Revision History

Revision No.	History	Draft Date	Remark	Editor
1.0	- First SPEC. Release	27th Jun. 2016	-	J.Y.Lee
1.1	- Change of Function Block Diagram [M471A1K43CB1] on page 10~11 - Change of Physical Dimensions on page 42~43	29th Jun. 2016	-	J.Y.Lee
1.2	- Change of Physical Dimensions on page 42~43	24th Feb. 2017	-	J.Y.Lee
1.21	- Correction of Typo	7th Mar. 2017	-	J.Y.Lee
1.3	- Addition of DDR4-2666	31th Mar. 2017	-	J.Y.Lee
1.4	- Correct typo. - Update Input/output functional description. - Update Single-ended AC & DC Input Levels for Command and Address table. - Update Differential AC and DC Input Levels table. - Update Single-ended Levels for CK_t, CK_c table. - Add Address, Command and Control Overshoot and Undershoot specifications. - Add Data, Strobe and Mask Overshoot and Undershoot Specifications. - Update Cross Point Voltage for Differential Input Signals (CK) - Add CMOS rail to rail Input Levels. - Add AC and DC Logic Input Levels for DQS Signals. - Add Peak voltage calculation method. - Add Differential Input Cross Point Voltage (DQS). - Add Differential Input Slew Rate Definition DQS). - Add AC AND DC OUTPUT MEASUREMENT LEVELS. - Correct Single-ended AC & DC Output Levels table. - Update Speed Bin Table Note. - Update Timing parameters by speed grade. - Add Rounding Algorithms. - Add The DQ input receiver compliance mask for voltage and timing. - Add Command, Control, and Address Setup, Hold, and Derating. - Add DDR4 Function Matrix	4th Apr, 2018	Final	S.J.Park J.Y.Bae
1.5	- Update functional block diagram for 8GB, 1Gx64 Module (Populated as 1 rank of x8 DDR4 SDRAMs).	11th Apr, 2018	Final	J.Y.Bae

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260pin Unbuffered SODIMM based on 8Gb C-die

1. DDR4 Unbuffered SODIMM ORDERING INFORMATION

[Table 1] Ordering Information Table

Part Number 2)	Density	Organization	Component Composition 1)	Number of Rank	Height
M471A5244CB0-CPB/RC/TD	4GB	512Mx64	512Mx16(K4A8G165WC-BC##)*4	1	30mm
M471A1K43CB1-CPB/RC/TD	8GB	1Gx64	1Gx8(K4A8G085WC-BC##)*8	1	30mm
M471A2K43CB1-CPB/RC/TD	16GB	2Gx64	1Gx8(K4A8G085WC-BC##)*16	2	30mm

NOTE :
1) "##"- PB/RC/TD
2) PB(2133Mbps 15-15-15)/RC(2400Mbps 17-17-17)/TD(2666Mbps 19-19-19)
- DDR4-2666(19-19-19) is backward compatible to lower frequency.

2. KEY FEATURES

[Table 2] Speed Bins

Speed	DDR4-1600	DDR4-1866	DDR4-2133	DDR4-2400	DDR4-2666	Unit
	11-11-11	13-13-13	15-15-15	17-17-17	19-19-19	
tCK(min)	1.25	1.071	0.937	0.833	0.75	ns
CAS Latency	11	13	15	17	19	nCK
tRCD(min)	13.75	13.92	14.06	14.16	14.25	ns
tRP(min)	13.75	13.92	14.06	14.16	14.25	ns
tRAS(min)	35	34	33	32	32	ns
tRC(min)	48.75	47.92	47.06	46.16	46.25	ns

- JEDEC standard 1.2V ± 0.06V Power Supply
- V_{DDQ} = 1.2V ± 0.06V
- 800 MHz f_{CK} for 1600Mb/sec/pin, 933 MHz f_{CK} for 1866Mb/sec/pin, 1067MHz f_{CK} for 2133Mb/sec/pin,1200MHz f_{CK} for 2400Mb/sec/pin, 1333MHz f_{CK} for 2666Mb/sec/pin
- 16 Banks (4 Bank Groups)
- Programmable $\overline{CAS}$ Latency: 10,11,12,13,14,15,16,17,18,19,20
- Programmable Additive Latency (Posted $\overline{CAS}$): 0, CL - 2, or CL - 1 clock
- Programmable $\overline{CAS}$ Write Latency (CWL) = 9,11 (DDR4-1600), 10,12 (DDR4-1866), 11,14 (DDR4-2133),12,16 (DDR4-2400) and 14,18 (DDR4-2666)
- Burst Length: 8, 4 with tCCD = 4 which does not allow seamless read or write [either On the fly using A12 or MRS]
- Bi-directional Differential Data Strobe
- On Die Termination using ODT pin
- Average Refresh Period 7.8us at lower then T_{CASE} 85°C, 3.9us at 85°C < $T_{CASE} \leq$ 95°C
- Asynchronous Reset

3. ADDRESS CONFIGURATION

Organization	Row Address	Column Address	Bank Group Address	Bank Address	Auto Precharge
512Mx16(8Gb) based Module	A0-A15	A0-A9	BG0	BA0-BA1	A10/AP
1Gx8(8Gb) based Module	A0-A15	A0-A9	BG0-BG1	BA0-BA1	A10/AP

4. Unbuffered SODIMM PIN CONFIGURATIONS (Front side/Back side)

Pin	Front	Pin	Back	Pin	Front	Pin	Back	Pin	Front	Pin	Back	Pin	Front	Pin	Back
1	VSS	2	VSS	79	DQ30	80	DQ31	157	CS1_n1	158	A13	235	VSS	236	DQ57
3	DQ5	4	DQ4	81	VSS	82	VSS	159	VDD	160	VDD	237	DQ56	238	VSS
5	VSS	6	VSS	83	DQ26	84	DQ27	161	ODT1	162	C0,CS2_n,NC	239	VSS	240	DQS7_c
7	DQ1	8	DQ0	85	VSS	86	VSS	163	VDD	164	VREFCA	241	DM7_n/ DBI7_n	242	DQS7_t
9	VSS	10	VSS	87	CB5,NC	88	CB4,NC	165	C1,CS3_n, NC	166	SA2	243	VSS	244	VSS
11	DQS0_c	12	DM0_n/ DBI0_n	89	VSS	90	VSS	167	VSS	168	VSS	245	DQ62	246	DQ63
13	DQS0_t	14	VSS	91	CB1,NC	92	CB0,NC	169	DQ37	170	DQ36	247	VSS	248	VSS
15	VSS	16	DQ6	93	VSS	94	VSS	171	VSS	172	VSS	249	DQ58	250	DQ59
17	DQ7	18	VSS	95	DQS8_c	96	DBI8_n	173	DQ33	174	DQ32	251	VSS	252	VSS
19	VSS	20	DQ2	97	DQS8_t	98	VSS	175	VSS	176	VSS	253	SCL	254	SDA
21	DQ3	22	VSS	99	VSS	100	CB6,NC	177	DQS4_c	178	DM4_n/ DBI4_n	255	VDDSPD	256	SA0
23	VSS	24	DQ12	101	CB2,NC	102	VSS	179	DQS4_t	180	VSS	257	VPP	258	Vtt
25	DQ13	26	VSS	103	VSS	104	CB7,NC	181	VSS	182	DQ39	259	VPP	260	SA1
27	VSS	28	DQ8	105	CB3,NC	106	VSS	183	DQ38	184	VSS				
29	DQ9	30	VSS	107	VSS	108	RESET_n	185	VSS	186	DQ35				
31	VSS	32	DQS1_c	109	CKE0	110	CKE1	187	DQ34	188	VSS				
33	DM1_n/ DBI1_n	34	DQS1_t	111	VDD	112	VDD	189	VSS	190	DQ45				
35	VSS	36	VSS	113	BG1	114	ACT_n	191	DQ44	192	VSS				
37	DQ15	38	DQ14	115	BG0	116	ALERT_n	193	VSS	194	DQ41				
39	VSS	40	VSS	117	VDD	118	VDD	195	DQ40	196	VSS				
41	DQ10	42	DQ11	119	A12	120	A11	197	VSS	198	DQS5_c				
43	VSS	44	VSS	121	A9	122	A7	199	DM5_n/ DBI5_n	200	DQS5_t				
45	DQ21	46	DQ20	123	VDD	124	VDD	201	VSS	202	VSS				
47	VSS	48	VSS	125	A8	126	A5	203	DQ46	204	DQ47				
49	DQ17	50	DQ16	127	A6	128	A4	205	VSS	206	VSS				
51	VSS	52	VSS	129	VDD	130	VDD	207	DQ42	208	DQ43				
53	DQS2_c	54	DM2_n/ DBI2_n	131	A3	132	A2	209	VSS	210	VSS				
55	DQS2_t	56	VSS	133	A1	134	EVENT_n	211	DQ52	212	DQ53				
57	VSS	58	DQ22	135	VDD	136	VDD	213	VSS	214	VSS				
59	DQ23	60	VSS	137	CK0_t	138	CK1_t	215	DQ49	216	DQ48				
61	VSS	62	DQ18	139	CK0_c	140	CK1_c	217	VSS	218	VSS				
63	DQ19	64	VSS	141	VDD	142	VDD	219	DQS6_c	220	DM6_n/ DBI6_n				
65	VSS	66	DQ28	143	Parity	144	A0	221	DQS6_t	222	VSS				
67	DQ29	68	VSS	145	BA1	146	A10/AP	223	VSS	224	DQ54				
69	VSS	70	DQ24	147	VDD	148	VDD	225	DQ55	226	VSS				
71	DQ25	72	VSS	149	CS0_n	150	BA0	227	VSS	228	DQ50				
73	VSS	74	DQS3_c	151	A14/WE_n	152	A16/RAS_n	229	DQ51	230	VSS				
75	DM3_n/ DBI3_n	76	DQS3_t	153	VDD	154	VDD	231	VSS	232	DQ60				
77	VSS	78	VSS	155	$\overline{ODT0}$	156	A15/CAS_n	233	DQ61	234	VSS				

