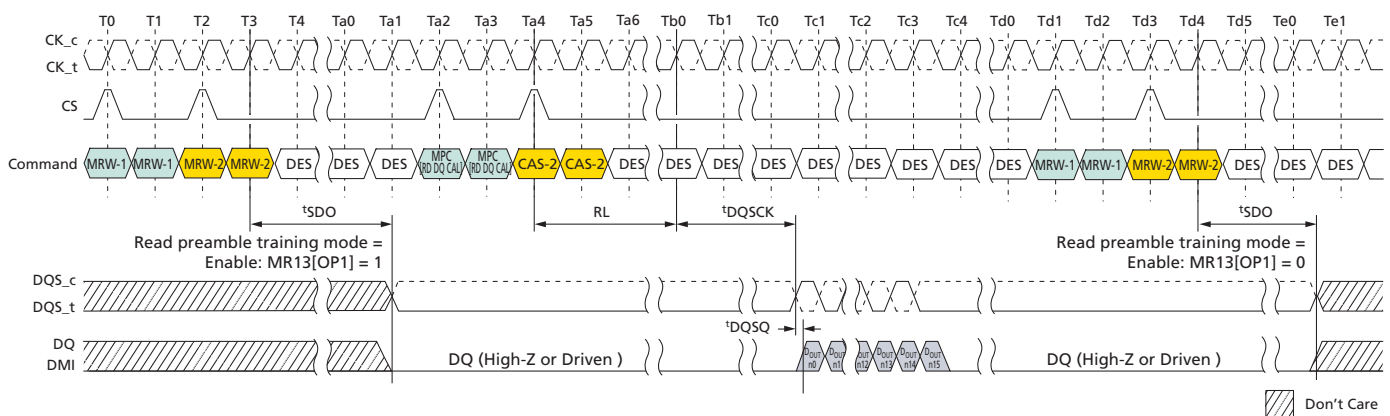
While in read preamble training mode, only READ DQ CALIBRATION commands may be issued.

- Issue an MPC[READ DQ CALIBRATION] command followed immediately by a CAS-2 command.
- Each time an MPC[READ DQ CALIBRATION] command followed by a CAS-2 is received by the device, a 16-bit data burst will, after the currently set RL, drive the eight bits programmed in MR32 followed by the eight bits programmed in MR40 on all I/O pins.
- The data pattern will be inverted for I/O pins with a 1 programmed in the corresponding invert mask mode register bit.
- Note that the pattern is driven on the DMI pins, but no DATA BUS INVERSION function is enabled, even if read DBI is enabled in the DRAM mode register.
- This command can be issued every  $t_{CCD}$  seamlessly.
- The operands received with the CAS-2 command must be driven LOW.

Read preamble training is exited within  $t_{SDO}$  after setting MR13 OP[1] = 0.

The device supports the READ preamble training as optional feature. Refer to vendor-specific data sheets.

Figure 142: Read Preamble Training



Note: 1. Read DQ calibration supports only BL16 operation.

## Electrical Specifications

### Absolute Maximum Ratings

Stresses greater than those listed in the table below may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at these conditions, or any other conditions outside those indicated in the operational sections of this document, is not implied. Exposure to absolute maximum rating conditions for extended periods may adversely affect reliability.

**Table 142: Absolute Maximum DC Ratings**

Parameter	Symbol	Min	Max	Unit	Notes
V <sub>DD1</sub> supply voltage relative to V <sub>SS</sub>	V <sub>DD1</sub>	-0.4	2.1	V	1
V <sub>DD2</sub> supply voltage relative to V <sub>SS</sub>	V <sub>DD2</sub>	-0.4	1.5	V	1
V <sub>DDQ</sub> supply voltage relative to V <sub>SS</sub>	V <sub>DDQ</sub>	-0.4	1.5	V	1
Voltage on any ball relative to V <sub>SS</sub>	V <sub>IN</sub> , V <sub>OUT</sub>	-0.4	1.5	V	
Storage temperature	T <sub>STG</sub>	-55	125	°C	2

- Notes:
1. For information about relationships between power supplies, see the Voltage Ramp and Device Initialization section.
  2. Storage temperature is the case surface temperature on the center/top side of the device. For measurement conditions, refer to the JE5D51-2 standard.

### AC and DC Operating Conditions

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

**Table 143: Recommended DC Operating Conditions**

Symbol	Min	Typ	Max	DRAM	Unit	Notes
V <sub>DD1</sub>	1.7	1.8	1.95	Core 1 power	V	1, 2
V <sub>DD2</sub>	1.06	1.1	1.17	Core 2 power/Input buffer power	V	1, 2, 3
V <sub>DDQ</sub>	1.06	1.1	1.17	I/O buffer power	V	2, 3

- Notes:
1. V<sub>DD1</sub> uses significantly less power than V<sub>DD2</sub>.
  2. The voltage range is for DC voltage only. DC voltage is the voltage supplied at the DRAM and is inclusive of all noise up to 20 MHz at the DRAM package ball.
  3. The voltage noise tolerance from DC to 20 MHz exceeding a peak-to-peak tolerance of 45mV at the DRAM ball is not included in the TdIVW.



**Table 144: Input Leakage Current**

Parameter/Condition	Symbol	Min	Max	Unit	Notes
Input leakage current	$I_L$	-4	4	$\mu\text{A}$	1, 2

- Notes:
1. For CK\_t, CK\_c, CKE, CS, CA, ODT\_CA, and RESET\_n. Any input  $0\text{V} \leq V_{IN} \leq V_{DD2}$ . (All other pins not under test = 0V.)
  2. CA ODT is disabled for CK\_t, CK\_c, CS, and CA.

**Table 145: Input/Output Leakage Current**

Parameter/Condition	Symbol	Min	Max	Unit	Notes
Input/Output leakage current	$I_{OZ}$	-5	5	$\mu\text{A}$	1, 2

- Notes:
1. For DQ, DQS\_t, DQS\_c, and DMI. Any I/O  $0\text{V} \leq V_{OUT} \leq V_{DDQ}$ .
  2. I/Os status are disabled: High Impedance and ODT off.

**Table 146: Operating Temperature Range**

Parameter/Condition	Symbol	Min	Max	Unit
Standard	$T_{OPER}$	Note 4	85	$^{\circ}\text{C}$
Elevated		85	Note 4	$^{\circ}\text{C}$

- Notes:
1. Operating temperature is the case surface temperature at the center of the top side of the device. For measurement conditions, refer to the JESD51-2 standard.
  2. When using the device in the elevated temperature range, some derating may be required. See Mode Registers for vendor-specific derating.
  3. Either the device case temperature rating or the temperature sensor can be used to set an appropriate refresh rate, determine the need for AC timing derating, and/or monitor the operating temperature (see Temperature Sensor). When using the temperature sensor, the actual device case temperature may be higher than the  $T_{OPER}$  rating that applies for the standard or elevated temperature range. For example,  $T_{CASE}$  could be above  $+85^{\circ}\text{C}$  when the temperature sensor indicates a temperature of less than  $+85^{\circ}\text{C}$ .
  4. Refer to Operating temperature range on top page.

## AC and DC Input Measurement Levels

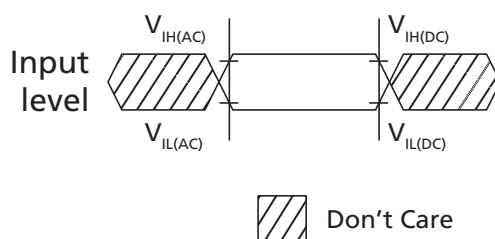
### Input Levels for CKE

Table 147: Input Levels

Parameter	Symbol	Min	Max	Unit	Notes
Input HIGH level (AC)	$V_{IH(AC)}$	$0.75 \times V_{DD2}$	$V_{DD2} + 0.2$	V	1
Input LOW level (AC)	$V_{IL(AC)}$	-0.2	$0.25 \times V_{DD2}$	V	1
Input HIGH level (DC)	$V_{IH(DC)}$	$0.65 \times V_{DD2}$	$V_{DD2} + 0.2$	V	
Input LOW level (DC)	$V_{IL(DC)}$	-0.2	$0.35 \times V_{DD2}$	V	

Note: 1. See the AC Overshoot and Undershoot section.

Figure 143: Input Timing Definition for CKE



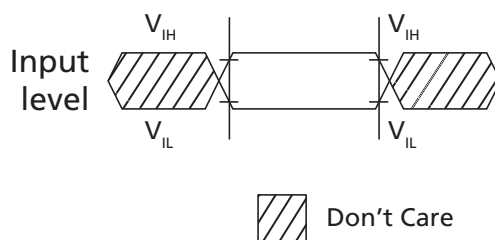
### Input Levels for RESET\_n and ODT\_CA

Table 148: Input Levels

Parameter	Symbol	Min	Max	Unit	Notes
Input HIGH level	$V_{IH}$	$0.80 \times V_{DD2}$	$V_{DD2} + 0.2$	V	1
Input LOW level	$V_{IL}$	-0.2	$0.20 \times V_{DD2}$	V	1

Note: 1. See the AC Overshoot and Undershoot section.

Figure 144: Input Timing Definition for RESET\_n and ODT\_CA

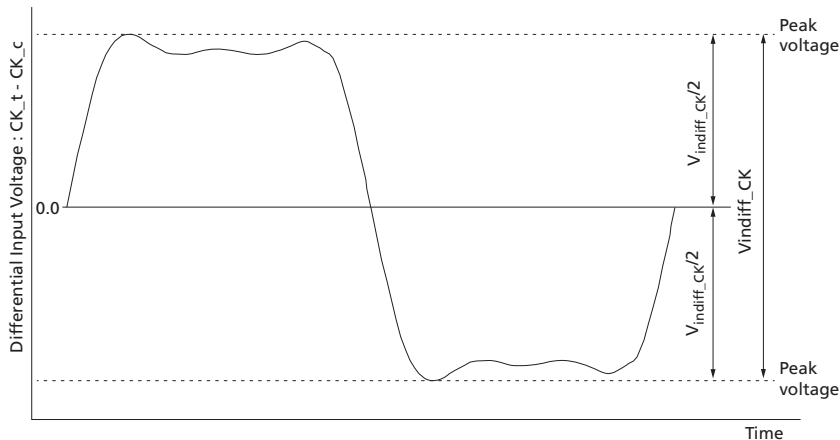


### Differential Input Voltage for CK

The minimum input voltage needs to satisfy both  $V_{indiff\_CK}$  and  $V_{indiff\_CK}/2$  specification at input receiver and their measurement period is  $1^tCK$ .  $V_{indiff\_CK}$  is the peak-to-peak

voltage centered on 0 volts differential and  $V_{\text{indiff\_CK}}/2$  is maximum and minimum peak voltage from 0 volts.

**Figure 145: CK Differential Input Voltage**



**Table 149: CK Differential Input Voltage**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit	Note
		Min	Max	Min	Max	Min	Max		
CK differential input voltage	$V_{\text{indiff\_CK}}$	420	–	380	–	360	–	mV	1

Note: 1. The peak voltage of differential CK signals is calculated in a following equation.

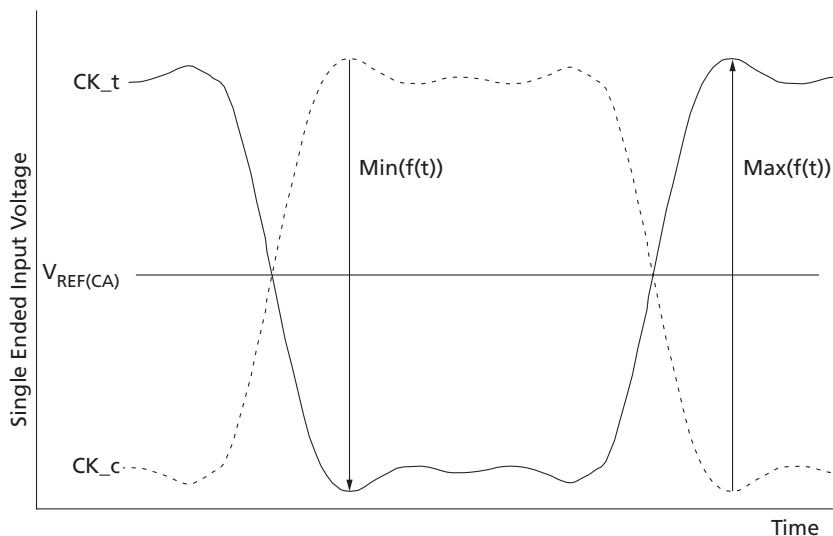
- $V_{\text{indiff\_CK}} = (\text{Maximum peak voltage}) - (\text{Minimum peak voltage})$
- Maximum peak voltage = MAX(f(t))
- Minimum peak voltage = MIN(f(t))
- $f(t) = V_{\text{CK\_t}} - V_{\text{CK\_c}}$

### Peak Voltage Calculation Method

The peak voltage of differential clock signals are calculated in a following equation.

- $V_{\text{IH.DIFF:peak}}$  voltage = MAX(f(t))
- $V_{\text{IL.DIFF:peak}}$  voltage = MIN(f(t))
- $f(t) = V_{\text{CK\_t}} - V_{\text{CK\_c}}$

Figure 146: Definition of Differential Clock Peak Voltage

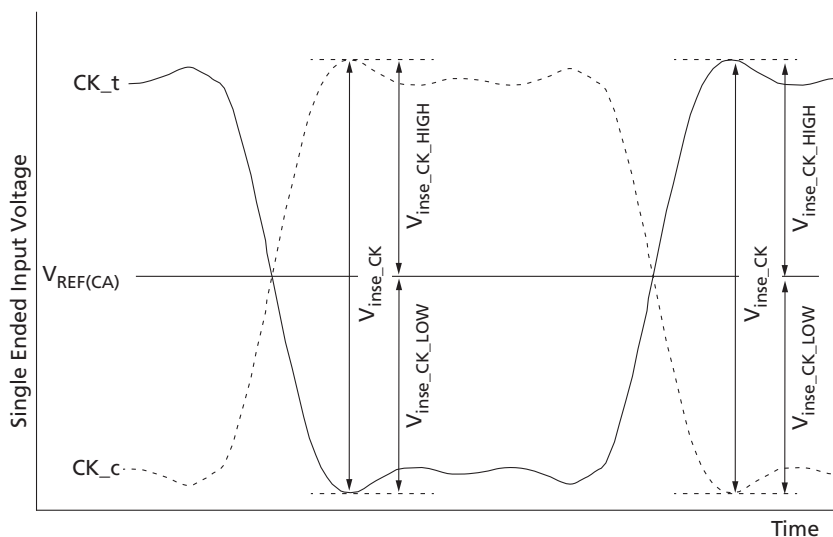


Note: 1.  $V_{REF(CA)}$  is device internal setting value by  $V_{REF}$  training.

