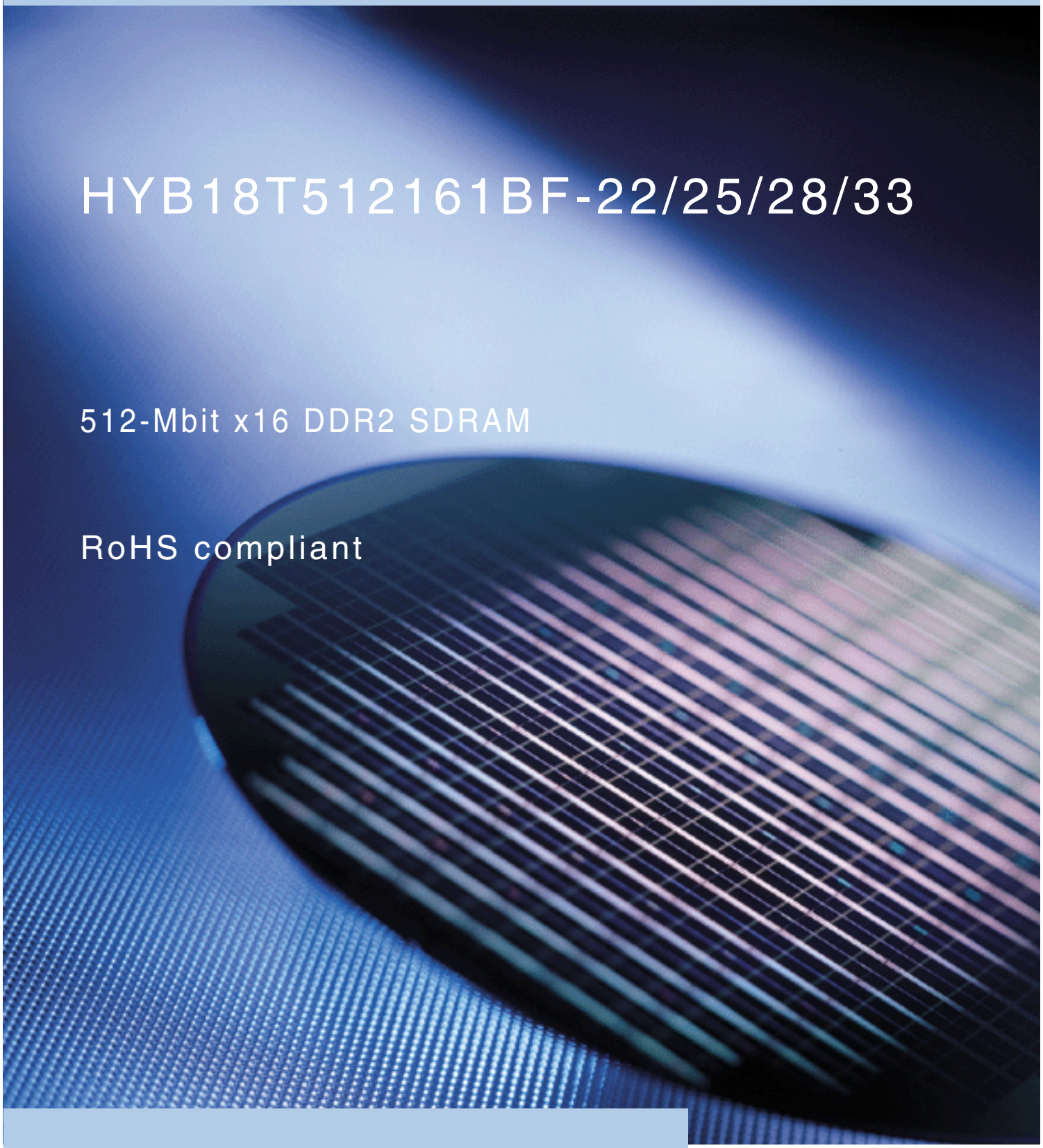
Data Sheet, Rev. 1.1, Aug. 2005

HYB18T512161BF-22/25/28/33

512-Mbit x16 DDR2 SDRAM

RoHS compliant



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Page	Subjects (major changes since last revision)
All	added speed sort -33
	added note 2

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1 Overview

This chapter gives an overview of the 512-Mbit Double-Data-Rate-Two SDRAM product family and describes its main characteristics.

1.1 Features

The 512-Mbit Double-Data-Rate-Two SDRAM offers the following key features:

- 1.8 V ± 0.1 V Power Supply
  1.8 V ± 0.1 V (SSTL_18) compatible I/O
- DRAM organizations with 16 data in/outputs
- Double Data Rate architecture: two data transfers per clock cycle four internal banks for concurrent operation
- Programmable $\overline{\text{CAS}}$ Latency: 3, 4, 5, 6, 7
- Programmable Burst Length: 4 and 8
- Differential clock inputs (CK and $\overline{\text{CK}}$)
- Bi-directional, differential data strobes (DQS and $\overline{\text{DQS}}$) are transmitted / received with data. Edge aligned with read data and center-aligned with write data.
- DLL aligns DQ and DQS transitions with clock
- $\overline{\text{DQS}}$ can be disabled for single-ended data strobe operation
- Commands entered on each positive clock edge, data and data mask are referenced to both edges of DQS
- Data masks (DM) for write data
- Posted $\overline{\text{CAS}}$ by programmable additive latency for better command and data bus efficiency
- Off-Chip-Driver impedance adjustment (OCD) and On-Die-Termination (ODT) for better signal quality.
- Auto-Precharge operation for read and write bursts
- Auto-Refresh, Self-Refresh and power saving Power-Down modes
- Average Refresh Period 7.8 µs at a T_{CASE} lower than 85 °C, 3.9 µs between 85 °C and 95 °C
- Full Strength and reduced Strength (60%) Data-Output Drivers
- 2kB page size
- Packages: P-TFBGA-84 for ×16 components
- RoHS Compliant Products[1)]

Table 1 Ordering Information for RoHS compliant products

Product Number	Org.	Clock (MHz)	Package
HYB18T512161BF–22/25/28/33	×16	450/400/350/300	P-TFBGA-84

1) RoHS Compliant Product: Restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment as defined in the directive 2002/95/EC issued by the European Parliament and of the Council of 27 January 2003. These substances include mercury, lead, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated biphenyl ethers.

1.2 Description

The 512-Mb DDR2 DRAM is a high-speed Double-Data-Rate-Two CMOS DRAM device containing 536,870,912 bits and internally configured as a quad-bank DRAM. The 512-Mb device is organized as 8 Mbit × 16 I/O × 4 banks chip. These devices achieve high speed transfer rates starting at 400 Mb/sec/pin for general applications.

The device is designed to comply with all DDR2 DRAM key features:

1. posted $\overline{\text{CAS}}$ with additive latency,
2. write latency = read latency - 1,
3. normal and weak strength data-output driver,
4. Off-Chip Driver (OCD) impedance adjustment
5. On-Die Termination (ODT) function.

All of the control and address inputs are synchronized with a pair of externally supplied differential clocks. Inputs are latched at the cross point of differential clocks (CK rising and $\overline{\text{CK}}$ falling). All I/Os are synchronized with a single ended DQS or differential DQS-$\overline{\text{DQS}}$ pair in a source synchronous fashion.

A 15-bit address bus for ×16 components is used to convey row, column and bank address information in a $\overline{\text{RAS}}$-$\overline{\text{CAS}}$ multiplexing style.

An Auto-Refresh and Self-Refresh mode is provided along with various power-saving power-down modes.

The functionality described and the timing specifications included in this data sheet are for the DLL Enabled mode of operation.

The DDR2 SDRAM is available in P-TFBGA package.

*Note: For product nomenclature see **Chapter 8** of this data sheet*

2 Pin Configuration and Block Diagrams

2.1 Pin Configuration

The pin configuration of a DDR2 SDRAM is listed by function in **Table 2**. The abbreviations used in the Pin#/Buffer Type columns are explained in **Table 3** and **Table 4** respectively. The pin numbering for the FBGA package is depicted in Figure 1 for ×4, Figure 2 for ×8 and Figure 3 for ×16.

Table 2 Pin Configuration of DDR SDRAM

Ball#/Pin#	Name	Pin Type	Buffer Type	Function
Clock Signals ×16 organization				
J8	CK	I	SSTL	**Clock Signal CK, Complementary Clock Signal $\overline{CK}$**
K8	$\overline{CK}$	I	SSTL	
K2	CKE	I	SSTL	**Clock Enable**
Control Signals ×16 organization				
K7	$\overline{RAS}$	I	SSTL	**Row Address Strobe (RAS), Column Address Strobe (CAS), Write Enable (WE)**
L7	$\overline{CAS}$	I	SSTL	
K3	$\overline{WE}$	I	SSTL	
L8	$\overline{CS}$	I	SSTL	**Chip Select**
Address Signals ×16 organization				
L2	BA0	I	SSTL	**Bank Address Bus 1:0**
L3	BA1	I	SSTL	
L1	NC	–	–	
M8	A0	I	SSTL	**Address Signal 12:0,Address Signal 10/Autoprecharge**
M3	A1	I	SSTL	
M7	A2	I	SSTL	
N2	A3	I	SSTL	
N8	A4	I	SSTL	
N3	A5	I	SSTL	
N7	A6	I	SSTL	
P2	A7	I	SSTL	
P8	A8	I	SSTL	
P3	A9	I	SSTL	
M2	A10	I	SSTL	
	AP	I	SSTL	
P7	A11	I	SSTL	
R2	A12	I	SSTL	

Table 2 Pin Configuration of DDR SDRAM

Ball#/Pin#	Name	Pin Type	Buffer Type	Function
Data Signals ×16 organization				
G8	DQ0	I/O	SSTL	**Data Signal 15:0**
G2	DQ1	I/O	SSTL	*Note: Bi-directional data bus. DQ[15:0] for ×16 components*
H7	DQ2	I/O	SSTL	
H3	DQ3	I/O	SSTL	
H1	DQ4	I/O	SSTL	
H9	DQ5	I/O	SSTL	
F1	DQ6	I/O	SSTL	
F9	DQ7	I/O	SSTL	
C8	DQ8	I/O	SSTL	
C2	DQ9	I/O	SSTL	
D7	DQ10	I/O	SSTL	
D3	DQ11	I/O	SSTL	
D1	DQ12	I/O	SSTL	
D9	DQ13	I/O	SSTL	
B1	DQ14	I/O	SSTL	
B9	DQ15	I/O	SSTL	
Data Strobe ×16 organization				
B7	UDQS	I/O	SSTL	**Data Strobe Upper Byte**
A8	$\overline{\text{UDQS}}$	I/O	SSTL	
F7	LDQS	I/O	SSTL	**Data Strobe Lower Byte**
E8	$\overline{\text{LDQS}}$	I/O	SSTL	
Data Mask ×16 organization				
B3	UDM	I	SSTL	**Data Mask Upper Byte**
F3	LDM	I	SSTL	**Data Mask Lower Byte**
Power Supplies ×16 organizations				
A9,C1,C3,C7, C9	V_{DDQ}	PWR	–	**I/O Driver Power Supply**
A1	V_{DD}	PWR	–	**Power Supply**
A7,B2,B8,D2, D8	V_{SSQ}	PWR	–	**Power Supply**
A3,E3	V_{SS}	PWR	–	**Power Supply**
Power Supplies ×16 organization				
J2	V_{REF}	AI	–	**I/O Reference Voltage**
E9, G1, G3, G7, G9	V_{DDQ}	PWR	–	**I/O Driver Power Supply**
J1	V_{DDL}	PWR	–	**Power Supply**
E1, J9, M9, R1	V_{DD}	PWR	–	**Power Supply**

Table 2 Pin Configuration of DDR SDRAM

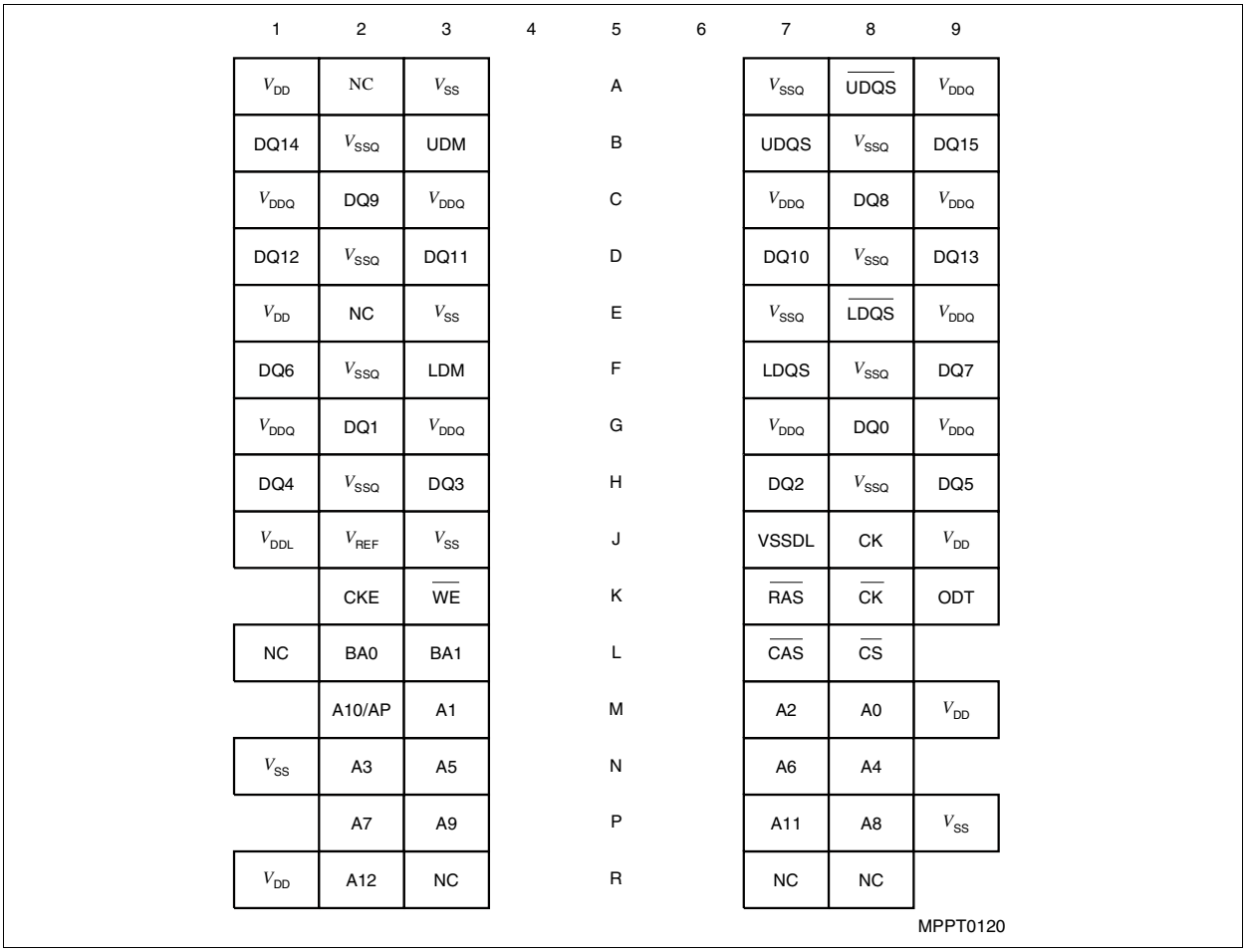
Ball#/Pin#	Name	Pin Type	Buffer Type	Function
E7, F2, F8, H2, H8	V_{SSQ}	PWR	–	**Power Supply**
J7	V_{SSDL}	PWR	–	**Power Supply**
J3,N1,P9	V_{SS}	PWR	–	**Power Supply**
Not Connected ×16 organization				
A2, E2, L1, R3, R7, R8	NC	NC	–	**Not Connected**
Other Pins ×16 organization				
K9	ODT	I	SSTL	**On-Die Termination Control**

Table 3 Abbreviations for Pin Type

Abbreviation	Description
I	Standard input-only pin. Digital levels.
O	Output. Digital levels.
I/O	I/O is a bidirectional input/output signal.
AI	Input. Analog levels.
PWR	Power
GND	Ground
NC	Not Connected

Table 4 Abbreviations for Buffer Type

Abbreviation	Description
SSTL	Serial Stub Terminated Logic (SSTL_18)
LV-CMOS	Low Voltage CMOS
CMOS	CMOS Levels
OD	Open Drain. The corresponding pin has 2 operational states, active low and tristate, and allows multiple devices to share as a wire-OR.



1	2	3	4	5	6	7	8	9
V_{DD}	NC	V_{SS}		A		V_{SSQ}	$\overline{\text{UDQS}}$	V_{DDQ}
DQ14	V_{SSQ}	UDM		B		UDQS	V_{SSQ}	DQ15
V_{DDQ}	DQ9	V_{DDQ}		C		V_{DDQ}	DQ8	V_{DDQ}
DQ12	V_{SSQ}	DQ11		D		DQ10	V_{SSQ}	DQ13
V_{DD}	NC	V_{SS}		E		V_{SSQ}	$\overline{\text{LDQS}}$	V_{DDQ}
DQ6	V_{SSQ}	LDM		F		LDQS	V_{SSQ}	DQ7
V_{DDQ}	DQ1	V_{DDQ}		G		V_{DDQ}	DQ0	V_{DDQ}
DQ4	V_{SSQ}	DQ3		H		DQ2	V_{SSQ}	DQ5
V_{DDL}	V_{REF}	V_{SS}		J		VSSDL	CK	V_{DD}
	CKE	$\overline{\text{WE}}$		K		$\overline{\text{RAS}}$	$\overline{\text{CK}}$	ODT
NC	BA0	BA1		L		$\overline{\text{CAS}}$	$\overline{\text{CS}}$	
	A10/AP	A1		M		A2	A0	V_{DD}
V_{SS}	A3	A5		N		A6	A4	
	A7	A9		P		A11	A8	V_{SS}
V_{DD}	A12	NC		R		NC	NC	

MPPT0120

Figure 1 Pin Configuration for ×16 components, P-TFBGA-84 (top view)

Note:

1. UDQS/$\overline{\text{UDQS}}$ is data strobe for DQ[15:8], LDQS/$\overline{\text{LDQS}}$ is data strobe for DQ[7:0]
2. LDM is the data mask signal for DQ[7:0], UDM is the data mask signal for DQ[15:8]
3. V_{DDL} and V_{DDSL} are power and ground for the DLL. They are isolated on the device from V_{DD}, V_{DDQ}, V_{SS} and V_{SSQ}.

2.2 512 Mbit DDR2 Addressing

Table 5 512-Mbit DDR2 Addressing

Configuration	32-Mbit x 16	Note
Bank Address	BA[1:0]	
Number of Banks	4	
Auto-Precharge	A10 / AP	
Row Address	A[12:0]	
Column Address	A[9:0]	
Number of Column Address Bits	10	1)
Number of I/Os	16	2)
Page Size [Bytes]	2048 (2K)	3)

1) Referred to as 'colbits'
2) Referred to as 'org'
3) PageSize = $2^{colbits} \times$ org/8 [Bytes

2.3 Block Diagrams

Block diagrams of the 512M DDR2 SDRAM component.

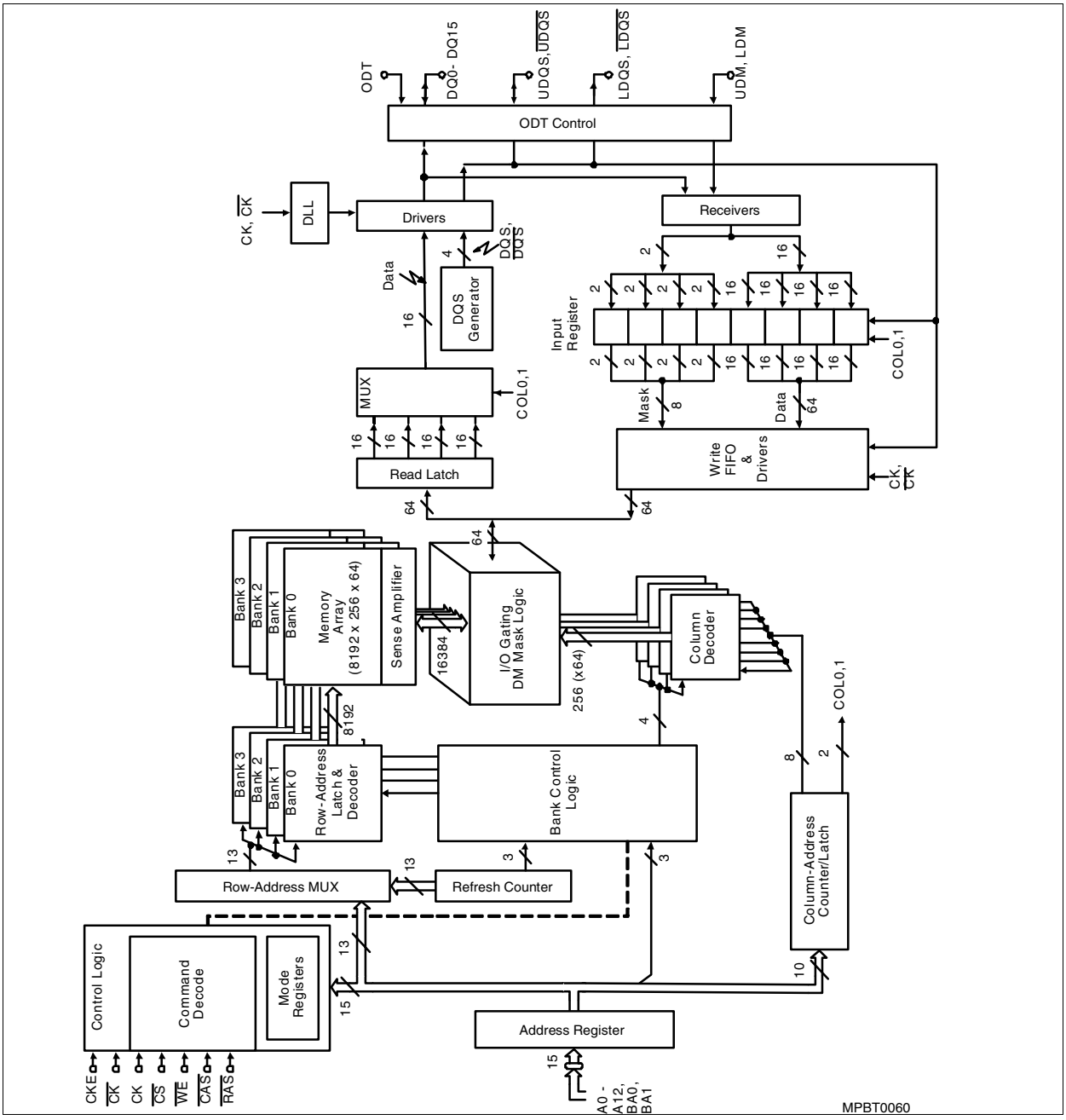


Figure 2 Block Diagram 8 Mbit × 16 I/O ×4 Internal Memory Banks

Note:

1. 32Mb × 16 Organisation with 13 Row, 2 Bank and 10 Column External Adresses
2. This Functional Block Diagram is intended to facilitate user understanding of the operation of the device; it does not represent an actual circuit implementation.
3. LDM, UDM is a unidirectional signal (input only), but is internally loaded to match the load of the bidirectional LDQS and UDQS signals.

3 Functional Description

3.1 Simplified State Diagram

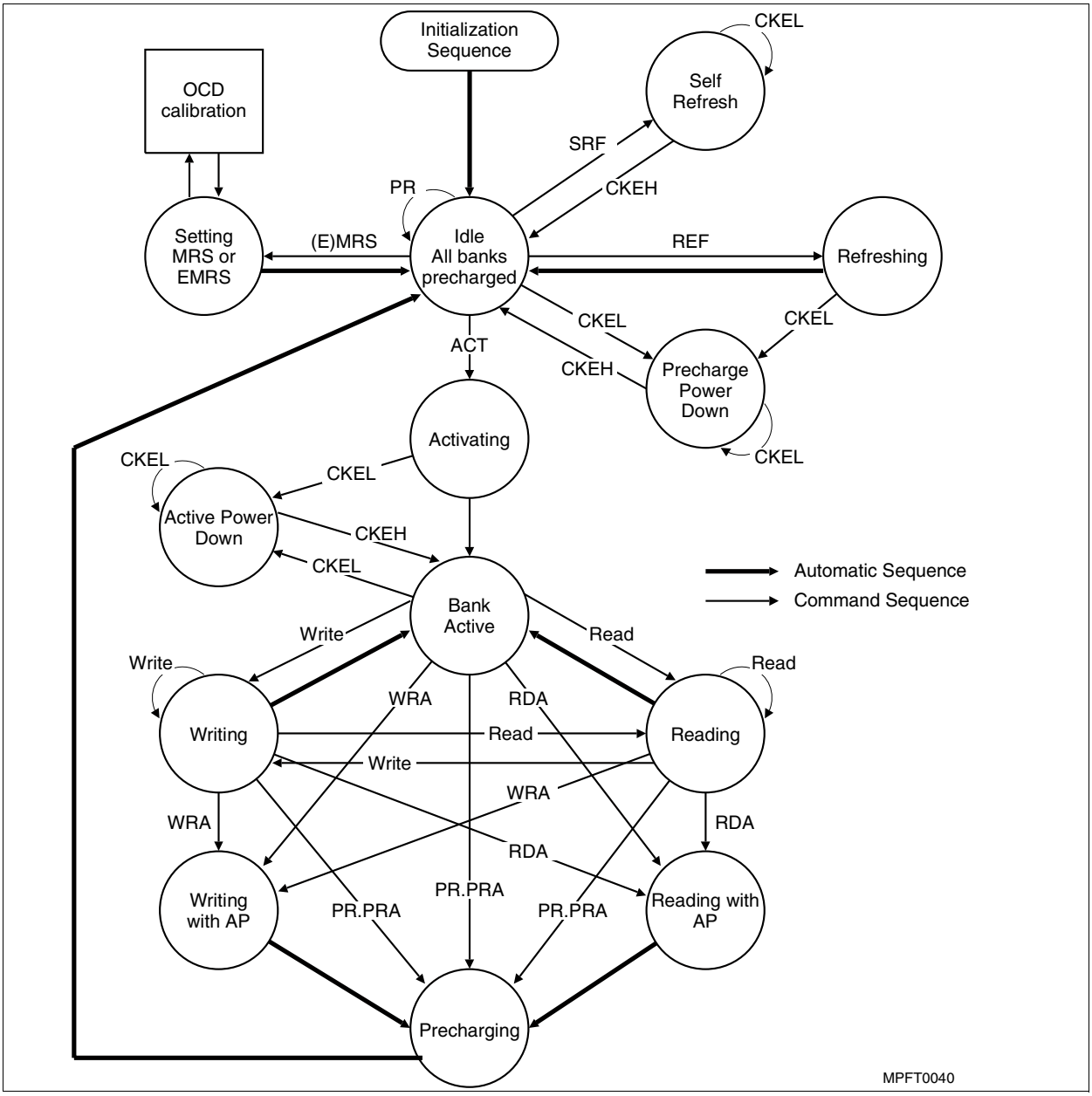


Figure 3 Simplified State Diagram

Note: This Simplified State Diagram is intended to provide a floorplan of the possible state transitions and the commands to control them. In particular situations involving more than one bank, enabling / disabling on-die termination, Power-Down entry / exit, timing restrictions during state transitions - among other things - are not captured in full detail.

3.2 Basic Functionality

Read and write accesses to the DDR2 SDRAM are burst oriented; accesses start at a selected location and continue for the burst length of four or eight in a programmed sequence.

Accesses begin with the registration of an Activate command, which is followed by a Read or Write command. The address bits registered coincident with the activate command are used to select the bank and row to be accessed. BA[1:0] selects the bank, A[12:0] selects the row for x16 components.

The address bits registered coincident with the Read or Write command are used to select the starting column location for the burst access and to determine if the Auto-Precharge command is to be issued.

Prior to normal operation, the DDR2 SDRAM must be initialized. The following sections provide detailed information covering device initialization, register definition, command description and device operation.

3.3 Power On and Initialization

DDR2 SDRAM's must be powered up and initialized in a predefined manner. Operational procedures other than those specified may result in undefined operation.

Power-up and Initialization Sequence

The following sequence is required for POWER UP and Initialization.

1. Apply power and attempt to maintain CKE below $0.2 \times V_{DDQ}$ and ODT at a low state (all other inputs may be undefined). To guarantee ODT off, V_{REF} must be valid and a low level must be applied to the ODT pin. Maximum power up interval for V_{DD} / V_{DDQ} is specified as 20.0 ms. The power interval is defined as the amount of time it takes for V_{DD} / V_{DDQ} to power-up from 0 V to V_{DDQ}. At least one of these two sets of conditions must be met:
   – V_{DD}, V_{DDL} and V_{DDQ} are driven from a single power converter output, AND
   – V_{TT} is limited to V_{DDQ} max/2, AND
   – V_{REF} tracks V_{DDQ}/2
   or
   – Apply V_{DD} before or at the same time as V_{DDL}.– Apply V_{DDL} before or at the same time as V_{DDQ}.– Apply V_{DDQ} before or at the same time as V_{TT} & V_{REF}.
2. Start clock (CK, $\overline{CK}$) and maintain stable power and clock condition for a minimum of 200 µs.
3. Apply NOP or Deselect commands and take CKE high.
4. Continue NOP or Deselect Commands for 400 ns, then issue a Precharge All command.
5. Issue EMRS(2) command.
6. Issue EMRS(3) command.
7. Issue EMRS(1) command to enable DLL.
8. Issue a MRS command for "DLL reset".
9. Issue Precharge-all command.
10. Issue 2 or more Auto-refresh commands.
11. Issue the final MRS command to turn the DLL on and to set the necessary operating parameter.
12. At least 200 clocks after step 8, issue EMRS(1) commands to either execute the OCD calibration or select the OCD default. Issue the final EMRS(1) command to exit OCD calibration mode and set the necessary operating parameters.
13. The DDR2 SDRAM is now ready for normal operation.

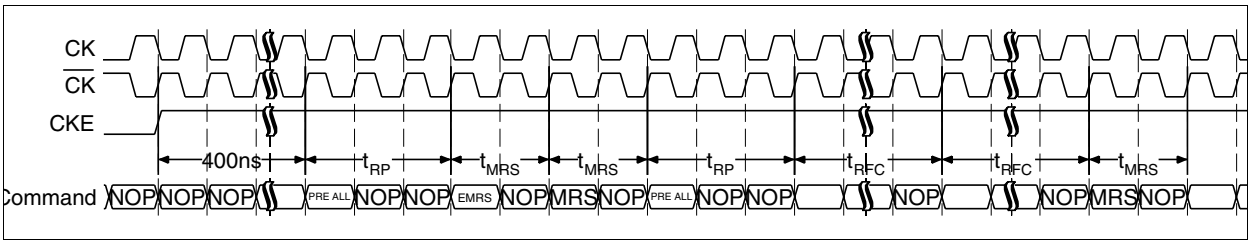


Figure 4 Initialization Sequence after Power up

3.4 Programming the Mode Register and Extended Mode Registers

For application flexibility, burst length, burst type, $\overline{\text{CAS}}$ latency, DLL reset function, write recovery time (WR) are user defined variables and must be programmed with a Mode Register Set (MRS) command. Additionally, DLL disable function, additive $\overline{\text{CAS}}$ latency, driver impedance, On Die Termination (ODT), single-ended strobe and Off Chip Driver impedance adjustment (OCD) are also user defined variables and must be programmed with an Extended Mode Register Set (EMRS) command. Contents of the Mode Register (MR) or Extended Mode Registers (EMR(1, 2, 3)) can be altered by re-executing the MRS and EMRS Commands. If the user chooses to modify only a subset of the MR or EMR variables, all variables must be redefined when the MRS or EMRS commands are issued. After initial power up, all MRS and EMRS Commands must be issued before read or write cycles may begin. All banks must be in a precharged state and CKE must be high at least one cycle before the Mode Register Set Command can be issued. Either MRS or EMRS Commands are activated by the low signals of $\overline{\text{CS}}$, $\overline{\text{RAS}}$, $\overline{\text{CAS}}$ and $\overline{\text{WE}}$ at the positive edge of the clock.When both bank addresses BA[1:0] are 0, the DDR2 SDRAM enables the MRS command. When the bank address BA0 is 1 and BA1 is 0, the DDR2 SDRAM enables the EMRS(1) command. The address input data during this cycle defines the parameters to be set as shown in the MRS and EMRS tables. A new command may be issued after the mode register set command cycle time (t_{MRD}). MRS, EMRS and DLL Reset do not affect array contents, which means reinstallation including those can be executed any time after power-up without affecting array contents.