5. PIN DESCRIPTION

Pin Name	Description
A0–A16	SDRAM address bus
BA0, BA1	SDRAM bank select
BG0, BG1	SDRAM bank group select
RAS_n[1)]	SDRAM row address strobe
CAS_n[2)]	SDRAM column address strobe
WE_n[3)]	SDRAM write enable
CS0_n–CS1_n	Rank Select Lines
CKE0, CKE1	SDRAM clock enable lines
ODT0, ODT1	Register on-die termination control lines
ACT_n	SDRAM activate
DQ0–DQ63	DIMM memory data bus
CB0–CB7	DIMM ECC check bits
DQS0_t–DQS8_t	SDRAM data strobes (positive line of differential pair)
DQS0_c–DQS8_c	SDRAM data strobes (negative line of differential pair)
DM0_n-DM8_n, DBI0_n-DBI8_n	SDRAM data masks/data bus inversion (x8-based x72 DIMMs)
CK0_t, CK1_t	SDRAM clocks (positive line of differential pair)
CK0_c, CK1_c	SDRAM clocks (negative line of differential pair)

Pin Name	Description
SCL	I^2C serial bus clock for SPD/TS
SDA	I^2C serial bus data line for SPD/TS
SA0~SA2	I^2C slave address select for SPD/TS
PARITY	SDRAM parity input
VDD	SDRAM I/O & core power supply
VPP	SDRAM activating power supply
C0,C1	Chip ID lines for 3DS components
VREFCA	SDRAM command/address reference supply
VSS	Power supply return (ground)
VDDSPD	Serial SPD/TS positive power supply
ALERT_n	SDRAM ALERT_n
RESET_n	Set SDRAMs to a Known State
EVENT_n	TS signals a thermal event has occurred
VTT	Termination supply for the Address, Command and Control bus
NC	No connection

NOTE :

1) RAS_n is a multiplexed function with A16.
2) CAS_n is a multiplexed function with A15.
3) WE_n is a multiplexed function with A14.

[Table 3] Temperature Sensor Characteristics

Grade	Range	Temperature Sensor Accuracy			Units	NOTE
		Min.	Typ.	Max.		
B	75 < Ta < 95	-	+/- 0.5	+/- 1.0	°C	-
	40 < Ta < 125	-	+/- 1.0	+/- 2.0		-
	-20 < Ta < 125	-	+/- 2.0	+/- 3.0		-
Resolution		0.25			°C /LSB	-

6. INPUT/OUTPUT FUNCTIONAL DESCRIPTION

[Table 4] Input/Output function description

Symbol	Type	Function
CK_t, CK_c	Input	Clock: CK_t and CK_c are differential clock inputs. All address and control input signals are sampled on the crossing of the positive edge of CK_t and negative edge of CK_c.
CKE, (CKE1)	Input	Clock Enable: CKE HIGH activates, and CKE Low deactivates, internal clock signals and device input buffers and output drivers. Taking CKE Low provides Precharge Power-Down and Self-Refresh operation (all banks idle), or Active Power-Down (row Active in any bank). CKE is synchronous for Self-Refresh exit. After VREFCA and Internal DQ Vref have become stable during the power on and initialization sequence, they must be maintained during all operations (including Self-Refresh). CKE must be maintained high throughout read and write accesses. Input buffers, excluding CK_t, CK_c, ODT and CKE are disabled during power-down. Input buffers, excluding CKE, are disabled during Self-Refresh.
CS_n, (CS1_n)	Input	Chip Select: All commands are masked when CS_n is registered HIGH. CS_n provides for external Rank selection on systems with multiple Ranks. CS_n is considered part of the command code.
C0,C1,C2	Input	Chip ID : Chip ID is only used for 3DS for 2,4,8high stack via TSV to select each slice of stacked component. Chip ID is considered part of the command code
ODT, (ODT1)	Input	On Die Termination: ODT (registered HIGH) enables RTT_NOM termination resistance internal to the DDR4 SDRAM. When enabled, ODT is only applied to each DQ, DQS_t, DQS_c and DM_n/DBI_n/ TDQS_t, NU/TDQS_c (When TDQS is enabled via Mode Register A11=1 in MR1) signal for x8 configurations. For x16 configuration ODT is applied to each DQ, DQSU_t, DQSU_c, DQSL_t, DQSL_c, DMU_n, and DML_n signal. The ODT pin will be ignored if MR1 is programmed to disable RTT_NOM.
ACT_n	Input	Activation Command Input : ACT_n defines the Activation command being entered along with CS_n. The input into RAS_n/A16, CAS_n/A15 and WE_n/A14 will be considered as Row Address A16, A15 and A14
RAS_n/A16. CAS_n/ A15. WE_n/A14	Input	Command Inputs: RAS_n/A16, CAS_n/A15 and WE_n/A14 (along with CS_n) define the command being entered. Those pins have multi function. For example, for activation with ACT_n Low, those are Addressing like A16,A15 and A14 but for non-activation command with ACT_n High, those are Command pins for Read, Write and other command defined in command truth table
DM_n/DBI_n/TDQS_t, (DMU_n/DBIU_n), (DML_n/DBIL_n)	Input/Output	Input Data Mask and Data Bus Inversion: DM_n is an input mask signal for write data. Input data is masked when DM_n is sampled LOW coincident with that input data during a Write access. DM_n is sampled on both edges of DQS. DM is muxed with DBI function by Mode Register A10,A11,A12 setting in MR5. For x8 device, the function of DM or TDQS is enabled by Mode Register A11 setting in MR1. DBI_n is an input/ output identifing whether to store/output the true or inverted data. If DBI_n is LOW, the data will be stored/ output after inversion inside the DDR4 SDRAM and not inverted if DBI_n is HIGH. TDQS is only supported in X8
BG0 - BG1	Input	Bank Group Inputs : BG0 - BG1 define to which bank group an Active, Read, Write or Precharge command is being applied. BG0 also determines which mode register is to be accessed during a MRS cycle. X4/8 have BG0 and BG1 but X16 has only BG0
BA0 - BA1	Input	Bank Address Inputs: BA0 - BA1 define to which bank an Active, Read, Write or Precharge command is being applied. Bank address also determines which mode register is to be accessed during a MRS cycle.
A0 - A17	Input	Address Inputs: Provide the row address for ACTIVATE Commands and the column address for Read/ Write commands to select one location out of the memory array in the respective bank. (A10/AP, A12/ BC_n, RAS_n/A16, CAS_n/A15 and WE_n/A14 have additional functions, see other rows.The address inputs also provide the op-code during Mode Register Set commands.A17 is only defined for the x4 configurations.
A10 / AP	Input	Auto-precharge: A10 is sampled during Read/Write commands to determine whether Autoprecharge should be performed to the accessed bank after the Read/Write operation. (HIGH: Autoprecharge; LOW: no Autoprecharge).A10 is sampled during a Precharge command to determine whether the Precharge applies to one bank (A10 LOW) or all banks (A10 HIGH). If only one bank is to be precharged, the bank is selected by bank addresses.
A12 / BC_n	Input	Burst Chop: A12 / BC_n is sampled during Read and Write commands to determine if burst chop (on-the-fly) will be performed. (HIGH, no burst chop; LOW: burst chopped). See command truth table for details.
RESET_n	Input	Active Low Asynchronous Reset: Reset is active when RESET_n is LOW, and inactive when RESET_n is HIGH. RESET_n must be HIGH during normal operation. RESET_n is a CMOS rail to rail signal with DC high and low at 80% and 20% of V_{DD}.
DQ	Input / Output	Data Input/ Output: Bi-directional data bus. If CRC is enabled via Mode register then CRC code is added at the end of Data Burst. Any DQ from DQ0~DQ3 may indicate the internal Vref level during test via Mode Register Setting MR4 A4=High. During this mode, RTT value should be set to Hi-Z. Refer to vendor specific datasheets to determine which DQ is used.