### Single-Ended Input Voltage for Clock

The minimum input voltage need to satisfy  $V_{inse\_CK}$ ,  $V_{inse\_CK\_HIGH}$ , and  $V_{inse\_CK\_LOW}$  specification at input receiver.

Figure 147: Clock Single-Ended Input Voltage



Note: 1.  $V_{REF(CA)}$  is device internal setting value by  $V_{REF}$  training.

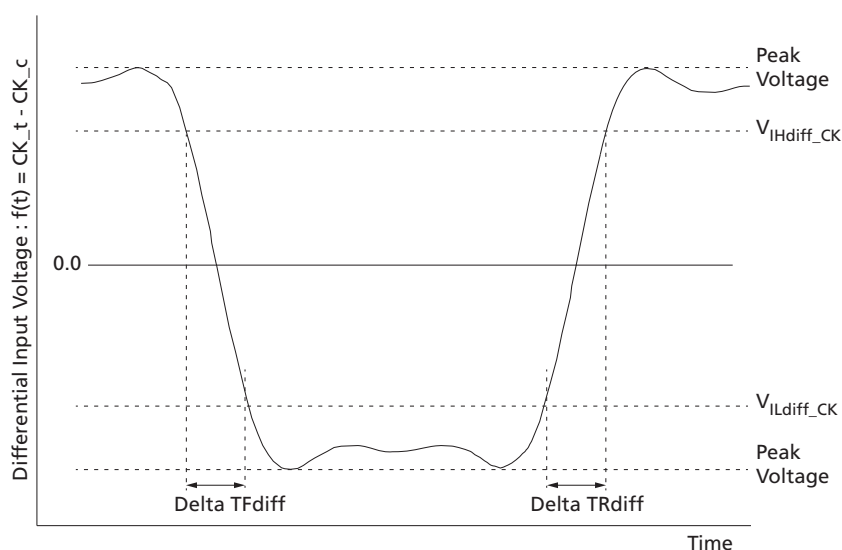
**Table 150: Clock Single-Ended Input Voltage**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Clock single-ended input voltage	$V_{inse\_CK}$	210	–	190	–	180	–	mV
Clock single-ended input voltage HIGH from $V_{REF(CA)}$	$V_{inse\_CK\_HIGH}$	105	–	95	–	90	–	mV
Clock single-ended input voltage LOW from $V_{REF(CA)}$	$V_{inse\_CK\_LOW}$	105	–	95	–	90	–	mV

### Differential Input Slew Rate Definition for Clock

Input slew rate for differential signals (CK<sub>t</sub>, CK<sub>c</sub>) are defined and measured as shown below in figure and the tables.

**Figure 148: Differential Input Slew Rate Definition for CK<sub>t</sub>, CK<sub>c</sub>**



- Notes:
1. Differential signal rising edge from  $V_{ILdiff\_CK}$  to  $V_{IHdiff\_CK}$  must be monotonic slope.
  2. Differential signal falling edge from  $V_{IHdiff\_CK}$  to  $V_{ILdiff\_CK}$  must be monotonic slope.

**Table 151: Differential Input Slew Rate Definition for CK<sub>t</sub>, CK<sub>c</sub>**

Description	From	To	Defined by
Differential input slew rate for rising edge (CK <sub>t</sub> - CK <sub>c</sub> )	$V_{ILdiff\_CK}$	$V_{IHdiff\_CK}$	$ V_{ILdiff\_CK} - V_{IHdiff\_CK}  / \Delta TRdiff$
Differential input slew rate for falling edge (CK <sub>t</sub> - CK <sub>c</sub> )	$V_{IHdiff\_CK}$	$V_{ILdiff\_CK}$	$ V_{ILdiff\_CK} - V_{IHdiff\_CK}  / \Delta TFdiff$

**Table 152: Differential Input Level for CK\_t, CK\_c**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Differential Input HIGH	$V_{IHdiff\_CK}$	175	-	155	-	145	-	mV
Differential Input LOW	$V_{ILdiff\_CK}$	-	-175	-	-155	-	-145	mV

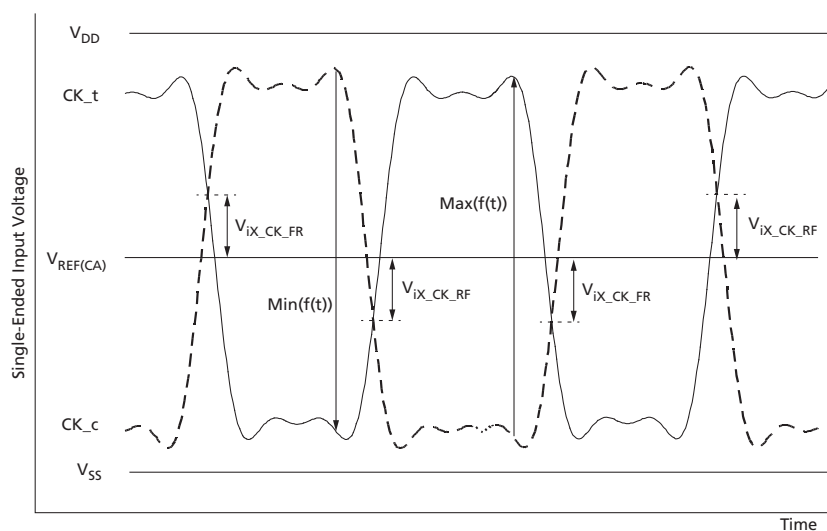
**Table 153: Differential Input Slew Rate for CK\_t, CK\_c**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Differential input slew rate for clock	SRIdiff_CK	2	14	2	14	2	14	V/ns

### Differential Input Cross-Point Voltage

The cross-point voltage of differential input signals (CK\_t, CK\_c) must meet the requirements in table below. The differential input cross-point voltage  $V_{IX}$  is measured from the actual cross-point of true and complement signals to the mid level that is  $V_{REF(CA)}$ .

**Figure 149:  $V_{ix}$  Definition (Clock)**



Note: 1. The base levels of  $V_{ix\_CK\_FR}$  and  $V_{ix\_CK\_RF}$  are  $V_{REF(CA)}$  that is device internal setting value by  $V_{REF}$  training.

**Table 154: Cross-Point Voltage for Differential Input Signals (Clock)**

Notes 1 and 2 apply to entire table

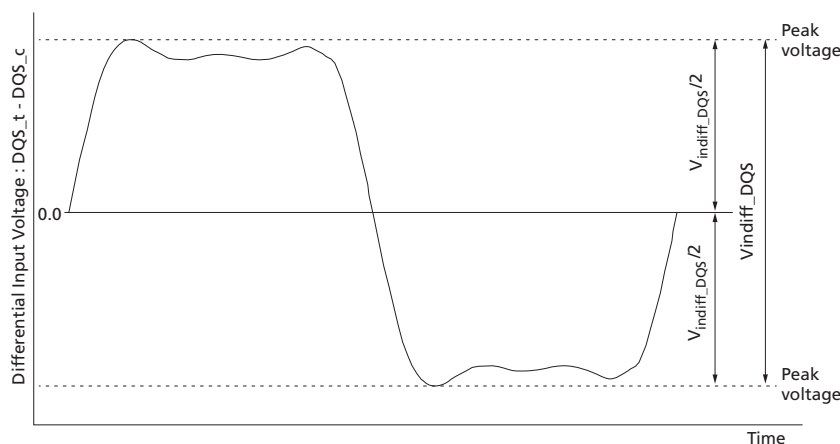
Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Clock single-ended cross-point voltage ratio	$V_{ix\_CK\_ratio}$	-	25	-	25	-	25	%

- Notes: 1.  $V_{ix\_CK\_ratio}$  is defined by this equation:  $V_{ix\_CK\_ratio} = V_{ix\_CK\_FR}/|MIN(f(t))|$   
 2.  $V_{ix\_CK\_ratio}$  is defined by this equation:  $V_{ix\_CK\_ratio} = V_{ix\_CK\_RF}/MAX(f(t))$

### Differential Input Voltage for DQS

The minimum input voltage needs to satisfy both  $V_{indiff\_DQS}$  and  $V_{indiff\_DQS}/2$  specification at input receiver and their measurement period is 1UI ( $^tCK/2$ ).  $V_{indiff\_DQS}$  is the peak to peak voltage centered on 0 volts differential and  $V_{indiff\_DQS}/2$  is maximum and minimum peak voltage from 0 volts.

**Figure 150: DQS Differential Input Voltage**



**Table 155: DQS Differential Input Voltage**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit	Note
		Min	Max	Min	Max	Min	Max		
DQS differential input voltage	$V_{indiff\_DQS}$	360	-	360	-	340	-	mV	1

Note: 1. The peak voltage of differential DQS signals is calculated in a following equation.

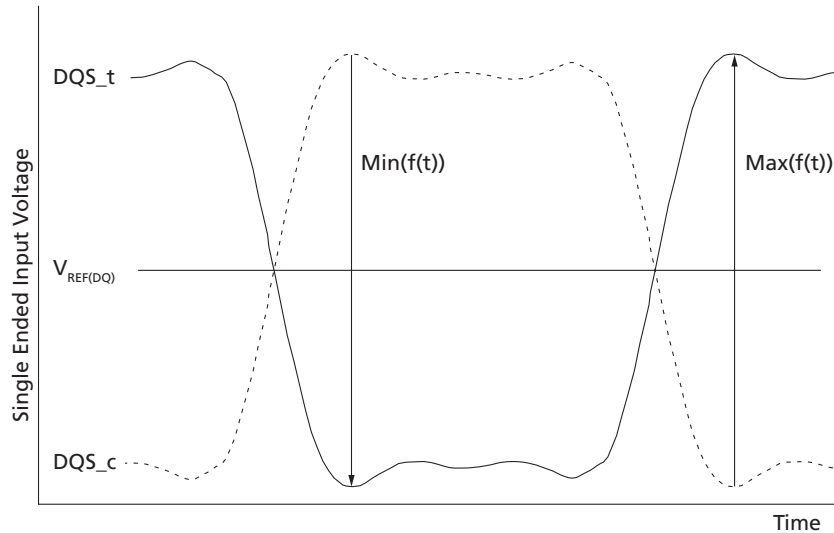
- $V_{indiff\_DQS} = (\text{Maximum peak voltage}) - (\text{Minimum peak voltage})$
- $\text{Maximum peak voltage} = MAX(f(t))$
- $\text{Minimum peak voltage} = MIN(f(t))$
- $f(t) = V_{DQS\_t} - V_{DQS\_c}$

### Peak Voltage Calculation Method

The peak voltage of differential DQS signals are calculated in a following equation.

- $V_{IH,DIFF,peak}$  voltage =  $MAX(f(t))$
- $V_{IL,DIFF,peak}$  voltage =  $MIN(f(t))$
- $f(t) = V_{DQS\_t} - V_{DQS\_c}$

Figure 151: Definition of Differential DQS Peak Voltage

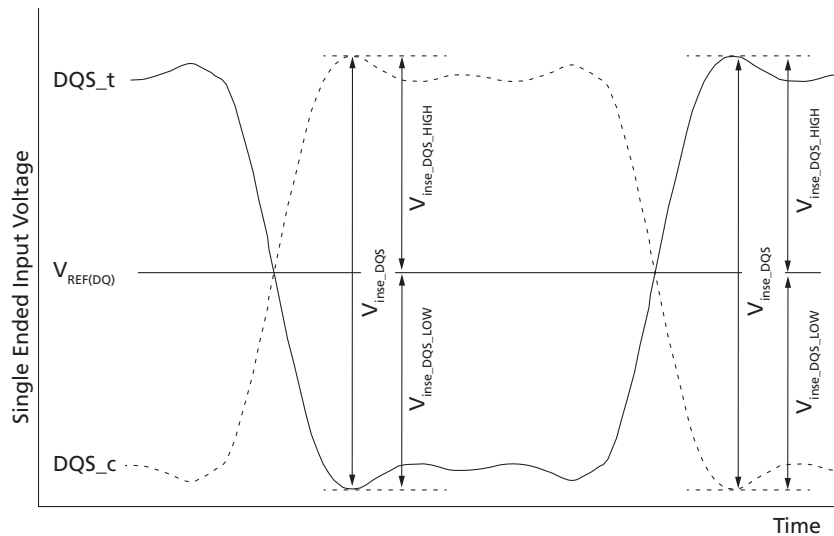


Note: 1.  $V_{REF(DQ)}$  is device internal setting value by  $V_{REF}$  training.

### Single-Ended Input Voltage for DQS

The minimum input voltage need to satisfy  $V_{inse\_DQS}$ ,  $V_{inse\_DQS\_HIGH}$ , and  $V_{inse\_DQS\_LOW}$  specification at input receiver.

Figure 152: DQS Single-Ended Input Voltage



Note: 1.  $V_{REF(DQ)}$  is device internal setting value by  $V_{REF}$  training.