3.5 DDR2 SDRAM Mode Register Set (MRS)

The mode register stores the data for controlling the various operating modes of DDR2 SDRAM. It programs CAS latency, burst length, burst sequence, test mode, DLL reset, Write Recovery (WR) and various vendor specific options to make DDR2 SDRAM useful for various applications. The default value of the mode register is not defined, therefore the mode register must be written after power-up for proper operation. The mode register is written by asserting low on CS, RAS, CAS, WE, BA[1:0], while controlling the state of address pins A[13:0]. The DDR2 SDRAM should be in all bank precharged (idle) mode with CKE already high prior to writing into the mode register. The mode register set command cycle time (t_{MRD}) is required to complete the write operation to the mode register. The mode register contents can be changed using the same command and clock cycle requirements during normal operation as long as all banks are in the precharged state. The mode register is divided into various fields depending on functionality. Burst length is defined by A[2:0] with options of 4 and 8 bit burst length. Burst address sequence type is defined by A3 and CAS latency is defined by A[6:4]. A7 is used for test mode and must be set to 0 for normal DRAM operation. A8 is used for DLL reset. A[11:9] are used for write recovery time (WR) definition for Auto-Precharge mode. With address bit A12 two Power-Down modes can be selected, a “standard mode” and a “low-power” Power-Down mode, where the DLL is disabled. Address bit A13 and all “higher” address bits have to be set to 0 for compatibility with other DDR2 memory products with higher memory densities.

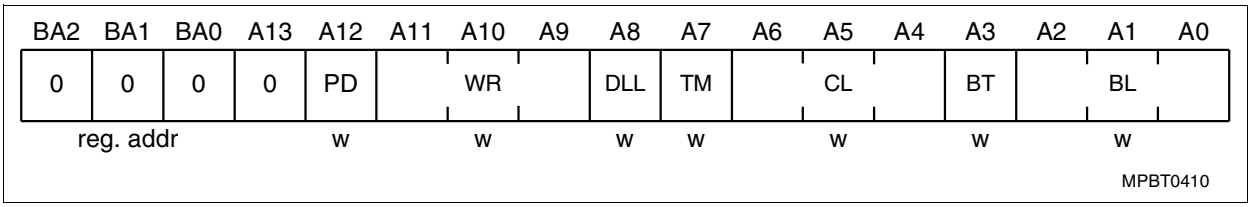


Table 6 Mode Register Definition (BA[2:0] = 000B)

Field	Bits	Type[1)]	Description
BA2	16	reg. addr.	**Bank Address [2]** *Note: BA2 not available on 256 Mbit and 512 Mbit components* 0_B **BA2**, Bank Address
BA1	15		**Bank Address [1]** 0_B **BA1**, Bank Address
BA0	14		**Bank Address [0]** 0_B **BA0**, Bank Address
A13	13		**Address Bus[13]** *Note: A13 is not available for 256 Mbit and x16 512 Mbit configuration* 0_B **A13**, Address bit 13
PD	12	w	**Active Power-Down Mode Select** 0_B **PD**, Fast exit 1_B **PD**, Slow exit
WR	[11:9]	w	**Write Recovery[2)]** *Note: All other bit combinations are illegal.* 001_B **WR**, 2 010_B **WR**, 3 011_B **WR**, 4 100_B **WR**, 5 101_B **WR**, 6
DLL	8	w	**DLL Reset** 0_B **DLL**, No 1_B **DLL**, Yes
TM	7	w	**Test Mode** 0_B **TM**, Normal Mode 1_B **TM**, Vendor specific test mode
CL	[6:4]	w	**CAS Latency** *Note: All other bit combinations are illegal.* 010_B **CL**, reserved 011_B **CL**, 3 100_B **CL**, 4 101_B **CL**, 5 110_B **CL**, 6 111_B **CL**, 7

Table 6 Mode Register Definition (BA[2:0] = 000B)

Field	Bits	Type[1)]	Description
BT	3	w	**Burst Type** 0_B **BT**, Sequential 1_B **BT**, Interleaved
BL	[2:0]	w	**Burst Length** *Note: All other bit combinations are illegal.* 010_B **BL**, 4 011_B **BL**, 8

1) w = write only register bits

2) Number of clock cycles for write recovery during auto-precharge. WR in clock cycles is calculated by dividing t_{WR} (in ns) by t_{CK} (in ns) and rounding up to the next integer: WR [cycles] ≥ t_{WR} (ns) / t_{CK} (ns). The mode register must be programmed to fulfill the minimum requirement for the analogue t_{WR} timing WR_{MIN} is determined by $t_{CK.MAX}$ and WR_{MAX} is determined by $t_{CK.MIN}$.

3.6 DDR2 SDRAM Extended Mode Register Set EMR(1)

The Extended Mode Register EMR(1) stores the data for enabling or disabling the DLL, output driver strength, additive latency, OCD program, ODT, DQS and output buffers disable, RQDS and RDQS enable. The default value of the extended mode register EMR(1) is not defined, therefore the extended mode register must be written after power-up for proper operation. The extended mode register is written by asserting low on CS, RAS, CAS, WE, BA1 and high on BA0, while controlling the state of the address pins

A0 is used for DLL enable or disable. A1 is used for enabling half-strength data-output driver. A2 and A6 enables On-Die termination (ODT) and sets the RTT value. A[5:3] are used for additive latency settings and A[9:7] enables the OCD impedance adjustment mode. A10 enables or disables the differential DQS and RDQS signals, A11 disables or enables RDQS. Address bit A12 have to be set to 0 for normal operation. With A12 set to 1 the SDRAM outputs are disabled and in Hi-Z. 1 on BA0 and 0 for BA1 have to be set to access the EMRS(1). A13 and all “higher” address bits have to be set to 0 for compatibility with other DDR2 memory products with higher memory densities. Refer to Extended Mode Register Definition.

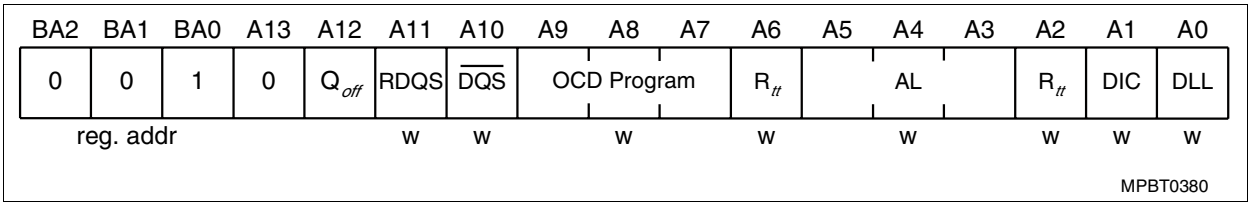


Table 7 Extended Mode Register Definition (BA[2:0] = 001B)

Field	Bits	Type[1)]	Description
BA2	16	reg. addr.	**Bank Address [2]** *Note: BA2 not available on 256 Mbit and 512 Mbit components* 0_B **BA2**, Bank Address
BA1	15		**Bank Address [1]** 0_B **BA1**, Bank Address
BA0	14		**Bank Address [0]** 0_B **BA0**, Bank Address

Table 7 Extended Mode Register Definition (BA[2:0] = 001B)

Field	Bits	Type[1)]	Description
A13	13	w	**Address Bus[13]** *Note: A13 is not available for 256 Mbit and x16 512 Mbit configuration* 0_B **A13**, Address bit 13
Qoff	12		**Output Disable** 0_B **QOff**, Output buffers enabled 1_B **QOff**, Output buffers disabled
RDQS	11		**Read Data Strobe Output (RDQS, RDQS)** 0_B **RDQS**, Disable 1_B **RDQS**, Enable
$\overline{DQS}$	10		**Complement Data Strobe (DQS Output)** 0_B **$\overline{DQS}$**, Enable 1_B **$\overline{DQS}$**, Disable
OCD Program	[9:7]		**Off-Chip Driver Calibration Program** 000_B **OCD**, OCD calibration mode exit, maintain setting 001_B **OCD**, Drive (1) 010_B **OCD**, Drive (0) 100_B **OCD**, Adjust mode 111_B **OCD**, OCD calibration default
AL	[5:3]		**Additive Latency** *Note: All other bit combinations are illegal.* 000_B **AL**, 0 001_B **AL**, 1 010_B **AL**, 2 011_B **AL**, 3 100_B **AL**, 4 101_B **AL**, 5 110_B **AL**, 6
R_{TT}	2,6		**Nominal Termination Resistance of ODT** 00_B **RTT**, ∞ (ODT disabled) 01_B **RTT**, 75 Ohm 10_B **RTT**, 150 Ohm 11_B **RTT**, 50 Ohm
DIC	1		**Off-chip Driver Impedance Control** 0_B **DIC**, Full (Driver Size = 100%) 1_B **DIC**, Reduced
DLL	0		**DLL Enable** 0_B **DLL**, Enable 1_B **DLL**, Disable

1) w = write only register bits

3.7 DLL Enable/Disable

The DLL must be enabled for normal operation. DLL enable is required during power up initialization, and upon returning to normal operation after having the DLL disabled. The DLL is automatically disabled when entering Self-Refresh operation and is automatically re-enabled and reset upon exit of Self-Refresh operation. Any time the DLL is reset, 200 clock cycles must occur before a Read command can be issued to allow time for the internal clock to be synchronized with the external clock. Failing to wait for synchronization to occur may result in a violation of the t_{AC} or t_{DQSCK} parameters.

3.8 Output Disable (Qoff)

Under normal operation, the DRAM outputs are enabled during Read operation for driving data (Qoff bit in the EMR(1) is set to 0). When the Qoff bit is set to 1, the DRAM outputs will be disabled. Disabling the DRAM outputs allows users to measure I_{DD} currents during Read operations, without including the output buffer current and external load currents.

3.9 Single-ended and Differential Data Strobe Signals

Table 8 lists all possible combinations for DQS, $\overline{\text{DQS}}$, RDQS, $\overline{\text{RQDS}}$ which can be programmed by A[11:10] address bits in EMRS. RDQS and $\overline{\text{RDQS}}$ are available in ×8 components only. If RDQS is enabled in ×8 components, the DM function is disabled. RDQS is active for reads and don't care for writes.

Table 8 Single-ended and Differential Data Strobe Signals

EMRS(1)		Strobe Function Matrix				Signaling
A11 (RDQS Enable)	**A10 ($\overline{\text{DQS}}$ Enable)**	**RDQS/DM**	**$\overline{\text{RDQS}}$**	**DQS**	**$\overline{\text{DQS}}$**	
0 (Disable)	0 (Enable)	DM	Hi-Z	DQS	$\overline{\text{DQS}}$	differential DQS signals
0 (Disable)	1 (Disable)	DM	Hi-Z	DQS	Hi-Z	single-ended DQS signals
1 (Enable)	0 (Enable)	RDQS	$\overline{\text{RDQS}}$	DQS	$\overline{\text{DQS}}$	differential DQS signals
1 (Enable)	1 (Disable)	RDQS	Hi-Z	DQS	Hi-Z	single-ended DQS signals

3.10 Extended Mode Register EMR(2)

The Extended Mode Registers EMR(2) and EMR(3) are reserved for future use and must be programmed when setting the mode register during initialization.The extended mode register EMR(2) is written by asserting LOW on $\overline{CS}$, $\overline{RAS}$, $\overline{CAS}$, $\overline{WE}$, BA0 and HIGH on BA1, while controlling the states of the address pins. The DDR2 SDRAM should be in all bank precharge with CKE already high prior to writing into the extended mode register. The mode register set command cycle time (t_{MRD}) must be satisfied to complete the write operation to the EMR(2). Mode register contents can be changed using the same command and clock cycle requirements during normal operation as long as all banks are in precharge state.

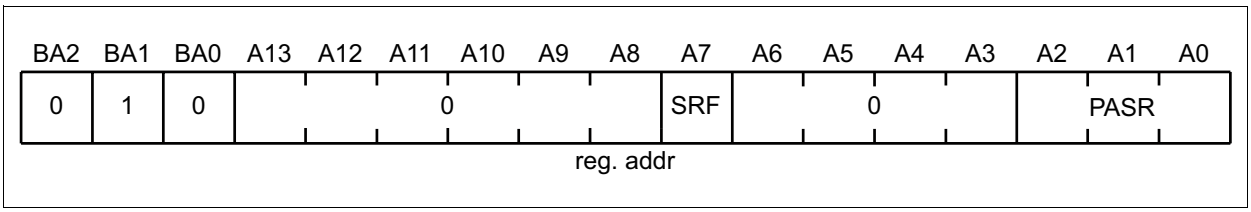


Table 9 EMRS(2) Programming Extended Mode register Definition (BA[2:0]=010_B)

Field	Bits	Type[1)]	Description
BA2	16	w	**Bank Address[2]** *Note: BA2 is not available on 256Mbit and 512Mbit components* 0_B **BA2**, Bank Address
BA	[15:14]	w	**Bank Adress[15:14]** 00_B **BA**, MRS 01_B **BA**, EMRS(1) 10_B **BA**, EMRS(2) 11_B **BA**, EMRS(3): Reserved
A	[13:7]	w	**Address Bus[13:0]** *Note: A13 is not available for 256 Mbit and x16 512 Mbit configuration* 0_B **A[13:0]**, Address bits
A	7	w	**Address Bus[7]** *Note: adapted self refresh rate for Tcase > 85°C* 0_B **A7**, disable 1_B **A7**, enable [2)3)]
A	[6:3]	w	**Address Bus[6:0]** 0_B **A[6:0]**, Address bits
Partial Self Refresh for 4 banks			
A	[2:0]	w	**Address Bus[2:0], Partial Array Self Refresh for 4 Banks** 000_B **PASR0**, Full Array 001_B **PASR1**, Half Array (BA[1:0]=00, 01) 010_B **PASR2**, Quarter Array (BA[1:0]=00) 011_B **PASR3**, Not defined 100_B **PASR4**, 3/4 array (BA[1:0]=01, 10, 11) 101_B **PASR5**, Half array (BA[1:0]=10, 11) 110_B **PASR6**, Quarter array (BA[1:0]=11) 111_B **PASR7**, Not defined

1) w = write only

2) When DRAM is operated at 85C ≤ T_{Case} ≤ 95C the extended self refresh rate must be enabled by setting bit A7 to "1" before the self refresh mode can be entered.
3) If PASR (Partial Array Self Refresh) is enabled, data located in areas of the array beyond the specified location will be lost if self refresh is entered. Data integrity will be maintained if tREF conditions are met and no Self Refresh command is issued

3.11 Extended Mode Register EMR(3)

The Extended Mode Register EMR(3) is reserved for future use and all bits except BA0 and BA1 must be programmed to 0 when setting the mode register during initialization. The EMRS(3) is written by asserting low on CS, RAS, CAS, WE, BA2 and high on BA0 and BA1, while controlling the state of the address pins.

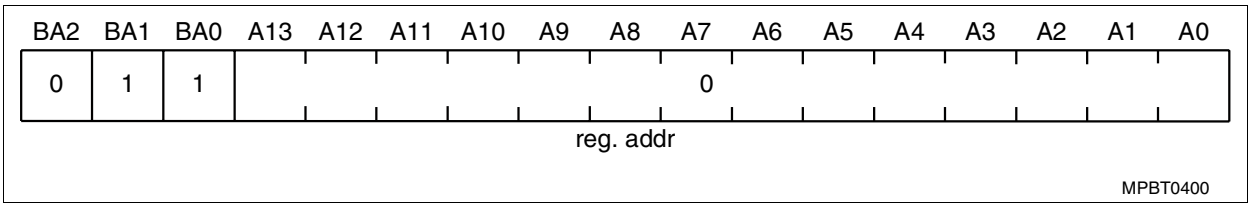


Table 10 EMR(3) Programming Extended Mode Register Definition (BA[2:0]=010$_B$)

Field	Bits	Type[1)]	Description
BA2	16	w	**Bank Address[2]** *Note: BA2 is not available on 256Mbit and 512Mbit components* 0_B **BA2**, Bank Address
BA1	15		**Bank Adress[1]** 1_B **BA1**, Bank Address
BA0	14		**Bank Adress[0]** 1_B **BA0**, Bank Address
A	[13:0]	w	**Address Bus[13:0]** *Note: A13 is not available for 256 Mbit and x16 512 Mbit configuration* 0_B **A[13:0]**, Address bits

1) w = write only

3.12 Off-Chip Driver (OCD) Impedance Adjustment

DDR2 SDRAM supports driver calibration feature and the flow chart below is an example of the sequence. Every calibration mode command should be followed by “OCD calibration mode exit” before any other command being issued. MRS should be set before entering OCD impedance adjustment and On Die Termination (ODT) should be carefully controlled depending on system environment.

OCD Impedance Adjustment Flow Chart

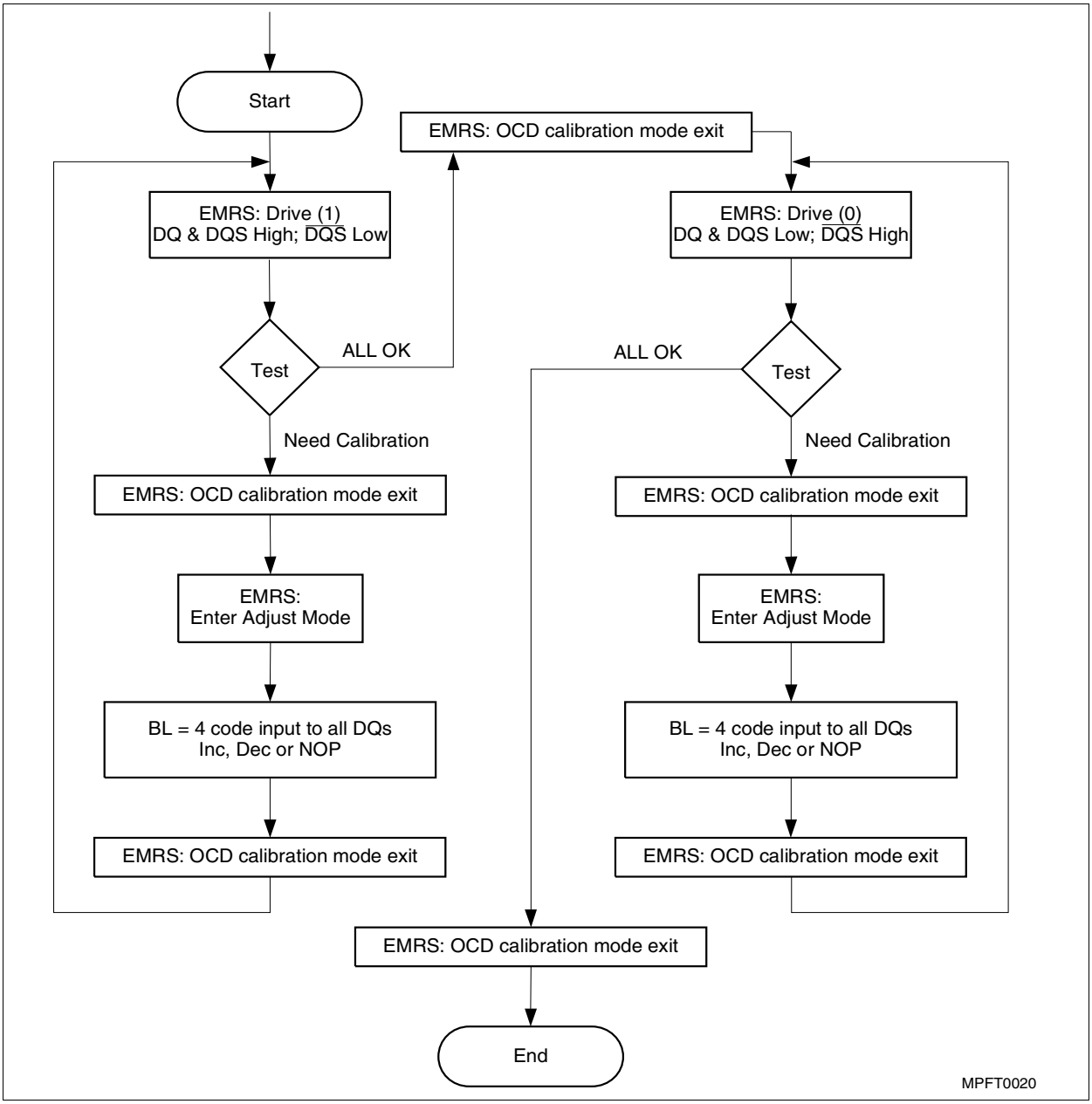


Figure 5 OCD Impedance Adjustment Flow Chart

Note: MR should be set before entering OCD impedance adjustment and ODT should be carefully controlled depending on system environment

Extended Mode Register Set for OCD impedance adjustment

OCD impedance adjustment can be done using the following EMRS(1) mode. In drive mode all outputs are driven out by DDR2 SDRAM and drive of RDQS is dependent on EMR(1) bit enabling RDQS operation. In Drive(1)mode, all DQ, DQS (and RDQS) signals are driven HIGH and all DQS (and RDQS) signals are driven LOW. In Drive(0) mode, all DQ, DQS (and RDQS) signals are driven LOW and all DQS (and RDQS) signals are driven HIGH. In adjust mode, BL = 4 of operation code data must be used. In case of OCD calibration default, output driver characteristics have a nominal impedance value of 18 Ohms during nominal temperature and voltage conditions. Output driver characteristics for OCD calibration default are specified in the following table. OCD applies only to normal full strength output drive setting defined by EMR(1) and if half strength is set, OCD default driver characteristics are not applicable. When OCD calibration adjust mode is used, OCD default output driver characteristics are not applicable. After OCD calibration is completed or driver strength is set to default, subsequent EMRS(1) commands not intended to adjust OCD characteristics must specify A[9:7] as'000' in order to maintain the default or calibrated value.

Table 11 Off Chip Driver Program

A9	A8	A7	Operation
0	0	0	OCD calibration mode exit
0	0	1	Drive(1) DQ, DQS, (RDQS) high and DQS ($\overline{\text{RDQS}}$) low
0	1	0	Drive(0) DQ, DQS, (RDQS) low and $\overline{\text{DQS}}$ ($\overline{\text{RDQS}}$) high
1	0	0	Adjust mode
1	1	1	OCD calibration default

OCD impedance adjust

To adjust output driver impedance, controllers must issue the ADJUST EMRS(1) command along with a 4 bit burst code to DDR2 SDRAM as in the following table. For this operation, Burst Length has to be set to BL = 4 via MRS command before activating OCD and controllers must drive the burst code to all DQs at the same time. DT0 in the table means all DQ bits at bit time 0, DT1 at bit time 1, and so forth. The driver output impedance is adjusted for all DDR2 SDRAM DQs simultaneously and after OCD calibration, all DQs of a given DDR2 SDRAM will be adjusted to the same driver strength setting. The maximum step count for adjustment is 16 and when the limit is reached, further increment or decrement code has no effect. The default setting may be any step within the maximum step count range. When Adjust mode command is issued, AL from previously set value must be applied.

For proper operation of adjust mode, WL = RL - 1 = AL + CL - 1 clocks and t_{DS} / t_{DH} should be met as shown in **Figure 6**. Input data pattern for adjustment, DT[0:3] is fixed and not affected by MRS addressing mode (i.e. sequential or interleave). Burst length of 4 have to be programmed in the MRS for OCD impedance adjustment.

Table 12 Off-Chip-Driver Adjust Program

4 bit burst code inputs to all DQs				Operation	
DT0	DT1	DT2	DT3	Pull-up driver strength	Pull-down driver strength
0	0	0	0	NOP (no operation)	NOP (no operation)
0	0	0	1	Increase by 1 step	NOP
0	0	1	0	Decrease by 1 step	NOP
0	1	0	0	NOP	Increase by 1 step
1	0	0	0	NOP	Decrease by 1 step
0	1	0	1	Increase by 1 step	Increase by 1 step
0	1	1	0	Decrease by 1 step	Increase by 1 step
1	0	0	1	Increase by 1 step	Decrease by 1 step

Table 12 Off-Chip-Driver Adjust Program

4 bit burst code inputs to all DQs				Operation	
DT0	DT1	DT2	DT3	Pull-up driver strength	Pull-down driver strength
1	0	1	0	Decrease by 1 step	Decrease by 1 step
Other Combinations				Illegal	

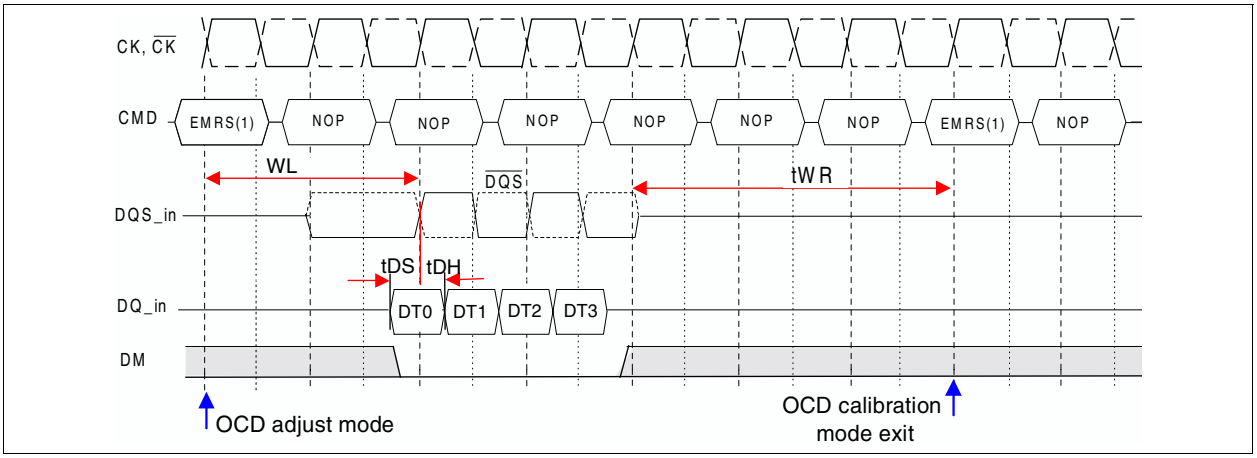


Figure 6 Timing Diagram Adjust Mode

Drive Mode

Both Drive(1) and Drive(0) are used for controllers to measure DDR2 SDRAM Driver impedance before OCD impedance adjustment. In this mode, all outputs are driven out t_{OIT} after “enter drive mode” command and all output drivers are turned-off t_{OIT} after “OCD calibration mode exit” command. See **Figure 7**.

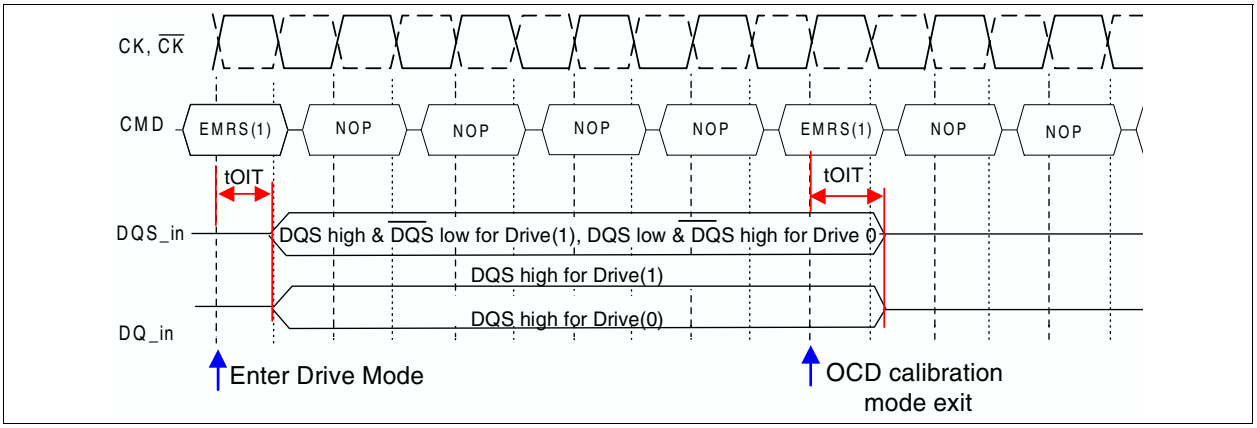


Figure 7 Timing Diagram Drive Mode

3.13 On-Die Termination (ODT)

On-Die Termination (ODT) is a new feature on DDR2 components that allows a DRAM to turn on/off termination resistance. DQS and RDQS are only terminated when enabled by EMR(1).

For ×16 configuration ODT is applied to each DQ, UDQS, UDQS, LDQS, LDQS, UDM and LDM signal via the ODT control pin. UDQS and LDQS are terminated only when enabled in the EMRS(1) by address bit A10 = 0.

The ODT feature is designed to improve signal integrity of the memory channel by allowing the DRAM controller to independently turn on/off termination resistance for any or all DRAM devices. The ODT function can be used for all active and standby modes. ODT is turned off and not supported in Self-Refresh mode.

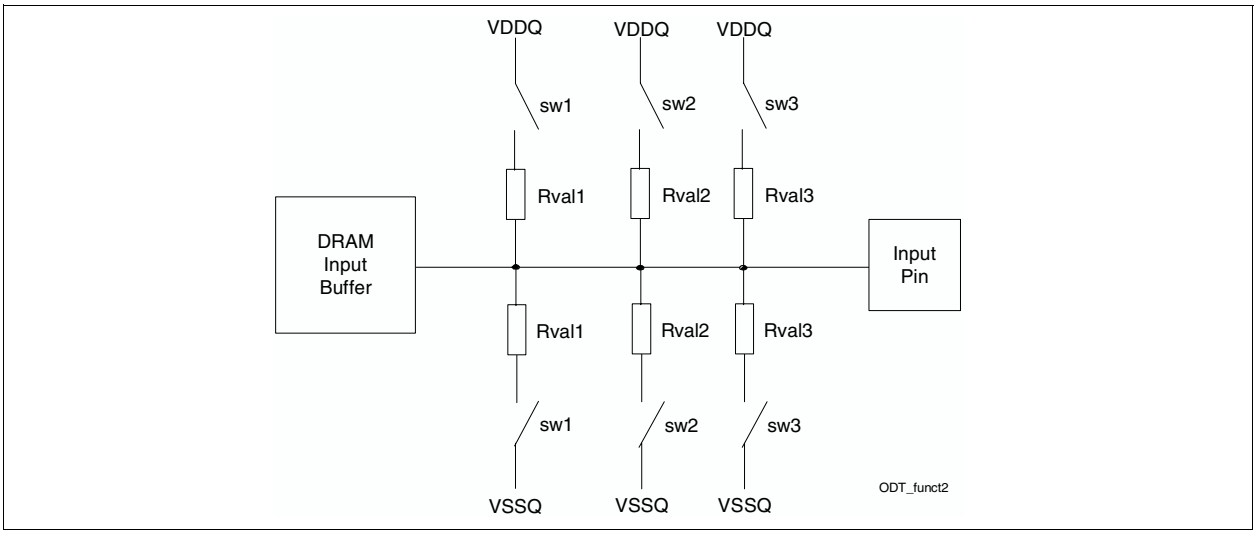


Figure 8 Functional Representation of ODT

Switch sw1, sw2 or sw3 are enabled by the ODT pin. Selection between sw1, sw2 or sw3 is determined by “RTT (nominal)” in EMRS(1) address bits A6 & A2.

Target: Rval1 = Rval2 = Rval3 = 2 × RTT

The ODT pin will be ignored if the Extended Mode Register (EMRS(1)) is programmed to disable ODT.

ODT Truth Tables

The ODT Truth Table shows which of the input pins are terminated depending on the state of address bit A10 and A11 in the EMRS(1) for the device organization (×16). To activate termination of any of these pins, the ODT function has to be enabled in the EMRS(1) by address bits A6 and A2.

Table 13 ODT Truth Table

Input Pin	EMRS(1) Address Bit A10	EMRS(1) Address Bit A11
x16 components		
DQ[7:0]	X	
DQ[15:8]	X	
LDQS	X	
$\overline{\text{LDQS}}$	0	X
UDQS	X	
$\overline{\text{UDQS}}$	0	X
LDM	X	
UDM	X	

Note: X = don't care; 0 = bit set to low; 1 = bit set to high

ODT timing modes

Depending on the operating mode asynchronous or synchronous ODT timings apply.

Asynchronous ODT timings (t_{AOFPD}, t_{AONPD}) apply when the on-die DLL is disabled.

These modes are:

- Slow Exit Active Power Down Mode (with MRS bit A12 is set to “1”)
- Precharge Power Down Mode

Synchronous ODT timings (t_{AOND}, t_{AOFD}, t_{AON}, t_{AOF}) apply for all other modes.