[Table 4] Input/Output function description

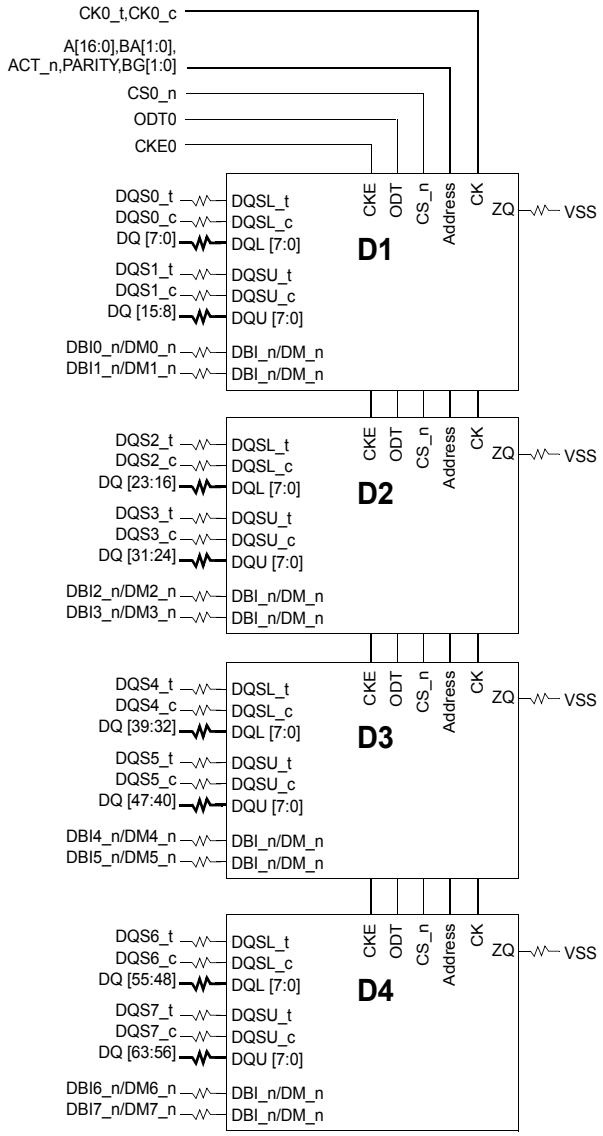
Symbol	Type	Function
DQS_t, DQS_c, DQSU_t, DQSU_c, DQSL_t, DQSL_c	Input / Output	Data Strobe: output with read data, input with write data. Edge-aligned with read data, centered in write data. For the x16, DQSL corresponds to the data on DQL0-DQL7; DQSU corresponds to the data on DQU0-DQU7. The data strobe DQS_t, DQSL_t and DQSU_t are paired with differential signals DQS_c, DQSL_c, and DQSU_c, respectively, to provide differential pair signaling to the system during reads and writes. DDR4 SDRAM supports differential data strobe only and does not support single-ended.
TDQS_t, TDQS_c	Output	Termination Data Strobe: TDQS_t/TDQS_c is applicable for x8 DRAMs only. When enabled via Mode Register A11 = 1 in MR1, the DRAM will enable the same termination resistance function on TDQS_t/ TDQS_c that is applied to DQS_t/DQS_c. When disabled via mode register A11 = 0 in MR1, DM/DBI/ TDQS will provide the data mask function or Data Bus Inversion depending on MR5; A11,12,10and TDQS_c is not used. x4/x16 DRAMs must disable the TDQS function via mode register A11 = 0 in MR1.
PAR	Input	Command and Address Parity Input: DDR4 Supports Even Parity check in DRAM with MR setting. Once it's enabled via Register in MR5, then DRAM calculates Parity with ACT_n,RAS_n/A16,CAS_n/A15,WE_n/ A14,BG0-BG1,BA0-BA1,A17-A0, and C0-C2 (3DS devices). Command and address inputs shall have parity check performed when commands are latched via the rising edge of CK_t and when CS_n is low.
ALERT_n	Input/Output	Alert : It has multi functions such as CRC error flag, Command and Address Parity error flag as Output signal. If there is error in CRC, then Alert_n goes LOW for the period time interval and goes back HIGH. If there is error in Command Address Parity Check, then Alert_n goes LOW for relatively long period until on going DRAM internal recovery transaction to complete. During Connectivity Test mode, this pin works as input. Using this signal or not is dependent on system. In case of not connected as Signal, ALERT_n Pin must be bounded to VDD on board.
TEN	Input	Connectivity Test Mode Enable: Required on X16 devices and optional input on x4/x8 with densities equal to or greater than 8Gb.HIGH in this pin will enable Connectivity Test Mode operation along with other pins. It is a CMOS rail to rail signal with AC high and low at 80% and 20% of VDD. Using this signal or not is dependent on System. This pin may be DRAM internally pulled low through a weak pull-down resistor to VSS.
NC		No Connect: No internal electrical connection is present.
VDDQ	Supply	DQ Power Supply: 1.2 V +/- 0.06 V
VSSQ	Supply	DQ Ground
VDD	Supply	Power Supply: 1.2 V +/- 0.06 V
VSS	Supply	Ground
VPP	Supply	DRAM Activating Power Supply: 2.5V (2.375V min, 2.75V max)
VREFCA	Supply	Reference voltage for CA
ZQ	Supply	Reference Pin for ZQ calibration

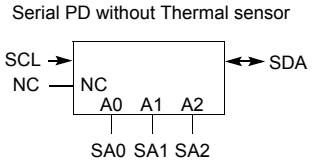
NOTE :

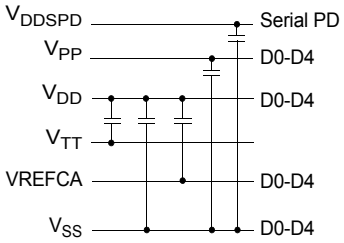
1) For PC4, VDD is 1.2 V. For PC4L VDD is TBD.
2) For PC4, VTT is 0.6 V. For PC4L VTT is TBD.