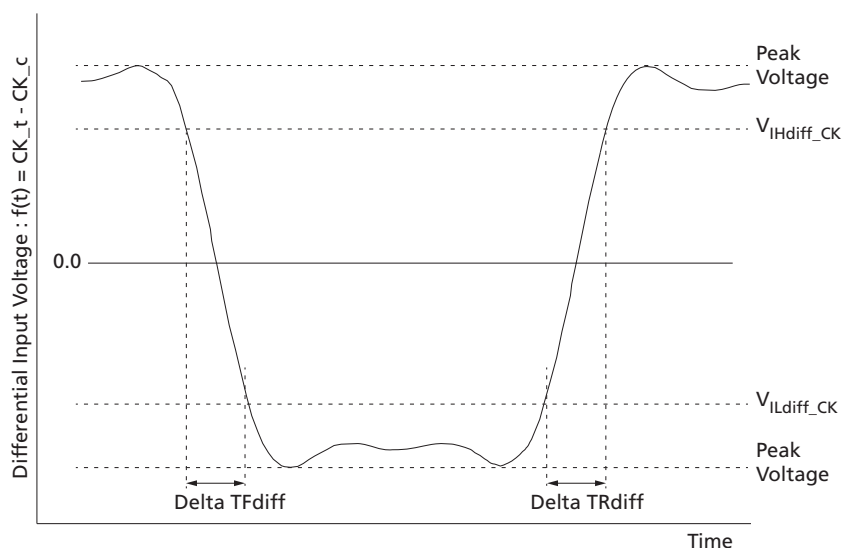
**Table 156: DQS Single-Ended Input Voltage**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
DQS single-ended input voltage	$V_{inse\_DQS}$	180	–	180	–	170	–	mV
DQS single-ended input voltage HIGH from $V_{REF(DQ)}$	$V_{inse\_DQS\_HIGH}$	90	–	90	–	85	–	mV
DQS single-ended input voltage LOW from $V_{REF(DQ)}$	$V_{inse\_DQS\_LOW}$	90	–	90	–	85	–	mV

### Differential Input Slew Rate Definition for DQS

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

**Figure 153: Differential Input Slew Rate Definition for DQS\_t, DQS\_c**



- Notes:
1. Differential signal rising edge from  $V_{ILdiff\_DQS}$  to  $V_{IHdiff\_DQS}$  must be monotonic slope.
  2. Differential signal falling edge from  $V_{IHdiff\_DQS}$  to  $V_{ILdiff\_DQS}$  must be monotonic slope.

**Table 157: Differential Input Slew Rate Definition for DQS\_t, DQS\_c**

Description	From	To	Defined by
Differential input slew rate for rising edge (DQS_t - DQS_c)	$V_{ILdiff\_DQS}$	$V_{IHdiff\_DQS}$	$ V_{ILdiff\_DQS} - V_{IHdiff\_DQS}  / \Delta TR_{diff}$
Differential input slew rate for falling edge (DQS_t - DQS_c)	$V_{IHdiff\_DQS}$	$V_{ILdiff\_DQS}$	$ V_{ILdiff\_DQS} - V_{IHdiff\_DQS}  / \Delta TF_{diff}$

**Table 158: Differential Input Level for DQS\_t, DQS\_c**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Differential Input HIGH	$V_{IHdiff\_DQS}$	140	-	140	-	120	-	mV
Differential Input LOW	$V_{ILdiff\_DQS}$	-	-140	-	-140	-	-120	mV

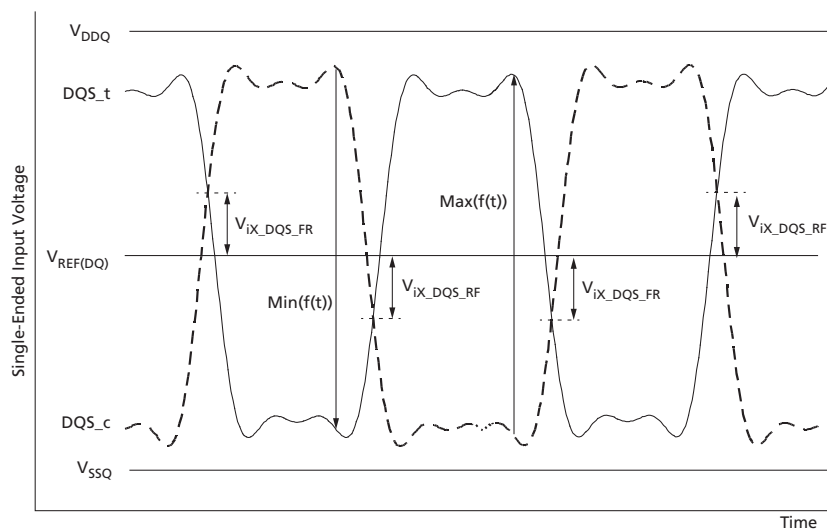
**Table 159: Differential Input Slew Rate for DQS\_t, DQS\_c**

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Differential input slew rate	SRldiff	2	14	2	14	2	14	V/ns

### Differential Input Cross-Point Voltage

The cross-point voltage of differential input signals (DQS\_t, DQS\_c) must meet the requirements in table below. The differential input cross-point voltage  $V_{IX}$  is measured from the actual cross-point of true and complement signals to the mid level that is  $V_{REF(DQ)}$ .

**Figure 154:  $V_{IX}$  Definition (DQS)**



Note: 1. The base levels of  $V_{IX\_DQS\_FR}$  and  $V_{IX\_DQS\_RF}$  are  $V_{REF(DQ)}$  that is device internal setting value by  $V_{REF}$  training.

**Table 160: Cross-Point Voltage for Differential Input Signals (DQS)**

Notes 1 and 2 apply to entire table

Parameter	Symbol	1600/1867		2133/2400/3200		3733/4267		Unit
		Min	Max	Min	Max	Min	Max	
Clock single-ended cross-point voltage ratio	$V_{ix\_DQS\_ratio}$	–	20	–	20	–	20	%

- Notes: 1.  $V_{ix\_DQS\_ratio}$  is defined by this equation:  $V_{ix\_DQS\_ratio} = V_{ix\_DQS\_FR}/|MIN(f(t))|$   
 2.  $V_{ix\_DQS\_ratio}$  is defined by this equation:  $V_{ix\_DQS\_ratio} = V_{ix\_DQS\_RF}/MAX(f(t))$

## Input Levels for ODT

**Table 161: Input Levels**

Parameter	Symbol	Min	Max	Unit	Notes
ODT input HIGH level (AC)	$V_{IHODT(AC)}$	$0.75 \times V_{DD2}$	$V_{DD2} + 0.2$	V	1
ODT input LOW level (AC)	$V_{ILODT(AC)}$	–0.2	$0.25 \times V_{DD2}$	V	1
ODT input HIGH level (DC)	$V_{IHODT(DC)}$	$0.65 \times V_{DD2}$	$V_{DD2} + 0.2$	V	
ODT input LOW level (DC)	$V_{ILODT(DC)}$	–0.2	$0.35 \times V_{DD2}$	V	

Note: 1. See the Overshoot and Undershoot section.

## Output Slew Rate and Overshoot/Undershoot specifications

### Single-Ended Output Slew Rate

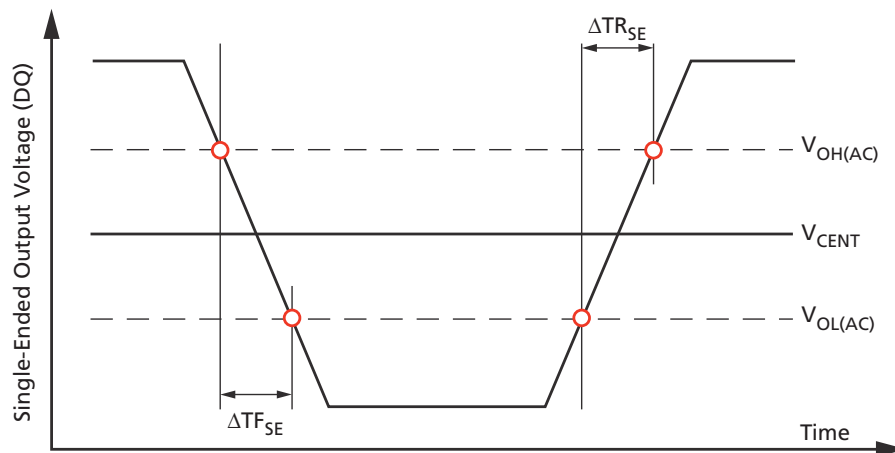
**Table 162: Single-Ended Output Slew Rate**

Note 1-5 applies to entire table

Parameter	Symbol	Value		Units
		Min	Max	
Single-ended output slew rate ( $V_{OH} = V_{DDQ}/3$ )	SRQse	3.5	9.0	V/ns
Output slew rate matching ratio (rise to fall)	–	0.8	1.2	–

- Notes: 1. SR = Slew rate; Q = Query output; se = Single-ended signal  
 2. Measured with output reference load.  
 3. The ratio of pull-up to pull-down slew rate is specified for the same temperature and voltage, over the entire temperature and voltage range. For a given output, it represents the maximum difference between pull-up and pull-down drivers due to process variation.  
 4. The output slew rate for falling and rising edges is defined and measured between  $V_{OL(AC)} = 0.2 \times V_{OH(DC)}$  and  $V_{OH(AC)} = 0.8 \times V_{OH(DC)}$ .  
 5. Slew rates are measured under average SSO conditions with 50% of the DQ signals per data byte switching.

Figure 155: Single-Ended Output Slew Rate Definition



### Differential Output Slew Rate

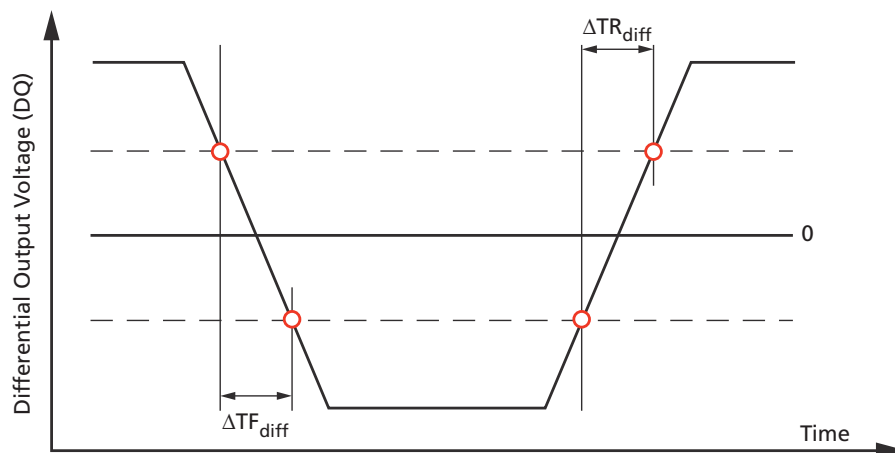
Table 163: Differential Output Slew Rate

Note 1-4 applies to entire table

Parameter	Symbol	Value		Units
		Min	Max	
Differential output slew rate ( $V_{OH} = V_{DDQ}/3$ )	SRQdiff	7	18	V/ns

- Notes:
1. SR = Slew rate; Q = Query output; se = Differential signal
  2. Measured with output reference load.
  3. The output slew rate for falling and rising edges is defined and measured between  $V_{OL(AC)} = 0.2 \times V_{OH(DC)}$  and  $V_{OH(AC)} = 0.8 \times V_{OH(DC)}$ .
  4. Slew rates are measured under average SSO conditions with 50% of the DQ signals per data byte switching.

Figure 156: Differential Output Slew Rate Definition



## Overshoot and Undershoot Specifications

**Table 164: AC Overshoot/Undershoot Specifications**

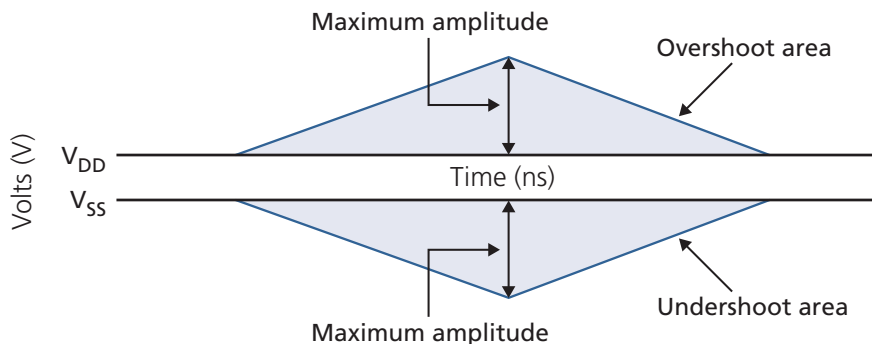
Parameter		1600	1866	3200	3733	4267	Unit
Maximum peak amplitude provided for overshoot area	MAX	0.3	0.3	0.3	0.3	0.3	V
Maximum peak amplitude provided for undershoot area	MAX	0.3	0.3	0.3	0.3	0.3	V
Maximum area above $V_{DD}/V_{DDQ}$	MAX	0.1	0.1	0.1	0.1	0.1	V-ns
Maximum area below $V_{SS}/V_{SSQ}$	MAX	0.1	0.1	0.1	0.1	0.1	V-ns

- Notes:
1.  $V_{DD}$  stands for  $V_{DD2}$  for CA[5:0], CK\_t, CS\_n, CE, and ODT.  $V_{DD}$  stands for  $V_{DDQ}$  for DQ, DMI, DQS\_t, and DQS\_c.
  2.  $V_{SS}$  stands for  $V_{SS}$  for CA[5:0], CK\_t, CK\_c, CS\_n, CE, and ODT.  $V_{SS}$  stands for  $V_{SSQ}$  for DQ, DMI, DQS\_t, and DQS\_c.
  3. Maximum peak amplitude values are referenced from actual  $V_{DD}$  and  $V_{SS}$  values.
  4. Maximum area values are referenced from maximum  $V_{DD}$  and  $V_{SS}$  values.