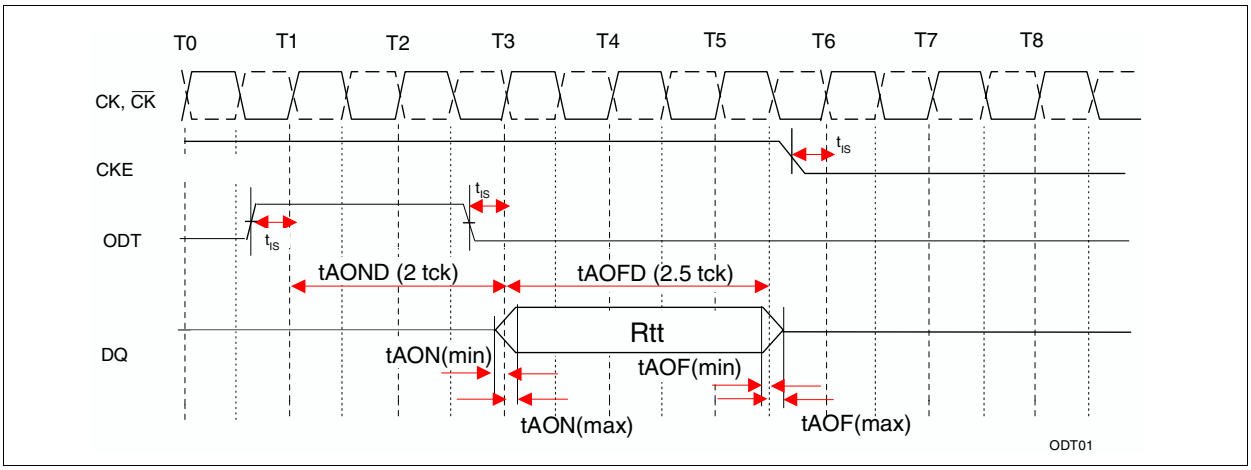


Figure 9 ODT Timing for Active and Standby (Idle) Modes (Synchronous ODT timings)

Note:

1. Synchronous ODT timings apply for Active Mode and Standby Mode with CKE HIGH and for the “Fast Exit” Active Power Down Mode (MRS bit A12 set to “0”). In all these modes the on-die DLL is enabled.
2. ODT turn-on time ($t_{AON.MIN}$) is when the device leaves high impedance and ODT resistance begins to turn on. ODT turn on time max. ($t_{AON.MAX}$) is when the ODT resistance is fully on. Both are measured from t_{AOND}.
3. ODT turn off time min. ($t_{AOF.MIN}$) is when the device starts to turn off the ODT resistance.ODT turn off time max. ($t_{AOF.MAX}$) is when the bus is in high impedance. Both are measured from t_{AOFD}.

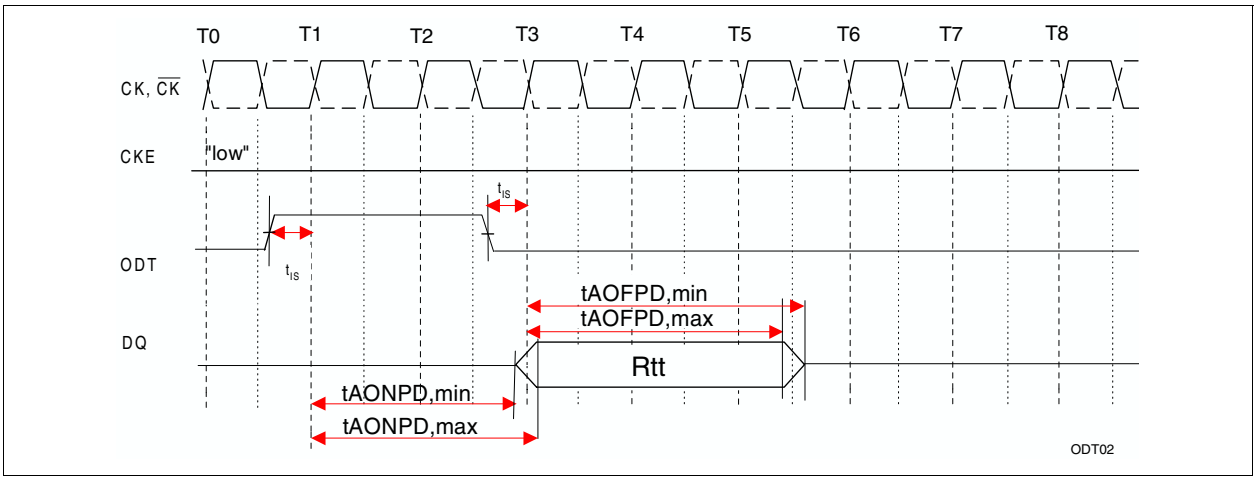


Figure 10 ODT Timing for Precharge Power-Down and Active Power-Down Mode

Note: Asynchronous ODT timings apply for Precharge Power-Down Mode and "Slow Exit" Active Power Down Mode (MRS bit A12 set to "1"), where the on-die DLL is disabled in this mode of operation.

ODT timing mode switch

When entering the Power Down Modes "Slow Exit" Active Power Down and Precharge Power Down two additional timing parameters (t_{ANPD} and t_{AXPD}) define if synchronous or asynchronous ODT timings have to be applied.

Mode entry

As long as the timing parameter $t_{ANPD.MIN}$ is satisfied when ODT is turned on or off before entering these power-down modes, synchronous timing parameters can be applied. If $t_{ANPD.MIN}$ is not satisfied, asynchronous timing parameters apply.

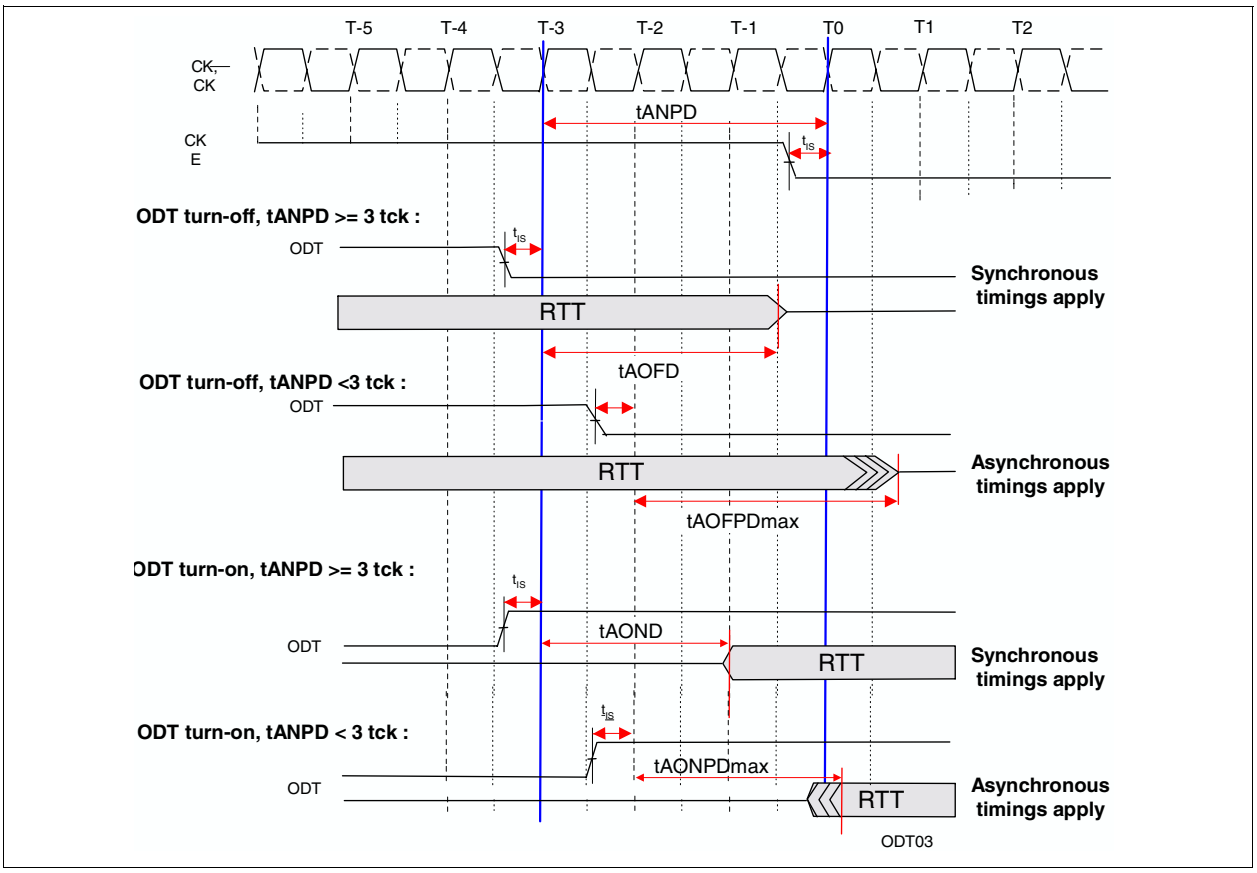


Figure 11 ODT Mode Entry Timing Diagram

Mode exit

As long as the timing parameter $t_{AXPD.MIN}$ is satisfied when ODT is turned on or off after exiting these power-down modes, synchronous timing parameters can be applied. If $t_{AXPD.MIN}$ is not satisfied, asynchronous timing parameters apply.

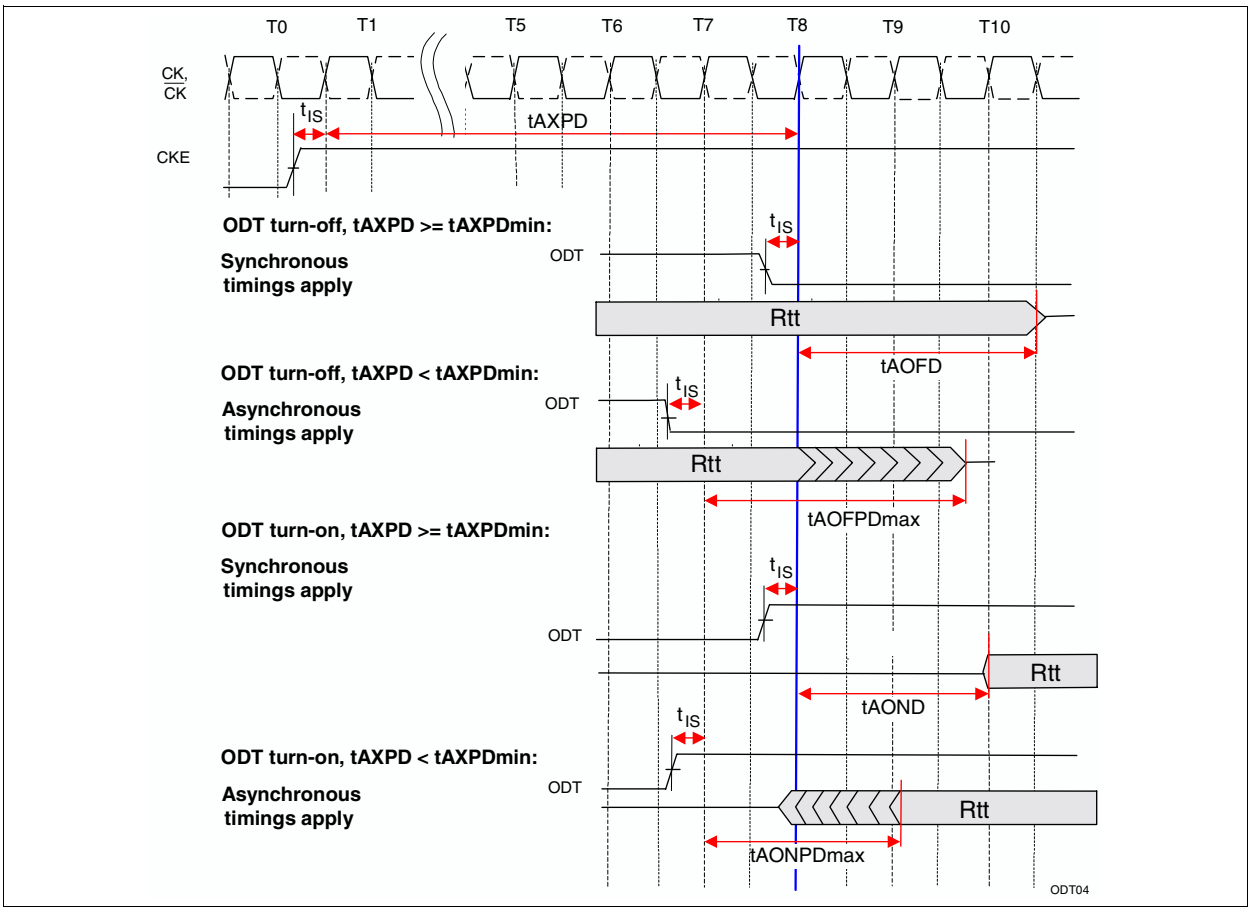


Figure 12 ODT Mode Exit Timing Diagram

3.14 Bank Activate Command

The Bank Activate command is issued by holding $\overline{CAS}$ and $\overline{WE}$ HIGH with $\overline{CS}$ and $\overline{RAS}$ LOW at the rising edge of the clock. The bank addresses BA[1:0] are used to select the desired bank. For ×16 components row addresses A0 through A12 have to be applied. The Bank Activate command must be applied before any Read or Write operation can be executed. Immediately after the bank active command, the DDR2 SDRAM can accept a read or write command (with or without Auto-Precharge) on the following clock cycle. If a R/W command is issued to a bank that has not satisfied the $t_{RCD.MIN}$ specification, then additive latency must be programmed into the device to delay the R/W command which is internally issued to the device. The additive latency value must be chosen to assure $t_{RCD.MIN}$ is satisfied. Additive latencies of 0, 1, 2, 3, 4 and 5 are supported. Once a bank has been activated it must be precharged before another Bank Activate command can be applied to the same bank. The bank active and precharge times are defined as t_{RAS} and t_{RP}, respectively. The minimum time interval between successive Bank Activate commands to the same bank is determined by t_{RC}. The minimum time interval between Bank Active commands to different banks is t_{RRD}.

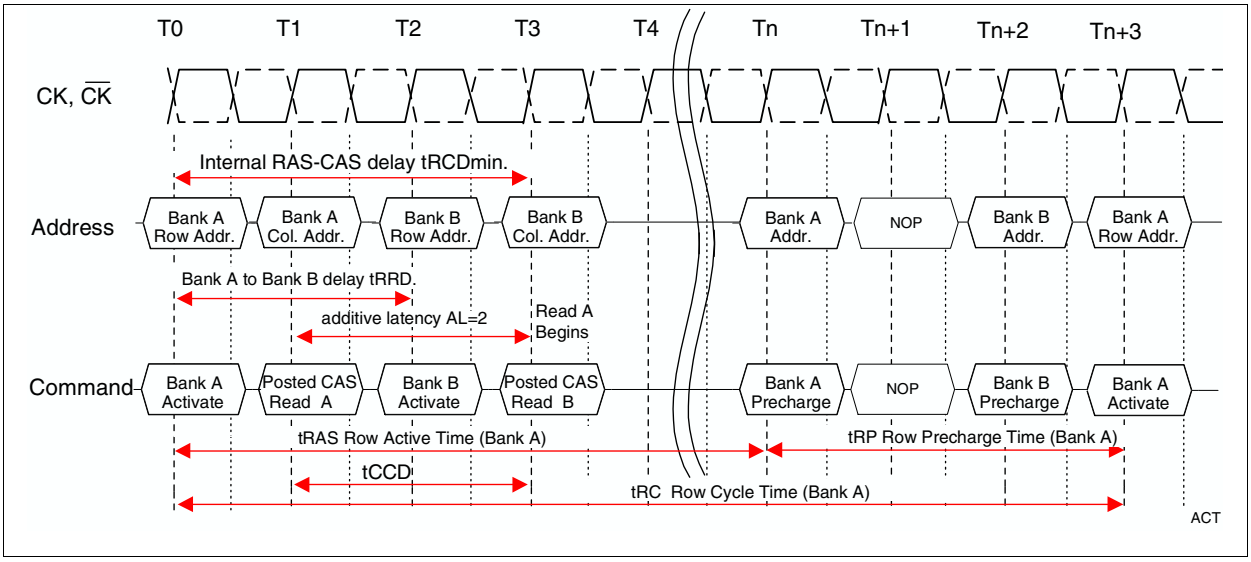


Figure 13 Bank Activate Command Cycle

t_{RCD} = 3, AL = 2, t_{RP} = 3, t_{RRD} = 2

3.15 Read and Write Commands and Access Modes

After a bank has been activated, a read or write cycle can be executed. This is accomplished by setting RAS HIGH, CS and CAS LOW at the clock's rising edge. WE must also be defined at this time to determine whether the access cycle is a read operation (WE HIGH) or a write operation (WE LOW). The DDR2 SDRAM provides a wide variety of fast access modes. A single Read or Write Command will initiate a serial read or write operation on successive clock cycles at data rates of up to 533 Mb/sec/pin for main memory. The boundary of the burst cycle is restricted to specific segments of the page length. For example, the 32 Mbit × 4 I/O × 4 Bank chip has a page length of 2048 bits (defined by CA[11, 9:0]). In case of a 4-bit burst operation (burst length = 4) the page length of 2048 is divided into 512 uniquely addressable segments (4-bits × I/O each). The 4-bit burst operation will occur entirely within one of the 512 segments (defined by CA[8:0]) starting with the column address supplied to the device during the Read or Write Command (CA[11, 9:0]). The second, third and fourth access will also occur within this segment, however, the burst order is a function of the starting address, and the burst sequence.In case of a 8-bit burst operation (burst length = 8) the page length of 2048 is divided into 256 uniquely addressable segments (8-bits × 4 I/O each). The 8-bit burst operation will occur entirely within one of the 256 segments (defined by CA[7:0]) beginning with the column address supplied to the device during the Read or Write Command (CA[11, 9:0]).A new burst access must not interrupt the previous 4 bit burst operation in case of BL = 4 setting. Therefore the minimum CAS to CAS delay (t_{CCD}) is a minimum of 2 clocks for read or write cycles.For 8 bit burst operation (BL = 8) the minimum CAS to CAS delay (t_{CCD}) is 4 clocks for read or write cycles.Burst interruption is allowed with 8 bit burst operation. For details see Chapter 3.20.

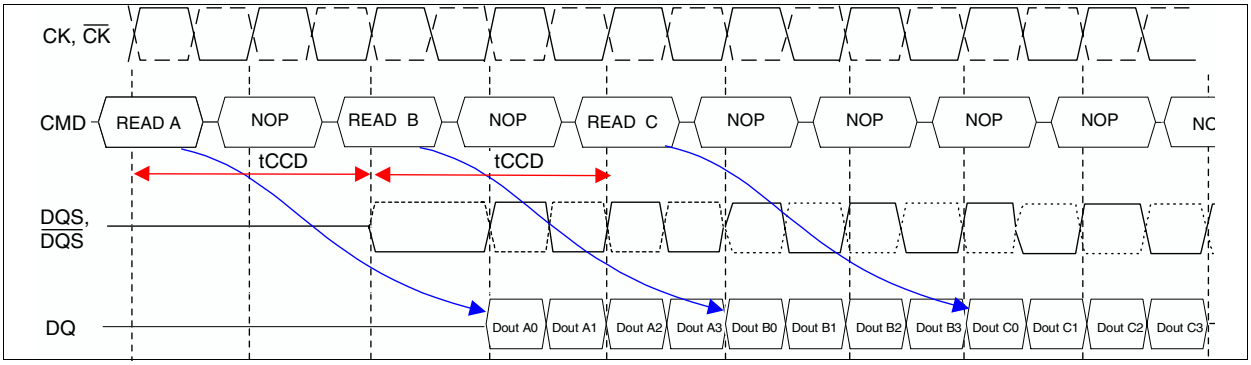


Figure 14 Read Timing Example

CL = 3, AL = 0, RL = 3, BL = 4

3.16 Posted $\overline{\text{CAS}}$

Posted $\overline{\text{CAS}}$ operation is supported to make command and data bus efficient for sustainable bandwidths in DDR2 SDRAM. In this operation, the DDR2 SDRAM allows a Read or Write command to be issued immediately after the bank activate command (or any time during the $\overline{\text{RAS}}$ to $\overline{\text{CAS}}$ delay time, t_{RCD} period). The command is held for the time of the Additive Latency (AL) before it is issued inside the device. The Read Latency (RL) is the sum of AL and the $\overline{\text{CAS}}$ latency (CL). Therefore if a user chooses to issue a Read/Write command before the $t_{RCD.MIN}$, then AL greater than 0 must be written into the EMR(1). The Write Latency (WL) is always defined as RL - 1 (Read Latency -1) where Read Latency is defined as the sum of Additive Latency plus $\overline{\text{CAS}}$ latency (RL=AL+CL). If a user chooses to issue a Read command after the $t_{RCD.MIN}$ period, the Read Latency is also defined as RL = AL + CL.

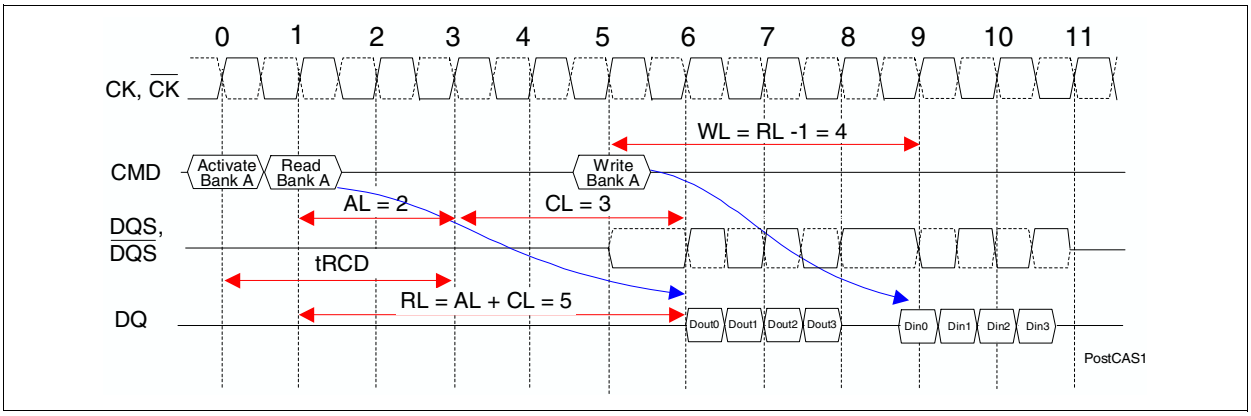


Figure 15 Activate to Read Timing Example: Read followed by a write to the same bank

Activate to Read delay < $t_{RCD.MIN}$: AL = 2 and CL = 3, RL = (AL + CL) = 5, WL = (RL -1) = 4, BL = 4

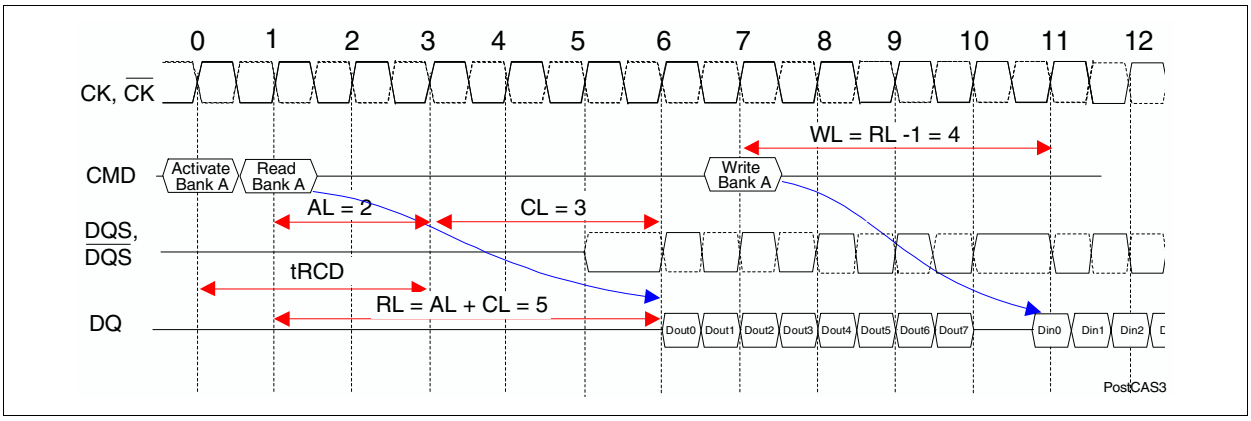


Figure 16 Read to Write Timing Example: Read followed by a write to the same bank

Activate to Read delay < $t_{RCD.MIN}$: AL = 2 and CL = 3, RL = (AL + CL) = 5, WL = (RL -1) = 4, BL = 8

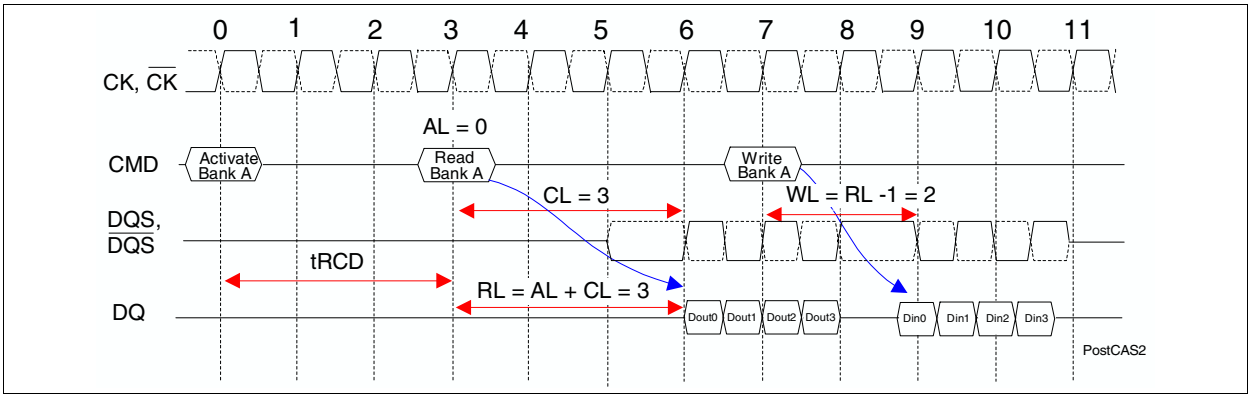


Figure 17 Read to Write Timing Example: Read followed by a write to the same bank

Activate to Read delay = $t_{RCD.MIN}$: AL = 0, CL = 3, RL = (AL + CL) = 3, WL = (RL -1) = 2, BL = 4

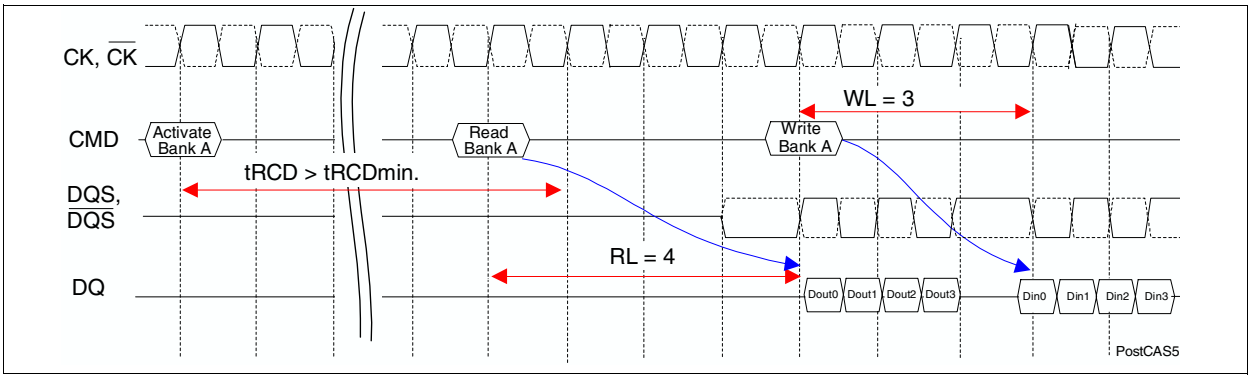


Figure 18 Read to Write Timing Example: Read followed by a write to the same bank

Activate to Read delay > $t_{RCD.MIN}$: AL = 1, CL = 3, RL = 4, WL = 3, BL = 4

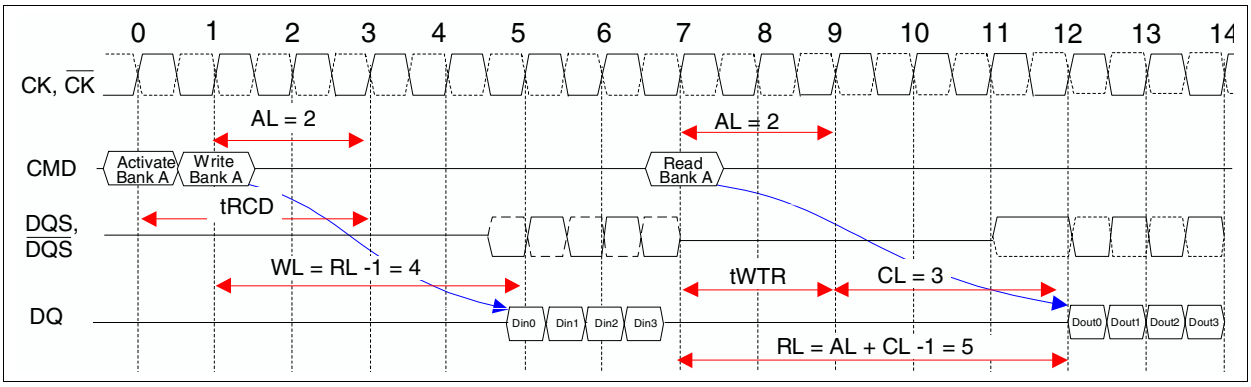


Figure 19 Write to Read Timing Example: Write followed by a read to the same bank

AL = 2, CL = 3, RL = 5, WL = 4, t_{WTR} = 2, BL = 4

3.17 Burst Mode Operation

Burst mode operation is used to provide a constant flow of data to memory locations (write cycle), or from memory locations (read cycle). The parameters that define how the burst mode will operate are burst sequence and burst length. The DDR2 SDRAM supports 4 bit and 8 bit burst modes only. For 8 bit burst mode, full interleave address ordering is supported, however, sequential address ordering is nibble based for ease of implementation. The burst length is programmable and defined by the addresses A[2:0] of the MR. The burst type, either sequential or interleaved, is programmable and defined by the address bit 3 (A3) of the MR. Seamless burst read or write operations are supported. Interruption of a burst read or write operation is prohibited, when burst length = 4 is programmed. For burst interruption of a read or write burst when burst length = 8 is used, see **Chapter 3.21**. A Burst Stop command is not supported on DDR2 SDRAM devices.

Table 14 Burst Length and Sequence

Burst Length	Starting Address (A2 A1 A0)	Sequential Addressing (decimal)	Interleave Addressing (decimal)
4	x 0 0	0, 1, 2, 3	0, 1, 2, 3
	x 0 1	1, 2, 3, 0	1, 0, 3, 2
	x 1 0	2, 3, 0, 1	2, 3, 0, 1
	x 1 1	3, 0, 1, 2	3, 2, 1, 0
8	0 0 0	0, 1, 2, 3, 4, 5, 6, 7	0, 1, 2, 3, 4, 5, 6, 7
	0 0 1	1, 2, 3, 0, 5, 6, 7, 4	1, 0, 3, 2, 5, 4, 7, 6
	0 1 0	2, 3, 0, 1, 6, 7, 4, 5	2, 3, 0, 1, 6, 7, 4, 5
	0 1 1	3, 0, 1, 2, 7, 4, 5, 6	3, 2, 1, 0, 7, 6, 5, 4
	1 0 0	4, 5, 6, 7, 0, 1, 2, 3	4, 5, 6, 7, 0, 1, 2, 3
	1 0 1	5, 6, 7, 4, 1, 2, 3, 0	5, 4, 7, 6, 1, 0, 3, 2
	1 1 0	6, 7, 4, 5, 2, 3, 0, 1	6, 7, 4, 5, 2, 3, 0, 1
	1 1 1	7, 4, 5, 6, 3, 0, 1, 2	7, 6, 5, 4, 3, 2, 1, 0

Notes

1. *PageSize and Length is a function of I/O organization:*
   128Mb x 4 organization (CA[9:0], CA11); Page Size = 1 kByte; Page Length = 2048
   64Mb x 8 organization (CA[9:0]); Page Size = 1 kByte; Page Length = 1024
   32Mb x 16 organization (CA[9:0]); Page Size = 2 kByte; Page Length = 1024
2. *Order of burst access for sequential addressing is "nibble-based" and therefore different from SDR or DDR components*

3.18 Read Command

The Read command is initiated by having $\overline{CS}$ and $\overline{CAS}$ LOW while holding $\overline{RAS}$ and $\overline{WE}$ HIGH at the rising edge of the clock. The address inputs determine the starting column address for the burst. The delay from the start of the command until the data from the first cell appears on the outputs is equal to the value of the read latency (RL). The data strobe output (DQS) is driven LOW one clock cycle before valid data (DQ) is driven onto the data bus. The first bit of the burst is synchronized with the rising edge of the data strobe (DQS). Each subsequent data-out appears on the DQ pin in phase with the DQS signal in a source synchronous manner. The RL is equal to an additive latency (AL) plus $\overline{CAS}$ latency (CL). The CL is defined by the Mode Register Set (MRS). The AL is defined by the Extended Mode Register Set (EMRS(1)).