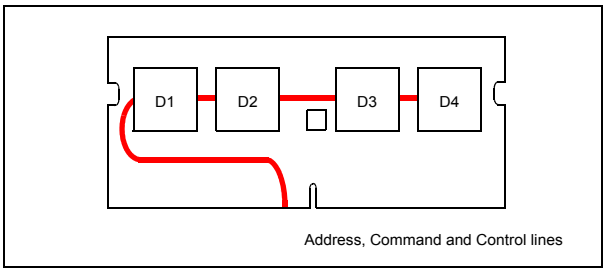
7. FUNCTION BLOCK DIAGRAM

7.1 4GB, 512Mx64 Module (Populated as 1 rank of x16 DDR4 SDRAMs)





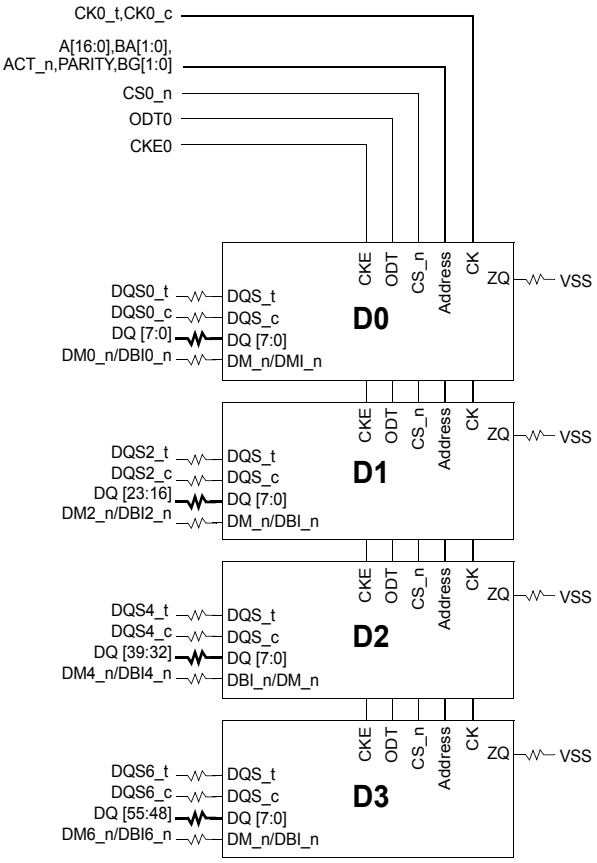


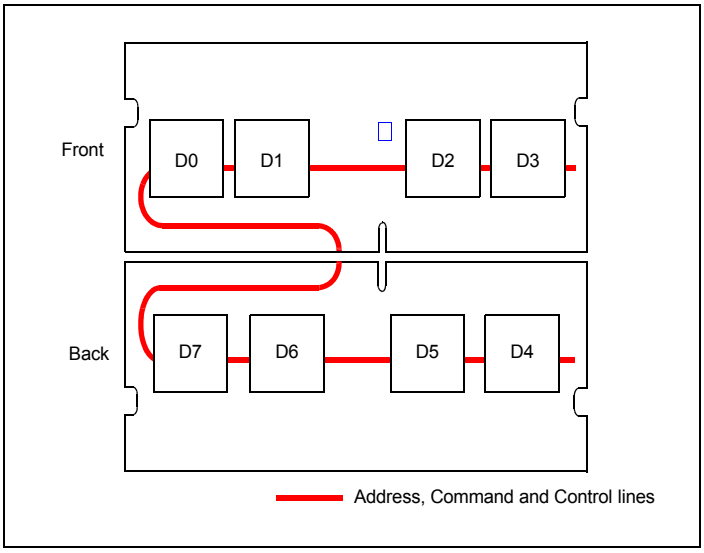


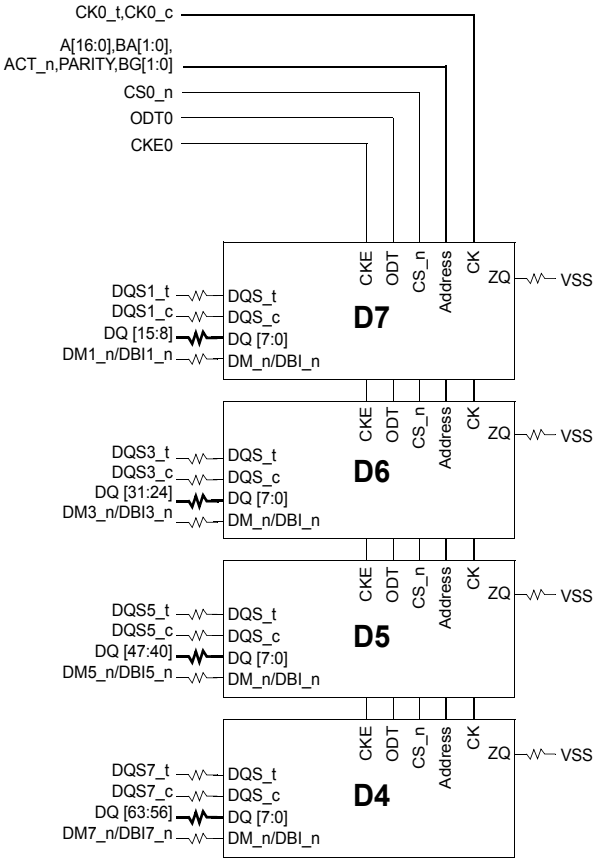
NOTE :

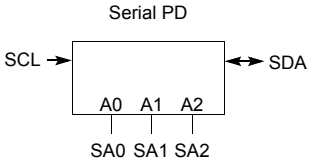
1) Unless otherwise noted, resistor values are 15Ω ± 5%.
2) ZQ resistors are 240Ω ± 1%. For all other resistor values refer to the appropriate wiring diagram.
3) CK1_t, CK1_c terminated with 75Ω ± 5% resistor.

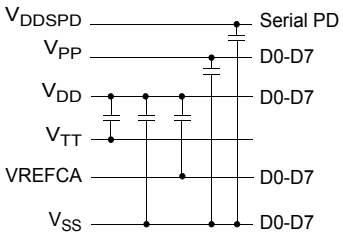
7.2 8GB, 1Gx64 Module (Populated as 1 rank of x8 DDR4 SDRAMs)