**Table 165: Overshoot/Undershoot Specification for CE and RESET**

Parameter	Specification
Maximum peak amplitude provided for overshoot area	0.35V
Maximum peak amplitude provided for undershoot area	0.35V
Maximum area above $V_{DD}$	0.8 V-ns
Maximum area below $V_{SS}$	0.8 V-ns

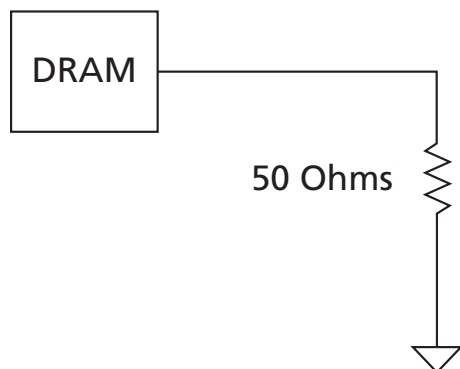
**Figure 157: Overshoot and Undershoot Definition**



## Driver Output Timing Reference Load

Timing reference loads are not intended as a precise representation of any particular system environment or depiction of an 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 158: Driver Output Timing Reference Load

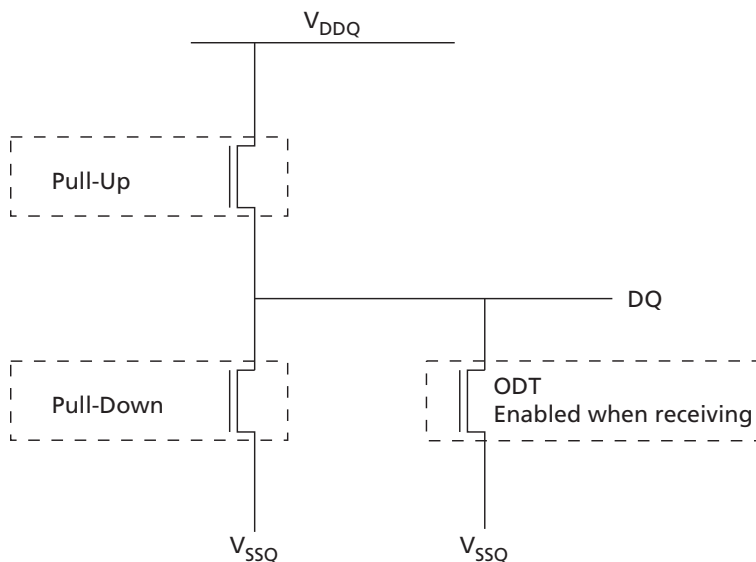


Note: 1. All output timing parameter values are reported with respect to this reference load; this reference load is also used to report slew rate.

## LVSTL I/O System

LVSTL I/O cells are comprised of a driver pull-up and pull-down and a terminator.

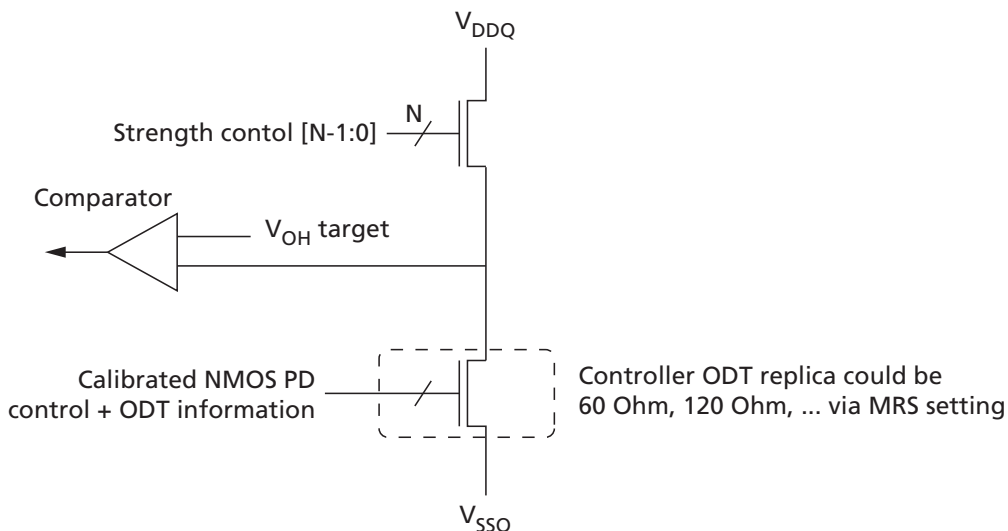
Figure 159: LVSTL I/O Cell



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

1. Calibrate the pull-down device against a 240 ohm resistor to  $V_{DDQ}$  via the ZQ pin.
  - Set strength control to minimum setting
  - Increase drive strength until comparator detects data bit is less than  $V_{DDQ}/3$
  - NMOS pull-down device is calibrated to 120 ohms
2. Calibrate the pull-up device against the calibrated pull-down device.
  - Set  $V_{OH}$  target and NMOS controller ODT replica via MRS ( $V_{OH}$  can be automatically controlled by ODT MRS)

- Set strength control to minimum setting
- Increase drive strength until comparator detects data bit is greater than  $V_{OH}$  target
- NMOS pull-up device is calibrated to  $V_{OH}$  target

**Figure 160: Pull-Up Calibration**


## Input/Output Capacitance

**Table 166: Input/Output Capacitance**

Notes 1 and 2 apply to entire table

Parameter	Symbol	Min	Max	Unit	Notes
Input capacitance, CK_t and CK_c	$C_{CK}$	0.5	0.9	pF	
Input capacitance delta, CK_t and CK_c	$C_{DCK}$	0	0.09		3
Input capacitance, all other input-only pins	$C_I$	0.5	0.9		4
Input capacitance delta, all other input-only pins	$C_{DI}$	-0.1	0.1		5
Input/output capacitance, DQ, DMI, DQS_t, DQS_c	$C_{IO}$	0.7	1.3		6
Input/output capacitance delta, DQS_t, DQS_c	$C_{DDQS}$	0	0.1		7
Input/output capacitance delta, DQ, DMI	$C_{DIO}$	-0.1	0.1		8
Input/output capacitance, ZQ pin	$C_{ZQ}$	0	5.0		

- Notes:
1. This parameter applies to LPDDR4 die only (does not include package capacitance).
  2. This parameter is not subject to production testing; it is verified by design and characterization. The capacitance is measured according to JEP147 (procedure for measuring input capacitance using a vector network analyzer), with  $V_{DD1}$ ,  $V_{DD2}$ ,  $V_{DDQ}$ , and  $V_{SS}$  applied; all other pins are left floating.
  3. Absolute value of  $C_{CK\_t} - C_{CK\_c}$ .
  4.  $C_I$  applies to CS, CKE, and CA[5:0].
  5.  $C_{DI} = C_I - 0.5 \times (C_{CK\_t} + C_{CK\_c})$ ; it does not apply to CKE.
  6. DMI loading matches DQ and DQS.
  7. Absolute value of  $C_{DQS\_t}$  and  $C_{DQS\_c}$ .

8.  $C_{D10} = C_{I0} - 0.5 \times (C_{DQS\_t} + C_{DQS\_c})$  in byte-lane.

## I<sub>DD</sub> Specification Parameters and Test Conditions

**Table 167: I<sub>DD</sub> Measurement Conditions**

Switching for CA								
CK_t 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. LOW =  $V_{IN} \leq V_{IL(DC)}$  MAX  
HIGH =  $V_{IN} \geq V_{IH(DC)}$  MIN  
STABLE = Inputs are stable at a HIGH or LOW level
  2. CS must always be driven LOW.
  3. 50% of CA bus is changing between HIGH and LOW once per clock for the CA bus.
  4. The pattern is used continuously during I<sub>DD</sub> measurement for I<sub>DD</sub> values that require switching on the CA bus.

**Table 168: CA Pattern for I<sub>DD4R</sub>**

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



**Table 168: CA Pattern for I<sub>DD4R</sub> (Continued)**

Clock Cycle Number	CKE	CS	Command	CA0	CA1	CA2	CA3	CA4	CA5
N+15	HIGH	LOW	DES	L	L	L	L	L	L

- Notes: 1. BA[2:0] = 010; CA[9:4] = 000000 OR 111111; Burst order CA[3:2] = 00 or 11 (same as LPDDR3 I<sub>DDR3</sub> specification).  
2. CA pins are kept LOW with DES CMD to reduce ODT current (different from LPDDR3 I<sub>DDR3</sub> specification).

**Table 169: CA Pattern for I<sub>DD4W</sub>**

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 specification).  
2. No burst ordering (different from LPDDR3 specification).  
3. CA pins are kept LOW with DES CMD to reduce ODT current (different from LPDDR3 specification).

**Table 170: Data Pattern for I<sub>DD4W</sub> (DBI Off)**

DBI Off Case										
	DQ[7]	DQ[6]	DQ[5]	DQ[4]	DQ[3]	DQ[2]	DQ[1]	DQ[0]	DBI	# of 1s
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

**Table 170: Data Pattern for I<sub>DD4W</sub> (DBI Off) (Continued)**

DBI Off Case										
	DQ[7]	DQ[6]	DQ[5]	DQ[4]	DQ[3]	DQ[2]	DQ[1]	DQ[0]	DBI	# of 1s
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
# of 1s	16	16	16	16	16	16	16	16		

Note: 1. Simplified pattern; same data pattern was applied to DQ[4], DQ[5], DQ[6], and DQ[7] to reduce complexity for I<sub>DD4W</sub> pattern programming.

**Table 171: Data Pattern for I<sub>DD4R</sub> (DBI Off)**

DBI Off Case										
	DQ[7]	DQ[6]	DQ[5]	DQ[4]	DQ[3]	DQ[2]	DQ[1]	DQ[0]	DBI	# of 1s
BL0	1	1	1	1	1	1	1	1	0	8

**Table 171: Data Pattern for I<sub>DD4R</sub> (DBI Off) (Continued)**

DBI Off Case										
	DQ[7]	DQ[6]	DQ[5]	DQ[4]	DQ[3]	DQ[2]	DQ[1]	DQ[0]	DBI	# of 1s
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	0	0	0	0	1	1	1	1	0	4
BL22	0	0	0	0	0	0	1	1	0	2
BL23	1	1	1	1	0	0	0	0	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	1	1	1	1	0	0	0	0	0	4
BL30	1	1	1	1	1	1	0	0	0	6
BL31	0	0	0	0	1	1	1	1	0	4
# of 1s	16	16	16	16	16	16	16	16		

Note: 1. Simplified pattern; same data pattern was applied to DQ[4], DQ[5], DQ[6], and DQ[7] to reduce complexity for I<sub>DD4W</sub> pattern programming.



Table 172: Data Pattern for I<sub>DD4W</sub> (DBI On)

DBI On Case										
	DQ[7]	DQ[6]	DQ[5]	DQ[4]	DQ[3]	DQ[2]	DQ[1]	DQ[0]	DBI	# of 1s
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
# of 1s	8	8	8	8	8	8	16	16	8	



Table 173: Data Pattern for I<sub>DD4R</sub> (DBI On)

DBI On Case										
	DQ[7]	DQ[6]	DQ[5]	DQ[4]	DQ[3]	DQ[2]	DQ[1]	DQ[0]	DBI	# of 1s
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	0	0	0	0	1	1	1	1	0	4
BL22	0	0	0	0	0	0	1	1	0	2
BL23	1	1	1	1	0	0	0	0	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	1	1	1	1	0	0	0	0	0	4
BL30	0	0	0	0	0	0	1	1	1	3
BL31	0	0	0	0	1	1	1	1	0	4
# of 1s	8	8	8	8	8	8	16	16	8	

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

I<sub>DD</sub> values are for the entire operating voltage range, and all of them are for the entire standard temperature range.

**Table 174: I<sub>DD</sub> Specification Parameters and Operating Conditions**

V<sub>DD2</sub>, V<sub>DDQ</sub> = 1.06–1.17V; V<sub>DD1</sub> = 1.70–1.95V

Parameter/Condition	Symbol	Power Supply	Notes
<b>Operating one bank active-precharge current:</b> $t_{CK} = t_{CK}$ (MIN); $t_{RC} = t_{RC}$ (MIN); CKE is HIGH; CS is LOW between valid commands; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD01</sub>	V <sub>DD1</sub>	
	I <sub>DD02</sub>	V <sub>DD2</sub>	
	I <sub>DD0Q</sub>	V <sub>DDQ</sub>	2
<b>Idle power-down standby current:</b> $t_{CK} = t_{CK}$ (MIN); CKE is LOW; CS is LOW; All banks are idle; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD2P1</sub>	V <sub>DD1</sub>	
	I <sub>DD2P2</sub>	V <sub>DD2</sub>	
	I <sub>DD2PQ</sub>	V <sub>DDQ</sub>	2
<b>Idle power-down standby current with clock stop:</b> CK <sub>t</sub> = LOW, CK <sub>c</sub> = HIGH; CKE is LOW; CS is LOW; All banks are idle; CA bus inputs are stable; Data bus inputs are stable; ODT is disabled	I <sub>DD2PS1</sub>	V <sub>DD1</sub>	
	I <sub>DD2PS2</sub>	V <sub>DD2</sub>	
	I <sub>DD2PSQ</sub>	V <sub>DDQ</sub>	2
<b>Idle non-power-down standby current:</b> $t_{CK} = t_{CK}$ (MIN); CKE is HIGH; CS is LOW; All banks are idle; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD2N1</sub>	V <sub>DD1</sub>	
	I <sub>DD2N2</sub>	V <sub>DD2</sub>	
	I <sub>DD2NQ</sub>	V <sub>DDQ</sub>	2
<b>Idle non-power-down standby current with clock stopped:</b> CK <sub>t</sub> = LOW; CK <sub>c</sub> = HIGH; CKE is HIGH; CS is LOW; All banks are idle; CA bus inputs are stable; Data bus inputs are stable; ODT is disabled	I <sub>DD2NS1</sub>	V <sub>DD1</sub>	
	I <sub>DD2NS2</sub>	V <sub>DD2</sub>	
	I <sub>DD2NSQ</sub>	V <sub>DDQ</sub>	2
<b>Active power-down standby current:</b> $t_{CK} = t_{CK}$ (MIN); CKE is LOW; CS is LOW; One bank is active; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD3P1</sub>	V <sub>DD1</sub>	
	I <sub>DD3P2</sub>	V <sub>DD2</sub>	
	I <sub>DD3PQ</sub>	V <sub>DDQ</sub>	2
<b>Active power-down standby current with clock stop:</b> CK <sub>t</sub> = LOW, CK <sub>c</sub> = HIGH; CKE is LOW; CS is LOW; One bank is active; CA bus inputs are stable; Data bus inputs are stable; ODT is disabled	I <sub>DD3PS1</sub>	V <sub>DD1</sub>	
	I <sub>DD3PS2</sub>	V <sub>DD2</sub>	
	I <sub>DD3PSQ</sub>	V <sub>DDQ</sub>	3
<b>Active non-power-down standby current:</b> $t_{CK} = t_{CK}$ (MIN); CKE is HIGH; CS is LOW; One bank is active; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD3N1</sub>	V <sub>DD1</sub>	
	I <sub>DD3N2</sub>	V <sub>DD2</sub>	
	I <sub>DD3NQ</sub>	V <sub>DDQ</sub>	3
<b>Active non-power-down standby current with clock stopped:</b> CK <sub>t</sub> = LOW, CK <sub>c</sub> = HIGH; CKE is HIGH; CS is LOW; One bank is active; CA bus inputs are stable; Data bus inputs are stable; ODT is disabled	I <sub>DD3NS1</sub>	V <sub>DD1</sub>	
	I <sub>DD3NS2</sub>	V <sub>DD2</sub>	
	I <sub>DD3NSQ</sub>	V <sub>DDQ</sub>	3
<b>Operating burst READ current:</b> $t_{CK} = t_{CK}$ (MIN); 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 is disabled	I <sub>DD4R1</sub>	V <sub>DD1</sub>	
	I <sub>DD4R2</sub>	V <sub>DD2</sub>	
	I <sub>DD4RQ</sub>	V <sub>DDQ</sub>	4