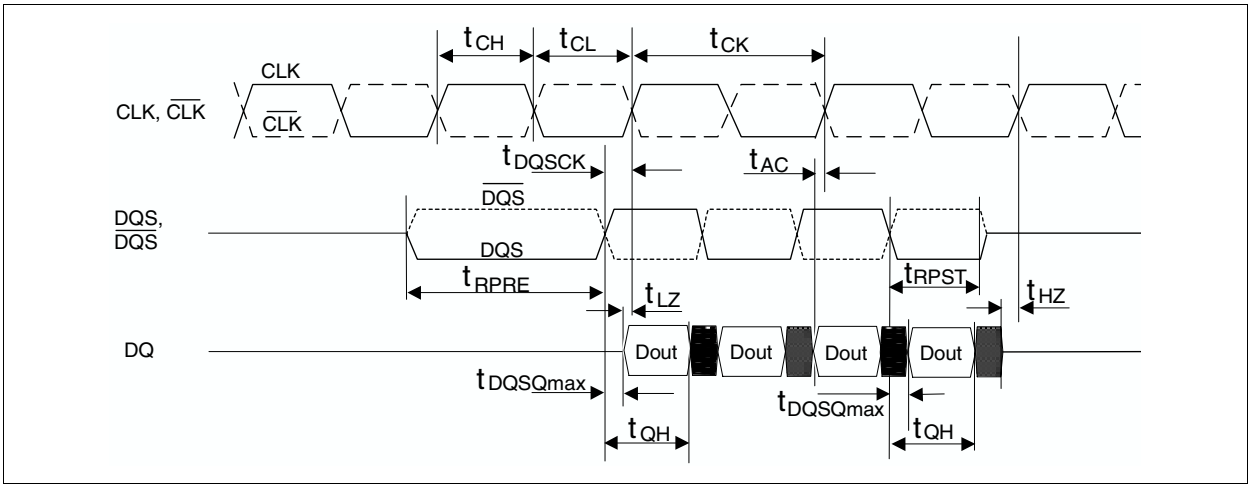


Figure 20 Basic Read Timing Diagram

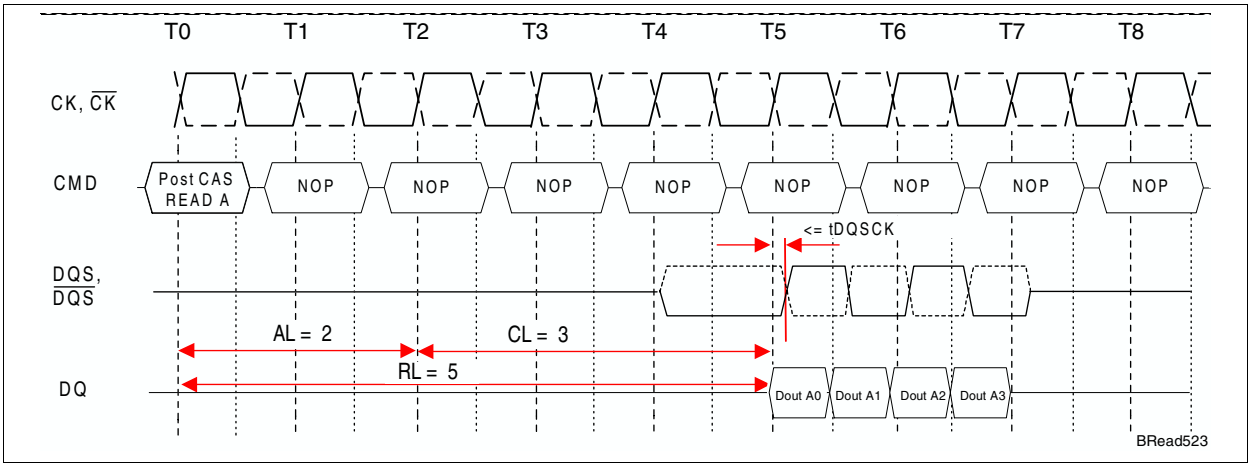


Figure 21 Read Operation Example 1

RL = 5 (AL = 2, CL = 3, BL = 4)

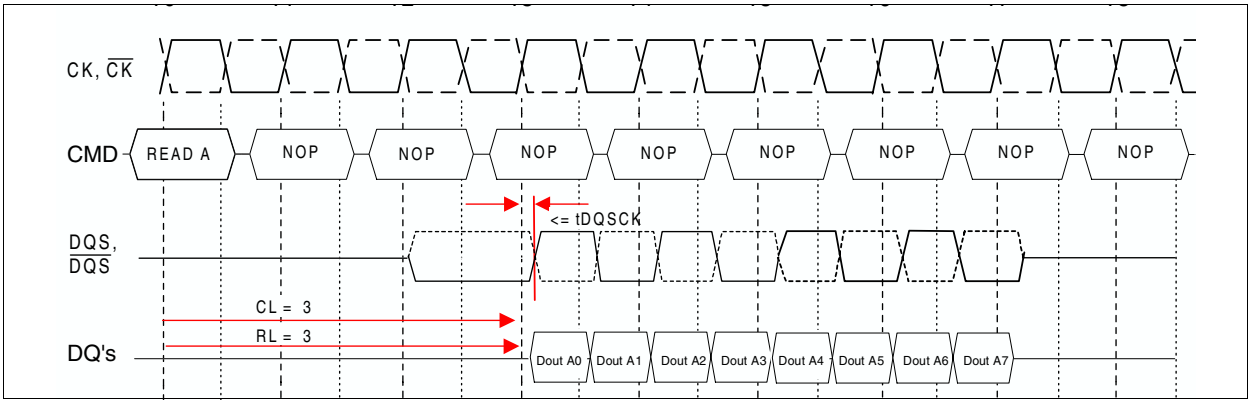


Figure 22 Read Operation Example 2

RL = 3 (AL = 0, CL = 3, BL = 8)

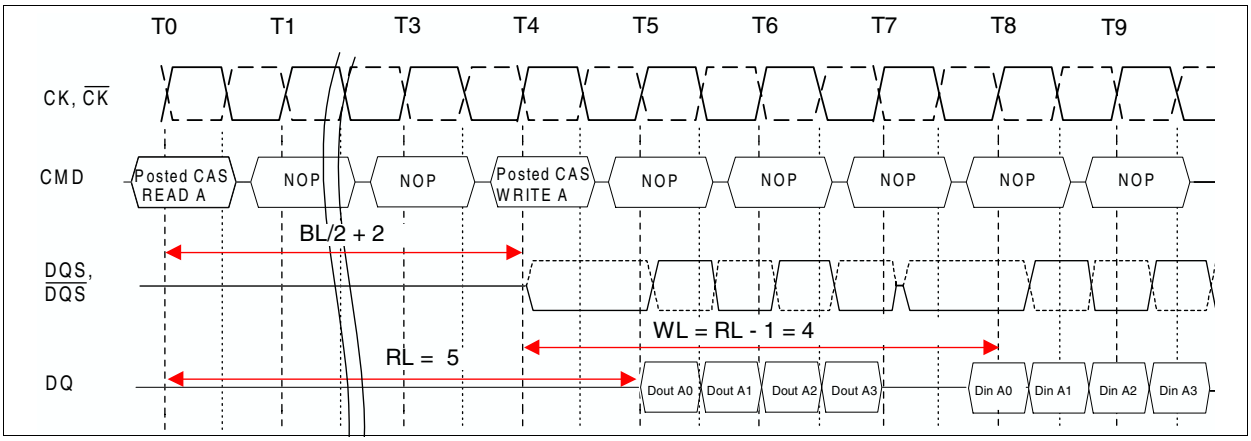


Figure 23 Read followed by Write Example

RL = 5, WL = (RL-1) = 4, BL = 4

The minimum time from the read command to the write command is defined by a read-to-write turn-around time, which is BL/2 + 2 clocks.

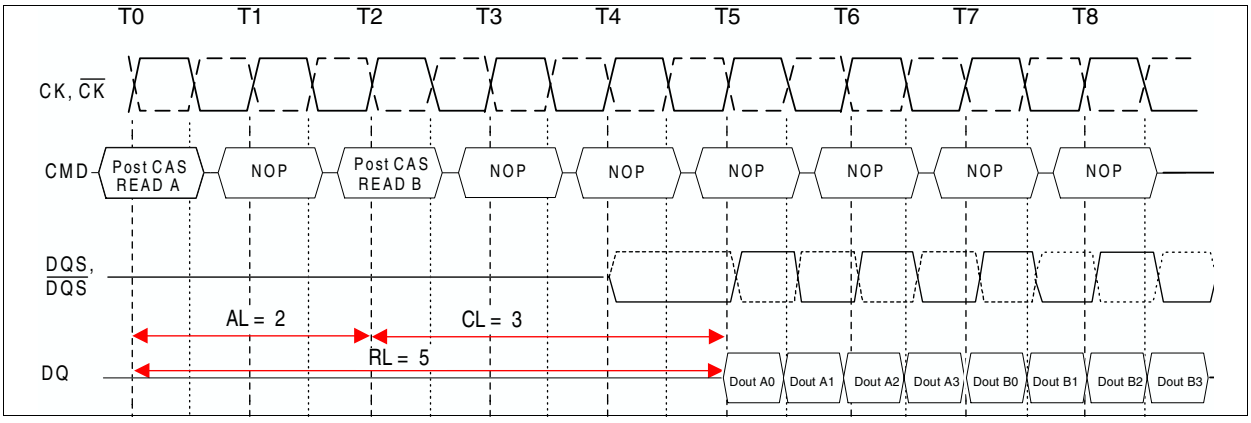


Figure 24 Seamless Read Operation Example 1

RL = 5, AL = 2, CL = 3, BL = 4

The seamless read operation is supported by enabling a read command at every BL / 2 number of clocks. This operation is allowed regardless of same or different banks as long as the banks are activated.

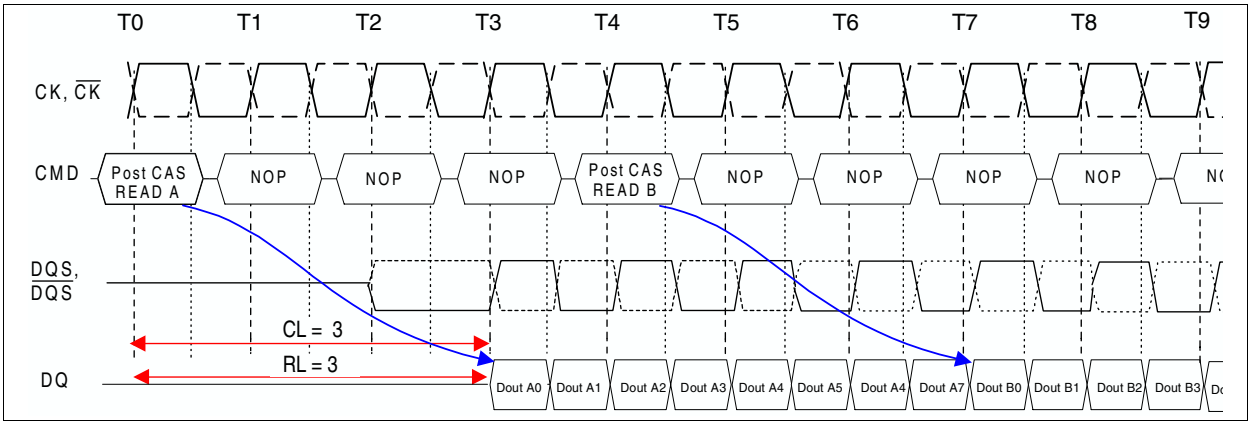


Figure 25 Seamless Read Operation Example 2

RL = 3, AL = 0, CL = 3, BL = 8 (non interrupting)

The seamless, non interrupting 8-bit read operation is supported by enabling a read command at every BL/2 number of clocks. This operation is allowed regardless of same or different banks as long as the banks are activated.

3.19 Write Command

The Write command is initiated by having $\overline{CS}$, $\overline{CAS}$ and $\overline{WE}$ LOW while holding $\overline{RAS}$ HIGH at the rising edge of the clock. The address inputs determine the starting column address. Write latency (WL) is defined by a read latency (RL) minus one and is equal to (AL + CL – 1). A data strobe signal (DQS) has to be driven LOW (preamble) a time t_{WPRE} prior to the WL. The first data bit of the burst cycle must be applied to the DQ pins at the first rising edge of the DQS following the preamble. The t_{DQSS} specification must be satisfied for write cycles. The subsequent burst bit data are issued on successive edges of the DQS until the burst length is completed. When the burst has finished, any additional data supplied to the DQ pins will be ignored. The DQ signal is ignored after the burst write operation is complete. The time from the completion of the burst write to bank precharge is named “write recovery time” (t_{WR}) and is the time needed to store the write data into the memory array. t_{WR} is an analog timing parameter (see **Chapter 5**) and is not the programmed value for WR in the MRS.

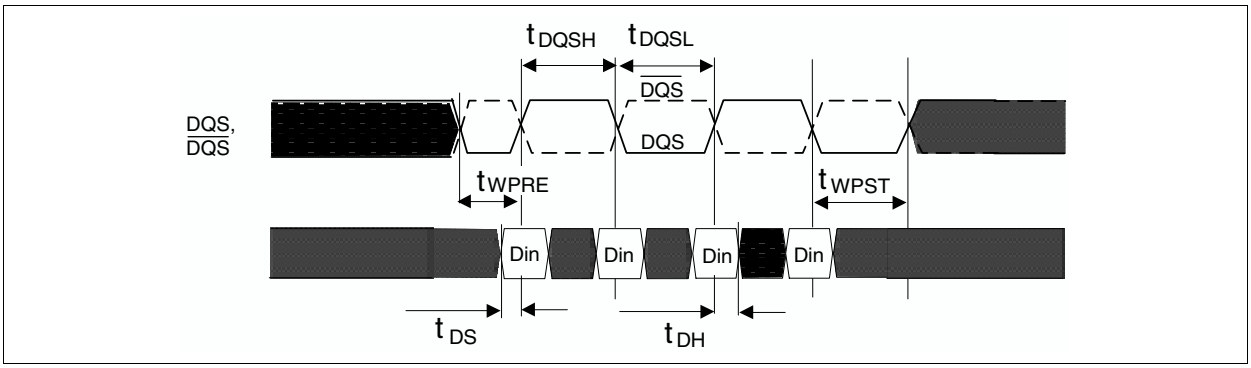


Figure 26 Basic Write Timing

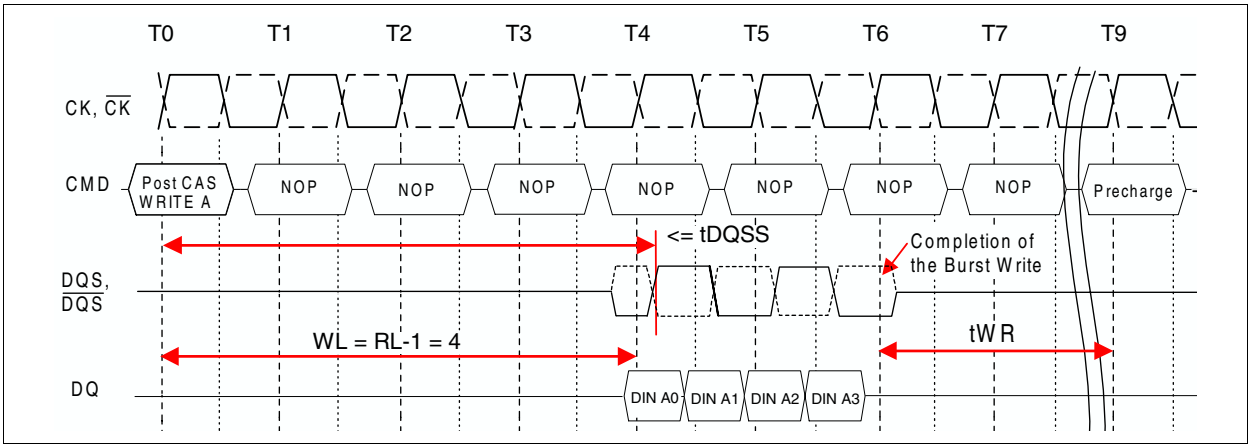


Figure 27 Write Operation Example 1

RL = 5 (AL = 2, CL = 3), WL = 4, BL = 4

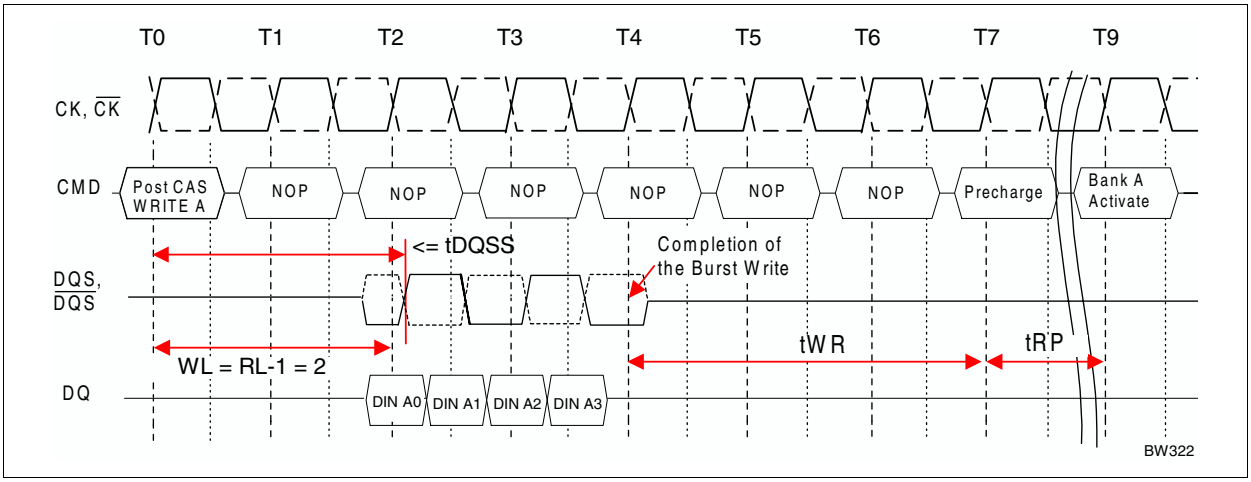


Figure 28 Write Operation Example 2

RL = 3 (AL = 0, CL = 3), WL = 2, BL = 4

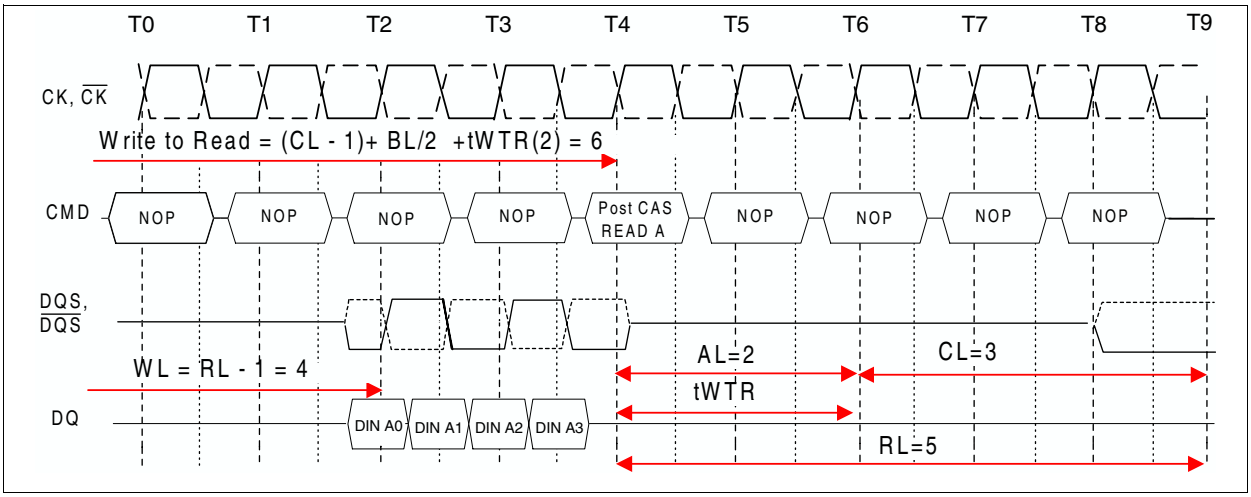


Figure 29 Write followed by Read Example

RL = 7 (AL = 2, CL = 5), WL = 6, t_{WTR} = 2, BL = 4

The minimum number of clocks from the write command to the read command is (CL - 1) +BL/2 + t_{WTR}, where t_{WTR} is the write-to-read turn-around time t_{WTR} expressed in clock cycles. The t_{WTR} is not a write recovery time (t_{WR}) but the time required to transfer 4 bit write data from the input buffer into sense amplifiers in the array.

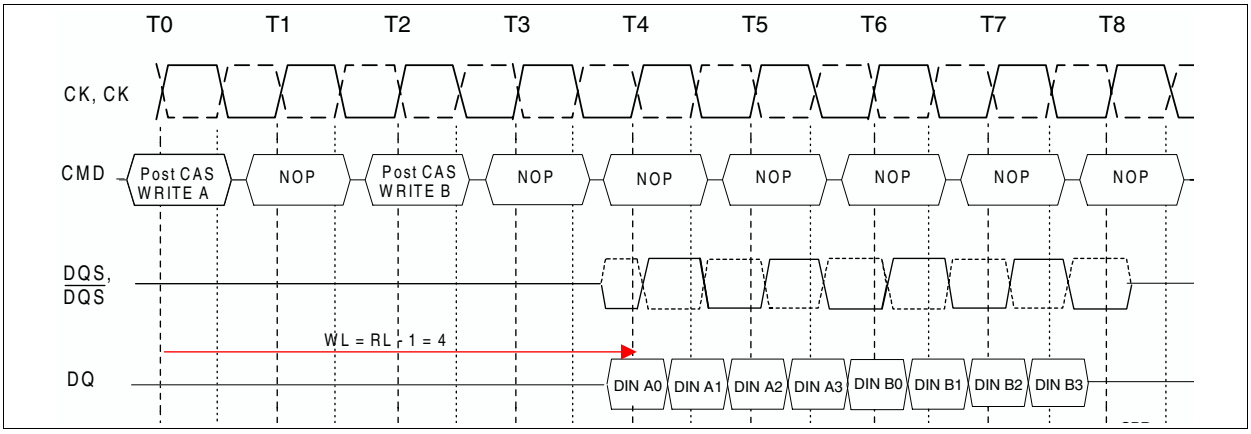


Figure 30 Seamless Write Operation Example 1

RL = 5, WL = 4, BL = 4

The seamless write operation is supported by enabling a write command every BL/2 number of clocks. This operation is allowed regardless of same or different banks as long as the banks are activated.

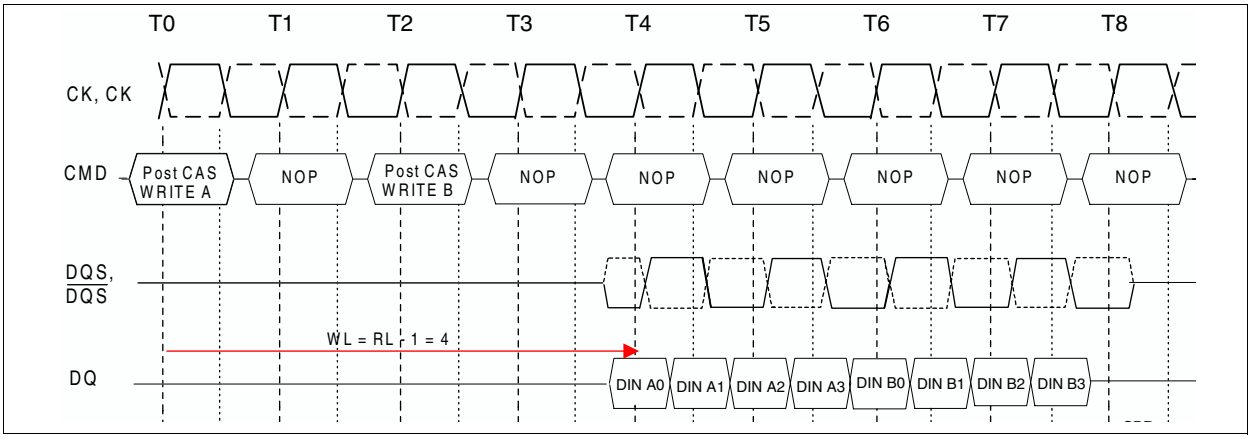


Figure 31 Seamless Write Operation Example 2

RL = 3, WL = 2, BL = 8, non interrupting

The seamless non interrupting 8-bit write operation is supported by enabling a write command at every BL/2 number of clocks. This operation is allowed regardless of same or different banks as long as the banks are activated.

3.20 Write Data Mask

One write data mask input (DM) for ×4 and ×8 components and two write data mask inputs (LDM, UDM) for ×16 components are supported on DDR2 SDRAM's, consistent with the implementation on DDR SDRAM's. It has identical timings on write operations as the data bits, and though used in a uni-directional manner, is internally loaded identically to data bits to insure matched system timing. Data mask is not used during read cycles. If DM is HIGH during a write burst coincident with the write data, the write data bit is not written to the memory. For ×8 components the DM function is disabled, when RDQS / $\overline{\text{RDQS}}$ are enabled by EMRS(1).

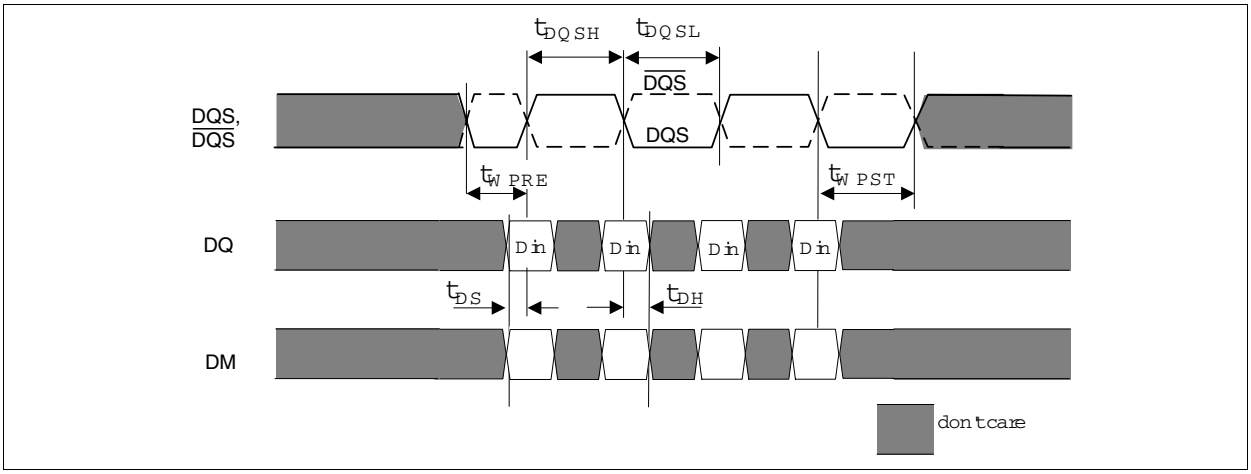


Figure 32 Write Data Mask Timing

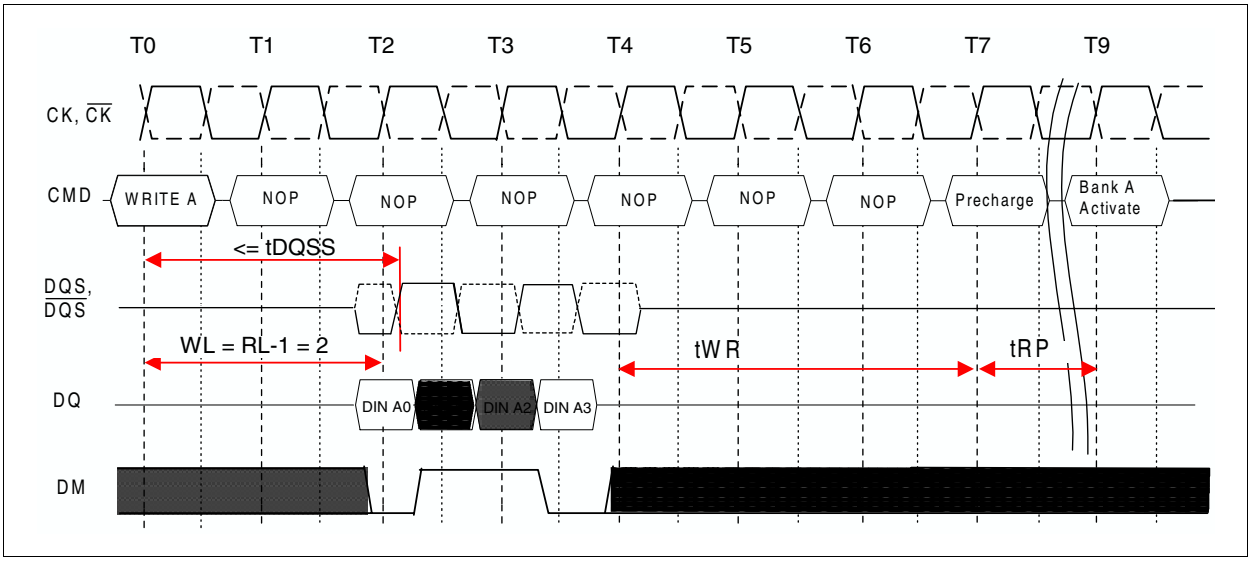


Figure 33 Write Operation with Data Mask Example

RL = 3 (AL = 0, CL = 3), WL = 2, t_{WR} = 3, BL = 4

3.21 Burst Interruption

Interruption of a read or write burst is prohibited for burst length of 4 and only allowed for burst length of 8 under the following conditions:

1. A Read Burst can only be interrupted by another Read command. Read burst interruption by a Write or Precharge Command is prohibited.
2. A Write Burst can only be interrupted by another Write command. Write burst interruption by a Read or Precharge Command is prohibited.
3. Read burst interrupt must occur exactly two clocks after the previous Read command. Any other Read burst interrupt timings are prohibited.
4. Write burst interrupt must occur exactly two clocks after the previous Write command. Any other Read burst interrupt timings are prohibited.
5. Read or Write burst interruption is allowed to any bank inside the DDR2 SDRAM.
6. Read or Write burst with Auto-Precharge enabled is not allowed to be interrupted.
7. Read burst interruption is allowed by a Read with Auto-Precharge command.
8. Write burst interruption is allowed by a Write with Auto-Precharge command.
9. All command timings are referenced to burst length set in the mode register. They are not referenced to the actual burst. For example, Minimum Read to Precharge timing is AL + BL/2 where BL is the burst length set in the mode register and not the actual burst (which is shorter because of interrupt). Minimum Write to Precharge timing is WL + BL/ 2 + t_{WR}, where t_{WR} starts with the rising clock after the un-interrupted burst end and not from the end of the actual burst end.

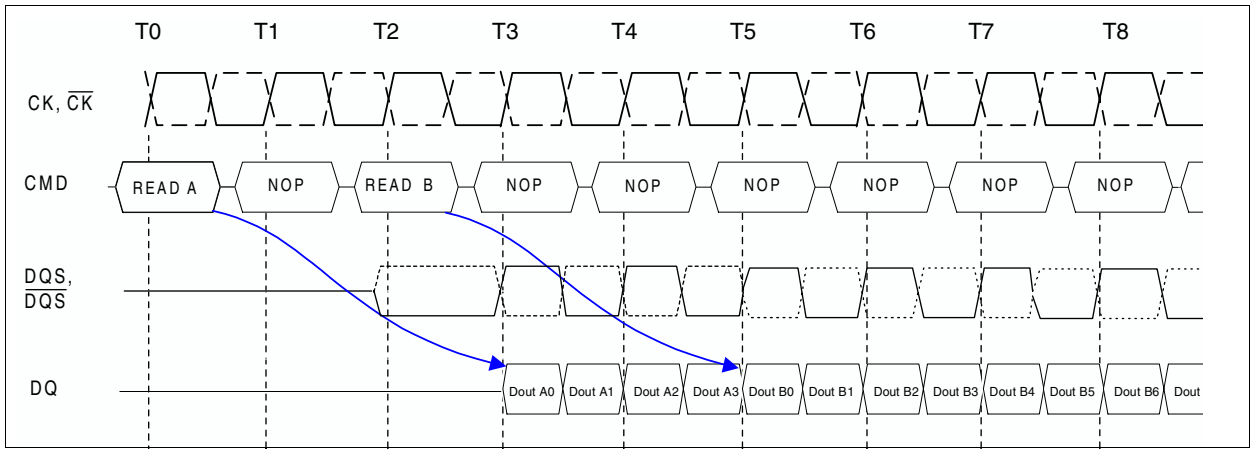


Figure 34 Read Interrupt Timing Example 1

CL = 3, AL = 0, RL = 3, BL = 8

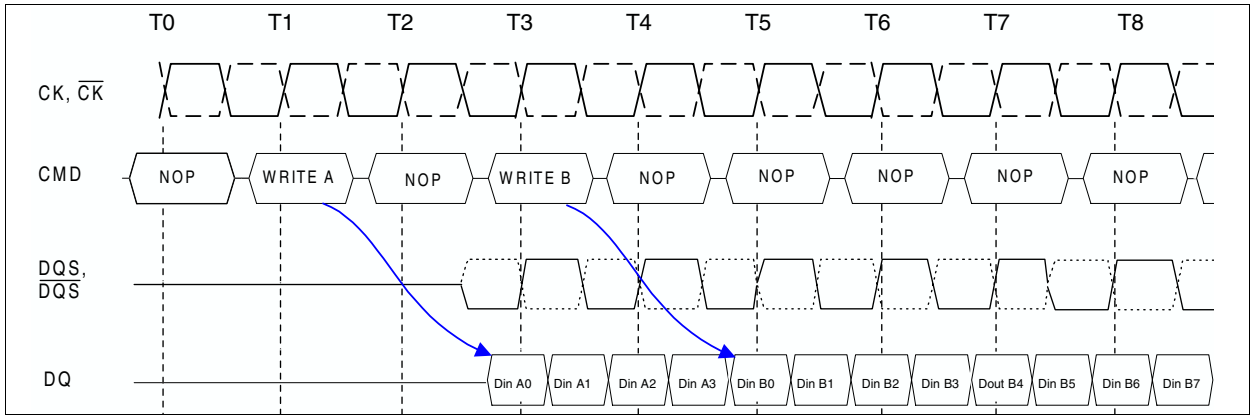


Figure 35 Write Interrupt Timing Example 2 CL = 3, AL = 0, WL = 2, BL = 8

3.22 Precharge Command

The Precharge Command is used to precharge or close a bank that has been activated. The Precharge Command is triggered when $\overline{CS}$, $\overline{RAS}$ and $\overline{WE}$ are LOW and $\overline{CAS}$ is HIGH at the rising edge of the clock. The Pre-charge Command can be used to precharge each bank independently or all banks simultaneously. 3 address bits A10, BA[1:0] are used to define which bank to precharge when the command is issued.