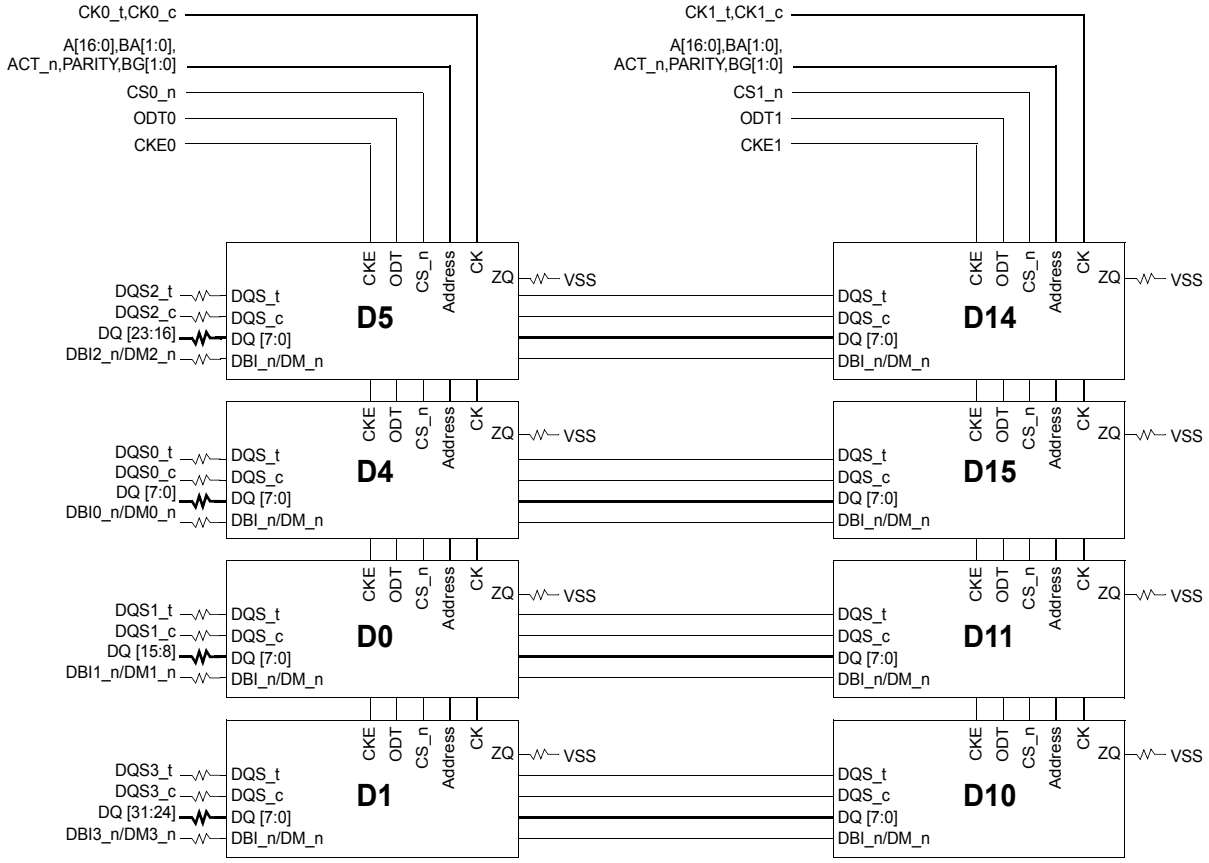


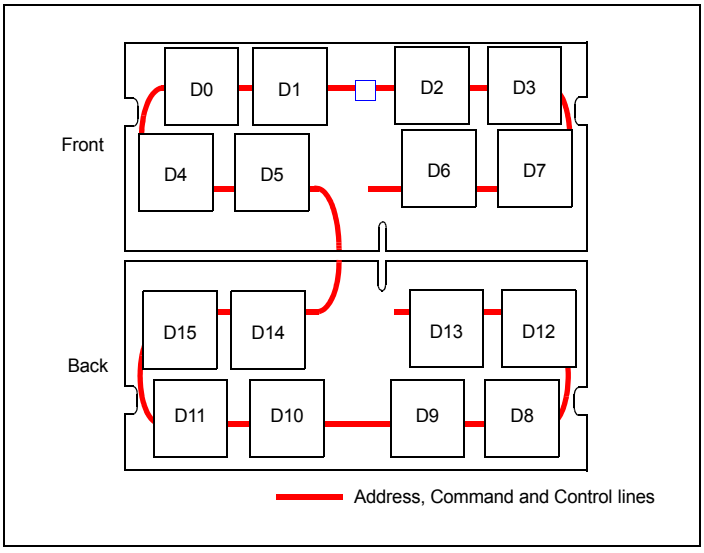




NOTE :
1) Unless otherwise noted, resistor values are 15Ω ± 5%.
2) ZQ resistors are 240Ω ± 1%. For all other resistor values refer to the appropriate wiring diagram.

7.3 16GB, 2Gx64 Module (Populated as 2 ranks of x8 DDR4 SDRAMs)

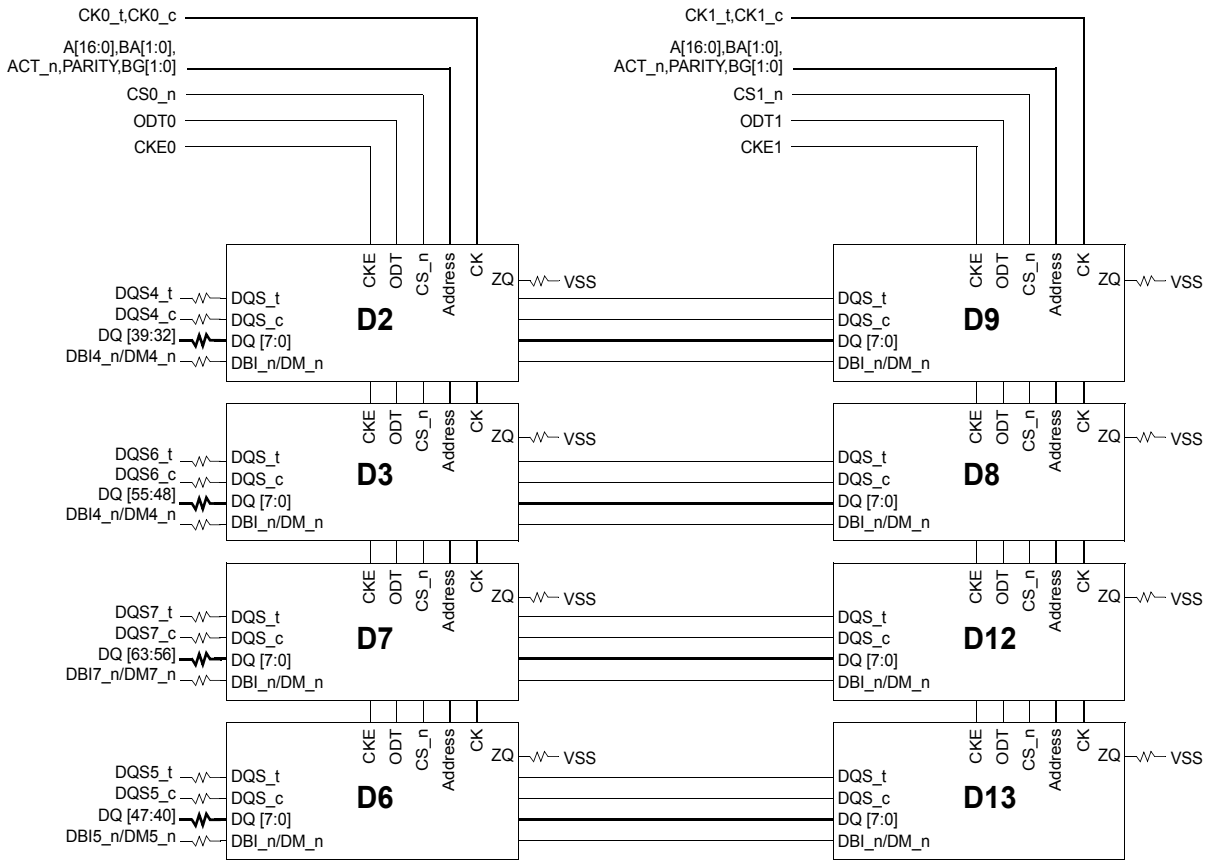


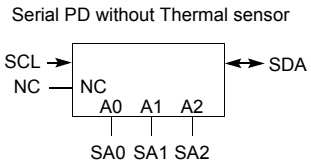


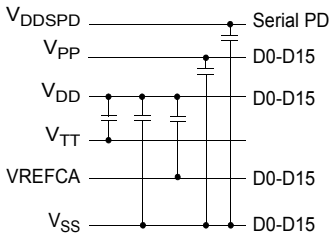
NOTE :

1) Unless otherwise noted, resistor values are 15Ω ± 5%.

2) ZQ resistors are 240Ω ± 1%. For all other resistor values refer to the appropriate wiring diagram.







NOTE:

1) Unless otherwise noted, resistor values are 15Ω ± 5%.
2) ZQ resistors are 240Ω ± 1%. For all other resistor values refer to the appropriate wiring diagram.
3) SDRAMs for ODD ranks (D8 to D15), which are placed on the back side of the module use the address mirroring for A4-A3, A6-A5, A8-A7, A13-A11, BA1-BA0 and BG1-BG0. More detail can be found in the DDR4 SODIMM Common Section of the Design Specification.

8. ABSOLUTE MAXIMUM RATINGS

[Table 5] Absolute Maximum DC Ratings

Symbol	Parameter	Rating	Units	NOTE
VDD	Voltage on VDD pin relative to Vss	-0.3 ~ 1.5	V	1,3
VDDQ	Voltage on VDDQ pin relative to Vss	-0.3 ~ 1.5	V	1,3
VPP	Voltage on VPP pin relative to Vss	-0.3 ~ 3.0	V	4
V_{IN}, V_{OUT}	Voltage on any pin except VREFCA relative to Vss	-0.3 ~ 1.5	V	1,3,5
T_{STG}	Storage Temperature	-55 to +100	°C	1,2

NOTE :

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. For the measurement conditions, please refer to JESD51-2 standard.
3) VDD and VDDQ must be within 300mV of each other at all times; and VREFCA must be not greater than 0.6 x VDDQ, When VDD and VDDQ are less than 500mV; VREFCA may be equal to or less than 300mV
4) VPP must be equal or greater than VDD/VDDQ at all times.
5) Overshoot area above 1.5 V is specified in 10.3.4, 10.3.5 and 10.3.6.