**Table 174: I<sub>DD</sub> Specification Parameters and Operating Conditions (Continued)**

V<sub>DD2</sub>, V<sub>DDQ</sub> = 1.06–1.17V; V<sub>DD1</sub> = 1.70–1.95V

Parameter/Condition	Symbol	Power Supply	Notes
<b>Operating burst WRITE current:</b> $t_{CK} = t_{CK}(\text{MIN})$ ; CS is LOW between valid commands; One bank is active; BL = 16 or 32; WL = WL (MIN); CA bus inputs are switching; 50% data change each burst transfer; ODT is disabled	I <sub>DD4W1</sub>	V <sub>DD1</sub>	
	I <sub>DD4W2</sub>	V <sub>DD2</sub>	
	I <sub>DD4WQ</sub>	V <sub>DDQ</sub>	3
<b>All-bank REFRESH burst current:</b> $t_{CK} = t_{CK}(\text{MIN})$ ; CKE is HIGH between valid commands; $t_{RC} = t_{RFCab}(\text{MIN})$ ; Burst refresh; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD51</sub>	V <sub>DD1</sub>	
	I <sub>DD52</sub>	V <sub>DD2</sub>	
	I <sub>DD5Q</sub>	V <sub>DDQ</sub>	3
<b>All-bank REFRESH average current:</b> $t_{CK} = t_{CK}(\text{MIN})$ ; CKE is HIGH between valid commands; $t_{RC} = t_{REFI}$ ; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD5AB1</sub>	V <sub>DD1</sub>	
	I <sub>DD5AB2</sub>	V <sub>DD2</sub>	
	I <sub>DD5ABQ</sub>	V <sub>DDQ</sub>	3
<b>Per-bank REFRESH average current:</b> $t_{CK} = t_{CK}(\text{MIN})$ ; CKE is HIGH between valid commands; $t_{RC} = t_{REFI}/8$ ; CA bus inputs are switching; Data bus inputs are stable; ODT is disabled	I <sub>DD5PB1</sub>	V <sub>DD1</sub>	
	I <sub>DD5PB2</sub>	V <sub>DD2</sub>	
	I <sub>DD5PBQ</sub>	V <sub>DDQ</sub>	3
<b>Power-down self refresh current:</b> CK <sub>t</sub> = LOW, CK <sub>c</sub> = HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable; Maximum 1x self refresh rate; ODT is disabled	I <sub>DD61</sub>	V <sub>DD1</sub>	5, 6
	I <sub>DD62</sub>	V <sub>DD2</sub>	5, 6
	I <sub>DD6Q</sub>	V <sub>DDQ</sub>	3, 5, 6

- Notes:
1. ODT disabled: MR11[2:0] = 000b.
  2. I<sub>DD</sub> current specifications are tested after the device is properly initialized.
  3. Measured currents are the summation of V<sub>DDQ</sub> and V<sub>DD2</sub>.
  4. Guaranteed by design with output load = 5pF and R<sub>ON</sub> = 40 ohm.
  5. The 1x self refresh rate is the rate at which the device is refreshed internally during self refresh before going into the elevated temperature range.
  6. This is the general definition that applies to full-array self refresh.
  7. For all I<sub>DD</sub> measurements, V<sub>IHCKE</sub> = 0.8 × V<sub>DD2</sub>; V<sub>ILCKE</sub> = 0.2 × V<sub>DD2</sub>.

## AC Timing

**Table 175: Clock Timing**

Parameter	Symbol	Min/ Max	Data Rate				Unit
			1600	3200	3733	4267	
Average clock period	$t_{CK(avg)}$	Min	1250	625	535	468	ps
		Max	100	100	100	100	ns
Average HIGH pulse width	$t_{CH(avg)}$	Min	0.46				$t_{CK(avg)}$
		Max	0.54				
Average LOW pulse width	$t_{CL(avg)}$	Min	0.46				$t_{CK(avg)}$
		Max	0.54				
Absolute clock period	$t_{CK(abs)}$	Min	$t_{CK(avg)min} + t_{JIT(per)min}$				ps
Absolute clock HIGH pulse width	$t_{CH(abs)}$	Min	0.43				$t_{CK(avg)}$
		Max	0.57				
Absolute clock LOW pulse width	$t_{CL(abs)}$	Min	0.43				$t_{CK(avg)}$
		Max	0.57				
Clock period jitter	$t_{JIT(per)allowed}$	Min	-70	-40	-34	-30	ps
		Max	70	40	34	30	
Maximum clock jitter between two consecutive clock cycles (includes clock period jitter)	$t_{JIT(cc)allowed}$	Max	140	80	68	60	ps

**Table 176: Read Output Timing**

Parameter	Symbol	Min/ Max	Data Rate							Unit	Notes
			533	1066	1600	2133	2667	3200	3733		
DQS output access time from CK_t/CK_c	$t_{DQSCK}$	Min	1500							ps	1
		Max	3500								
DQS output access time from CK_t/CK_c - voltage variation	$t_{DQSCK\_VOLT}$	Max	7							ps/mV	2
DQS output access time from CK_t/CK_c - temperature variation	$t_{DQSCK\_TEMP}$	Max	4							ps°/C	3
CK to DQS rank to rank variation	$t_{DQSCK\_rank2rank}$	Max	1.0							ns	4, 5
DQS_t, DQS_c to DQ skew total, per group, per access (DBI Disabled)	$t_{DQSQ}$	Max	0.18							UI	6
DQ output hold time total from DQS_t, DQS_c (DBI Disabled)	$t_{QH}$	Min	MIN( $t_{QSH}$ , $t_{QSL}$ )							ps	6



**Table 176: Read Output Timing (Continued)**

Parameter	Symbol	Min/ Max	Data Rate							Unit	Notes
			533	1066	1600	2133	2667	3200	3733		
Data output valid window time total, per pin (DBI-Disabled)	$t_{QW\_total}$	Min	0.75		0.73		0.68			UI	6, 11
DQS_t, DQS_c to DQ skew total, per group, per access (DBI-Enabled)	$t_{DQSQ\_DBI}$	Max	0.18							UI	6
DQ output hold time total from DQS_t, DQS_c (DBI-Enabled)	$t_{QH\_DBI}$	Min	MIN( $t_{QSH\_DBI}$ , $t_{QSL\_DBI}$ )							ps	6
Data output valid window time total, per pin (DBI-Enabled)	$t_{QW\_total\_DBI}$	Min	0.75		0.73		0.68			UI	6, 11
DQS_t, DQS_c differential output LOW time (DBI-Disabled)	$t_{QSL}$	Min	$t_{CL(ABS)} - 0.05$							$t_{CK(AVG)}$	9, 11
DQS_t, DQS_c differential output HIGH time (DBI-Disabled)	$t_{QSH}$	Min	$t_{CH(ABS)} - 0.05$							$t_{CK(AVG)}$	10, 11
DQS_t, DQS_c differential output LOW time (DBI-Enabled)	$t_{QSL\_DBI}$	Min	$t_{CL(ABS)} - 0.045$							$t_{CK(AVG)}$	9, 11
DQS_t, DQS_c differential output HIGH time (DBI-Enabled)	$t_{QSH\_DBI}$	Min	$t_{CH(ABS)} - 0.045$							$t_{CK(AVG)}$	10, 11
Read preamble	$t_{RPRE}$	Min	1.8							$t_{CK(AVG)}$	
Read postamble	$t_{RPST}$	Min	0.4 (or 1.4 if extra postamble is programmed in MR)							$t_{CK(AVG)}$	
DQS Low-Z from clock	$t_{LZ(DQS)}$	Min	$(RL \times t_{CK}) + t_{DQSCK(MIN)} - (t_{RPRE(MAX)} \times t_{CK}) - 200ps$							ps	
DQ Low-Z from clock	$t_{LZ(DQ)}$	Min	$(RL \times t_{CK}) + t_{DQSCK(MIN)} - 200ps$							ps	
DQS High-Z from clock	$t_{HZ(DQS)}$	Min	$(RL \times t_{CK}) + t_{DQSCK(MAX)} + (BL/2 \times t_{CK}) + (t_{RPST(MAX)} \times t_{CK}) - 100ps$							ps	
DQ High-Z from clock	$t_{HZ(DQ)}$	Min	$(RL \times t_{CK}) + t_{DQSCK(MAX)} + t_{DQSQ(MAX)} + (BL/2 \times t_{CK}) - 100ps$							ps	

- Notes:
1. This parameter includes DRAM process, voltage, and temperature variation. It also includes the AC noise impact for frequencies >20 MHz and a MAX voltage of 45mV peak-to-peak from DC-20 MHz at a fixed temperature on the package. The voltage supply noise must comply with the component MIN/MAX DC operating conditions.
  2.  $t_{DQSCK\_volt}$  MAX delay variation as a function of DC voltage variation for  $V_{DDQ}$  and  $V_{DD2}$ . The voltage supply noise must comply with the component MIN/MAX DC operating conditions. The voltage variation is defined as the  $MAX[abs(t_{DQSCKmin@V1} - t_{DQSCKmax@V2}), abs(t_{DQSCKmax@V1} - t_{DQSCKmin@V2})]/abs(V1 - V2)$ . For tester measurement  $V_{DDQ} = V_{DD2}$  is assumed.
  3.  $t_{DQSCK\_temp}$  MAX delay variation as a function of temperature.
  4. The same voltage and temperature are applied to  $t_{DQSCK\_rank2rank}$ .

5.  $t_{DQSK\_rank2rank}$  parameter is applied to multi-ranks per byte lane within a package consisting of the same design dies.
6. DQ-to-DQS differential jitter where the total includes the sum of deterministic and random timing terms for a specified BER.
7. The deterministic component of the total timing.
8. This parameter will be characterized and guaranteed by design.
9.  $t_{QSL}$  describes the instantaneous differential output low pulse width on DQS<sub>t</sub> - DQS<sub>c</sub>, as measured from one falling edge to the next consecutive rising edge.
10.  $t_{QSH}$  describes the instantaneous differential output high pulse width on DQS<sub>t</sub> - DQS<sub>c</sub>, as measured from one falling edge to the next consecutive rising edge.
11. This parameter is a function of input clock jitter. These values assume MIN  $t_{CH(abs)}$  and  $t_{CL(abs)}$ . When the input clock jitter MIN  $t_{CH(abs)}$  and  $t_{CL(abs)}$  is 0.44 or greater than  $t_{CK(avg)}$ , the MIN value of  $t_{QSL}$  will be  $t_{CL(abs)} - 0.04$  and  $t_{QSH}$  will be  $t_{CH(abs)} - 0.04$ .

**Table 177: Write Voltage and Timing**

 Note UI =  $t_{CK(AVG)}(MIN)/2$ 

Parameter	Symbol	Min/ Max	Data Rate						Unit	Notes
			533	1066	1600	2133	2667	3200		
Rx timing window total at $V_{dIVW}$ voltage levels	$TdIVW_{total}$	Max	0.22			0.25			UI	1, 2, 3
DQ and DMI input pulse width (at $V_{CENT\_DQ}$ )	$TdIPW$	Min	0.45						UI	7
DQ-to-DQS offset	$t_{DQS2DQ}$	Min	200						ps	6
		Max	800							
DQ-to-DQ offset	$t_{DQDQ}$	Max	30						ps	7
DQ-to-DQS offset temperature variation	$t_{DQS2DQ\_temp}$	Max	0.6						ps/°C	8
DQ-to-DQS offset voltage variation	$t_{DQS2DQ\_volt}$	Max	33						ps/50mV	9
WRITE command to first DQS transition	$t_{DQSS}$	Min	0.75						$t_{CK(avg)}$	
		Max	1.25							
DQS input HIGH-level width	$t_{DQSH}$	-	0.4						$t_{CK(avg)}$	
DQS input LOW-level width	$t_{DQSL}$	Min	0.4						$t_{CK(avg)}$	
DQS falling edge to CK setup time	$t_{DSS}$	Min	0.2						$t_{CK(avg)}$	
DQS falling edge from CK hold time	$t_{DSH}$	Min	0.2						$t_{CK(avg)}$	
Write postamble	$t_{WPST}$	Min	0.4 (or 1.4 if extra postamble is programmed in MR)						$t_{CK(avg)}$	
Write preamble	$t_{WPRE}$	Min	1.8						$t_{CK(avg)}$	

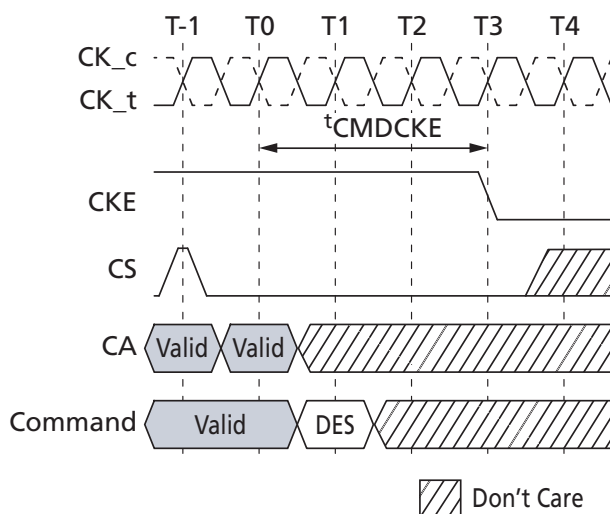
- Notes: 1. Data Rx mask voltage and timing parameters are applied per pin and include the DRAM DQ-to-DQS voltage AC noise impact for frequencies >20 MHz with a maximum voltage of 45mV peak-to-peak at a fixed temperature on the package. The voltage supply noise must comply to the component MIN/MAX DC operating conditions.