Table 15 Bank Selection for Precharge by Address Bits

A10	BA1	BA0	Precharge Bank(s)
0	0	0	Bank 0 only
0	0	1	Bank 1 only
0	1	0	Bank 2 only
0	1	1	Bank 3 only
1	Don't Care	Don't Care	all banks

Note: The bank address assignment is the same for activating and precharging a specific bank.

3.22.1 Read Followed by a Precharge

The following rules apply as long as the t_{RTP} timing parameter - Internal Read to Precharge Command delay time - is less or equal two clocks, which is the case for operating frequencies less or equal 266 MHz (DDR2 400 and 533 speed sorts).

Minimum Read to Precharge command spacing to the same bank = AL + BL/2 clocks. For the earliest possible precharge, the Precharge command may be issued on the rising edge which is "Additive Latency (AL) + BL/2 clocks" after a Read Command, as long as the minimum t_{RAS} timing is satisfied.

The term (t_{RTP} - $2\times t_{CK}$) is 0 clocks for operating frequencies less or equal 266 MHz (DDR2-400 and DDR2-533 product speed sorts). The term (t_{RTP} - $2\times t_{CK}$) is one clock for frequencies higher then 266 MHz (DDR2-667 speed sort).

A new bank active command may be issued to the same bank if the following two conditions are satisfied simultaneously:

1. The RAS precharge time (t_{RP}) has been satisfied from the clock at which the precharge begins.
2. The RAS cycle time ($t_{RC.MIN}$) from the previous bank activation has been satisfied.

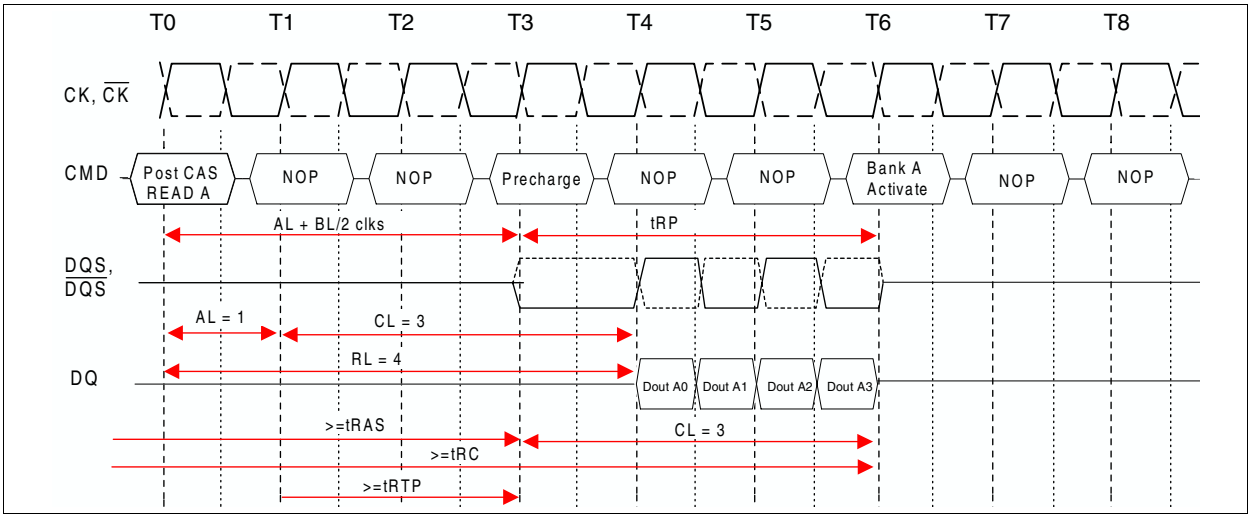


Figure 36 Read Operation Followed by Precharge Example 1

RL = 4 (AL = 1, CL = 3), BL = 4, $t_{RTP} \leq 2$ CKs

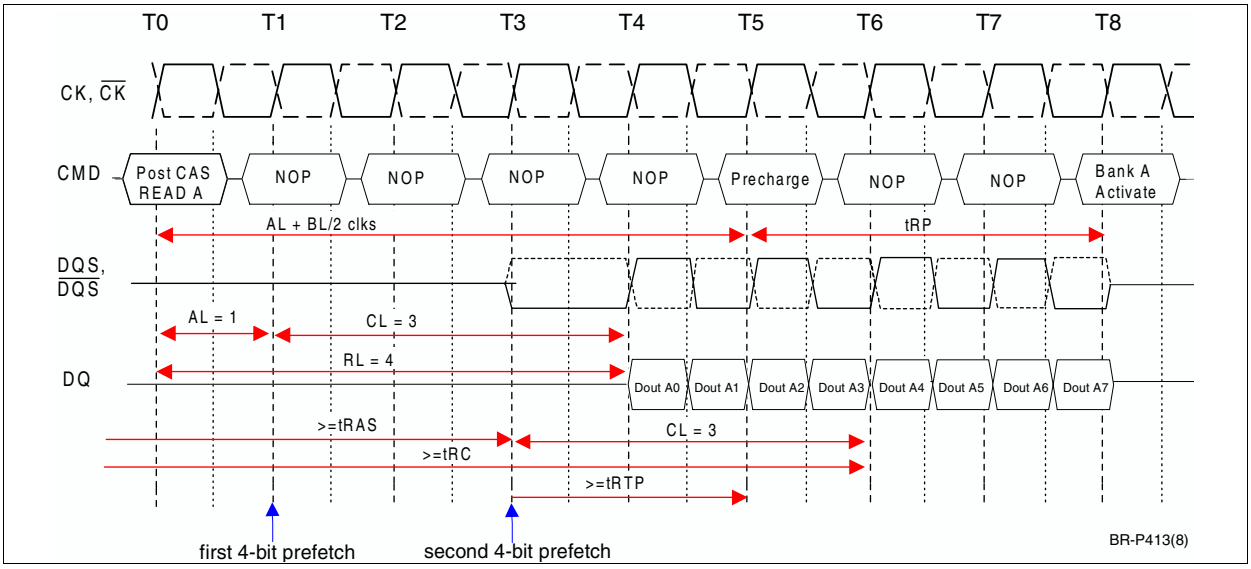


Figure 37 Read Operation Followed by Precharge Example 2

RL = 4 (AL = 1, CL = 3), BL = 8, $t_{RTP} \leq 2$ CKs

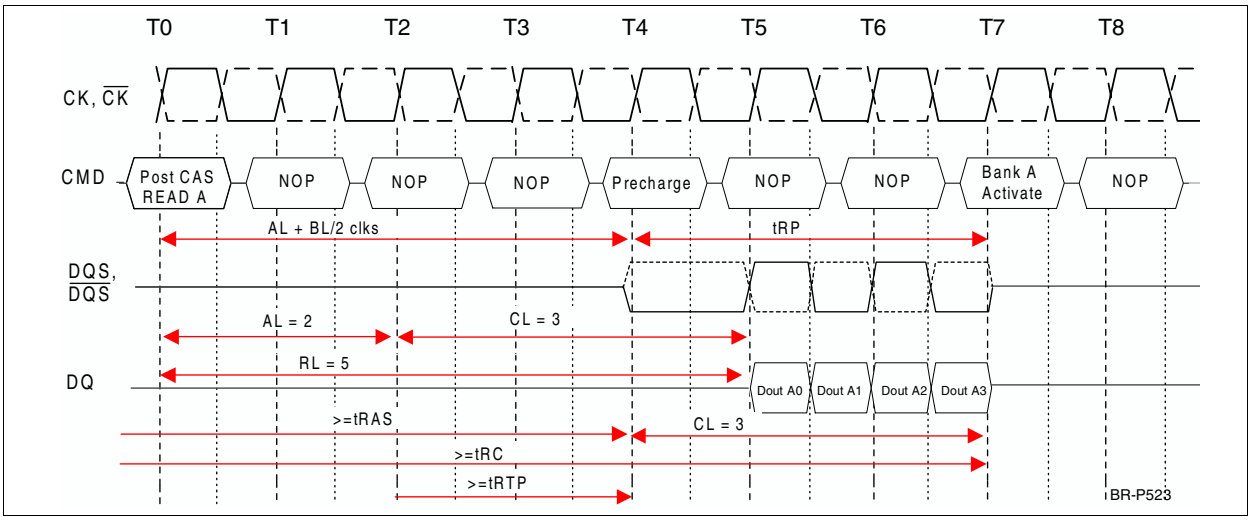


Figure 38 Read Operation Followed by Precharge Example 3

RL = 5 (AL = 2, CL = 3), BL = 4, $t_{RTP} \leq 2$ CKs

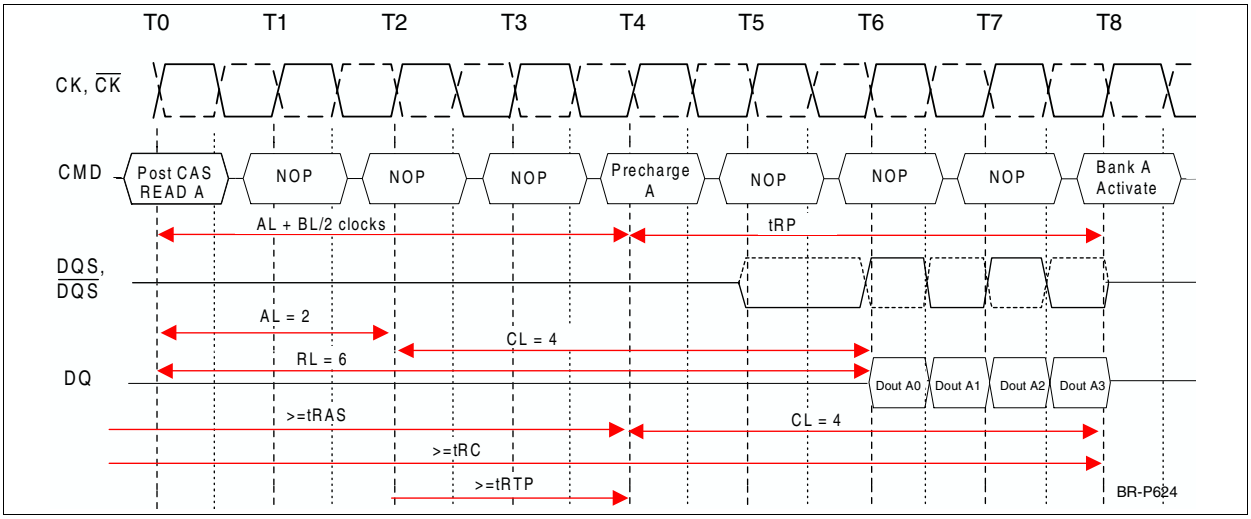


Figure 39 Read Operation Followed by Precharge Example 4

RL = 6, (AL = 2, CL = 4), BL = 4, $t_{RTP} \leq 2$ CKs

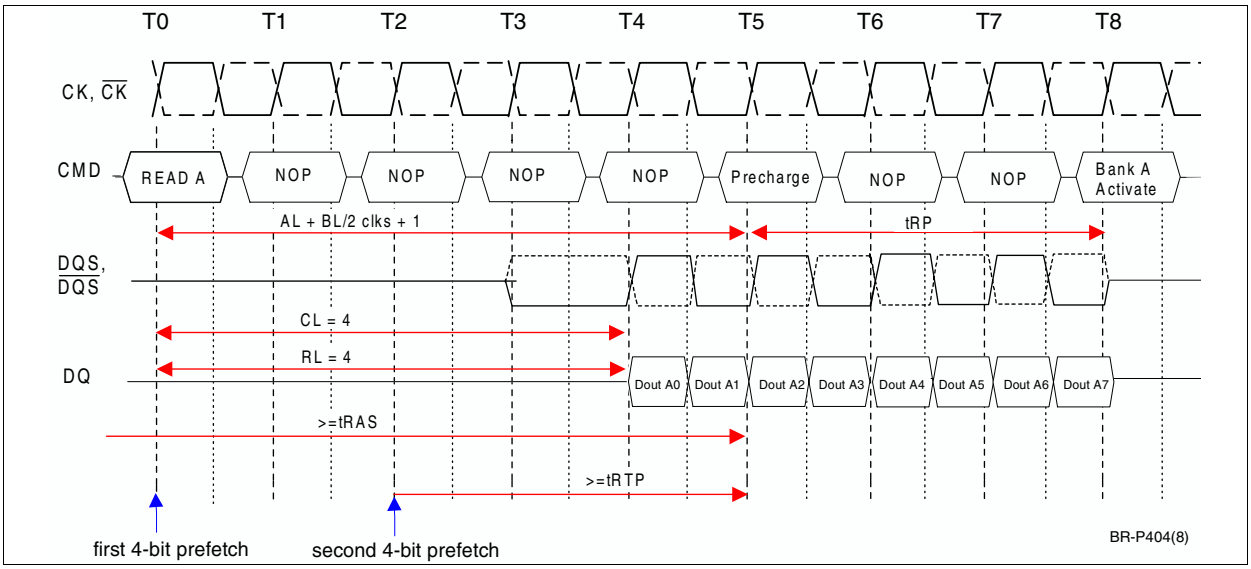


Figure 40 Read Operation Followed by Precharge Example 5

RL = 4, (AL = 0, CL = 4), BL = 8, $t_{RTP} > 2$ CKs

3.22.2 Write followed by Precharge

Minimum Write to Precharge command spacing to the same bank = WL + BL/2 + t_{WR}. For write cycles, a delay must be satisfied from the completion of the last burst write cycle until the Precharge command can be issued. This delay is known as a write recovery time (t_{WR}) referenced from the completion of the burst write to the Precharge command. No Precharge command should be issued prior to the t_{WR} delay, as DDR2 SDRAM does not support any burst interrupt by a Precharge command. t_{WR} is an analog timing parameter (see **Chapter 5.7**) and is not the programmed value WR in the MR.

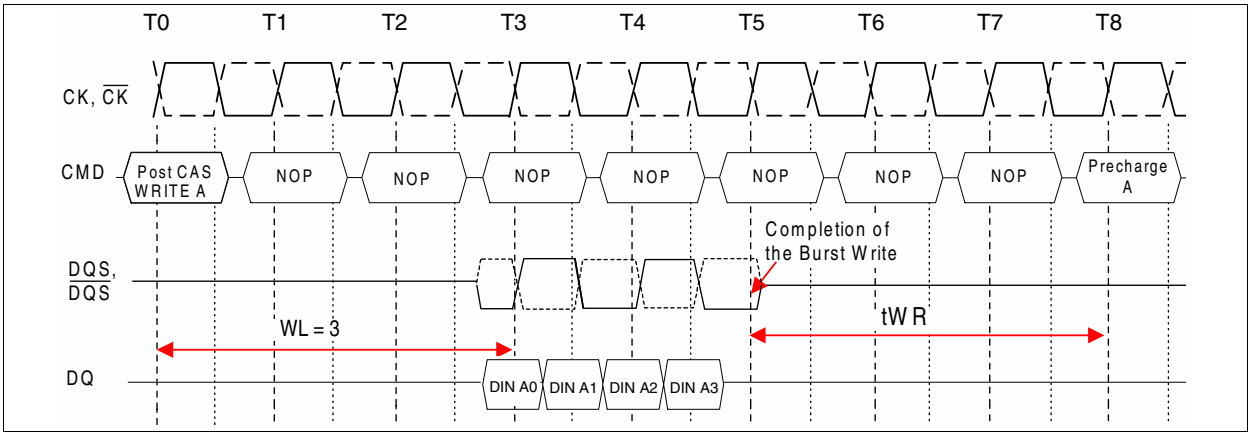


Figure 41 Write followed by Precharge Example 1

WL = (RL - 1) = 3, BL = 4, t_{WR} = 3

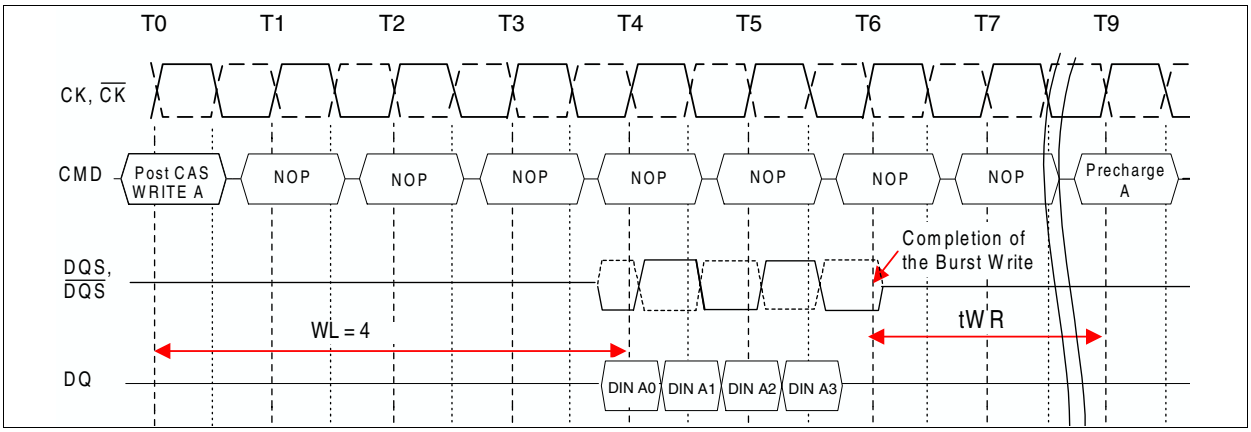


Figure 42 Write followed by Precharge Example 2

WL = (RL - 1) = 4, BL = 4, t_{WR} = 3

3.23 Auto-Precharge Operation

Before a new row in an active bank can be opened, the active bank must be precharged using either the Precharge Command or the Auto-Precharge function. When a Read or a Write Command is given to the DDR2 SDRAM, the $\overline{CAS}$ timing accepts one extra address, column address A10, to allow the active bank to automatically begin precharge at the earliest possible moment during the burst read or write cycle. If A10 is LOW when the Read or Write Command is issued, then normal Read or Write burst operation is executed and the bank remains active at the completion of the burst sequence. If A10 is HIGH when the Read or Write Command is issued, then the Auto-Precharge function is enabled. During Auto-Precharge, a Read Command will execute as normal with the exception that the active bank will begin to precharge internally on the rising edge which is $\overline{CAS}$ Latency (CL) clock cycles before the end of the read burst. Auto-Precharge is also implemented for Write Commands. The Precharge operation engaged by the Auto-Precharge command will not begin until the last data of the write burst sequence is properly stored in the memory array. This feature allows the precharge operation to be partially or completely hidden during burst read cycles (dependent upon $\overline{CAS}$ Latency) thus improving system performance for random data access. The RAS lockout circuit internally delays the Precharge operation until the array restore operation has been completed so that the Auto-Precharge command may be issued with any read or write command.

3.23.1 Read with Auto-Precharge

If A10 is 1 when a Read Command is issued, the Read with Auto-Precharge function is engaged. The DDR2 SDRAM starts an Auto-Precharge operation on the rising edge which is (AL + BL/2) cycles later from the Read with AP command if $t_{RAS.MIN}$ and t_{RTP} are satisfied. If $t_{RAS.MIN}$ is not satisfied at the edge, the start point of Auto-Precharge operation will be delayed until $t_{RAS.MIN}$ is satisfied. If $t_{RTP.MIN}$ is not satisfied at the edge, the start point of Auto-Precharge operation will be delayed until $t_{RTP.MIN}$ is satisfied.

In case the internal precharge is pushed out by t_{RTP}, t_{RP} starts at the point where the internal precharge happens (not at the next rising clock edge after this event). So for BL = 4 the minimum time from Read with Auto-Precharge to the next Activate command becomes AL + t_{RTP} + t_{RP}. For BL = 8 the time from Read with Auto-Precharge to the next Activate command is AL + 2 + t_{RTP} + t_{RP}. Note that (t_{RTP} + t_{RP}) has to be rounded up to the next integer value. In any event internal precharge does not start earlier than two clocks after the last 4-bit prefetch.

A new bank active command may be issued to the same bank if the following two conditions are satisfied simultaneously:

1. The $\overline{RAS}$ precharge time (t_{RP}) has been satisfied from the clock at which the Auto-Precharge begins.
2. The $\overline{RAS}$ cycle time (t_{RC}) from the previous bank activation has been satisfied.

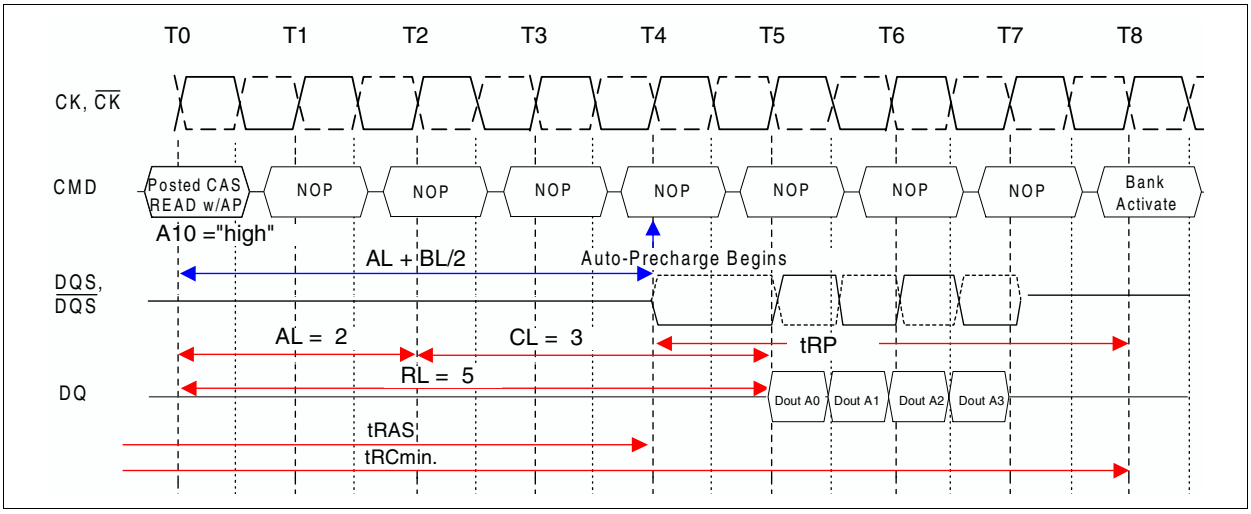


Figure 43 Read with Auto-Precharge Example 1, followed by an Activation to the Same Bank (t_{RC} Limit)

RL = 5 (AL = 2, CL = 3), BL = 4, $t_{RTP} \leq 2$ CKs

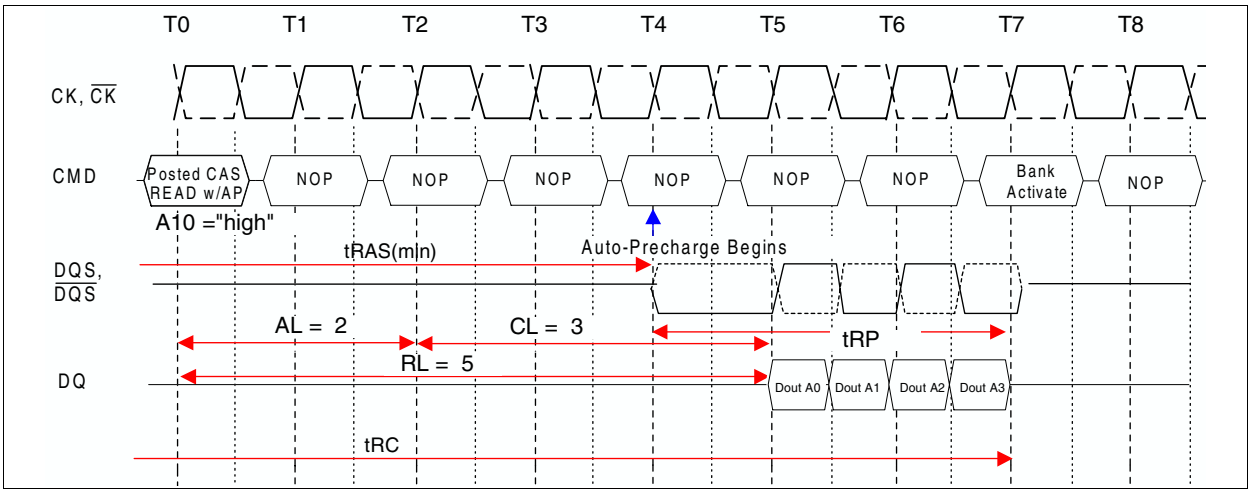


Figure 44 Read with Auto-Precharge Example 2, followed by an Activation to the Same Bank (t_{RAS} Limit)

RL = 5 (AL = 2, CL = 3), BL = 4, $t_{RTP} \leq 2$ CKs

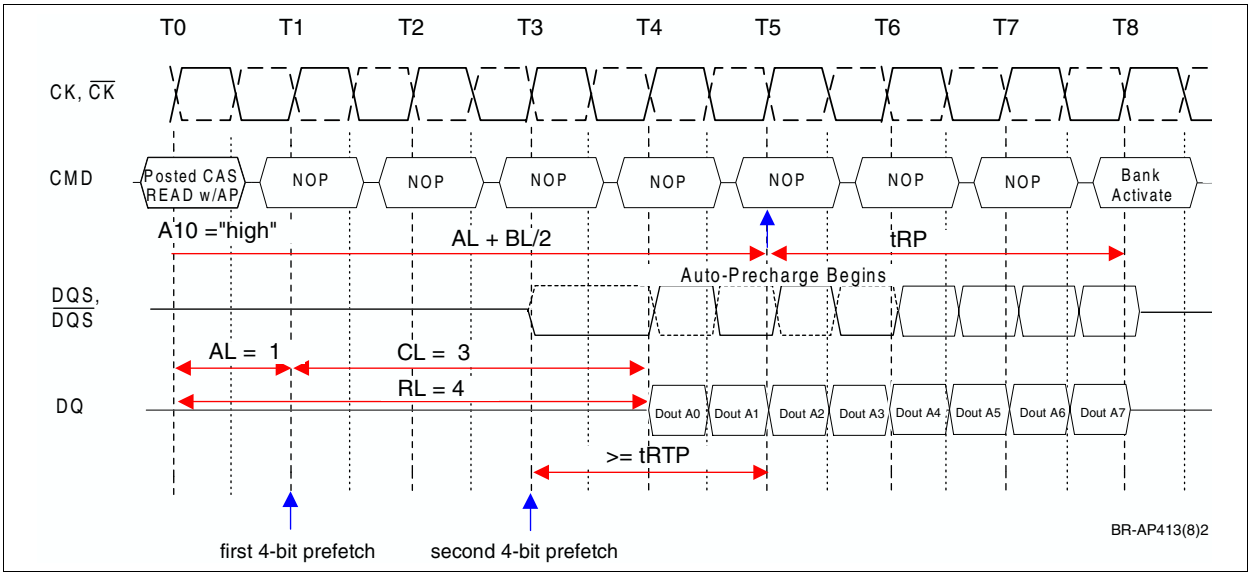


Figure 45 Read with Auto-Precharge Example 3, followed by an Activation to the Same Bank

RL = 4 (AL = 1, CL = 3), BL = 8, $t_{RTP} \leq 2$ CKs

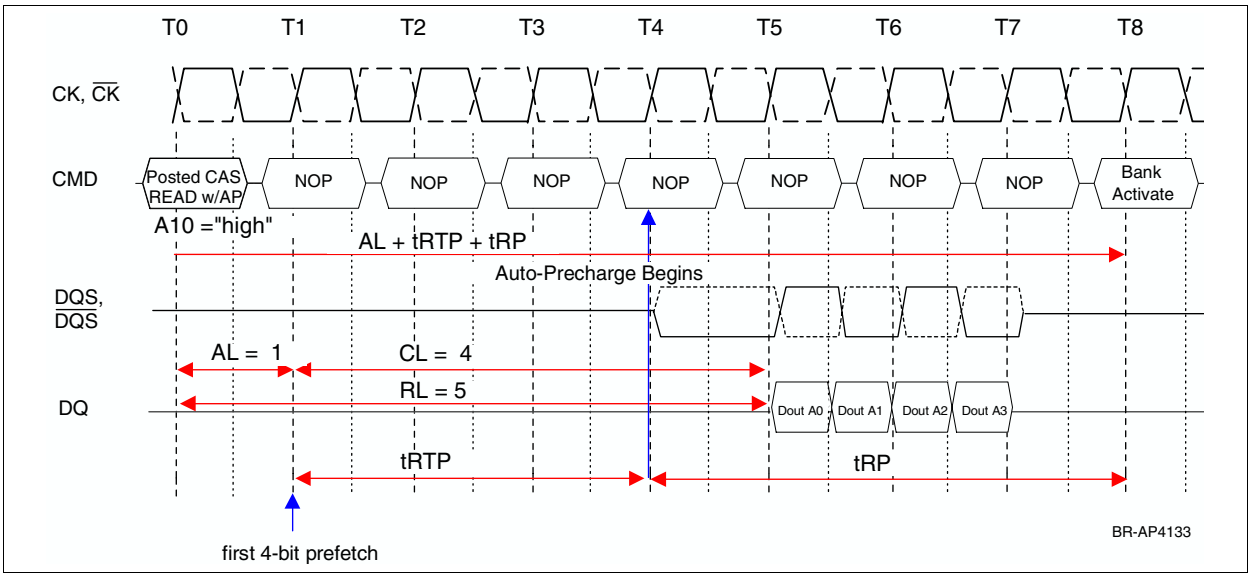


Figure 46 Read with Auto-Precharge Example 4, followed by an Activation to the Same Bank,

RL = 5 (AL = 1, CL = 4), BL = 4, $t_{RTP} = 3$ CKs

3.23.2 Write with Auto-Precharge

If A10 is HIGH when a Write Command is issued, the Write with Auto-Precharge function is engaged. The DDR2 SDRAM automatically begins precharge operation after the completion of the write burst plus the write recovery time delay (WR), programmed in the MRS register, as long as t_{RAS} is satisfied. The bank undergoing Auto-Precharge from the completion of the write burst may be reactivated if the following two conditions are satisfied.

1. The last data-in to bank activate delay time (t_{DAL} = WR + t_{RP}) has been satisfied.
2. The RAS cycle time (t_{RC}) from the previous bank activation has been satisfied.

In DDR2 SDRAM's the write recovery time delay (WR) has to be programmed into the MRS mode register. As long as the analog t_{WR} timing parameter is not violated, WR can be programmed between 2 and 6 clock cycles. Minimum Write to Activate command spacing to the same bank = WL + BL/2 + t_{DAL}.