9. AC & DC OPERATING CONDITIONS

[Table 6] Recommended DC Operating Conditions

Symbol	Parameter	Rating			Unit	NOTE
		Min.	Typ.	Max.		
VDD	Supply Voltage	1.14	1.2	1.26	V	1,2,3
VDDQ	Supply Voltage for Output	1.14	1.2	1.26	V	1,2,3
VPP	Peak-to-Peak Voltage	2.375	2.5	2.75	V	3

NOTE :

1) Under all conditions V_{DDQ} must be less than or equal to V_{DD}.
2) V_{DDQ} tracks with V_{DD}. AC parameters are measured with V_{DD} and V_{DDQ} tied together.
3) DC bandwidth is limited to 20MHz.

10. AC & DC INPUT MEASUREMENT LEVELS

10.1 AC & DC Logic Input Levels for Single-Ended Signals

[Table 7] Single-ended AC & DC Input Levels for Command and Address

Symbol	Parameter	DDR4-1600/1866/2133/2400		DDR4-2666		Unit	NOTE
		Min.	Max.	Min.	Max.		
VIH.CA(DC75)	DC input logic high	V_{REFCA}+ 0.075	VDD	-	-	V	
VIH.CA(DC65)		-	-	V_{REFCA}+ 0.065	VDD		
VIL.CA(DC75)	DC input logic low	VSS	V_{REFCA}-0.075	-	-	V	
VIL.CA(DC65)		-	-	VSS	V_{REFCA}-0.065		
VIH.CA(AC100)	AC input logic high	V_{REF} + 0.1	Note 2	-	-	V	
VIH.CA(AC90)		-	-	V_{REF} + 0.09	Note 2		1
VIL.CA(AC100)	AC input logic low	Note 2	V_{REF} - 0.1	-	-	V	
VIL.CA(AC90)		-	-	Note 2	V_{REF} - 0.09		1
VREFCA(DC)	Reference Voltage for ADD, CMD inputs	0.49*VDD	0.51*VDD	0.49*VDD	0.51*VDD	V	2,3

NOTE :
1) See “Overshoot and Undershoot Specifications” on section10.3.
2) The AC peak noise on VREFCA may not allow VREFCA to deviate from VREFCA(DC) by more than ± 1% VDD (for reference : approx. ± 12mV)
3) For reference : approx. VDD/2 ± 12mV.

10.2 AC and DC Input Measurement Levels: V_{REF} Tolerances.

The DC-tolerance limits and ac-noise limits for the reference voltages V_{REFCA} is illustrated in Figure 1. It shows a valid reference voltage V_{REF}(t) as a function of time. (V_{REF} stands for V_{REFCA}).

V_{REF}(DC) is the linear average of V_{REF}(t) over a very long period of time (e.g. 1 sec). This average has to meet the min/max requirement in Table 7. Furthermore V_{REF}(t) may temporarily deviate from V_{REF}(DC) by no more than ± 1% V_{DD}.

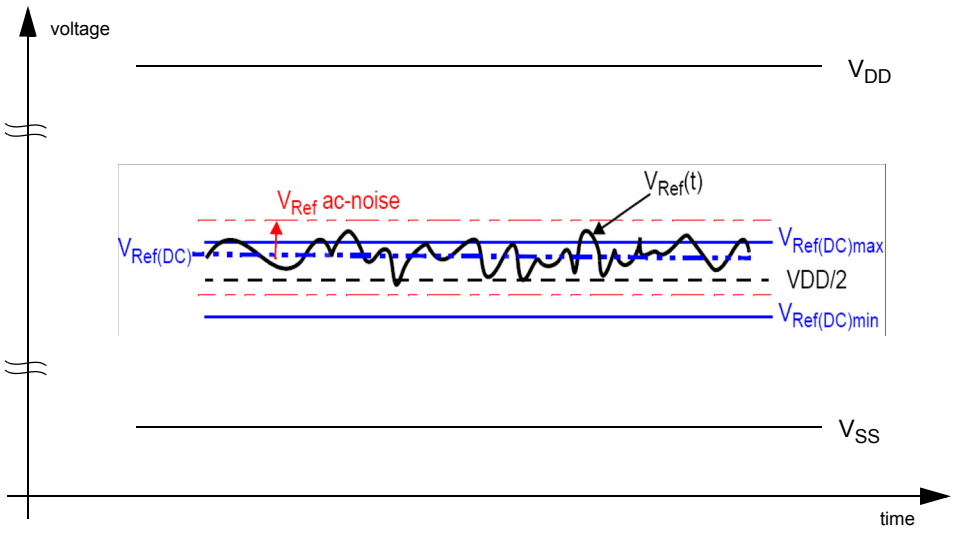


Figure 1. Illustration of V_{REF}(DC) tolerance and V_{REF} AC-noise limits

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

"V_{REF}" shall be understood as V_{REF}(DC), as defined in Figure 1.

This clarifies, that DC-variations of V_{REF} affect the absolute voltage a signal has to reach to achieve a valid high or low level and therefore the time to which setup and hold is measured. System timing and voltage budgets need to account for V_{REF}(DC) deviations from the optimum position within the data-eye of the input signals.

This also clarifies that the DRAM setup/hold specification and derating values need to include time and voltage associated with V_{REF} AC-noise. Timing and voltage effects due to AC-noise on V_{REF} up to the specified limit (+/-1% of V_{DD}) are included in DRAM timings and their associated deratings.

10.3 AC and DC Logic Input Levels for Differential Signals

10.3.1 Differential Signals Definition

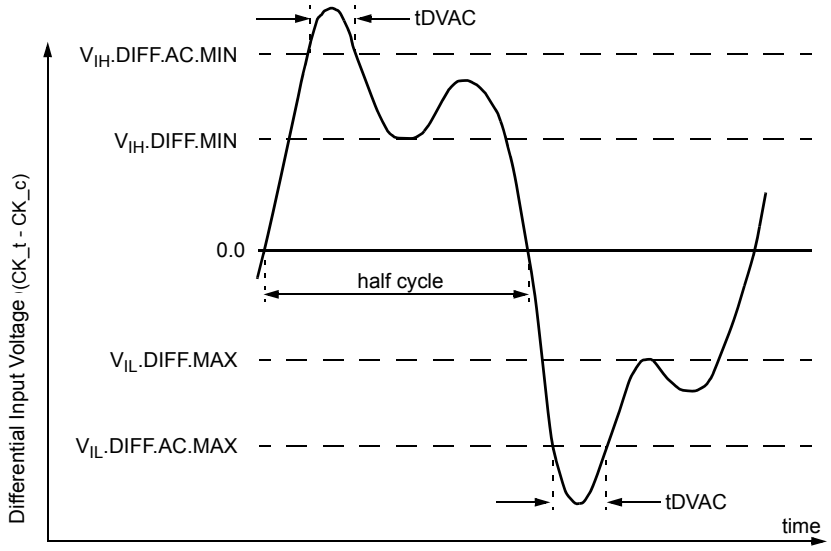


Figure 2. Definition of differential ac-swing and "time above ac-level" t_{DVAC}

NOTE:
1) Differential signal rising edge from VIL.DIFF.MAX to VIH.DIFF.MIN must be monotonic slope.
2) Differential signal falling edge from VIH.DIFF.MIN to VIL.DIFF.MAX must be monotonic slope.