2. Rx differential DQ-to-DQS jitter total timing window at the  $V_{dIVV}$  voltage levels.
3. Defined over the DQ internal  $V_{REF}$  range. The Rx mask at the pin must be within the internal  $V_{REF}$  DQ range irrespective of the input signal common mode.
4. Rx mask defined for one pin toggling with other DQ signals in a steady state.
5. DQ-only minimum input pulse width defined at the  $V_{CENT\_DQ(pin\_mid)}$ .
6. DQ-to-DQS offset is within byte from DRAM pin to DRAM internal latch. Includes all DRAM process, voltage, and temperature variations.
7. DQ-to-DQ offset defined within byte from DRAM pin to DRAM internal latch for a given component.
8.  $t_{DQS2DQ}$  (MAX) delay variation as a function of temperature.
9.  $t_{DQS2DQ}$  (MAX) delay variation as a function of the DC voltage variation for  $V_{DDQ}$  and  $V_{DD2}$ . It includes the  $V_{DDQ}$  and  $V_{DD2}$  AC noise impact for frequencies >20 MHz and MAX voltage of 45mV peak-to-peak from DC-20 MHz at a fixed temperature on the package. For tester measurement,  $V_{DDQ} = V_{DD2}$  is assumed.

**Table 178: CKE Input Timing**

Parameter	Symbol	Min/ Max	Data Rate				Unit	Notes
			1600	3200	3733	4267		
CKE minimum pulse width (HIGH and LOW pulse width)	$t_{CKE}$	Min	MAX(7.5ns, 4nCK)				ns	1
Delay from valid command to CKE input LOW	$t_{CMDCKE}$	Min	MAX(1.75ns, 3nCK)				ns	1
Valid clock requirement after CKE input LOW	$t_{CKELCK}$	Min	MAX(5ns, 5nCK)				ns	1
Valid CS requirement before CKE input LOW	$t_{CSCKE}$	Min	1.75				ns	
Valid CS requirement after CKE input LOW	$t_{CKELCS}$	Min	MAX(5ns, 5nCK)				ns	1
Valid Clock requirement before CKE Input HIGH	$t_{CKCKEH}$	Min	MAX(1.75ns, 3nCK)				ns	1
Exit power-down to next valid command delay	$t_{XP}$	Min	MAX(7.5ns, 5nCK)				ns	1
Valid CS requirement before CKE input HIGH	$t_{CSCKEH}$	Min	1.75				ns	
Valid CS requirement after CKE input HIGH	$t_{CKEHCS}$	Min	MAX(7.5ns, 5nCK)				ns	1
Valid clock and CS requirement after CKE input LOW after MRW command	$t_{MRWCKEL}$	Min	MAX(14ns, 10nCK)				ns	1
Valid clock and CS requirement after CKE input LOW after ZQ calibration start command	$t_{ZQCKE}$	Min	MAX(1.75ns, 3nCK)				ns	1

Note: 1. Delay time has to satisfy both analog time(ns) and clock count(nCK). For example,  $t_{CMDCKE}$  will not expire until CK has toggled through at least 3 full cycles ( $3t_{CK}$ ) and 3.75ns has transpired. The case which 3nCK is applied to is shown below.

**Figure 161:  $t_{\text{CMDCKE}}$  Timing**

**Table 179: Command Address Input Timing**

Parameter	Symbol	Min/ Max	Data Rate								Unit	Notes
			533	1066	1600	2133	2667	3200	3733	4267		
Command/address valid window (referenced from CA $V_{IL}/V_{IH}$ to CK $V_{IX}$ )	$t_{\text{cIVW}}$	Min	0.3						0.35	0.4	$t_{\text{CK(avg)}}$	1, 2, 3
Address and control input pulse width (referenced to $V_{\text{REF}}$ )	$t_{\text{cIPW}}$	Min	0.55	0.55	0.55	0.6	0.6	0.6	0.7	0.8	$t_{\text{CK(avg)}}$	4

- Notes:
1. CA Rx mask timing parameters at the pin including voltage and temperature drift.
  2. Rx differential CA to CK jitter total timing window at the  $V_{\text{cIVW}}$  voltage levels.
  3. Defined over the CA internal  $V_{\text{REF}}$  range. The Rx mask at the pin must be within the internal  $V_{\text{REF(CA)}}$  range irrespective of the input signal common mode.
  4. CA only minimum input pulse width defined at the  $V_{\text{CENT\_CA}}$  (pin mid).

**Table 180: Boot Timing Parameters (10–55 MHz)**

Parameter	Symbol	Min/ Max	Value	Unit
Clock cycle time	$t_{\text{CKb}}$	Min	18	ns
		Max	100	
DQS output data access time from CK	$t_{\text{DQSCk b}}$	Min	1.0	ns
		Max	10.0	
DQS edge to output data edge	$t_{\text{DQSQb}}$	Max	1.2	ns

**Table 181: Mode Register Timing Parameters**

Parameter	Symbol	Min/ Max	Data Rate				Unit
			1600	3200	3733	4267	
MODE REGISTER WRITE (MRW) command period	$t^{MRW}$	Min	MAX(10ns, 10nCK)				ns
MODE REGISTER READ (MRR) command period	$t^{MRR}$	Min	8				$t^{CK(avg)}$
Additional time after $t^{XP}$ has expired until the MRR command may be issued	$t^{MRRI}$	Min	$t^{RCD(min)} + 3nCK$				ns
Delay from MRW command to DQS driven out	$t^{SDO}$	Max	MAX(12nCK, 20ns)				ns

**Table 182: Core Timing Parameters**

Refresh rate is determined by the value in MR4 OP[2:0]

Parameter	Symbol	Min/ Max	Data Rate								Unit	Notes
			533	1066	1600	2133	2667	3200	3733	4267		
READ latency (DBI disabled)	RL-A	Min	6	10	14	20	24	28	32	36	$t^{CK(avg)}$	
READ latency (DBI enabled)	RL-B	Min	6	12	16	22	28	32	36	40	$t^{CK(avg)}$	
WRITE latency (Set A)	WL-A	Min	4	6	8	10	12	14	16	18	$t^{CK(avg)}$	
WRITE latency (Set B)	WL-B	Min	4	8	12	18	22	26	30	34	$t^{CK(avg)}$	
ACTIVATE-to-ACTIVATE command period (same bank)	$t^{RC}$	Min	$t^{RAS} + t^{RPab}$ (with all-bank precharge) $t^{RAS} + t^{RPpb}$ (with per-bank precharge)								ns	1
Minimum self refresh time (entry to exit)	$t^{SR}$	Min	MAX(15ns, 3nCK)								ns	
Self refresh exit to next valid command delay	$t^{XSR}$	Min	MAX( $t^{RFCab} + 7.5ns$ , 2nCK)								ns	
CAS-to-CAS delay	$t^{CCD}$	Min	8								$t^{CK(avg)}$	
CAS-to-CAS delay masked write	$t^{CCDMW}$	MIN	32								$t^{CK(avg)}$	
Internal READ-to-PRE-CHARGE command delay	$t^{RTP}$	Min	MAX(7.5ns, 8nCK)								ns	
RAS-to-CAS delay	$t^{RCD}$	Min	MAX(18ns, 4nCK)								ns	
Row precharge time (single bank)	$t^{RPpb}$	Min	MAX(18ns, 3nCK)								ns	
Row precharge time (all banks)	$t^{RPab}$	Min	MAX(21ns, 3nCK)								ns	

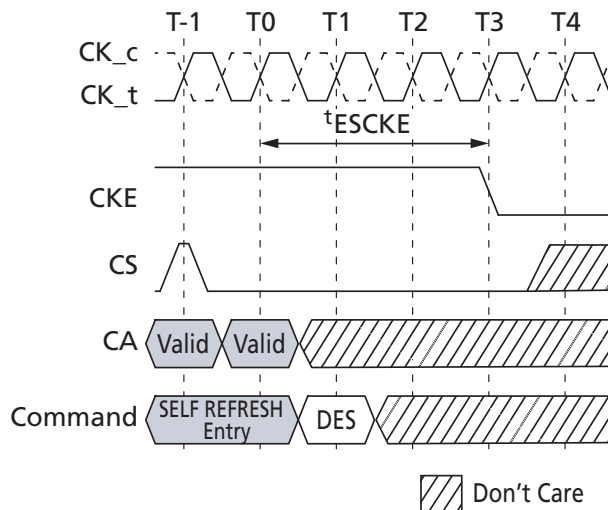
**Table 182: Core Timing Parameters (Continued)**

Refresh rate is determined by the value in MR4 OP[2:0]

Parameter	Symbol	Min/ Max	Data Rate								Unit	Notes
			533	1066	1600	2133	2667	3200	3733	4267		
Row active time	$t_{RAS}$	Min	MAX(42ns, 3nCK)								ns	1
		Max	MIN( $9 \times t_{REFI} \times \text{Refresh Rate}^1$ , 70.2)								$\mu\text{s}$	
Write recovery time	$t_{WR}$	Min	MAX(18ns, 4nCK)								ns	
Write-to-read delay	$t_{WTR}$	Min	MAX(10ns, 8nCK)								ns	
Active bank A to active bank B	$t_{RRD}$	Min	MAX(10ns, 4nCK)								ns	
Precharge-to-precharge delay	$t_{PPD}$	Min	4								$t_{CK}(\text{avg})$	2
Four-bank activate window	$t_{FAW}$	Min	40								ns	
Delay from SRE command to CKE input LOW	$t_{ESCKE}$	Min	MAX(1.75ns, 3nCK)								–	3

- Notes:
1. DRAM devices should be evenly addressed when being accessed. Disproportionate accesses to a particular row address may result in reduction of the product lifetime.
  2. Precharge to precharge timing restriction does not apply to AUTO PRECHARGE commands.
  3. Delay time has to satisfy both analog time(ns) and clock count (nCK). It means that  $t_{ESCKE}$  will not expire until CK has toggled through at least three full cycles (3  $t_{CK}$ ) and 1.75ns has transpired. The case which 3nCK is applied to is shown below.

**Figure 162:  $t_{ESCKE}$  Timing**



**Table 183: CA Bus ODT Timing**

Parameter	Symbol	Min/ Max	Data Rate
			533-4267
CA ODT value update time	$t_{ODTUP}$	Min	RU(20ns/ $t_{CK}$ ,avg)

**Table 184: CA Bus Training Parameters**

Parameter	Symbol	Min/ Max	Data Rate				Unit	Notes
			1600	3200	3733	4267		
Valid clock requirement after CKE Input LOW	$t_{CKELCK}$	Min	MAX(5ns, 5nCK)				$t_{CK}$	
Data setup for $V_{REF}$ training mode	$t_{DStrain}$	Min	2				ns	
Data hold for $V_{REF}$ training mode	$t_{DHtrain}$	Min	2				ns	
Asynchronous data read	$t_{ADR}$	Max	20				ns	
CA BUS TRAINING command-to-command delay	$t_{CACD}$	Min	RU( $t_{ADR}/t_{CK}$ )				$t_{CK}$	1
Valid strobe requirement before CKE LOW	$t_{DQSCKE}$	Min	10				ns	
First CA BUS TRAINING command following CKE LOW	$t_{CAENT}$	Min	250				ns	
$V_{REF}$ step time – multiple steps	$t_{VREF-ca\_LONG}$	Max	250				ns	
$V_{REF}$ step time – one step	$t_{VREF-ca\_SHORT}$	Max	80				ns	
Valid clock requirement before CS HIGH	$t_{CKPRECS}$	Min	$2t_{CK} + t_{XP}$				–	
Valid clock requirement after CS HIGH	$t_{CKPSTCS}$	Min	MAX(7.5ns, 5nCK)				–	
Minimum delay from CS to DQS toggle in command bus training	$t_{CS\_VREF}$	Min	2				$t_{CK}$	
Minimum delay from CKE HIGH to strobe High-Z	$t_{CKEHDQS}$	Min	10				ns	
CA bus training CKE HIGH to DQ tri-state	$t_{MRZ}$	Min	1.5				ns	
ODT turn-on latency from CKE	$t_{CKELODTon}$	Min	20				ns	
ODT turn-off latency from CKE	$t_{CKEHODT-off}$	Min	20				ns	

Note: 1. If  $t_{CACD}$  is violated, the data for samples that violate  $t_{CACD}$  will not be available, except for the last sample (where  $t_{CACD}$  after this sample is met). Valid data for the last sample will be available after  $t_{ADR}$ .

**Table 185: Asynchronous ODT Turn On and Turn Off Timing**

Symbol	800–2133 MHz	Unit
$t_{ODTon,min}$	1.5	ns
$t_{ODTon,max}$	3.5	ns
$t_{ODToff,min}$	1.5	ns
$t_{ODToff,max}$	3.5	ns

**Table 186: Temperature Derating Parameters**

Parameter	Symbol	Min/ Max	Data Rate				Unit
			1600	3200	3733	4267	
DQS output access time from CK_t/ CK_c (derated)	$t_{DQSCKd}$	Max	3600				ps
RAS-to-CAS delay (derated)	$t_{RCDd}$	Min	$t_{RCD} + 1.875$				ns
ACTIVATE-to-ACTIVATE command pe- riod (same bank, derated)	$t_{RCd}$	Min	$t_{RC} + 3.75$				ns
Row active time (derated)	$t_{RASd}$	Min	$t_{RAS} + 1.875$				ns
Row precharge time (derated)	$t_{RPd}$	Min	$t_{RP} + 1.875$				ns
Active bank A to active bank B (derat- ed)	$t_{RRD}$	Min	$t_{RRD} + 1.875$				ns

Note: 1. Timing derating applies for the operation at 85°C to 105°C.