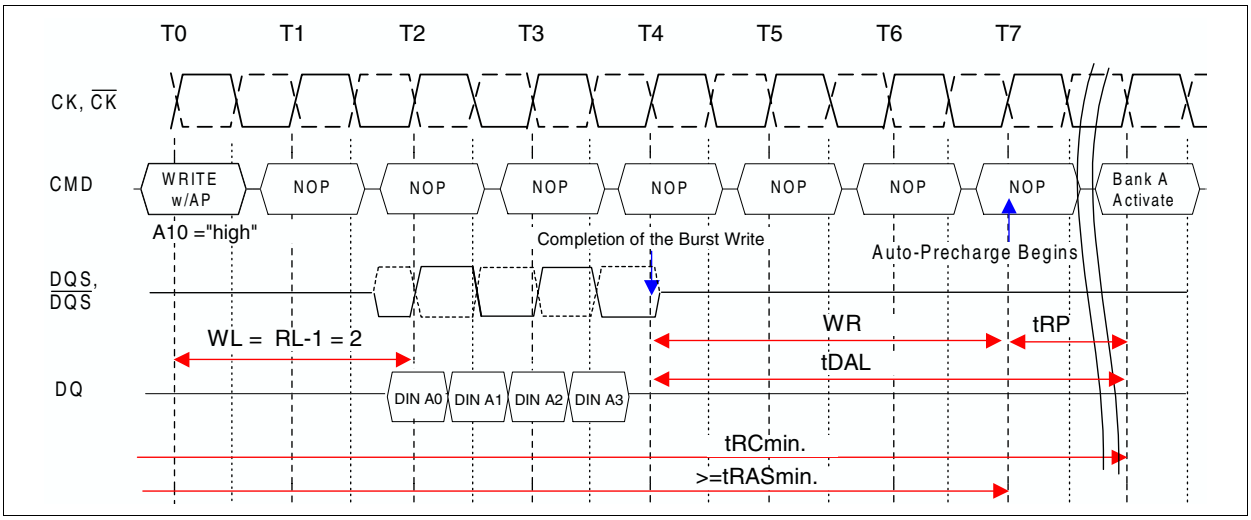


Figure 47 Write with Auto-Precharge Example 1 (t_{RC} Limit)

WL = 2, t_{DAL} = 6 (WR = 3, t_{RP} = 3), BL = 4

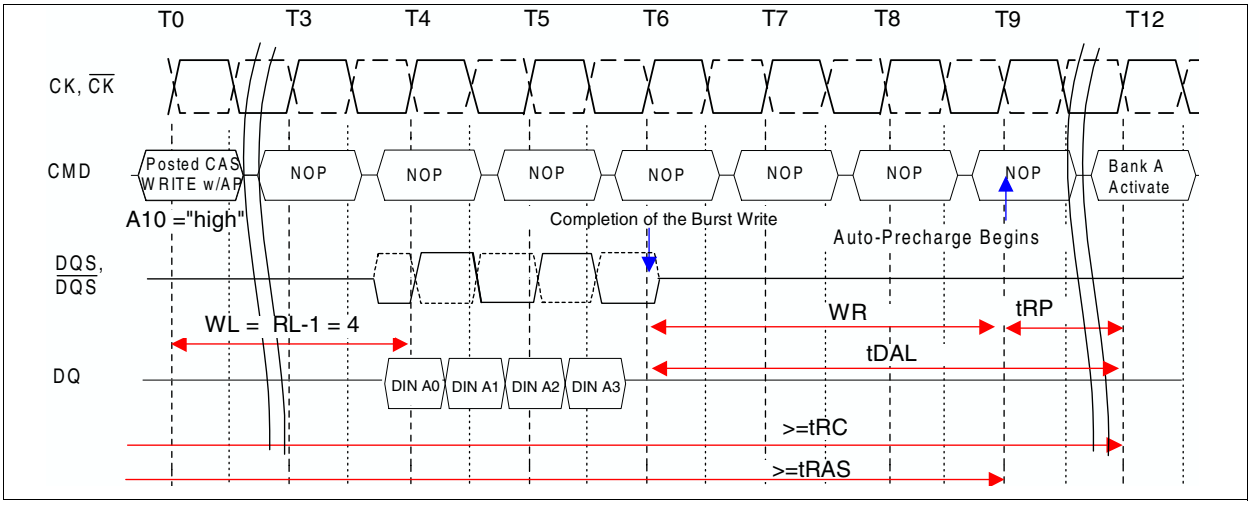


Figure 48 Write with Auto-Precharge Example 2 (WR + t_{RP} Limit)

WL = 4, t_{DAL} = 6 (WR = 3, t_{RP} = 3), BL = 4

3.23.3 Read or Write to Precharge Command Spacing Summary

The following table summarizes the minimum command delays between Read, Read w/AP, Write, Write w/AP to the Precharge commands to the same banks and Precharge-All commands.

Table 16 Minimum Command Delays

From Command	To Command	Minimum Delay between "From Command" to "To Command"	Unit	Note
READ	PRECHARGE (to same banks as READ)	AL + BL/2 + max(t_{RTP}, 2) - 2×t_{CK}	t_{CK}	1)2)
	PRECHARGE-ALL	AL + BL/2 + max(t_{RTP}, 2) - 2×t_{CK}	t_{CK}	1)2)
READ w/AP	PRECHARGE (to same banks as READ w/AP)	AL + BL/2 + max(t_{RTP}, 2) - 2×t_{CK}	t_{CK}	1)2)
	PRECHARGE-ALL	AL + BL/2 + max(t_{RTP}, 2) - 2×t_{CK}	t_{CK}	1)2)
WRITE	PRECHARGE (to same banks as WRITE)	WL + BL/2 + t_{WR}	t_{CK}	2)
	PRECHARGE-ALL	WL + BL/2 + t_{WR}	t_{CK}	2)
WRITE w/AP	PRECHARGE (to same banks as WRITE w/AP)	WL + BL/2 + WR	t_{CK}	2)
	PRECHARGE-ALL	WL + BL/2 + WR	t_{CK}	2)
PRECHARGE	PRECHARGE (to same banks as PRECHARGE)	1	t_{CK}	2)
	PRECHARGE-ALL	1	t_{CK}	2)
PRECHARGE-ALL	PRECHARGE	1	t_{CK}	2)
	PRECHARGE-ALL	1	t_{CK}	2)

1) RU{t_{RTP}(ns) / t_{CK}(ns)} must be used, where RU stands for "Round Up"

2) For a given bank, the precharge period should be counted from the latest precharge command, either one bank precharge or precharge-all, issued to that bank. The precharge period is satisfied after $t_{RP,all}$ depending on the latest precharge command issued to that bank

3.23.4 Concurrent Auto-Precharge

DDR2 devices support the “Concurrent Auto-Precharge” feature. A Read with Auto-Precharge enabled, or a Write with Auto-Precharge enabled, may be followed by any command to the other bank, as long as that command does not interrupt the read or write data transfer, and all other related limitations (e.g. contention between Read data and Write data must be avoided externally and on the internal data bus).

The minimum delay from a Read or Write command with Auto-Precharge enabled, to a command to a different bank, is summarized in the Command Delay Table. As defined, the WL = RL - 1 for DDR2 devices which allows the command gap and corresponding data gaps to be minimized.

Table 17 Command Delay Table

From Command	To Command (different bank, non-interrupting command)	Minimum Delay with Concurrent Auto-Precharge Support	Unit	Note
WRITE w/AP	Read or Read w/AP	(CL -1) + (BL/2) + t_{WTR}	t_{CK}	
	Write or Write w/AP	BL/2	t_{CK}	
	Precharge or Activate	1	t_{CK}	1)
Read w/AP	Read or Read w/AP	BL/2	t_{CK}	
	Write or Write w/AP	BL/2 + 2	t_{CK}	
	Precharge or Activate	1	t_{CK}	1)

1) This rule only applies to a selective Precharge command to another bank, a Precharge-All command is illegal

3.24 Refresh

DDR2 SDRAM requires a refresh of all rows in any rolling 64 ms interval. The necessary refresh can be generated in one of two ways: by explicit Auto-Refresh commands or by an internally timed Self-Refresh mode.

3.24.1 Auto-Refresh Command

Auto-Refresh is used during normal operation of the DDR2 SDRAM’s. This command is non persistent, so it must be issued each time a refresh is required. The refresh addressing is generated by the internal refresh controller. This makes the address bits ”don’t care” during an Auto-Refresh command. The DDR2 SDRAM requires Auto-Refresh cycles at an average periodic interval of $t_{REFI.MAX}$.

When $\overline{CS}$, $\overline{RAS}$ and $\overline{CAS}$ are held LOW and $\overline{WE}$ HIGH at the rising edge of the clock, the chip enters the Auto-Refresh mode. All banks of the SDRAM must be precharged and idle for a minimum of the precharge time (t_{RP}) before the Auto-Refresh Command can be applied. An internal address counter supplies the addresses during the refresh cycle. No control of the external address bus is required once this cycle has started.

When the refresh cycle has completed, all banks of the SDRAM will be in the precharged (idle) state. A delay between the Auto-Refresh Command and the next Activate Command or subsequent Auto-Refresh Command must be greater than or equal to the Auto-Refresh cycle time (t_{RFC}).

To allow for improved efficiency in scheduling and switching between tasks, some flexibility in the absolute refresh interval is provided. A maximum of eight Auto-Refresh commands can be posted to any given DDR2 SDRAM, meaning that the maximum absolute interval between any Auto-Refresh command and the next Auto-Refresh command is $9 \times t_{REFI}$.

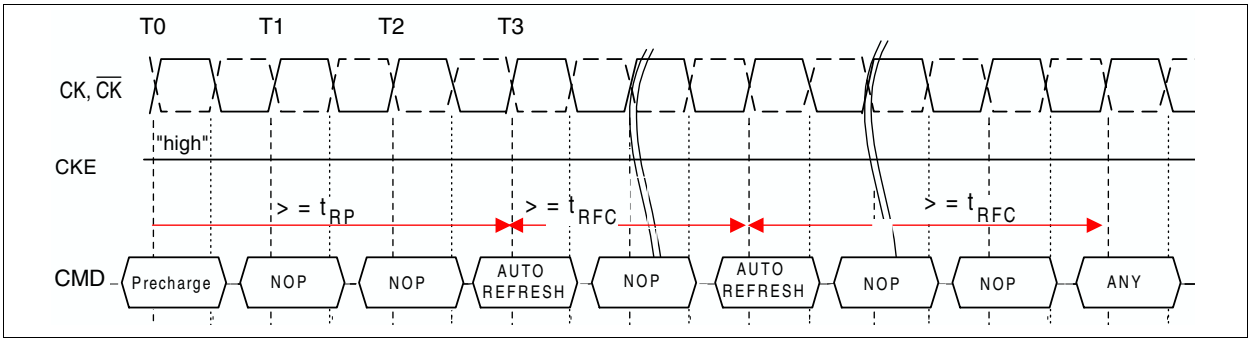


Figure 49 Auto Refresh Timing

3.24.2 Self-Refresh Command

The Self-Refresh command can be used to retain data, even if the rest of the system is powered down. When in the Self-Refresh mode, the DDR2 SDRAM retains data without external clocking. The DDR2 SDRAM device has a built-in timer to accommodate Self-Refresh operation. The Self-Refresh Command is defined by having $\overline{CS}$, $\overline{RAS}$, $\overline{CAS}$ and CKE held LOW with $\overline{WE}$ HIGH at the rising edge of the clock. The device must be in idle state and ODT must be turned off before issuing Self Refresh command, by either driving ODT pin LOW or using EMRS(1) command. Once the command is registered, CKE must be held LOW to keep the device in Self-Refresh mode. The DLL is automatically disabled upon entering Self Refresh and is automatically enabled upon exiting Self Refresh. When the DDR2 SDRAM has entered Self-Refresh mode all of the external control signals, except CKE, are “don’t care”. The DRAM initiates a minimum of one Auto Refresh command internally within t_{CKE} period once it enters Self Refresh mode. The clock is internally disabled during Self-Refresh Operation to save power. The minimum time that the DDR2 SDRAM must remain in Self Refresh mode is t_{CKE}. The user may change the external clock frequency or halt the external clock one clock after Self-Refresh entry is registered, however, the clock must be restarted and stable before the device can exit Self-Refresh operation.

The procedure for exiting Self Refresh requires a sequence of commands. First, the clock must be stable prior to CKE going back HIGH. Once Self-Refresh Exit command is registered, a delay of at least t_{XSNR} must be satisfied before a valid command can be issued to the device to allow for any internal refresh in progress. CKE must remain HIGH for the entire Self-Refresh exit period t_{XSRD} for proper operation. Upon exit from Self Refresh, the DDR2 SDRAM can be put back into Self Refresh mode after t_{XSNR} expires. NOP or deselect commands must be registered on each positive clock edge during the Self-Refresh exit interval t_{XSNR}. ODT should be turned off during t_{XSNR}.

The use of Self Refresh mode introduces the possibility that an internally timed refresh event can be missed when CKE is raised for exit from Self Refresh mode. Upon exit from Self Refresh, the DDR2 SDRAM requires a minimum of one extra auto refresh command before it is put back into Self Refresh Mode.

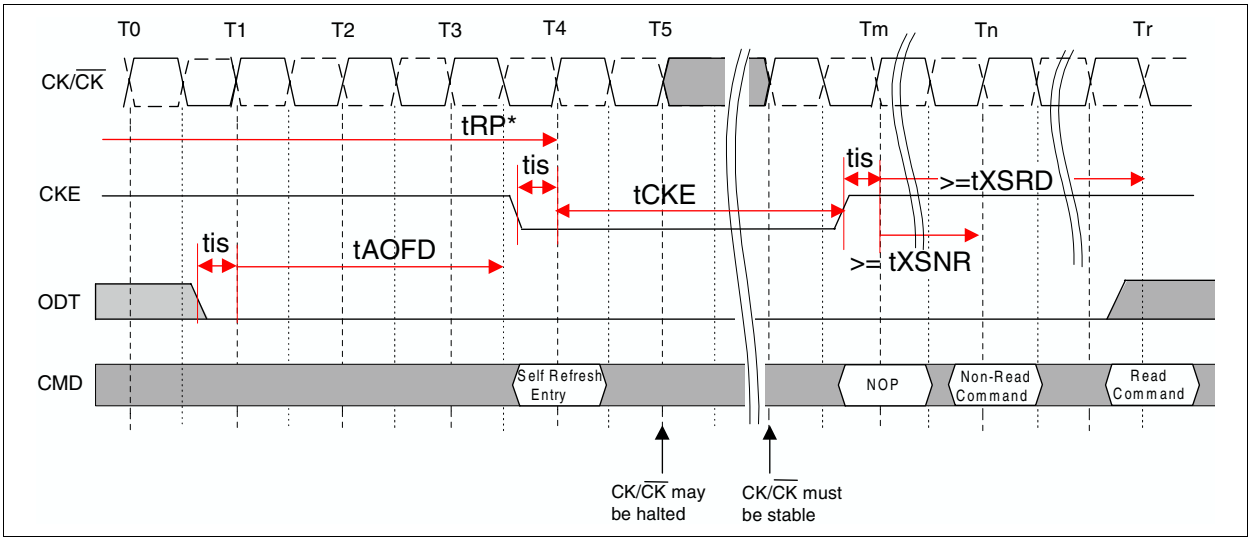


Figure 50 Self Refresh Timing

Note:

1. Device must be in the “All banks idle” state before entering Self Refresh mode.
2. t_{XSRD} (≥ 200 t_{CK}) has to be satisfied for a Read or a Read with Auto-Precharge command.
3. t_{XSNR} has to be satisfied for any command except a Read or a Read with Auto-Precharge command
4. Since CKE is an SSTL input, V_{REF} must be maintained during Self Refresh.

3.25 Power-Down

Power-down is synchronously entered when CKE is registered LOW, along with NOP or Deselect command. CKE is not allowed to go LOW while mode register or extended mode register command time, or read or write operation is in progress. CKE is allowed to go LOW while any other operation such as row activation, Precharge, Auto-Precharge or Auto-Refresh is in progress, but power-down I_{DD} specification will not be applied until finishing those operations.

The DLL should be in a locked state when power-down is entered. Otherwise DLL should be reset after exiting power-down mode for proper read operation. DRAM design guarantees it’s DLL in a locked state with any CKE intensive operations as long as DRAM controller complies with DRAM specifications.

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

For Active Power-down two different power saving modes can be selected within the MRS register, address bit A12. When A12 is set to LOW this mode is referred as “standard active power-down mode” and a fast power-down exit timing defined by the t_{XARD} timing parameter can be used. When A12 is set to HIGH this mode is referred as a power saving “low power active power-down mode”. This mode takes longer to exit from the power-down mode and the t_{XARDS} timing parameter has to be satisfied.

Entering power-down deactivates the input and output buffers, excluding CK, $\overline{CK}$, ODT and CKE. Also the DLL is disabled upon entering Precharge Power-down or slow exit active power-down, but the DLL is kept enabled during fast exit active power-down. In power-down mode, CKE LOW and a stable clock signal must be maintained at the inputs of the DDR2 SDRAM, and all other input signals are “Don’t Care”. Power-down duration is limited by 9 times t_{REFI} of the device.

Power-Down Entry

Active Power-down mode can be entered after an Activate command. Precharge Power-down mode can be entered after a Precharge, Precharge-All or internal precharge command. It is also allowed to enter power-down mode after an Auto-Refresh command or MRS / EMRS(1) command when t_{MRD} is satisfied.

Active Power-down mode entry is prohibited as long as a Read Burst is in progress, meaning CKE should be kept HIGH until the burst operation is finished. Therefore Active Power-Down mode entry after a Read or Read with Auto-Precharge command is allowed after RL + BL/2 is satisfied.

Active Power-down mode entry is prohibited as long as a Write Burst and the internal write recovery is in progress. In case of a write command, active power-down mode entry is allowed when WL + BL/2 + t_{WTR} is satisfied.

In case of a write command with Auto-Precharge, Power-down mode entry is allowed after the internal precharge command has been executed, which is WL + BL/2 + WR starting from the write with Auto-Precharge command. In this case the DDR2 SDRAM enters the Precharge Power-down mode.

Power-Down Exit

The power-down state is synchronously exited when CKE is registered HIGH (along with a NOP or Deselect command). A valid, executable command can be applied with power-down exit latency, t_{XP}, t_{XARD} or t_{XARDS}, after CKE goes HIGH. Power-down exit latencies are defined in chapter 7.2.

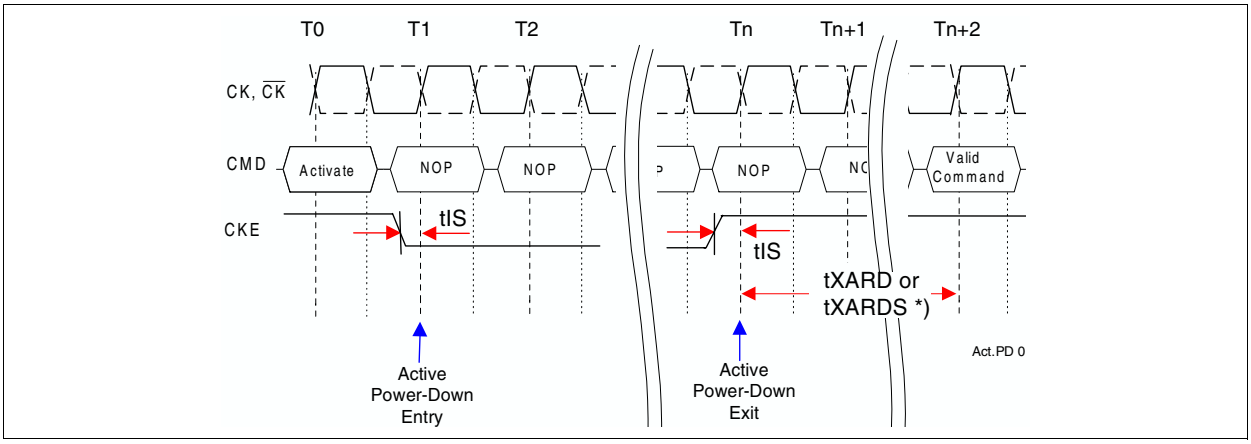


Figure 51 Active Power-Down Mode Entry and Exit after an Activate Command

Note: Active Power-Down mode exit timing t_{XARD} ("fast exit") or t_{XARDS} ("slow exit") depends on the programmed state in the MR, address bit A12.

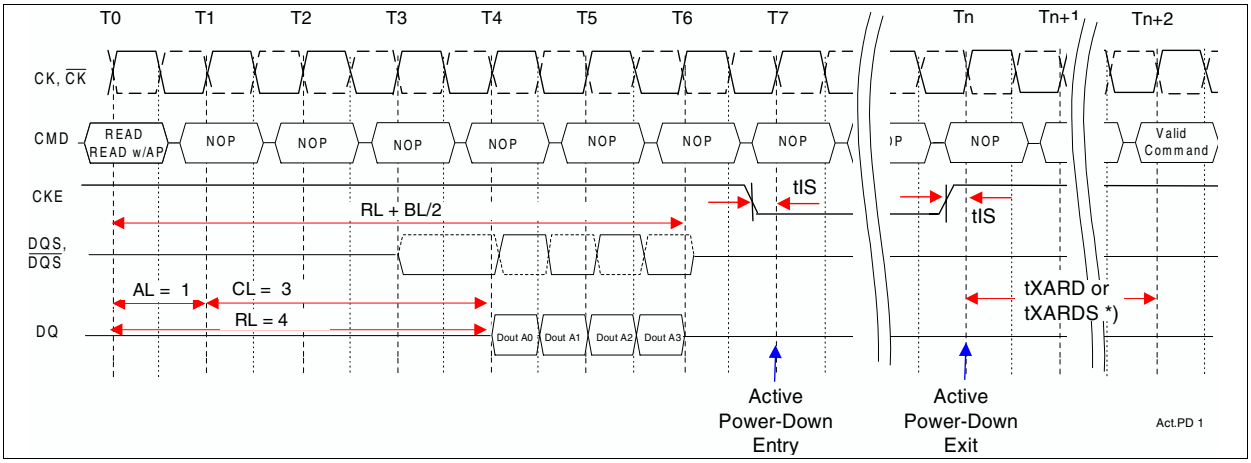


Figure 52 Active Power-Down Mode Entry and Exit Example after a Read Command
RL = 4 (AL = 1, CL =3), BL = 4

Note: Active Power-Down mode exit timing t_{XARD} ("fast exit") or t_{XARDS} ("slow exit") depends on the programmed state in the MR, address bit A12.

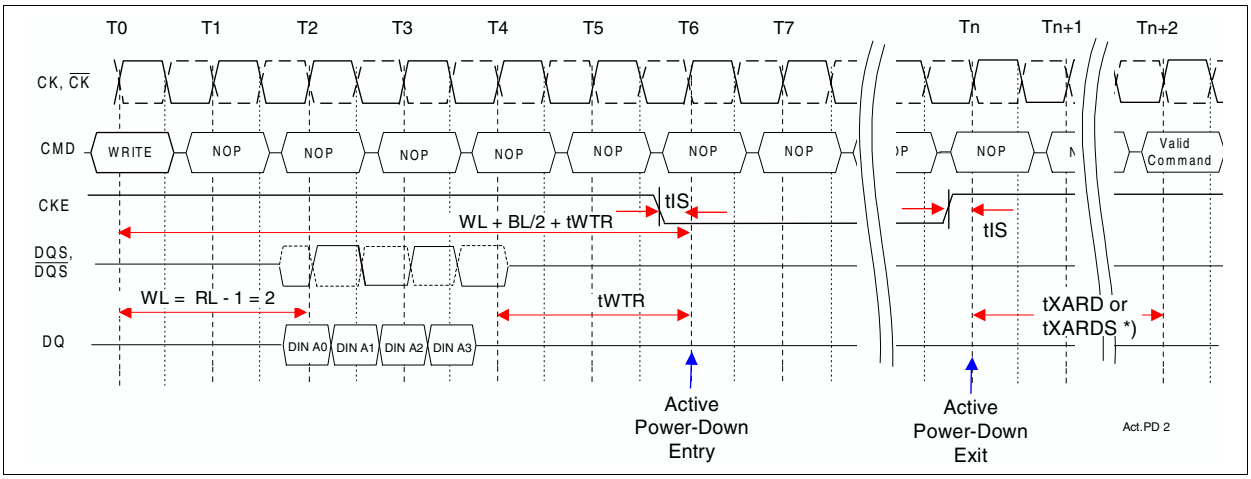


Figure 53 Active Power-Down Mode Entry and Exit Example after a Write Command
WL = 2, t_{WTR} = 2, BL = 4

Note: Active Power-Down mode exit timing t_{XARD} ("fast exit") or t_{XARDS} ("slow exit") depends on the programmed state in the MR, address bit A12.

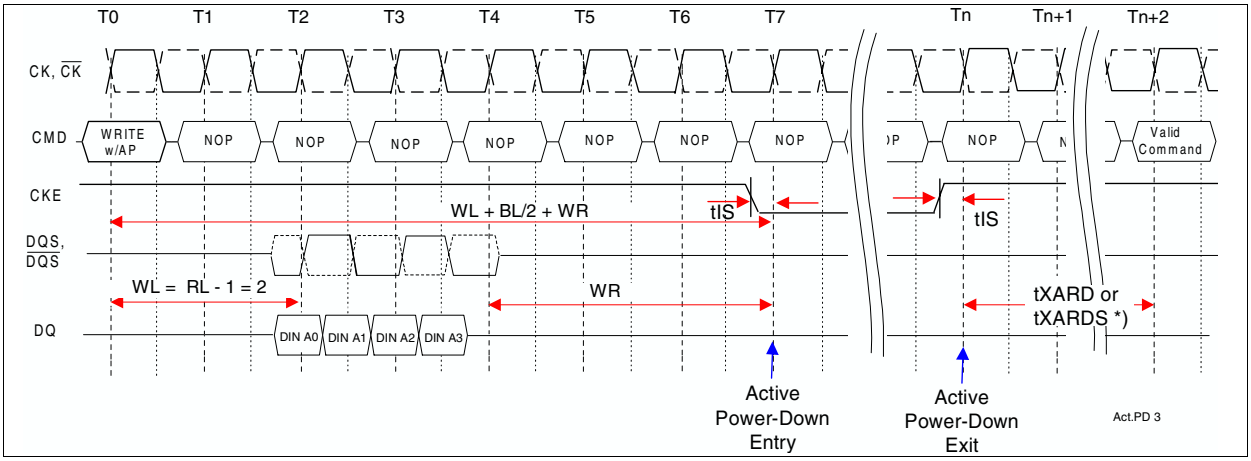


Figure 54 Active Power-Down Mode Entry and Exit Example after a Write Command with AP
WL = 2, WR = 3, BL = 4

Note: Active Power-Down mode exit timing t_{XARD} ("fast exit") or t_{XARDS} ("slow exit") depends on the programmed state in the MR, address bit A12. WR is the programmed value in the MRS mode register.

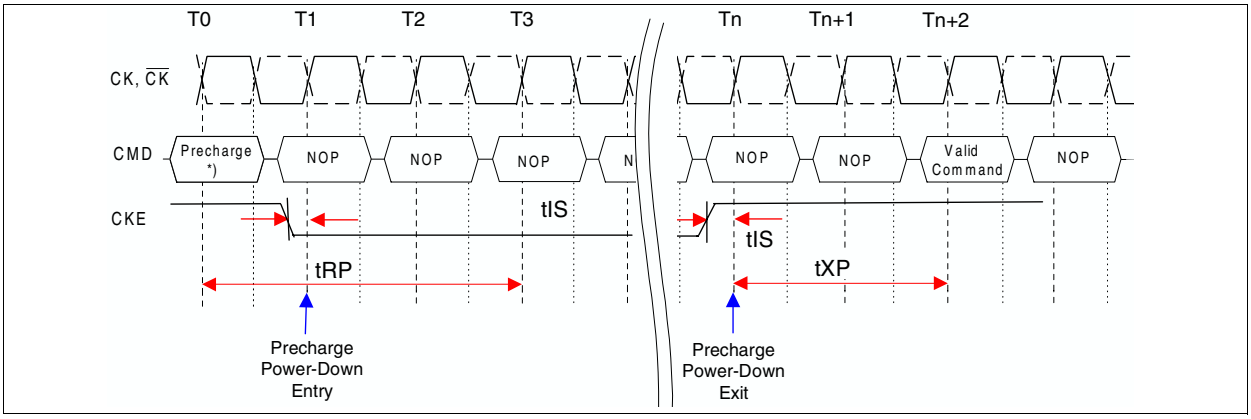


Figure 55 Precharge Power Down Mode Entry and Exit

Note: "Precharge" may be an external command or an internal precharge following Write with AP.

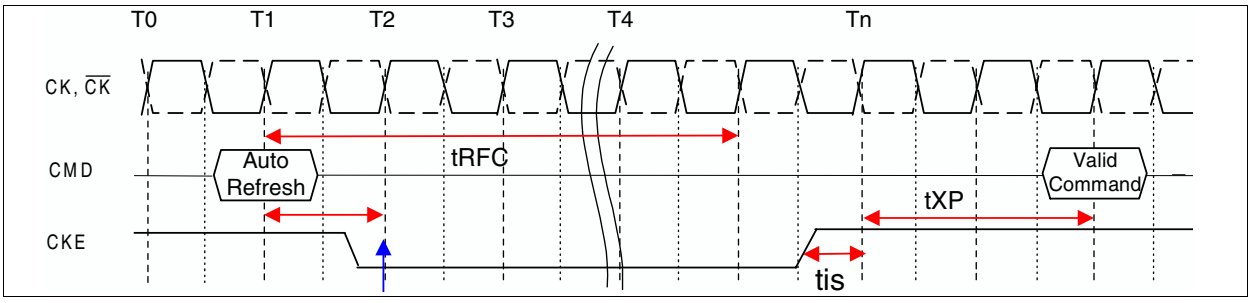


Figure 56 Auto-Refresh command to Power-Down entry

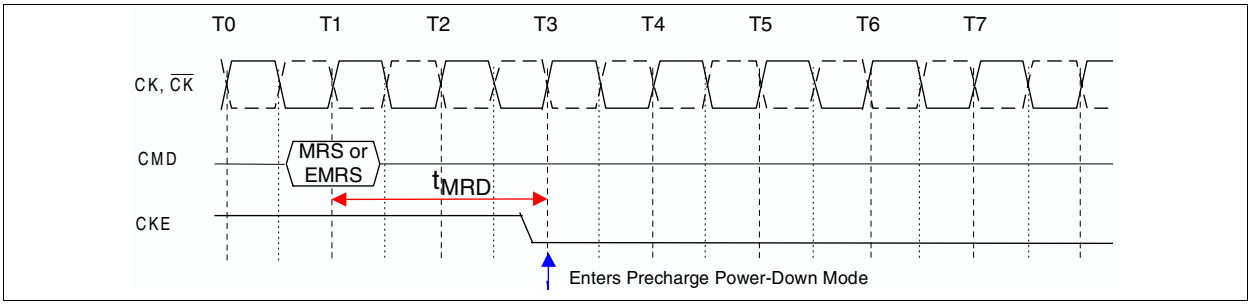


Figure 57 MRS, EMRS command to Power-Down entry

3.26 Other Commands

3.26.1 No Operation Command

The No Operation Command (NOP) should be used in cases when the SDRAM is in a idle or a wait state. The purpose of the No Operation Command is to prevent the SDRAM from registering any unwanted commands between operations. A No Operation Command is registered when $\overline{CS}$ is LOW with $\overline{RAS}$, $\overline{CAS}$, and $\overline{WE}$ held HIGH at the rising edge of the clock. A No Operation Command will not terminate a previous operation that is still executing, such as a burst read or write cycle.

3.26.2 Deselect Command

The Deselect Command performs the same function as a No Operation Command. Deselect Command occurs when $\overline{CS}$ is brought HIGH, the $\overline{RAS}$, $\overline{CAS}$, and $\overline{WE}$ signals become don't care.

3.27 Input Clock Frequency Change

During operation the DRAM input clock frequency can be changed under the following conditions:

- During Self-Refresh operation
- DRAM is in Precharge Power-down mode and ODT is completely turned off.

In the Precharge Power-down mode the DDR2-SDRAM has to be in Precharged Power-down mode and idle. ODT must be already turned off and CKE must be at a logic LOW state. After a minimum of two clock cycles after t_{RP} and t_{AOFD} have been satisfied the input clock frequency can be changed. A stable new clock frequency has to be provided, before CKE can be changed to a HIGH logic level again. After t_{XP} has been satisfied a DLL RESET command via EMRS(1) has to be issued. During the following DLL re-lock period of 200 clock cycles, ODT must remain off. After the DLL-re-lock period the DRAM is ready to operate with the new clock frequency.

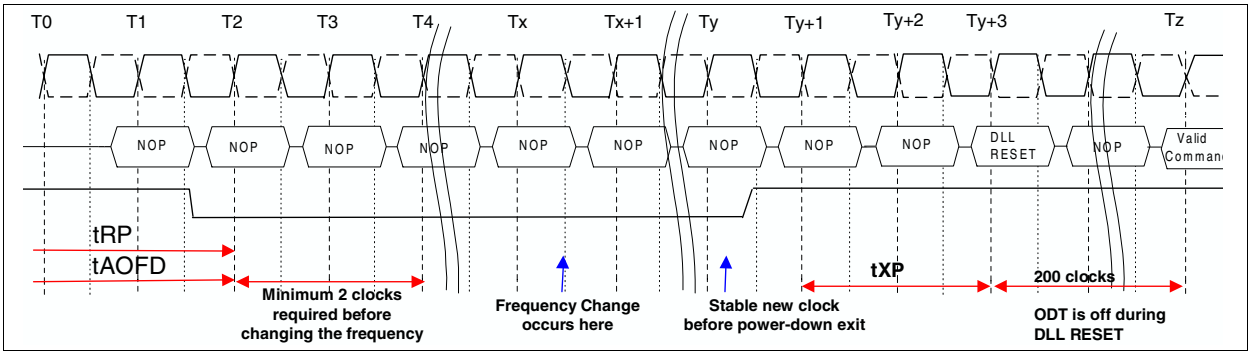


Figure 58 Input Frequency Change Example during Precharge Power-Down mode

3.28 Asynchronous CKE LOW Reset Event

In a given system, Asynchronous Reset event can occur at any time without prior knowledge. In this situation, memory controller is forced to drop CKE asynchronously LOW, immediately interrupting any valid operation. DRAM requires CKE to be maintained HIGH for all valid operations as defined in this data sheet. If CKE asynchronously drops LOW during any valid operation, the DRAM is not guaranteed to preserve the contents of the memory array. If this event occurs, the memory controller must satisfy a time delay (t_{DELAY}) before turning off the clocks. Stable clocks must exist at the input of DRAM before CKE is raised HIGH again. The DRAM must be fully re-initialized as described the initialization sequence (Power On and Initialization, step 4 through 13). DRAM is ready for normal operation after the initialization sequence. See Chapter 7 for t_{DELAY} specification.