10.3.2 Differential Swing Requirements for Clock (CK_t - CK_c)

[Table 8] Differential AC and DC Input Levels

Symbol	Parameter	DDR4 -1600/1866/2133		DDR4 -2400/2666		unit	NOTE
		min	max	min	max		
V_{IHdiff}	differential input high	+0.150	NOTE 3	0.135	NOTE 3	V	1
V_{ILdiff}	differential input low	NOTE 3	-0.150	NOTE 3	-0.135	V	1
V_{IHdiff}(AC)	differential input high ac	2 x (V_{IH}(AC) - V_{REF})	NOTE 3	2 x (V_{IH}(AC) - V_{REF})	NOTE 3	V	2
V_{ILdiff}(AC)	differential input low ac	NOTE 3	2 x (V_{IL}(AC) - V_{REF})	NOTE 3	2 x (V_{IL}(AC) - V_{REF})	V	2

NOTE :
1) Used to define a differential signal slew-rate.
2) for CK_t - CK_c use $V_{IH.CA}$/$V_{IL.CA}$(AC) of ADD/CMD and V_{REFCA};
3) These values are not defined; however, the differential signals CK_t - CK_c, need to be within the respective limits ($V_{IH.CA}$(DC) max, $V_{IL.CA}$(DC)min) for single-ended signals as well as the limitations for overshoot and undershoot.

[Table 9] Allowed Time Before Ringback (tDVAC) for CK_t - CK_c

Slew Rate [V/ns]	tDVAC [ps] @ $\|V_{IH/Ldiff}(AC)\|$ = 200mV	
	min	max
> 4.0	120	-
4.0	115	-
3.0	110	-
2.0	105	-
1.8	100	-
1.6	95	-
1.4	90	-
1.2	85	-
1.0	80	-
< 1.0	80	-

10.3.3 Single-ended Requirements for Differential Signals

Each individual component of a differential signal (CK_t, CK_c) has also to comply with certain requirements for single-ended signals.

CK_t and CK_c have to approximately reach VSEHmin / VSELmax (approximately equal to the ac-levels (VIH.CA(AC) / VIL.CA(AC)) for ADD/CMD signals) in every half-cycle.

Note that the applicable ac-levels for ADD/CMD might be different per speed-bin etc. E.g., if Different value than VIH.CA(AC100)/VIL.CA(AC100) is used for ADD/CMD signals, then these ac-levels apply also for the single-ended signals CK_t and CK_c.

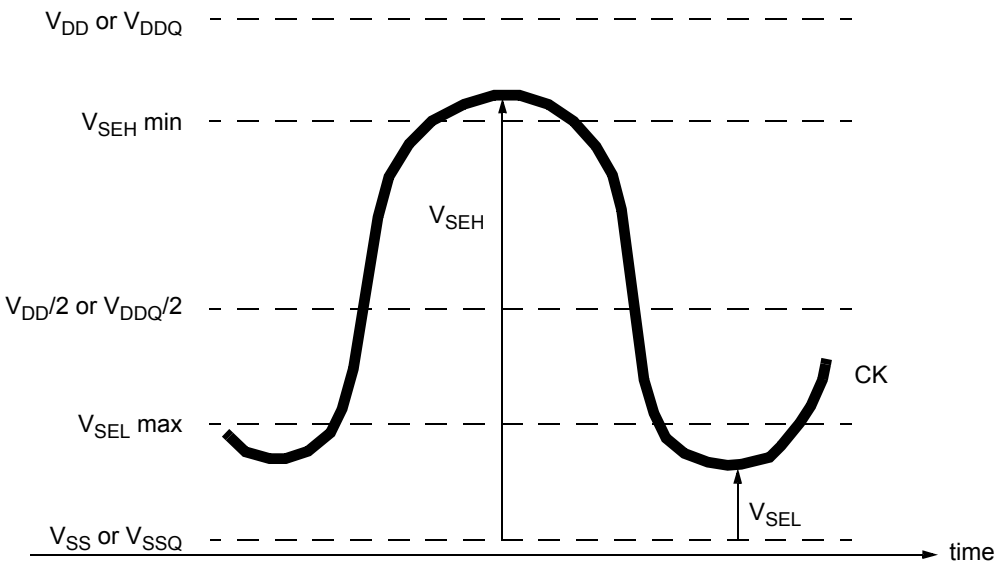


Figure 3. Single-ended requirement for differential signals.

Note that, while ADD/CMD signal requirements are with respect to VrefCA, the single-ended components of differential signals have a requirement with respect to VDD / 2; this is nominally the same. The transition of single-ended signals through the ac-levels is used to measure setup time. For single-ended components of differential signals the requirement to reach VSELmax, VSEHmin has no bearing on timing, but adds a restriction on the common mode characteristics of these signals.

[Table 10] Single-ended Levels for CK_t, CK_c

Symbol	Parameter	DDR4-1600/1866/2133		DDR4-2400/2666		Unit	NOTE
		Min	Max	Min	Max		
V_{SEH}	Single-ended high-level for CK_t, CK_c	(VDD/2)+0.100	NOTE3	(VDD/2)+0.95	NOTE3	V	1, 2
V_{SEL}	Single-ended low-level for CK_t, CK_c	NOTE3	(VDD/2)-0.100	NOTE3	(VDD/2)-0.95	V	1, 2

NOTE :

1) For CK_t - CK_c use $V_{IH.CA}/V_{IL.CA}$(AC) of ADD/CMD;

2) V_{IH}(AC)/V_{IL}(AC) for ADD/CMD is based on V_{REFCA};

3) These values are not defined, however the single-ended signals CK_t - CK_c need to be within the respective limits ($V_{IH.CA}$(DC) max, $V_{IL.CA}$(DC)min) for single-ended signals as well as the limitations for overshoot and undershoot.

10.3.4 Address, Command and Control Overshoot and Undershoot specifications

[Table 11] AC overshoot/undershoot specification for Address, Command and Control pins

Parameter	Symbol	Specification					Unit	NOTE
		DDR4-1600	DDR4-1866	DDR4-2133	DDR4-2400	DDR4-2666		
Maximum peak amplitude above VAOS	VAOSP	0.06				TBD	V	
Upper boundary of overshoot area AAOS1	VAOS	VDD +0.24				TBD	V	1
Maximum peak amplitude allowed for undershoot	VAUS	0.30				TBD	V	
Maximum overshoot area per 1 tCK above VAOS	AAOS2	0.0083	0.0071	0.0062	0.0055	TBD	V-ns	
Maximum overshoot area per 1 tCK between VDD and VAOS	AAOS1	0.2550	0.2185	0.1914	0.1699	TBD	V-ns	
Maximum undershoot area per 1 tCK below VSS	AAUS	0.2644	0.2265	0.1984	0.1762	TBD	V-ns	
(A0-A13,A17,BG0-BG1,BA0-BA1,ACT_n,RAS_n/A16,CAS_n/A15,WE_n/A14,CS_n,CKE,ODT,C2-C0)								

NOTE :

1) The value of VAOS matches VDD absolute max as defined in Table 5 Absolute Maximum DC Ratings if VDD equals VDD max as defined in Table 6 Recommended DC Operating Conditions. If VDD is above the recommended operating conditions, VAOS remains at VDD absolute max as defined in Table 5.