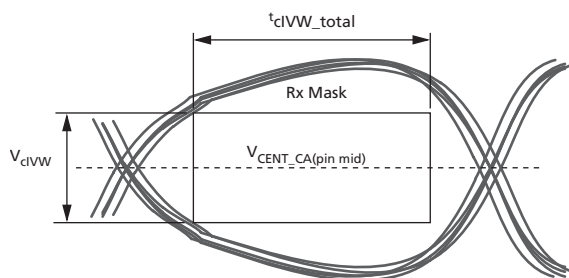


## CA Rx Voltage and Timing

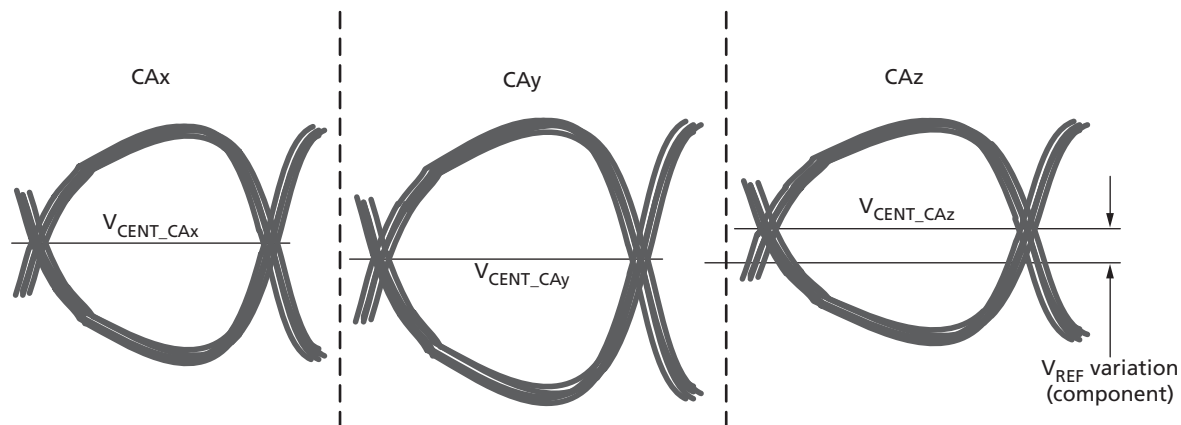
The command and address (CA), including CS input receiver compliance mask for voltage and timing, is shown in the CA Receiver (Rx) Mask figure below. All CA and CS signals apply the same compliance mask and operate in single data rate mode.

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

**Figure 163: CA Receiver (Rx) Mask**

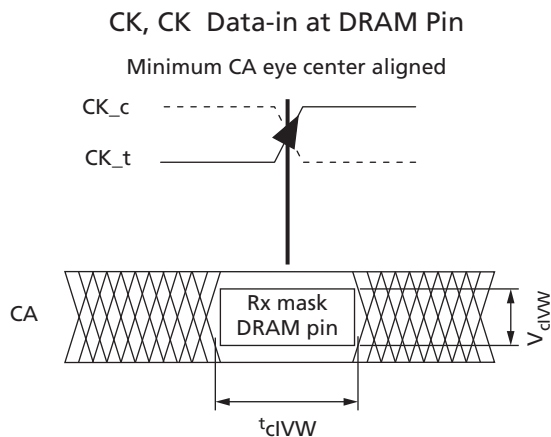


**Figure 164: Across Pin  $V_{REF}$  (CA) Voltage Variation**



$V_{CENT\_CA(pin\ mid)}$  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, which is, the 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 CA Rx mask. The component-level  $V_{REF}$  will be set by the system to account for  $R_{ON}$  and ODT settings.

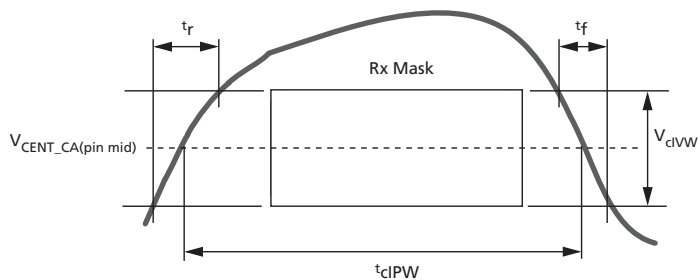
Figure 165: CA Timings at the DRAM Pins



TcIVW for all CA signals is defined as centered on the CK\_t/CK\_c crossing at the DRAM pin.

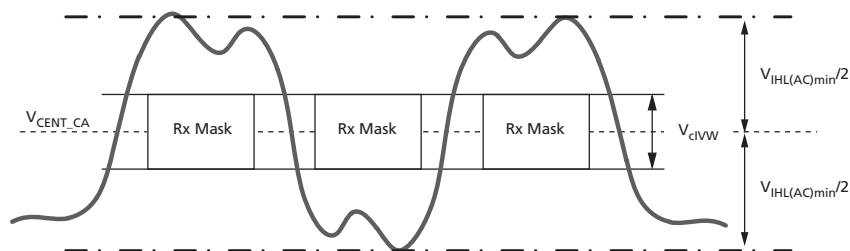
Note: 1. All of the timing terms in above figure are measured from the CK\_t/CK\_c to the center(midpoint) of the TcIVW window taken at the VcIVW\_total voltage levels centered around  $V_{CENT\_CA(pin\ mid)}$ .

Figure 166: CA  $t_{cIPW}$  and SRIN\_cIVW Definition (for Each Input Pulse)



Note: 1.  $SRIN\_cIVW = V_{dIVW\_total} / (t_r \text{ or } t_f)$ ; signal must be monotonic within  $t_r$  and  $t_f$  range.

Figure 167: CA  $V_{IHL\_AC}$  Definition (for Each Input Pulse)



**Table 187: DRAM CMD/ADR, CS**
 $UI = t_{CK(AVG)MIN}$ 

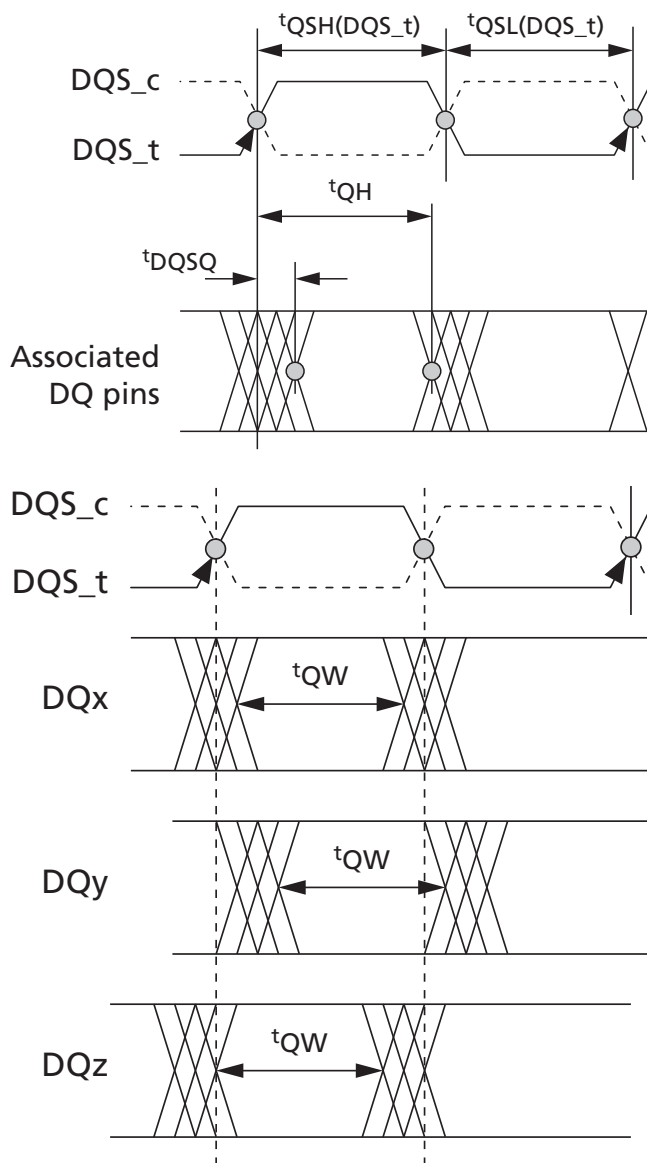
Symbol	Parameter	DQ – 1333 <sup>7</sup>		DQ – 1600/1867		DQ – 3200/3733		DQ – 4267		Unit	Notes
		Min	Max	Min	Max	Min	Max	Min	Max		
$V_{cIVW}$	Rx mask voltage peak-to-peak	–	175	–	175	–	155	–	145	mV	1, 2, 3
$V_{IHL(AC)}$	CA AC input pulse amplitude peak-to-peak	210	–	210	–	190	–	180	–	mV	4, 6
SRIN_cIVW	Input slew rate over $V_{cIVW}$	1	7	1	7	1	7	1	7	V/ns	5

- Notes:
1. CA Rx mask voltage and timing parameters at the pin, including voltage and temperature drift.
  2. Rx mask voltage  $V_{cIVW}$  total (MAX) must be centered around  $V_{CENT\_CA(pin\ mid)}$ .
  3. Defined over the CA internal  $V_{REF}$  range. The Rx mask at the pin must be within the internal  $V_{REF(CA)}$  range irrespective of the input signal common mode.
  4. CA-only input pulse signal amplitude into the receiver must meet or exceed  $V_{IHL(AC)}$  at any point over the total UI. No timing requirement above level.  $V_{IHL(AC)}$  is the peak-to-peak voltage centered around  $V_{CENT\_CA(pin\ mid)}$ , such that  $V_{IHL(AC)}/2$  (MIN) must be met both above and below  $V_{CENT\_CA}$ .
  5. Input slew rate over  $V_{cIVW}$  mask is centered at  $V_{CENT\_CA(pin\ mid)}$ .
  6.  $V_{IHL(AC)}$  does not have to be met when no transitions are occurring.
  7. The Rx voltage and absolute timing requirements apply for DQ operating frequencies at or below 1333 for all speed bins. For example the  $t_{cIVW}(ps) = 450ps$  at or below 1333 operating frequencies.

## DQ Tx Voltage and Timing

### DRAM Data Timing

Figure 168: Read Data Timing Definitions –  $t_{QH}$  and  $t_{DQSQ}$  Across DQ Signals per DQS Group



## DQ Rx Voltage and Timing

The DQ input receiver mask for voltage and timing is applied per pin, as shown in the DQ Receiver (Rx) Mask figure below. The total mask ( $V_{dIVW\_total}$ ,  $TdIVW\_total$ ) defines the area that the input signal must not encroach in order for the DQ input receiver to successfully capture an input signal. The mask is a receiver property, and it is not the valid data eye.

Figure 169: DQ Receiver (Rx) Mask

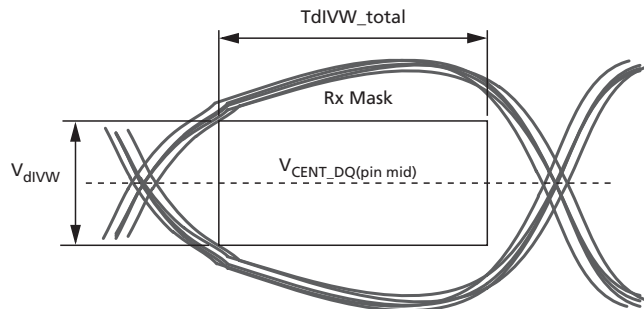
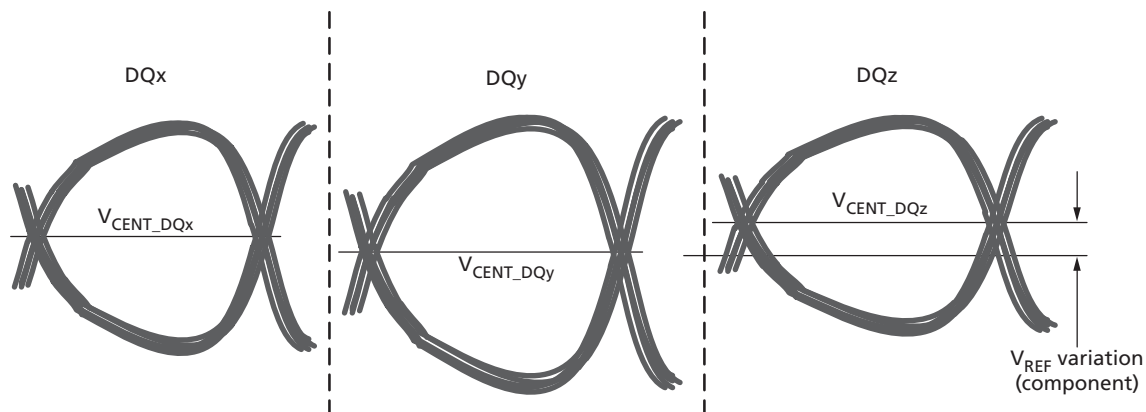
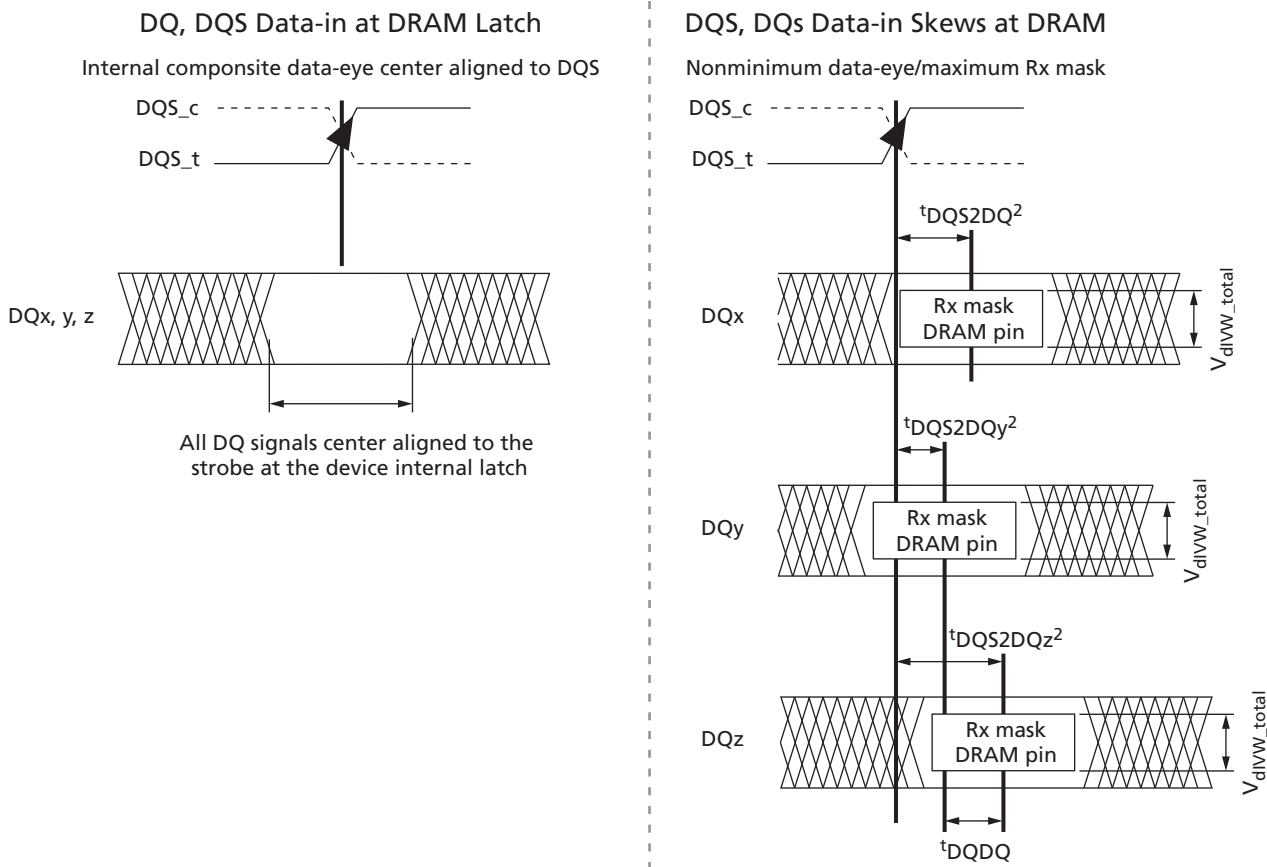