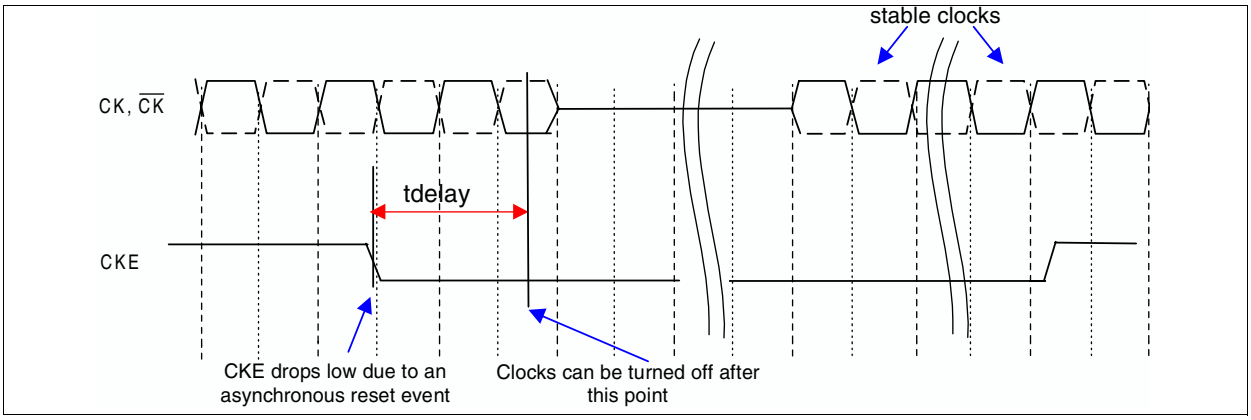


Figure 59 Asynchronous Low Reset Event

3.29 DLL off mode

For very low frequency operations between 50 MHz and 250 MHz the DLL off mode is supported. Entering this mode requires an Extended Mode Register Set command disabling the DLL by setting A0 to 1. For 250 MHz clock speed and faster DLL on mode operation is recommended.

Most of the commands and timings described in chapter 3 are also applicable for DLL off mode. Differences exist for the frequency range, the initialization and the timing of WR command and RD command.

3.29.1 DLL off Frequency Definition

Table 18 DLL off Frequency Definition

Speed Grade			–22		–25		–28		–33		Unit
Parameter		**Symbol**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**—**
Clock Frequency	@ CL = 6	t_{CK}	50	250	50	250	50	250	50	250	MHz

4 Truth Tables

Table 19 Command Truth Table

Function	CKE		CS	RAS	CAS	WE	BA0 BA1	A[13:11]	A10	A[9:0]	Note[1)2)3)]
	Previous Cycle	Current Cycle									
(Extended) Mode Register Set	H	H	L	L	L	L	BA	OP Code			4)5)
Auto-Refresh	H	H	L	L	L	H	X	X	X	X	4)
Self-Refresh Entry	H	L	L	L	L	H	X	X	X	X	4)6)
Self-Refresh Exit	L	H	H	X	X	X	X	X	X	X	4)6)7)
			L	H	H	H					
Single Bank Precharge	H	H	L	L	H	L	BA	X	L	X	4)5)
Precharge all Banks	H	H	L	L	H	L	X	X	H	X	4)
Bank Activate	H	H	L	L	H	H	BA	Row Address			4)5)
Write	H	H	L	H	L	L	BA	Column	L	Column	4)5)8)
Write with Auto-Precharge	H	H	L	H	L	L	BA	Column	H	Column	4)5)8)
Read	H	H	L	H	L	H	BA	Column	L	Column	4)5)8)
Read with Auto-Precharge	H	H	L	H	L	H	BA	Column	H	Column	4)5)8)
No Operation	H	X	L	H	H	H	X	X	X	X	4)
Device Deselect	H	X	H	X	X	X	X	X	X	X	4)
Power Down Entry	H	L	H	X	X	X	X	X	X	X	4)9)
			L	H	H	H					
Power Down Exit	L	H	H	X	X	X	X	X	X	X	4)9)
			L	H	H	H					

1) The state of ODT does not affect the states described in this table. The ODT function is not available during Self Refresh.
2) "X" means "H or L (but a defined logic level)".
3) Operation that is not specified is illegal and after such an event, in order to guarantee proper operation, the DRAM must be powered down and then restarted through the specified initialization sequence before normal operation can continue.
4) All DDR2 SDRAM commands are defined by states of $\overline{CS}$, $\overline{WE}$, $\overline{RAS}$, $\overline{CAS}$, and CKE at the rising edge of the clock.
5) Bank addresses BA[1:0] determine which bank is to be operated upon. For (E)MRS BA[1:0] selects an (Extended) Mode Register.
6) V_{REF} must be maintained during Self Refresh operation.
7) Self Refresh Exit is asynchronous.
8) Burst reads or writes at BL = 4 cannot be terminated. See **Chapter 3.21** for details.
9) The Power Down Mode does not perform any refresh operations. The duration of Power Down is therefore limited by the refresh requirements outlined in **Chapter 3.28**

Table 20 Clock Enable (CKE) Truth Table for Synchronous Transitions

Current State[1]	CKE		Command (N)[2)3)] RAS, CAS, WE, CS	Action (N)[2)]	Note[4)5)]
	Previous Cycle[6)] (N-1)	Current Cycle[6)] (N)			
Power-Down	L	L	X	Maintain Power-Down	7)8)11)
	L	H	DESELECT or NOP	Power-Down Exit	7)9)10)11)
Self Refresh	L	L	X	Maintain Self Refresh	8)11)12)
	L	H	DESELECT or NOP	Self Refresh Exit	9)12)13)14)
Bank(s) Active	H	L	DESELECT or NOP	Active Power-Down Entry	7)9)10)11)15)
All Banks Idle	H	L	DESELECT or NOP	Precharge Power-Down Entry	9)10)11)15)
	H	L	AUTOREFRESH	Self Refresh Entry	7)11)14)16)
Any State other than listed above	H	H	Refer to the Command Truth Table		17)

1) Current state is the state of the DDR2 SDRAM immediately prior to clock edge N.
2) Command (N) is the command registered at clock edge N, and Action (N) is a result of Command (N)
3) The state of ODT does not affect the states described in this table. The ODT function is not available during Self Refresh. See **Chapter 3.13**.
4) CKE must be maintained HIGH while the device is in OCD calibration mode.
5) Operation that is not specified is illegal and after such an event, in order to guarantee proper operation, the DRAM must be powered down and then restarted through the specified initialization sequence before normal operation can continue.
6) CKE (N) is the logic state of CKE at clock edge N; CKE (N-1) was the state of CKE at the previous clock edge.
7) The Power-Down Mode does not perform any refresh operations. The duration of Power-Down Mode is therefor limited by the refresh requirements
8) "X" means "don't care (including floating around V_{REF})" in Self Refresh and Power Down. However ODT must be driven HIGH or LOW in Power Down if the ODT function is enabled (Bit A2 or A6 set to "1" in EMRS(1)).
9) All states and sequences not shown are illegal or reserved unless explicitly described elsewhere in this document.
10) Valid commands for Power-Down Entry and Exit are NOP and DESELECT only.
11) $t_{CKE.MIN}$ of 3 clocks means CKE must be registered on three consecutive positive clock edges. CKE must remain at the valid input level the entire time it takes to achieve the 3 clocks of registration. Thus, after any CKE transition, CKE may not transition from its valid level during the time period of $t_{IS} + 2 \times t_{CKE} + t_{IH}$.
12) V_{REF} must be maintained during Self Refresh operation.
13) On Self Refresh Exit DESELECT or NOP commands must be issued on every clock edge occurring during the tXSNR period. Read commands may be issued only after t_{XSRD} (200 clocks) is satisfied.
14) Valid commands for Self Refresh Exit are NOP and DESELCT only.
15) Power-Down and Self Refresh can not be entered while Read or Write operations, (Extended) mode Register operations, Precharge or Refresh operations are in progress. See **Chapter 3.25** and **Chapter 3.24.2** for a detailed list of restrictions.
16) Self Refresh mode can only be entered from the All Banks Idle state.
17) Must be a legal command as defined in the Command Truth Table.

Table 21 Data Mask (DM) Truth Table

Name (Function)	DM	DQs	Note
Write Enable	L	Valid	1)
Write Inhibit	H	X	1)

1) Used to mask write data; provided coincident with the corresponding data.

5 Electrical Characteristics

Table 22 DRAM Component Operating Temperature Range

Symbol	Parameter	Rating	Unit	Notes
T_{CASE}	Operating Temperature	0 to 95	°C	1)2)3)4)

1) Operating Temperature is the case surface temperature on the center / top side of the DRAM.
2) The operating temperature range are the temperatures where all DRAM specification will be supported. During operation, the DRAM case temperature must be maintained between 0 - 95 oC under all other specification parameters.
3) Above 85 °C case temperature the Auto-Refresh command interval has to be reduced to t_{REFI} = 3.9 µs.
4) When operating this product in the 85°C to 95°C T_{CASE} temperature range, the High Temperature Self Refresh has to be enabled by setting EMR(2) bit A7 to “1“. Note, when the High Temperature Self Refresh is enabled there is an increase of I_{DD6} by approximately 50%

5.1 Absolute Maximum Ratings

Table 23 Absolute Maximum Ratings

Symbol	Parameter	Rating		Unit	Notes
		min	max		
V_{DD}	Voltage on V_{DD} pin relative to V_{SS}	–1.0	2.3	V	1)
V_{DDQ}	Voltage on V_{DDQ} pin relative to V_{SS}	–0.5	2.3	V	1)
V_{DDL}	Voltage on VDDL pin relative to V_{SS}	–0.5	2.3	V	1)
V_{IN}, V_{OUT}	Voltage on any pin relative to V_{SS}	–0.5	2.3	V	1)
T_J	Junction Temperature		125	°C	1)
T_{STG}	Storage Temperature	–55	150	°C	1)2)

1) Stresses greater than those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.
2) Storage Temperature is the case surface temperature on the center/top side of the DRAM.

5.2 DC Characteristics

Table 24 Recommended DC Operating Conditions (SSTL_18)

Symbol	Parameter	Rating			Unit	Notes
		Min.	Typ.	Max.		
V_{DD}	Supply Voltage	1.7	1.8	1.9	V	1)2)
V_{DDDL}	Supply Voltage for DLL	1.7	1.8	1.9	V	1)2)
V_{DDQ}	Supply Voltage for Output	1.7	1.8	1.9	V	1)2)
V_{DD}	Supply Voltage	1.9	2.0	2.1	V	2)3)
V_{DDDL}	Supply Voltage for DLL	1.9	2.0	2.1	V	2)3)
V_{DDQ}	Supply Voltage for Output	1.9	2.0	2.1	V	2)3)
V_{REF}	Input Reference Voltage	$0.49 \times V_{DDQ}$	$0.5 \times V_{DDQ}$	$0.51 \times V_{DDQ}$	V	4)5)
V_{TT}	Termination Voltage	V_{REF} – 0.04	V_{REF}	V_{REF} + 0.04	V	6)

1) HYB18T512161BF–[25/28/33]

2) V_{DDQ} tracks with V_{DD}, V_{DDDL} tracks with V_{DD}. AC parameters are measured with V_{DD}, V_{DDQ} and V_{DDDL} tied together.

3) HYB18T512161BF–22

4) The value of V_{REF} may be selected by the user to provide optimum noise margin in the system. Typically the value of V_{REF} is expected to be about $0.5 \times V_{DDQ}$ of the transmitting device and V_{REF} is expected to track variations in V_{DDQ}.

5) Peak to peak ac noise on V_{REF} may not exceed ± 2% V_{REF} (dc)

6) V_{TT} is not applied directly to the device. V_{TT} is a system supply for signal termination resistors, is expected to be set equal to V_{REF}, and must track variations in die dc level of V_{REF}.

Table 25 ODT DC Electrical Characteristics

Parameter / Condition	Symbol	Min.	Nom.	Max.	Unit	Note
Termination resistor impedance value for EMRS(1)[A6,A2] = [0,1]; 75 Ohm	Rtt1(eff)	60	75	90	Ω	1)
Termination resistor impedance value for EMRS(1)[A6,A2] =[1,0]; 150 Ohm	Rtt2(eff)	120	150	180	Ω	1)
Termination resistor impedance value for EMRS(1)(A6,A2)=[1,1]; 50 Ohm	Rtt3(eff)	40	50	60	Ω	1)
Deviation of V_M with respect to V_{DDQ} / 2	delta V_M	–6.00	—	+ 6.00	%	2)

1) Measurement Definition for Rtt(eff): Apply $V_{IH(ac)}$ and $V_{IL(ac)}$ to test pin separately, then measure current $I(V_{IHac})$ and $I(V_{ILac})$ respectively. $Rtt(eff) = (V_{IH(ac)} – V_{IL(ac)}) / (I(V_{IHac}) – I(V_{ILac}))$.

2) Measurement Definition for V_M: Turn ODT on and measure voltage (V_M) at test pin (midpoint) with no load: $\text{delta } V_M = ((2 \times V_M / V_{DDQ}) – 1) \times 100\%$

Table 26 Input and Output Leakage Currents

Symbol	Parameter / Condition	Min.	Max.	Unit	Notes
IIL	Input Leakage Current; any input 0 V < VIN < V_{DD}	–2	+2	µA	1)
IOL	Output Leakage Current; 0 V < VOUT < V_{DDQ}	–5	+5	µA	2)

1) all other pins not under test = 0 V

2) DQ's, LDQS, $\overline{\text{LDQS}}$, UDQS, $\overline{\text{UDQS}}$, DQS, $\overline{\text{DQS}}$, RDQS, $\overline{\text{RDQS}}$ are disabled and ODT is turned off

5.3 DC & AC Characteristics

DDR2 SDRAM pin timing are specified for either single ended or differential mode depending on the setting of the EMRS(1) "Enable $\overline{DQS}$" mode bit; timing advantages of differential mode are realized in system design. The method by which the DDR2 SDRAM pin timing are measured is mode dependent. In single ended mode, timing relationships are measured relative to the rising or falling edges of DQS crossing at V_{REF}. In differential mode, these timing relationships are measured relative to the crosspoint of DQS and its complement, $\overline{DQS}$. This distinction in timing methods is verified by design and characterization but not subject to production test. In single ended mode, the $\overline{DQS}$ (and $\overline{RDQS}$) signals are internally disabled and don't care.

Table 27 DC & AC Logic Input Levels for DDR2-800

Symbol	Parameter	DDR2-800		Units
		Min.	Max.	
$V_{IH(dc)}$	DC input logic high	V_{REF} + 0.125	V_{DDQ} + 0.3	V
$V_{IL(dc)}$	DC input low	–0.3	V_{REF} – 0.125	V
$V_{IH(ac)}$	AC input logic high	V_{REF} + 0.250	—	V
$V_{IL(ac)}$	AC input low	—	V_{REF} – 0.250	V

Table 28 Single-ended AC Input Test Conditions

Symbol	Condition	Value	Unit	Notes
V_{REF}	Input reference voltage	0.5 x V_{DDQ}	V	1)
$V_{SWING.MAX}$	Input signal maximum peak to peak swing	1.0	V	1)
SLEW	Input signal minimum Slew Rate	1.0	V / ns	2)3)

1) Input waveform timing is referenced to the input signal crossing through the V_{REF} level applied to the device under test.
2) The input signal minimum Slew Rate is to be maintained over the range from $V_{IH(ac).MIN}$ to V_{REF} for rising edges and the range from V_{REF} to $V_{IL(ac).MAX}$ for falling edges as shown in **Figure 60**
3) AC timings are referenced with input waveforms switching from $V_{IL(ac)}$ to $V_{IH(ac)}$ on the positive transitions and $V_{IH(ac)}$ to $V_{IL(ac)}$ on the negative transitions.

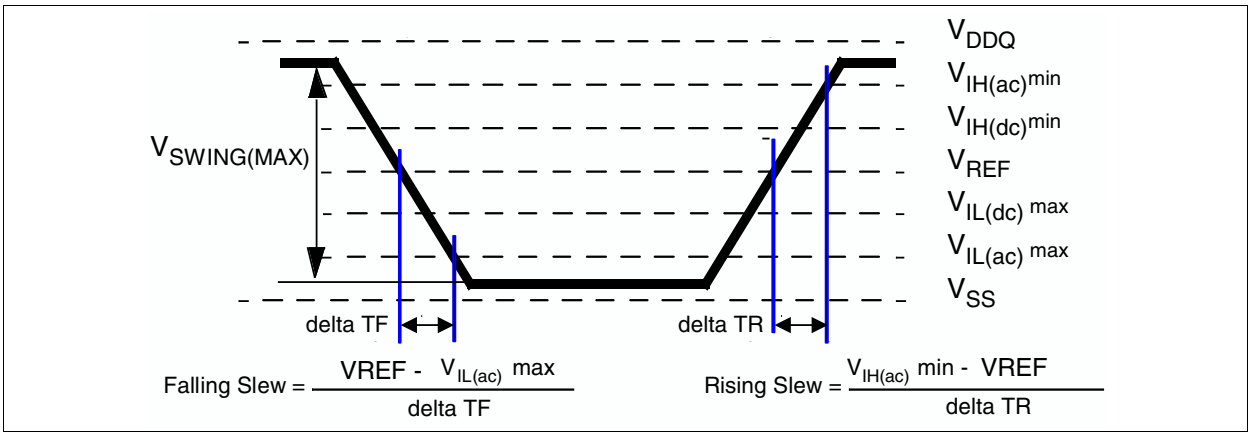


Figure 60 Single-ended AC Input Test Conditions Diagram

Table 29 Differential DC and AC Input and Output Logic Levels

Symbol	Parameter	Min.	Max.	Unit	Notes
$V_{IN(dc)}$	DC input signal voltage	–0.3	V_{DDQ} + 0.3	—	1)
$V_{ID(dc)}$	DC differential input voltage	0.25	V_{DDQ} + 0.6	—	2)
$V_{ID(ac)}$	AC differential input voltage	0.5	V_{DDQ} + 0.6	V	3)
$V_{IX(ac)}$	AC differential cross point input voltage	$0.5 \times V_{DDQ}$ – 0.175	$0.5 \times V_{DDQ}$ + 0.175	V	4)
$V_{OX(ac)}$	AC differential cross point output voltage	$0.5 \times V_{DDQ}$ – 0.125	$0.5 \times V_{DDQ}$ + 0.125	V	5)

1) $V_{IN(dc)}$ specifies the allowable DC execution of each input of differential pair such as CK, $\overline{CK}$, DQS, $\overline{DQS}$ etc.
2) $V_{ID(dc)}$ specifies the input differential voltage $V_{TR} - V_{CP}$ required for switching. The minimum value is equal to $V_{IH(dc)} - V_{IL(dc)}$.
3) $V_{ID(ac)}$ specifies the input differential voltage $V_{TR} - V_{CP}$ required for switching. The minimum value is equal to $V_{IH(ac)} - V_{IL(ac)}$.
4) The value of $V_{IX(ac)}$ is expected to equal $0.5 \times V_{DDQ}$ of the transmitting device and $V_{IX(ac)}$ is expected to track variations in V_{DDQ}. $V_{IX(ac)}$ indicates the voltage at which differential input signals must cross.
5) The value of $V_{OX(ac)}$ is expected to equal $0.5 \times V_{DDQ}$ of the transmitting device and $V_{OX(ac)}$ is expected to track variations in V_{DDQ}. $V_{OX(ac)}$ indicates the voltage at which differential input signals must cross.

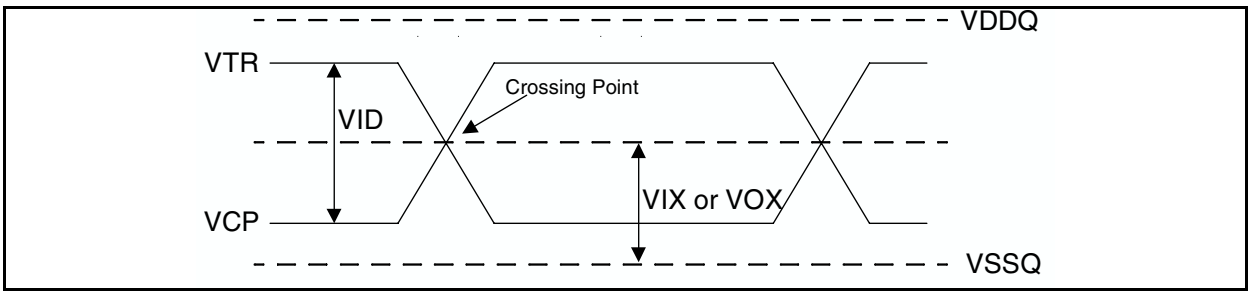


Figure 61 Differential DC and AC Input and Output Logic Levels Diagram

5.4 Output Buffer Characteristics

Table 30 Full Strength Calibrated Pull-up Driver Characteristics

Voltage (V)	Calibrated Pull-up Driver Current [mA]				
	Nominal Minimum[1] (21 Ohms)	Nominal Low[2] (18.75 Ohms)	Nominal (18 ohms)[3]	Nominal High[2] (17.25 Ohms)	Nominal Maximum[4] (15 Ohms)
0.2	–9.5	–10.7	–11.4	–11.8	–13.3
0.3	–14.3	–16.0	–16.5	–17.4	–20.0
0.4	–18.3	–21.0	–21.2	–23.0	–27.0

1) The driver characteristics evaluation conditions are Nominal Minimum 95 °C (T_{CASE}). V_{DDQ} = 1.7 V, any process
2) The driver characteristics evaluation conditions are Nominal Low and Nominal High 25 °C (T_{CASE}), V_{DDQ} = 1.8 V, any process
3) The driver characteristics evaluation conditions are Nominal 25 °C (T_{CASE}), V_{DDQ} = 1.8 V, typical process
4) The driver characteristics evaluation conditions are Nominal Maximum 0 °C (T_{CASE}), V_{DDQ} = 1.9 V, any process

Table 31 Full Strength Calibrated Pull-down Driver Characteristics

Voltage (V)	Calibrated Pull-down Driver Current [mA]				
	Nominal Minimum[1] (21 Ohms)	Nominal Low[2] (18.75 Ohms)	Nominal[3] (18 ohms)	Nominal High[2] (17.25 Ohms)	Nominal Maximum[4] (15 Ohms)
0.2	9.5	10.7	11.5	11.8	13.3
0.3	14.3	16.0	16.6	17.4	20.0
0.4	18.7	21.0	21.6	23.0	27.0

1) The driver characteristics evaluation conditions are Nominal Minimum 95 °C (T_{CASE}). V_{DDQ} = 1.7 V, any process
2) The driver characteristics evaluation conditions are Nominal Low and Nominal High 25 °C (T_{CASE}), V_{DDQ} = 1.8V, any process
3) The driver characteristics evaluation conditions are Nominal 25 °C (T_{CASE}), V_{DDQ} = 1.8 V, typical process
4) The driver characteristics evaluation conditions are Nominal Maximum 0 °C (T_{CASE}), V_{DDQ} = 1.9 V, any process

5.5 Input / Output Capacitance

Table 32 Input / Output Capacitance

Symbol	Parameter	Min.	Max.	Unit
CCK	Input capacitance, CK and $\overline{CK}$	1.0	2.0	pF
CDCK	Input capacitance delta, CK and $\overline{CK}$	—	0.25	pF
CI	Input capacitance, all other input-only pins	1.0	1.75	pF
CDI	Input capacitance delta, all other input-only pins	—	0.25	pF
CIO	Input/output capacitance, DQ, DM, DQS, $\overline{DQS}$, RDQS, $\overline{RDQS}$	2.5	3.5	pF
CDIO	Input/output capacitance delta, DQ, DM, DQS, $\overline{DQS}$, RDQS, $\overline{RDQS}$	—	0.5	pF

5.6 Overshoot and Undershoot Specification

Table 33 AC Overshoot / Undershoot Specification for Address and Control Pins

Parameter	–22	–25	–28	–33	Unit
Maximum peak amplitude allowed for overshoot area	0.5	0.5	0.5	0.5	V
Maximum peak amplitude allowed for undershoot area	0.5	0.5	0.5	0.5	V
Maximum overshoot area above V_{DD}	0.80	0.80	0.80	0.80	V.ns
Maximum undershoot area below V_{SS}	0.80	0.80	0.80	0.80	V.ns

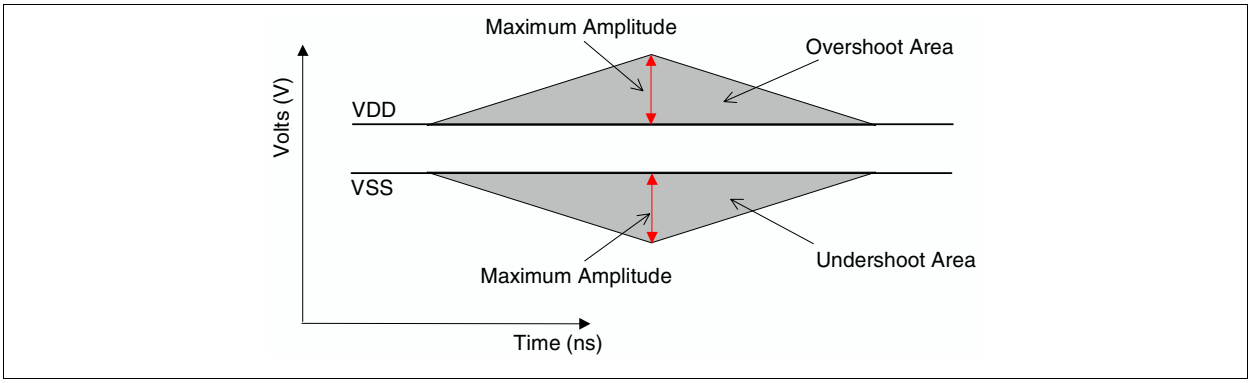


Figure 62 AC Overshoot / Undershoot Diagram for Address and Control Pins

Table 34 AC Overshoot / Undershoot Specification for Clock, Data, Strobe and Mask Pins

Parameter	–22	–25	–28	–33	Unit
Maximum peak amplitude allowed for overshoot area	0.9	0.9	0.9	0.9	V
Maximum peak amplitude allowed for undershoot area	0.9	0.9	0.9	0.9	V
Maximum overshoot area above V_{DDQ}	0.23	0.23	0.23	0.23	V.ns
Maximum undershoot area below V_{SSQ}	0.23	0.23	0.23	0.23	V.ns

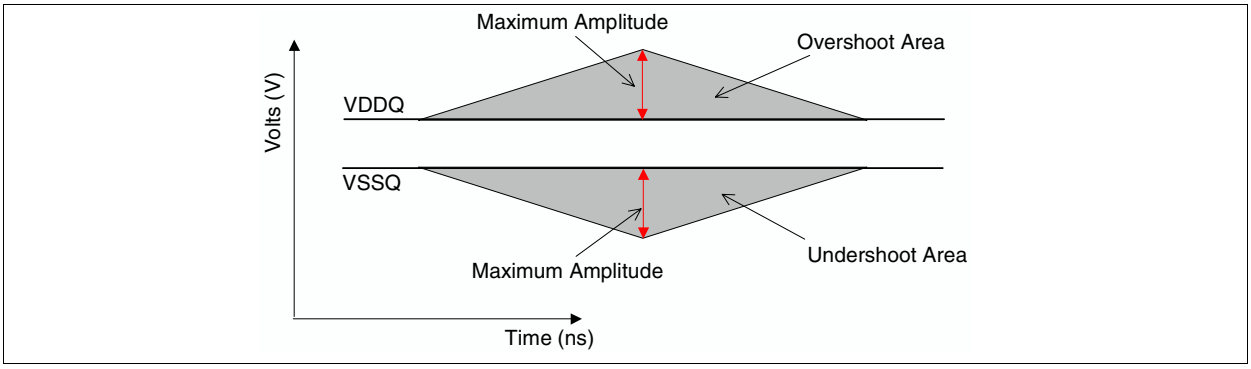


Figure 63 AC Overshoot / Undershoot Diagram for Clock, Data, Strobe and Mask Pins

5.7 AC Characteristics

5.7.1 Speed Grade Definitions

Table 35 Speed Grade Definition

Speed Grade			–22		–25		–28		–33		Unit	Note
Parameter		**Symbol**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**		
Clock Frequency	@ CL = 3	t_{CK}	3.75	8	3.75	8	3.75	8	3.75	8	ns	1)2)3)4)
	@ CL = 4	t_{CK}	3.75	8	3.75	8	3.75	8	3.75	8	ns	1)2)3)4)
	@ CL = 5	t_{CK}	3	8	3	8	3	8	3.33	8	ns	1)2)3)4)
	@ CL = 6	t_{CK}	2.5	8	2.5	8	2.8	8	3.33	8	ns	1)2)3)4)
	@ CL = 7	t_{CK}	2.2	8	—	—	—	—	—	—	ns	1)2)3)4)
Row Active Time		t_{RAS}	45	70000	45	70000	45	70000	45	70000	ns	1)2)3)4) 5)
Row Cycle Time		t_{RC}	60	—	60	—	60	—	60	—	ns	1)2)3)4)
RAS-CAS-Delay		t_{RCD}	15	—	15	—	15	—	15	—	ns	1)2)3)4)
Row Precharge Time		t_{RP}	15	—	15	—	15	—	15	—	ns	1)2)3)4)

1) Timings are guaranteed with CK/$\overline{CK}$ differential Slew Rate of 2.0 V/ns. For DQS signals timings are guaranteed with a differential Slew Rate of 2.0 V/ns in differential strobe mode and a Slew Rate of 1 V/ns in single ended mode. For other Slew Rates see Chapter 8Timings are further guaranteed for normal OCD drive strength (EMRS(1) A1 = 0) under the “Reference Load for Timing Measurements” according to Chapter 8.1 only.

2) The CK/$\overline{CK}$ input reference level (for timing reference to CK/$\overline{CK}$) is the point at which CK and $\overline{CK}$ cross. The DQS / $\overline{DQS}$, RDQS / $\overline{RDQS}$, input reference level is the crosspoint when in differential strobe mode; The input reference level for signals other than CK/CK, DQS / DQS, RDQS / RDQS is defined in Chapter 8.3.

3) Inputs are not recognized as valid until V_{REF} stabilizes. During the period before V_{REF} stabilizes, CKE = 0.2 x V_{DDQ} is recognized as low.

4) The output timing reference voltage level is V_{TT}. See section 8 for the reference load for timing measurements.

5) $t_{RAS.MAX}$ is calculated from the maximum amount of time a DDR2 device can operate without a refresh command which is equal to 9 x t_{REFI}.

5.7.2 AC Timing Parameters

List of Timing Parameters

Table 36 Timing Parameter by Speed Grade

Parameter	Symbol	–22		–25		Unit	Notes 1)2)3)4) 5)6)
		Min.	Max.	Min.	Max.		
DQ output access time from CK / $\overline{CK}$	t_{AC}	–450	+450	–500	+500	ps	
$\overline{CAS}$ A to $\overline{CAS}$ B command period	t_{CCD}	2	—	2	—	t_{CK}	
CK, $\overline{CK}$ high-level width	t_{CH}	0.45	0.55	0.45	0.55	t_{CK}	
CKE minimum high and low pulse width	t_{CKE}	3	—	3	—	t_{CK}	
CK, $\overline{CK}$ low-level width	t_{CL}	0.45	0.55	0.45	0.55	t_{CK}	
Auto-Precharge write recovery + precharge time	t_{DAL}	WR + t_{RP}	—	WR + t_{RP}	—	t_{CK}	7)18)
Minimum time clocks remain ON after CKE asynchronously drops LOW	t_{DELAY}	t_{IS} + t_{CK} + t_{IH}	—	t_{IS} + t_{CK} + t_{IH}	—	ns	8)
DQ and DM input hold time (differential data strobe)	t_{DH}	345	—	375	—	ps	9)
DQ and DM input hold time (single ended data strobe)	t_{DH1}	345	—	375	—	ps	9)
DQ and DM input pulse width (each input)	t_{DIPW}	0.35	—	0.35	—	t_{CK}	
DQS output access time from CK / $\overline{CK}$	t_{DQSCK}	–450	+450	–500	+500	ps	9)
DQS input low (high) pulse width (write cycle)	$t_{DQSL,H}$	0.35	—	0.35	—	t_{CK}	
DQS-DQ skew (for DQS & associated DQ signals)	t_{DQSQ}	—	450	—	450	ps	10)
Write command to 1st DQS latching transition	t_{DQSS}	WL – 0.25	WL + 0.25	WL – 0.25	WL + 0.25	t_{CK}	
DQ and DM input setup time (differential data strobe)	t_{DS}	345	—	375	—	ps	9)
DQ and DM input setup time (single ended data strobe)	t_{DS1}	345	—	375	—	ps	9)
DQS falling edge hold time from CK (write cycle)	t_{DSH}	0.2	—	0.2	—	t_{CK}	
DQS falling edge to CK setup time (write cycle)	t_{DSS}	0.2	—	0.2	—	t_{CK}	
Clock half period	t_{HP}	MIN. (t_{CL}, t_{CH})		MIN. (t_{CL}, t_{CH})			11)
Data-out high-impedance time from CK / $\overline{CK}$	t_{HZ}	—	$t_{AC.MAX}$	—	$t_{AC.MAX}$	ps	12)
Address and control input hold time	t_{IH}	650	—	700	—	ps	
Address and control input pulse width (each input)	t_{IPW}	0.6	—	0.6	—	t_{CK}	
Address and control input setup time	t_{IS}	650	—	700	—	ps	
DQ low-impedance time from CK / $\overline{CK}$	$t_{LZ(DQ)}$	2 × $t_{AC.MIN}$	$t_{AC.MAX}$	2 × $t_{AC.MIN}$	$t_{AC.MAX}$	ps	12)
DQS low-impedance from CK / $\overline{CK}$	$t_{LZ(DQS)}$	$t_{AC.MIN}$	$t_{AC.MAX}$	$t_{AC.MIN}$	$t_{AC.MAX}$	ps	12)
Mode register set command cycle time	t_{MRD}	2	—	2	—	t_{CK}	

Table 36 Timing Parameter by Speed Grade

Parameter	Symbol	–22		–25		Unit	Notes 1)2)3)4) 5)6)
		Min.	Max.	Min.	Max.		
OCD drive mode output delay	t_{OIT}	0	12	0	12	ns	
Data output hold time from DQS	t_{QH}	t_{HP}–t_{QHS}	—	t_{HP}–t_{QHS}	—		
Data hold skew factor	t_{QHS}	—	600	—	600	ps	
Average periodic refresh Interval	t_{REFI}	—	7.8	—	7.8	µs	13)14)
		—	3.9	—	3.9	µs	13)15)
Auto-Refresh to Active/Auto-Refresh command period	t_{RFC}	105	—	105	—	ns	16)
Read preamble	t_{RPRE}	0.9	1.1	0.9	1.1	t_{CK}	12)
Read postamble	t_{RPST}	0.40	0.60	0.40	0.60	t_{CK}	12)
Active bank A to Active bank B command period	t_{RRD}	10	—	10	—	ns	14)17)
Internal Read to Precharge command delay	t_{RTP}	7.5	—	7.5	—	ns	
Write preamble	t_{WPRE}	0.35 x t_{CK}	—	0.35 x t_{CK}	—	t_{CK}	
Write postamble	t_{WPST}	0.40	0.60	0.40	0.60	t_{CK}	17)
Write recovery time for write without Auto-Precharge	t_{WR}	13	—	15	—	ns	
Write recovery time for write with Auto-Precharge	WR	t_{WR}/t_{CK}		t_{WR}/t_{CK}		t_{CK}	18)
Internal Write to Read command delay	t_{WTR}	7.5	—	7.5	—	ns	19)
Exit power down to any valid command (other than NOP or Deselect)	t_{XARD}	2	—	2	—	t_{CK}	20)
Exit active power-down mode to Read command (slow exit, lower power)	t_{XARDS}	9 – AL	—	8 – AL	—	t_{CK}	20)
Exit precharge power-down to any valid command (other than NOP or Deselect)	t_{XP}	2	—	2	—	t_{CK}	
Exit Self-Refresh to non-Read command	t_{XSNR}	t_{RFC} +10	—	t_{RFC} +10	—	ns	
Exit Self-Refresh to Read command	t_{XSRD}	200	—	200	—	t_{CK}	

1) V_{DDQ}, V_{DD} refer to **Chapter 1**.
2) Timing that is not specified is illegal and after such an event, in order to guarantee proper operation, the DRAM must be powered down and then restarted through the specified initialization sequence before normal operation can continue.
3) Timings are guaranteed with CK/$\overline{CK}$ differential Slew Rate of 2.0 V/ns. For DQS signals timings are guaranteed with a differential Slew Rate of 2.0 V/ns in differential strobe mode and a Slew Rate of 1 V/ns in single ended mode. For other Slew Rates see **Chapter 5** of this data sheet.
4) The CK / $\overline{CK}$ input reference level (for timing reference to CK / $\overline{CK}$) is the point at which CK and $\overline{CK}$ cross.
The DQS / $\overline{DQS}$, RDQS/ $\overline{RDQS}$, input reference level is the crosspoint when in differential strobe mode;
The input reference level for signals other than CK/$\overline{CK}$, DQS / $\overline{DQS}$, RDQS / $\overline{RDQS}$ is defined in **Chapter 5.3** of this data sheet.
5) Inputs are not recognized as valid until V_{REF} stabilizes. During the period before V_{REF} stabilizes, CKE = 0.2 x V_{DDQ} is recognized as low.
6) The output timing reference voltage level is V_{TT}. See **Chapter 5** for the reference load for timing measurements.
7) For each of the terms, if not already an integer, round to the next highest integer. t_{CK} refers to the application clock period. WR refers to the WR parameter stored in the MR.
8) The clock frequency is allowed to change during self-refresh mode or precharge power-down mode. In case of clock frequency change during power-down, a specific procedure is required as described in **Chapter 3.27**.

9) timing is referenced to vref-crossing; minimal Slewrate at input pin should be 3V/ns
10) Consists of data pin skew and output pattern effects, and p-channel to n-channel variation of the output drivers as well as output Slew Rate mis-match between DQS / $\overline{\text{DQS}}$ and associated DQ in any given cycle.
11) MIN (t_{CL}, t_{CH}) refers to the smaller of the actual clock low time and the actual clock high time as provided to the device (i.e. this value can be greater than the minimum specification limits for t_{CL} and t_{CH}).
12) The t_{HZ}, t_{RPST} and t_{LZ}, t_{RPRE} parameters are referenced to a specific voltage level, which specify when the device output is no longer driving ($t_{HZ,}$ t_{RPST}), or begins driving ($t_{LZ,}$ t_{RPRE}). t_{HZ} and t_{LZ} transitions occur in the same access time windows as valid data transitions.These parameters are verified by design and characterization, but not subject to production test.
13) The Auto-Refresh command interval has be reduced to 3.9 µs when operating the DDR2 DRAM in a temperature range between 85 °C and 95 °C.
14)0 °C ≤ T_{CASE} ≤ 85 °C
15) 85 °C < T_{CASE} ≤ 95 °C
16) A maximum of eight Auto-Refresh commands can be posted to any given DDR2 SDRAM device.
17) The maximum limit for the t_{WPST} parameter is not a device limit. The device operates with a greater value for this parameter, but system performance (bus turnaround) degrades accordingly.
18) WR must be programmed to fulfill the minimum requirement for the t_{WR} timing parameter, where WR_{MIN}[cycles] = t_{WR}(ns)/t_{CK}(ns) rounded up to the next integer value. t_{DAL} = WR + (t_{RP}/t_{CK}). For each of the terms, if not already an integer, round to the next highest integer. t_{CK} refers to the application clock period. WR refers to the WR parameter stored in the MRS.
19) Minimum t_{WTR} is two clocks when operating the DDR2-SDRAM at frequencies ≤ 200 MHz.
20) User can choose two different active power-down modes for additional power saving via MRS address bit A12. In “standard active power-down mode” (MR, A12 = “0”) a fast power-down exit timing t_{XARD} can be used. In “low active power-down mode” (MR, A12 =”1”) a slow power-down exit timing t_{XARDS} has to be satisfied.

Table 37 Timing Parameter by Speed Grade

Parameter	Symbol	–28		–33		Unit	Notes 1)2)3)4) 5)6)
		Min.	Max.	Min.	Max.		
DQ output access time from CK / $\overline{\text{CK}}$	t_{AC}	–550	+550	–600	+600	ps	
$\overline{\text{CAS}}$ A to $\overline{\text{CAS}}$ B command period	t_{CCD}	2	—	2	—	t_{CK}	
CK, $\overline{\text{CK}}$ high-level width	t_{CH}	0.45	0.55	0.45	0.55	t_{CK}	
CKE minimum high and low pulse width	t_{CKE}	3	—	3	—	t_{CK}	
CK, $\overline{\text{CK}}$ low-level width	t_{CL}	0.45	0.55	0.45	0.55	t_{CK}	
Auto-Precharge write recovery + precharge time	t_{DAL}	WR + t_{RP}	—	WR + t_{RP}	—	t_{CK}	7)18)
Minimum time clocks remain ON after CKE asynchronously drops LOW	t_{DELAY}	t_{IS} + t_{CK} + t_{IH}	—	t_{IS} + t_{CK} + t_{IH}	—	ns	8)
DQ and DM input hold time (differential data strobe)	t_{DH}	400	—	420	—	ps	9)
DQ and DM input hold time (single ended data strobe)	t_{DH1}	400	—	420	—	ps	9)
DQ and DM input pulse width (each input)	t_{DIPW}	0.35	—	0.35	—	t_{CK}	
DQS output access time from CK / $\overline{\text{CK}}$	t_{DQSCK}	–550	+550	–600	+600	ps	9)
DQS input low (high) pulse width (write cycle)	$t_{DQSL,H}$	0.35	—	0.35	—	t_{CK}	
DQS-DQ skew (for DQS & associated DQ signals)	t_{DQSQ}	—	450	—	450	ps	10)
Write command to 1st DQS latching transition	t_{DQSS}	WL – 0.25	WL + 0.25	WL – 0.25	WL + 0.25	t_{CK}	

Table 37 Timing Parameter by Speed Grade

Parameter	Symbol	–28		–33		Unit	Notes 1)2)3)4) 5)6)
		Min.	Max.	Min.	Max.		
DQ and DM input setup time (differential data strobe)	t_{DS}	400	—	420	—	ps	9)
DQ and DM input setup time (single ended data strobe)	t_{DS1}	400	—	420	—	ps	9)
DQS falling edge hold time from CK (write cycle)	t_{DSH}	0.2	—	0.2	—	t_{CK}	
DQS falling edge to CK setup time (write cycle)	t_{DSS}	0.2	—	0.2	—	t_{CK}	
Clock half period	t_{HP}	MIN. (t_{CL}, t_{CH})		MIN. (t_{CL}, t_{CH})			11)
Data-out high-impedance time from CK / $\overline{CK}$	t_{HZ}	—	$t_{AC.MAX}$	—	$t_{AC.MAX}$	ps	12)
Address and control input hold time	t_{IH}	750	—	800	—	ps	
Address and control input pulse width (each input)	t_{IPW}	0.6	—	0.6	—	t_{CK}	
Address and control input setup time	t_{IS}	750	—	800	—	ps	
DQ low-impedance time from CK / $\overline{CK}$	$t_{LZ(DQ)}$	2 × $t_{AC.MIN}$	$t_{AC.MAX}$	2 × $t_{AC.MIN}$	$t_{AC.MAX}$	ps	12)
DQS low-impedance from CK / $\overline{CK}$	$t_{LZ(DQS)}$	$t_{AC.MIN}$	$t_{AC.MAX}$	$t_{AC.MIN}$	$t_{AC.MAX}$	ps	12)
Mode register set command cycle time	t_{MRD}	2	—	2	—	t_{CK}	
OCD drive mode output delay	t_{OIT}	0	12	0	12	ns	
Data output hold time from DQS	t_{QH}	t_{HP}–t_{QHS}	—	t_{HP}–t_{QHS}	—		
Data hold skew factor	t_{QHS}	—	600	—	600	ps	
Average periodic refresh Interval	t_{REFI}	—	7.8	—	7.8	µs	13)14)
		—	3.9	—	3.9	µs	13)15)
Auto-Refresh to Active/Auto-Refresh command period	t_{RFC}	105	—	105	—	ns	16)
Read preamble	t_{RPRE}	0.9	1.1	0.9	1.1	t_{CK}	12)
Read postamble	t_{RPST}	0.40	0.60	0.40	0.60	t_{CK}	12)
Active bank A to Active bank B command period	t_{RRD}	10	—	10	—	ns	14)17)
Internal Read to Precharge command delay	t_{RTP}	7.5	—	7.5	—	ns	
Write preamble	t_{WPRE}	0.35 x t_{CK}	—	0.35 x t_{CK}	—	t_{CK}	
Write postamble	t_{WPST}	0.40	0.60	0.40	0.60	t_{CK}	17)
Write recovery time for write without Auto-Precharge	t_{WR}	15	—	15	—	ns	
Write recovery time for write with Auto-Precharge	WR	t_{WR}/t_{CK}		t_{WR}/t_{CK}		t_{CK}	18)
Internal Write to Read command delay	t_{WTR}	7.5	—	7.5	—	ns	19)
Exit power down to any valid command (other than NOP or Deselect)	t_{XARD}	2	—	2	—	t_{CK}	20)
Exit active power-down mode to Read command (slow exit, lower power)	t_{XARDS}	7 – AL	—	6 – AL	—	t_{CK}	20)

Table 37 Timing Parameter by Speed Grade

Parameter	Symbol	–28		–33		Unit	Notes 1)2)3)4) 5)6)
		Min.	Max.	Min.	Max.		
Exit precharge power-down to any valid command (other than NOP or Deselect)	t_{XP}	2	—	2	—	t_{CK}	
Exit Self-Refresh to non-Read command	t_{XSNR}	t_{RFC} +10	—	t_{RFC} +10	—	ns	
Exit Self-Refresh to Read command	t_{XSRD}	200	—	200	—	t_{CK}	

1) V_{DDQ}, V_{DD} refer to **Chapter 1**.
2) Timing that is not specified is illegal and after such an event, in order to guarantee proper operation, the DRAM must be powered down and then restarted through the specified initialization sequence before normal operation can continue.
3) Timings are guaranteed with CK/$\overline{CK}$ differential Slew Rate of 2.0 V/ns. For DQS signals timings are guaranteed with a differential Slew Rate of 2.0 V/ns in differential strobe mode and a Slew Rate of 1 V/ns in single ended mode. For other Slew Rates see **Chapter 5** of this data sheet.
4) The CK / $\overline{CK}$ input reference level (for timing reference to CK / $\overline{CK}$) is the point at which CK and $\overline{CK}$ cross.
The DQS / $\overline{DQS}$, RDQS/ $\overline{RDQS}$, input reference level is the crosspoint when in differential strobe mode;
The input reference level for signals other than CK/$\overline{CK}$, DQS / $\overline{DQS}$, RDQS / $\overline{RDQS}$ is defined in **Chapter 5.3** of this data sheet.
5) Inputs are not recognized as valid until V_{REF} stabilizes. During the period before V_{REF} stabilizes, CKE = 0.2 x V_{DDQ} is recognized as low.
6) The output timing reference voltage level is V_{TT}. See **Chapter 5**for the reference load for timing measurements.
7) For each of the terms, if not already an integer, round to the next highest integer. t_{CK} refers to the application clock period. WR refers to the WR parameter stored in the MR.
8) The clock frequency is allowed to change during self-refresh mode or precharge power-down mode. In case of clock frequency change during power-down, a specific procedure is required as described in **Chapter 3.27**.
9) timing is referenced to vref-crossing; minimal Slewrate at input pin should be 3V/ns
10) Consists of data pin skew and output pattern effects, and p-channel to n-channel variation of the output drivers as well as output Slew Rate mis-match between DQS / $\overline{DQS}$ and associated DQ in any given cycle.
11) MIN (t_{CL}, t_{CH}) refers to the smaller of the actual clock low time and the actual clock high time as provided to the device (i.e. this value can be greater than the minimum specification limits for t_{CL} and t_{CH}).
12) The t_{HZ}, t_{RPST} and t_{LZ}, t_{RPRE} parameters are referenced to a specific voltage level, which specify when the device output is no longer driving ($t_{HZ,}$ t_{RPST}), or begins driving ($t_{LZ,}$ t_{RPRE}). t_{HZ} and t_{LZ} transitions occur in the same access time windows as valid data transitions.These parameters are verified by design and characterization, but not subject to production test.
13) The Auto-Refresh command interval has be reduced to 3.9 µs when operating the DDR2 DRAM in a temperature range between 85 °C and 95 °C.
14) 0 °C ≤ T_{CASE} ≤ 85 °C
15) 85 °C < T_{CASE} ≤ 95 °C
16) A maximum of eight Auto-Refresh commands can be posted to any given DDR2 SDRAM device.
17) The maximum limit for the t_{WPST} parameter is not a device limit. The device operates with a greater value for this parameter, but system performance (bus turnaround) degrades accordingly.
18) WR must be programmed to fulfill the minimum requirement for the t_{WR} timing parameter, where WR_{MIN}[cycles] = t_{WR}(ns)/t_{CK}(ns) rounded up to the next integer value. t_{DAL} = WR + (t_{RP}/t_{CK}). For each of the terms, if not already an integer, round to the next highest integer. t_{CK} refers to the application clock period. WR refers to the WR parameter stored in the MRS.
19) Minimum t_{WTR} is two clocks when operating the DDR2-SDRAM at frequencies ≤ 200 MHz.
20) User can choose two different active power-down modes for additional power saving via MRS address bit A12. In “standard active power-down mode” (MR, A12 = “0”) a fast power-down exit timing t_{XARD} can be used. In “low active power-down mode” (MR, A12 =”1”) a slow power-down exit timing t_{XARDS} has to be satisfied.

5.7.3 ODT AC Electrical Characteristics

Table 38 ODT AC Electrical Characteristics and Operating Conditions for all bins

Symbol	Parameter / Condition			Unit	Note
		Min.	Max.		
t_{AOND}	ODT turn-on delay	2	2	t_{CK}	
t_{AON}	ODT turn-on	$t_{AC.MIN}$	$t_{AC.MAX}$ + 0.7 ns	ns	1)
t_{AONPD}	ODT turn-on (Power-Down Modes)	$t_{AC.MIN}$ + 2 ns	2 t_{CK} + $t_{AC.MAX}$ + 1 ns	ns	
t_{AOFD}	ODT turn-off delay	2.5	2.5	t_{CK}	
t_{AOF}	ODT turn-off	$t_{AC.MIN}$	$t_{AC.MAX}$ + 0.6 ns	ns	2)
t_{AOFPD}	ODT turn-off (Power-Down Modes)	$t_{AC.MIN}$ + 2 ns	2.5 t_{CK} + $t_{AC.MAX}$ + 1 ns	ns	
t_{ANPD}	ODT to Power Down Mode Entry Latency	3	—	t_{CK}	
t_{AXPD}	ODT Power Down Exit Latency	8	—	t_{CK}	

1) ODT turn on time min. is when the device leaves high impedance and ODT resistance begins to turn on. ODT turn on time max is when the ODT resistance is fully on. Both are measure from t_{AOND}.

2) ODT turn off time min. is when the device starts to turn off ODT resistance. ODT turn off time max is when the bus is in high impedance. Both are measured from t_{AOFD}.

6 Specifications and Conditions

Table 39 I_{DD} Measurement Conditions

Parameter	Symbol	Note
Operating Current - One bank Active - Precharge $t_{CK} = t_{CK(IDD)}$, $t_{RC} = t_{RC(IDD)}$, $t_{RAS} = t_{RAS.MIN(IDD)}$, CKE is HIGH, $\overline{CS}$ is HIGH between valid commands. Address and control inputs are switching; Databus inputs are switching.	I_{DD0}	1)2)3)4) 5)6)
Operating Current - One bank Active - Read - Precharge I_{OUT} = 0 mA, BL = 4, $t_{CK} = t_{CK(IDD)}$, $t_{RC} = t_{RC(IDD)}$, $t_{RAS} = t_{RAS.MIN(IDD)}$, $t_{RCD} = t_{RCD(IDD)}$, AL = 0, CL = CL(IDD); CKE is HIGH, $\overline{CS}$ is HIGH between valid commands. Address and control inputs are switching; Databus inputs are switching.	I_{DD1}	1)2)3)4) 5)6)
Precharge Power-Down Current All banks idle; CKE is LOW; $t_{CK} = t_{CK(IDD)}$;Other control and address inputs are stable; Data bus inputs are floating.	I_{DD2P}	1)2)3)4) 5)6)
Precharge Standby Current All banks idle; $\overline{CS}$ is HIGH; CKE is HIGH; $t_{CK} = t_{CK(IDD)}$; Other control and address inputs are switching, Data bus inputs are switching.	I_{DD2N}	1)2)3)4) 5)6)
Precharge Quiet Standby Current All banks idle; $\overline{CS}$ is HIGH; CKE is HIGH; $t_{CK} = t_{CK(IDD)}$; Other control and address inputs are stable, Data bus inputs are floating.	I_{DD2Q}	1)2)3)4) 5)6)
Active Power-Down Current All banks open; $t_{CK} = t_{CK(IDD)}$, CKE is LOW; Other control and address inputs are stable; Data bus inputs are floating. MRS A12 bit is set to “0” (Fast Power-down Exit).	$I_{DD3P(0)}$	1)2)3)4) 5)6)
Active Power-Down Current All banks open; $t_{CK} = t_{CK(IDD)}$, CKE is LOW; Other control and address inputs are stable, Data bus inputs are floating. MRS A12 bit is set to 1 (Slow Power-down Exit);	$I_{DD3P(1)}$	1)2)3)4) 5)6)
Active Standby Current All banks open; $t_{CK} = t_{CK(IDD)}$; $t_{RAS} = t_{RAS.MAX(IDD)}$, $t_{RP} = t_{RP(IDD)}$; CKE is HIGH, $\overline{CS}$ is HIGH between valid commands. Address inputs are switching; Data Bus inputs are switching;	I_{DD3N}	1)2)3)4) 5)6)
Operating Current Burst Read: All banks open; Continuous burst reads; BL = 4; AL = 0, CL = $CL_{(IDD)}$; $t_{CK} = t_{CK(IDD)}$; $t_{RAS} = t_{RAS.MAX.(IDD)}$, $t_{RP} = t_{RP(IDD)}$; CKE is HIGH, $\overline{CS}$ is HIGH between valid commands. Address inputs are switching; Data Bus inputs are switching; I_{OUT} = 0 mA.	I_{DD4R}	1)2)3)4) 5)6)
Operating Current Burst Write: All banks open; Continuous burst writes; BL = 4; AL = 0, CL = $CL_{(IDD)}$; $t_{CK} = t_{CK(IDD)}$; $t_{RAS} = t_{RAS.MAX(IDD)}$, $t_{RP} = t_{RP(IDD)}$; CKE is HIGH, $\overline{CS}$ is HIGH between valid commands. Address inputs are switching; Data Bus inputs are switching;	I_{DD4W}	1)2)3)4) 5)6)
Burst Refresh Current $t_{CK} = t_{CK(IDD)}$, Refresh command every $t_{RFC} = t_{RFC(IDD)}$ interval, CKE is HIGH, $\overline{CS}$ is HIGH between valid commands, Other control and address inputs are switching, Data bus inputs are switching.	I_{DD5B}	1)2)3)4) 5)6)
Distributed Refresh Current $t_{CK} = t_{CK(IDD)}$, Refresh command every t_{REFI} = 7.8 µs interval, CKE is LOW and $\overline{CS}$ is HIGH between valid commands, Other control and address inputs are switching, Data bus inputs are switching.	I_{DD5D}	1)2)3)4) 5)6)

Table 39 I_{DD} Measurement Conditions

Parameter	Symbol	Note
Self-Refresh Current CKE ≤ 0.2 V; external clock off, CK and $\overline{CK}$ at 0 V; Other control and address inputs are floating, Data bus inputs are floating.	I_{DD6}	1)2)3)4) 5)6)
Operating Bank Interleave Read Current 1. All banks interleaving reads, I_{OUT} = 0 mA; BL = 4, CL = $CL_{(IDD)}$, AL = $t_{RCD(IDD)}$ -1 × $t_{CK(IDD)}$; t_{CK} = $t_{CK(IDD)}$, t_{RC} = $t_{RC(IDD)}$, t_{RRD} = $t_{RRD(IDD)}$; CKE is HIGH, $\overline{CS}$ is HIGH between valid commands. Address bus inputs are stable during deselects; Data bus is switching. 2. Timing pattern: DDR2-800-666: A0 RA0 D D D A1 RA1 D D D A2 RA2 D D D A3 RA3 D D D D D D(23 clocks)	I_{DD7}	1)2)3)4) 5)6)7)

1) V_{DDQ} = 2.0 V ± 0.1 V; V_{DD} = 2.0 V ± 0.1 V
2) I_{DD} specifications are tested after the device is properly initialized.
3) I_{DD} parameter are specified with ODT disabled.
4) Data Bus consists of DQ, DM, DQS, $\overline{DQS}$, RDQS, $\overline{RDQS}$, LDQS, $\overline{LDQS}$, UDQS and $\overline{UDQS}$.
5) Definitions for I_{DD}: see **Table 40**
6) Timing parameter minimum and maximum values for I_{DD} current measurements are defined in chapter 7..
7) A = Activate, RA = Read with Auto-Precharge, D=DESELECT

Table 40 Definition for I_{DD}

Parameter	Description
LOW	defined as $V_{IN} \leq V_{IL(ac).MAX}$
HIGH	defined as $V_{IN} \geq V_{IH(ac).MIN}$
STABLE	defined as inputs are stable at a HIGH or LOW level
FLOATING	defined as inputs are V_{REF} = V_{DDQ} / 2
SWITCHING	defined as: Inputs are changing between high and low every other clock (once per two clocks) for address and control signals, and inputs changing between high and low every other clock (once per clock) for DQ signals not including mask or strobes

Table 41 I_{DD} Specification

Speed Grade	–22	–25	-28	-33	Unit	Note
Symbol	**Max.**	**Max.**	**Max.**	**Max.**		
I_{DD0}	tbd	tbd	tbd	tbd	mA	×16
I_{DD1}	tbd	tbd	tbd	tbd	mA	×16
I_{DD2P}	tbd	tbd	tbd	tbd	mA	
I_{DD2N}	tbd	tbd	tbd	tbd	mA	
I_{DD2Q}	tbd	tbd	tbd	tbd	mA	
$I_{DD3P(0)}$	tbd	tbd	tbd	tbd	mA	1)
$I_{DD3P(1)}$	tbd	tbd	tbd	tbd	mA	2)
I_{DD3N}	tbd	tbd	tbd	tbd	mA	
I_{DD4R}	tbd	tbd	tbd	tbd	mA	×16
I_{DD4W}	tbd	tbd	tbd	tbd	mA	×16
I_{DD5B}	tbd	tbd	tbd	tbd	mA	
I_{DD5D}	tbd	tbd	tbd	tbd	mA	3)
I_{DD6}	tbd	tbd	tbd	tbd	tbd	3)
I_{DD7}	tbd	tbd	tbd	tbd	mA	×16

1) MRS(12)=0

2) MRS(12)=1

3) $0 \leq T_{CASE} \leq 85°C$

6.1 I_{DD} Test Conditions

For testing the I_{DD} parameters, the following timing parameters are used:

Table 42 I_{DD} Measurement Test Condition

Parameter		Symbol	–22	–25	–28	–33	Unit	Notes
CAS Latency		CL_{IDD}	7	6	6	6	t_{CK}	
Clock Cycle Time		t_{CKIDD}	2.5	2.5	2.5	2.5	ns	
Active to Read or Write delay		$t_{RCD.IDD}$	15	15	15	15	ns	
Active to Active / Auto-Refresh command period		$t_{RC.IDD}$	60	60	60	60	ns	
Active bank A to Active bank B command delay		$t_{RRD.IDD}$	10	10	10	10	ns	1)
Active to Precharge Command			45	45	45	45	ns	
		$t_{RAS.MIN.IDD}$	70000	70000	70000	70000	ns	
Precharge Command Period		$t_{RAS.MAX.IDD}$	15	15	15	15	ns	
Auto-Refresh to Active / Auto-Refresh command period		$t_{RP.IDD}$	105	105	105	105	ns	
Average periodic Refresh interval	$0°C \le T_{CASE} \le 85°C$	$t_{RFC.IDD}$	7.8	7.8	7.8	7.8	µs	
	$85°C \le T_{CASE} \le 95°C$	t_{REFI}	3.9	3.9	3.9	3.9	µs	

1) ×16 (2 kB page size)

6.1.1 On Die Termination (ODT) Current

The ODT function adds additional current consumption to the DDR2 SDRAM when enabled by the EMRS(1). Depending on address bits A6 & A2 in the EMRS(1) a “weak” or “strong” termination can be selected. The current consumption for any terminated input pin depends on whether the input pin is in tri-state or driving “0” or “1”, as long a ODT is enabled during a given period of time.. See **Table 43**

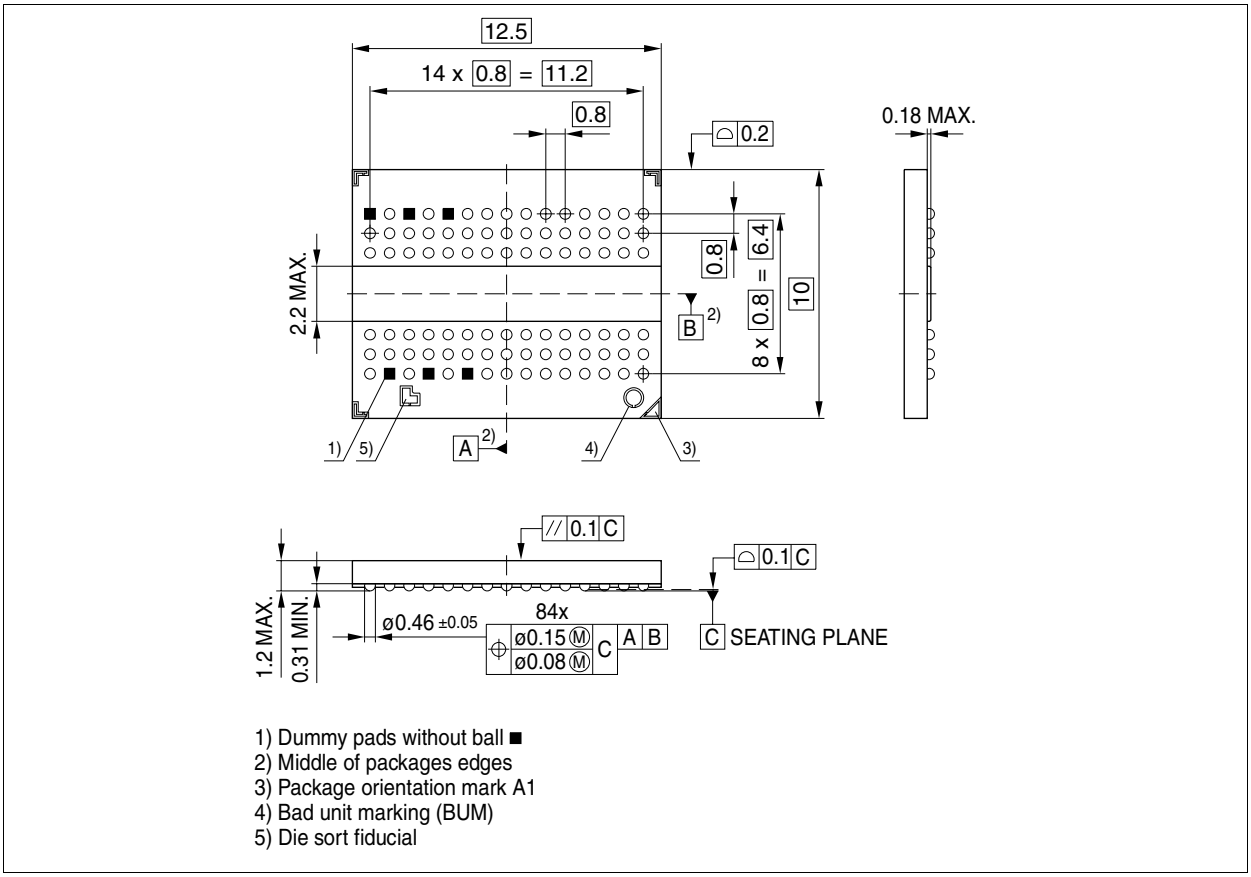
Table 43 ODT current per terminated input pin

ODT Current		EMRS(1) State	Min.	Typ.	Max.	Unit
Enabled ODT current per DQadded I_{DDQ} current for ODT enabled; ODT is HIGH; Data Bus inputs are floating	I_{ODTO}	A6 = 0, A2 = 1	5	6	7.5	mA/DQ
		A6 = 1, A2 = 0	2.5	3	3.75	mA/DQ
		A6 = 1, A2 = 1	7.5	9	11.25	mA/DQ
Active ODT current per DQadded I_{DDQ} current for ODT enabled; ODT is HIGH; worst case of Data Bus inputs are stable or switching.	I_{ODTT}	A6 = 0, A2 = 1	10	12	15	mA/DQ
		A6 = 1, A2 = 0	5	6	7.5	mA/DQ
		A6 = 1, A2 = 1	15	18	22.5	mA/DQ

Note: For power consumption calculations the ODT duty cycle has to be taken into account

7 Package

7.1 Package Dimension



1) Dummy pads without ball ■
2) Middle of packages edges
3) Package orientation mark A1
4) Bad unit marking (BUM)
5) Die sort fiducial

Figure 64 Package Outline P-TFBGA-84 (top view)

7.2 Package Thermal Characteristics

Table 44 Package thermal characteristics

JESD51	Theta_jA[1]						Theta_jC[2]
JEDEC Board	1s0p			2s0p			
Air Flow	0 m/s	1 m/s	3 m/s	0 m/s	1 m/s	3 m/s	
Rth[K/W]	69	53	47	41	35	33	5

1) Junction to Ambient thermal resistance. The value has been obtained by simulation using the conditions stated in the JEDEC JESD-51 standard.

2) Junction to Case thermal resistance. The value has been obtained by simulation.

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