Figure 170: Across Pin  $V_{REF}$  DQ Voltage Variation



$V_{CENT\_DQ(pin\_mid)}$  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  $V_{CENT\_DQ}$  is defined by the center, which is the widest opening of the cumulative data input eye as shown in the figure above. This clarifies that any DRAM component level variation must be accounted for within the DRAM Rx mask. The component-level  $V_{REF}$  will be set by the system to account for  $R_{ON}$  and ODT settings.

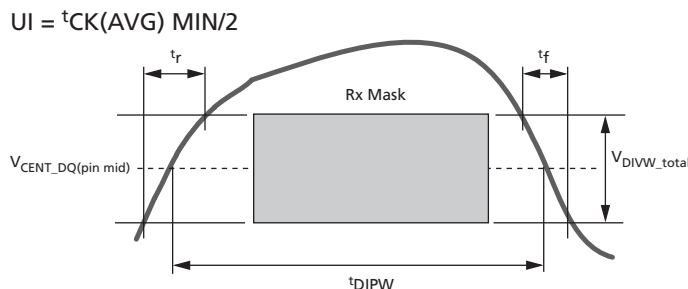
Figure 171: DQ-to-DQS  $t_{DQS2DQ}$  and  $t_{DQDQ}$



- Notes:
1. These timings at the DRAM pins are referenced from the internal latch.
  2.  $t_{DQS2DQ}$  is measured at the center (midpoint) of the TdIVW window.
  3. DQz represents the MAX  $t_{DQS2DQ}$  in this example.
  4. DQy represents the MIN  $t_{DQS2DQ}$  in this example.

All of the timing terms in DQ to DQS\_t are measured from the DQS\_t/DQS\_c to the center (midpoint) of the TdIVW window taken at the  $V_{dIVW\_total}$  voltage levels centered around  $V_{CENT\_DQ(pin\_mid)}$ . In figure above, the timings at the pins are referenced with respect to all DQ signals center-aligned to the DRAM internal latch. The data-to-data offset is defined as the difference between the MIN and MAX  $t_{DQS2DQ}$  for a given component.

Figure 172: DQ  $t_{DIPW}$  and SRIN\_divW Definition for Each Input Pulse



Note: 1.  $SRIN\_divW = V_{divW\_total} / (t_r \text{ or } t_f)$  signal must be monotonic within  $t_r$  and  $t_f$  range.

Figure 173: DQ  $V_{IHL(AC)}$  Definition (for Each Input Pulse)

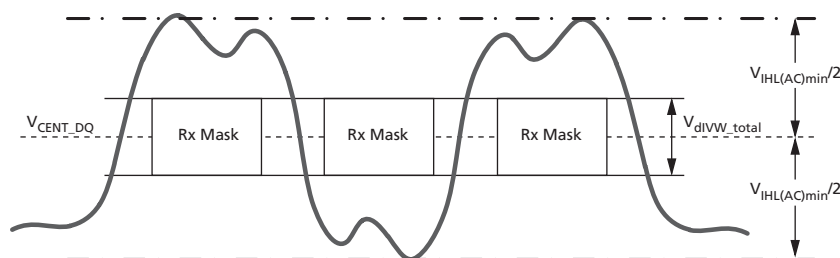


Table 188: DQs In Receive Mode

Note  $UI = t_{CK(AVG)}(MIN)/2$

Symbol	Parameter	1600/1867		2133/2400		3200/3733		4267		Unit	Notes
		Min	Max	Min	Max	Min	Max	Min	Max		
$V_{divW\_total}$	Rx mask voltage – peak-to-peak	–	140	–	140	–	140	–	120	mV	1, 2, 3
$V_{IHL(AC)}$	DQ AC input pulse amplitude peak-to-peak	180	–	180	–	180	–	170	–	mV	5, 7
SRIN_divW	Input slew rate over $V_{divW\_total}$	1	7	1	7	1	7	1	7	V/ns	6

- Notes:
1. Data Rx mask voltage and timing parameters are applied per pin and include the DRAM DQ-to-DQS voltage AC noise impact for frequencies >20 MHz with a maximum voltage of 45mV peak-to-peak at a fixed temperature on the package. The voltage supply noise must comply to the component MIN/MAX DC operating conditions.
  2. Rx mask voltage  $V_{divW\_total}$  (MAX) must be centered around  $V_{CENT\_DQ(pin\_mid)}$ .
  3. Defined over the DQ internal  $V_{REF}$  range. The Rx mask at the pin must be within the internal  $V_{REF}$  DQ range irrespective of the input signal common mode.
  4. Deterministic component of the total Rx mask voltage or timing. Parameter will be characterized and guaranteed by design.
  5. DQ-only input pulse amplitude into the receiver must meet or exceed  $V_{IHL(AC)}$  at any point over the total UI. No timing requirement above level.  $V_{IHL(AC)}$  is the peak-to-peak voltage centered around  $V_{CENT\_DQ(pin\_mid)}$ , such that  $V_{IHL(AC)}/2$  (MIN) must be met both above and below  $V_{CENT\_DQ}$ .
  6. Input slew rate over  $V_{divW}$  mask centered at  $V_{CENT\_DQ(pin\_mid)}$ .

7.  $V_{IHL(AC)}$  does not have to be met when no transitions are occurring.

## Clock Specification

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

**Table 189: Definitions and Calculations**

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



**Table 189: Definitions and Calculations (Continued)**

Symbol	Description	Calculation	Notes
$t_{ERR(nper)}$ , allowed	The specified clock jitter allowance over $n$ cycles.		
$t_{ERR(nper),min}$	The minimum $t_{ERR(nper)}$ .	$t_{ERR(nper),min} = (1 + 0.68LN(n)) \times t_{JIT(per),min}$	2
$t_{ERR(nper),max}$	The maximum $t_{ERR(nper)}$ .	$t_{ERR(nper),max} = (1 + 0.68LN(n)) \times t_{JIT(per),max}$	2
$t_{JIT(duty)}$	Defined with absolute and average specifications for $t_{CH}$ and $t_{CL}$ , respectively.	$t_{JIT(duty),min} =$ $MIN((t_{CH(ABS),min} - t_{CH(avg),min}),$ $(t_{CL(ABS),min} - t_{CL(avg),min})) \times t_{CK(avg)}$  $t_{JIT(duty),max} =$ $MAX((t_{CH(ABS),max} - t_{CH(avg),max}),$ $(t_{CL(ABS),max} - t_{CL(avg),max})) \times t_{CK(avg)}$	

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

### $t_{CK(ABS)}$ , $t_{CH(ABS)}$ , and $t_{CL(ABS)}$

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

**Table 190:  $t_{CK(ABS)}$ ,  $t_{CH(ABS)}$ , and  $t_{CL(ABS)}$  Definitions**

Parameter	Symbol	Minimum	Unit
Absolute clock period	$t_{CK(ABS)}$	$t_{CK(avg),min} + t_{JIT(per),min}$	ps <sup>1</sup>
Absolute clock HIGH pulse width	$t_{CH(ABS)}$	$t_{CH(avg),min} + t_{JIT(duty),min}^2/t_{CK(avg),min}$	$t_{CK(avg)}$
Absolute clock LOW pulse width	$t_{CL(ABS)}$	$t_{CL(avg),min} + t_{JIT(duty),min}^2/t_{CK(avg),min}$	$t_{CK(avg)}$

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

## Clock Period Jitter

LPDDR4 devices can tolerate some clock period jitter without core timing parameter derating. This section describes device timing requirements with clock period jitter ( $t_{JIT(per)}$ ) in excess of the values found in the AC Timing table. Calculating cycle time derating and clock cycle derating are also described.

### Clock Period Jitter Effects on Core Timing Parameters

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

### Cycle Time Derating for Core Timing Parameters

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

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

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

### Clock Cycle Derating for Core Timing Parameters

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

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

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

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

### Clock Jitter Effects on Command/Address Timing Parameters

Command/address timing parameters ( $t_{IS}$ ,  $t_{IH}$ ,  $t_{ISb}$ ,  $t_{IHb}$ ) are measured from a command/address signal (CS or CA[5:0]) transition edge to its respective clock signal (CK<sub>t</sub>/CK<sub>c</sub>) crossing. The specification values are not affected by the  $t_{JIT(per)}$  applied, because the setup and hold times are relative to the clock signal crossing that latches the command/address. Regardless of clock jitter values, these values must be met.

### Clock Jitter Effects on READ Timing Parameters

#### $t_{RPRE}$

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

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

For example, if the measured jitter into a LPDDR4 device has  $t_{CK(avg)} = 625ps$ ,  $t_{JIT(per),act,min} = -xx$ , and  $t_{JIT(per),act,max} = +xx$  ps, then  $t_{RPRE,min,derated} = 0.9 - (t_{JIT(per),act,max} - t_{JIT(per),allowed,max}) / t_{CK(avg)} = 0.9 - (xx - xx) / xx = yy$   $t_{CK(avg)}$ .

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

These parameters are measured from a specific clock edge to a data signal transition ( $DM_n$  or  $DQ_m$ , where:  $n = 0,1$ ; and  $m = 0-15$ , and specified timings must be met with respect to that clock edge. Therefore, they are not affected by  $t_{JIT}(\text{per})$ .

 **$t_{QSH}$ ,  $t_{QSL}$** 

These parameters are affected by duty cycle jitter, represented by  $t_{CH}(\text{abs})\text{min}$  and  $t_{CL}(\text{abs})\text{min}$ . These parameters determine the absolute data-valid window at the device pin. The absolute minimum data-valid window at the device pin =  $\text{MIN} \{ (t_{QSH}(\text{abs})\text{min} - t_{DQSQ}\text{max}), (t_{QSL}(\text{abs})\text{min} - t_{DQSQ}\text{max}) \}$ . This minimum data valid window must be met at the target frequency regardless of clock jitter.

 **$t_{RPST}$** 

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

**Clock Jitter Effects on WRITE Timing Parameters**
 **$t_{DS}$ ,  $t_{DH}$** 

These parameters are measured from a data signal ( $DM_n$  or  $DQ_m$ , where  $n = 0, 1$  and  $m = 0-15$ ) transition edge to its respective data strobe signal ( $DQSn\_t$ ,  $DQSn\_c$ :  $n = 0,1$ ) crossing. The specification values are not affected by the amount of  $t_{JIT}(\text{per})$  applied, because the setup and hold times are relative to the data strobe signal crossing that latches the command/address. Regardless of clock jitter values, these values must be met.

 **$t_{DSS}$ ,  $t_{DSH}$** 

These parameters are measured from a data signal ( $DQSn\_t$ ,  $DQSn\_c$ ) crossing to its respective clock signal ( $CK\_t$ ,  $CK\_c$ ) crossing. When the device is operated with input clock jitter, this parameter needs to be derated by the actual  $t_{JIT}(\text{per})\text{act}$  of the input clock in excess of the allowed period jitter  $t_{JIT}(\text{per})\text{allowed}$ .

 **$t_{DQSS}$** 

$t_{DQSS}$  is measured from a data strobe signal ( $DQSn\_t$ ,  $DQSn\_c$ ) crossing to its respective clock signal ( $CK\_t$ ,  $CK\_c$ ) crossing. When the device is operated with input clock jitter, this parameter must be derated by the actual  $t_{JIT}(\text{per})\text{act}$  of the input clock in excess of  $t_{JIT}(\text{per})\text{allowed}$ .

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

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

For example, if the measured jitter into an LPDDR4 device has  $t_{CK}(\text{avg}) = 625\text{ps}$ ,  $t_{JIT}(\text{per}),\text{act, min} = -xx\text{ps}$ , and  $t_{JIT}(\text{per}),\text{act,max} = +xx\text{ps}$ , then:

$$t_{DQSS}(\text{min,derated}) = 0.75 - (-xx + yy)/625 = \text{xxxx } t_{CK}(\text{avg})$$

$$t_{DQSS}(\text{max,derated}) = 1.25 - (xx - yy)/625 = \text{xxxx } t_{CK}(\text{avg})$$

## **Revision History**

### **Rev. D – 3/17**

- Added QDP die
- Added DS, DT, and NQ package codes
- Added XT temperature range

### **Rev. C – 11/16**

- Added -053 speed grade

### **Rev. B – 8/16**

- Production release

### **Rev. A – 5/16**

- Initial Preliminary release (reference document: PDF: 09005aef865c23a1366b\_z0am\_qdp\_mobile\_lpddr4.pdf – Rev. B 3/16 EN)