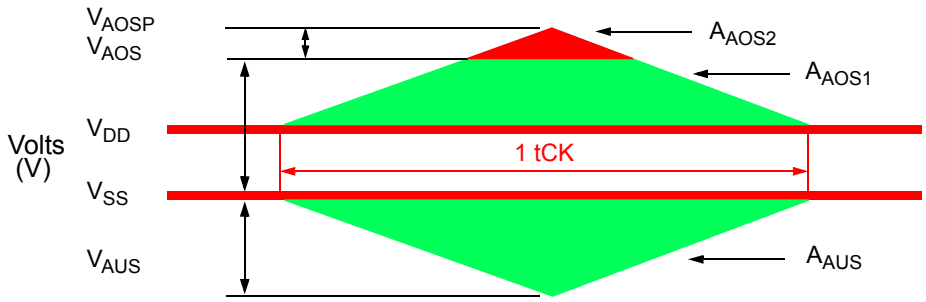


Figure 4. Address, Command and Control Overshoot and Undershoot Definition

10.3.5 Clock Overshoot and Undershoot Specifications

[Table 12] AC overshoot/undershoot specification for Clock

Parameter	Symbol	Specification					Unit	NOTE
		DDR4-1600	DDR4-1866	DDR4-2133	DDR4-2400	DDR4-2666		
Maximum peak amplitude above VCOS	VCOSP	0.06				TBD	V	
Upper boundary of overshoot area ADOS1	VCOS	VDD +0.24				TBD	V	1
Maximum peak amplitude allowed for undershoot	VCUS	0.30				TBD	V	
Maximum overshoot area per 1 UI above VCOS	ACOS2	0.0038	0.0032	0.0028	0.0025	TBD	V-ns	
Maximum overshoot area per 1 UI between VDD and VDOS	ACOS1	0.1125	0.0964	0.0844	0.0750	TBD	V-ns	
Maximum undershoot area per 1 UI below VSS	ACUS	0.1144	0.0980	0.0858	0.0762	TBD	V-ns	
(CK_t, CK_c)								

NOTE :
1) The value of VCOS matches VDD absolute max as defined in Table 5 Absolute Maximum DC Ratings if VDD equals VDD max as defined in Table 6 Recommended DC Operating Conditions. If VDD is above the recommended operating conditions, VCOS remains at VDD absolute max as defined in Table 5.

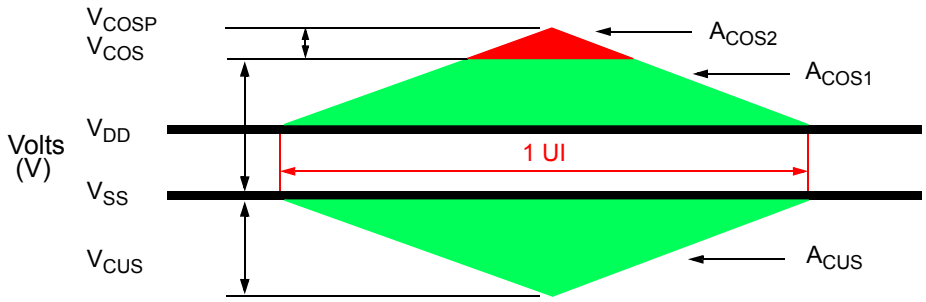


Figure 5. Clock Overshoot and Undershoot Definition

10.3.6 Data, Strobe and Mask Overshoot and Undershoot Specifications

[Table 13] AC overshoot/undershoot specification for Data, Strobe and Mask

Parameter	Symbol	Specification					Unit	NOTE
		DDR4-1600	DDR4-1866	DDR4-2133	DDR4-2400	DDR4-2666		
Maximum peak amplitude above VDOS	VDOSP	0.16	0.16	0.16	0.16	TBD	V	
Upper boundary of overshoot area ADOS1	VDOS	VDDQ + 0.24				TBD	V	1
Lower boundary of undershoot area ADUS1	VDUS	0.30	0.30	0.30	0.30	TBD	V	2
Maximum peak amplitude below VDUS	VDUSP	0.10	0.10	0.10	0.10	TBD	V	
Maximum overshoot area per 1 UI above VDOS	ADOS2	0.0150	0.0129	0.0113	0.0100	TBD	V-ns	
Maximum overshoot area per 1 UI between VDDQ and VDOS	ADOS1	0.1050	0.0900	0.0788	0.0700	TBD	V-ns	
Maximum undershoot area per 1 UI between VSSQ and VDUS1	ADUS1	0.1050	0.0900	0.0788	0.0700	TBD	V-ns	
Maximum undershoot area per 1 UI below VDUS	ADUS2	0.0150	0.0129	0.0113	0.0100	TBD	V-ns	

NOTE :
1) The value of VDOS matches (VIN, VOUT) max as defined in Table 5 Absolute Maximum DC Ratings if VDDQ equals VDDQ max as defined in Table 6 Recommended DC Operating Conditions. If VDDQ is above the recommended operating conditions, VDOS remains at (VIN, VOUT) max as defined in Table 5.
2) The value of VDUS matches (VIN, VOUT) min as defined in Table 5 Absolute Maximum DC Ratings

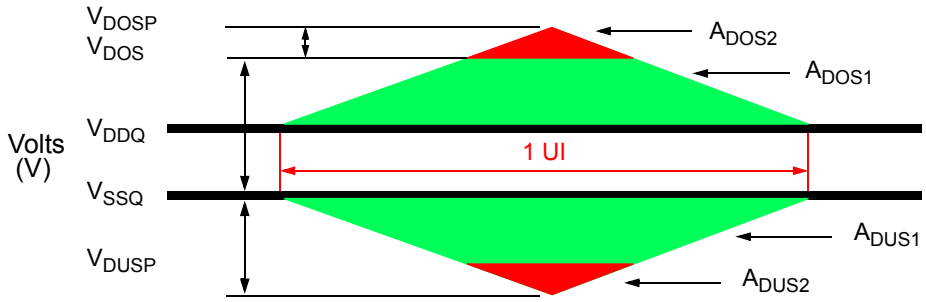


Figure 6. Data, Strobe and Mask Overshoot and Undershoot Definition

10.4 Slew Rate Definitions

10.4.1 Slew Rate Definitions for Differential Input Signals (CK)

Input slew rate for differential signals (CK_t, CK_c) are defined and measured as shown in Table 14 and Figure 7.

[Table 14] Differential Input Slew Rate Definition

Description	Measured		Defined by
	from	to	
Differential input slew rate for rising edge (CK_t - CK_c)	$V_{ILdiffmax}$	$V_{IHdiffmin}$	$[V_{IHdiffmin} - V_{ILdiffmax}]$ / DeltaTRdiff
Differential input slew rate for falling edge (CK_t - CK_c)	$V_{IHdiffmin}$	$V_{ILdiffmax}$	$[V_{IHdiffmin} - V_{ILdiffmax}]$ / DeltaTFdiff

NOTE :
1) The differential signal (i,e.,CK_t - CK_c) must be linear between these thresholds.

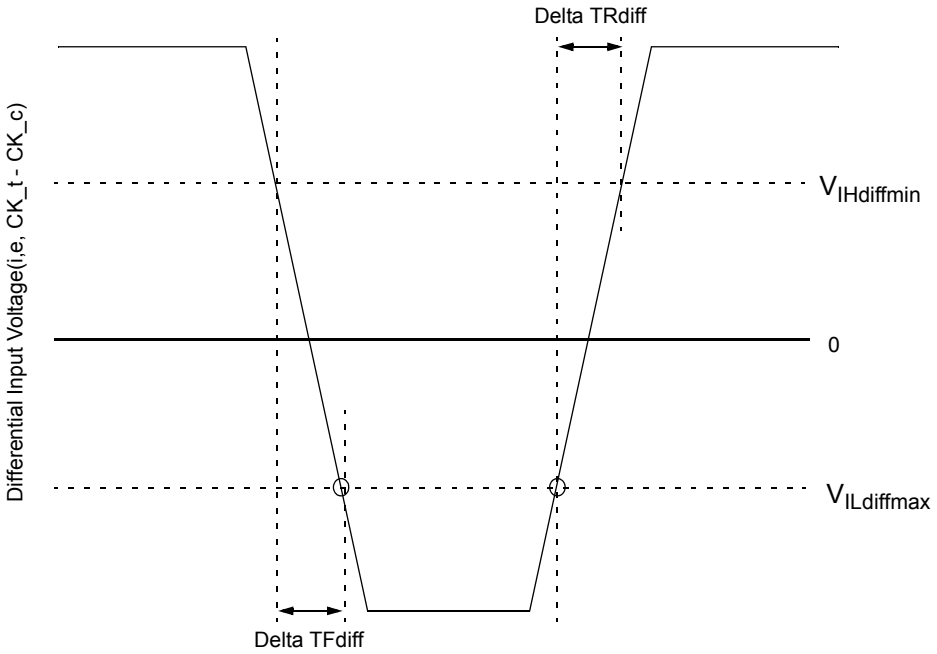


Figure 7. Differential Input Slew Rate Definition for CK_t, CK_c

10.4.2 Slew Rate Definition for Single-ended Input Signals (CMD/ADD)

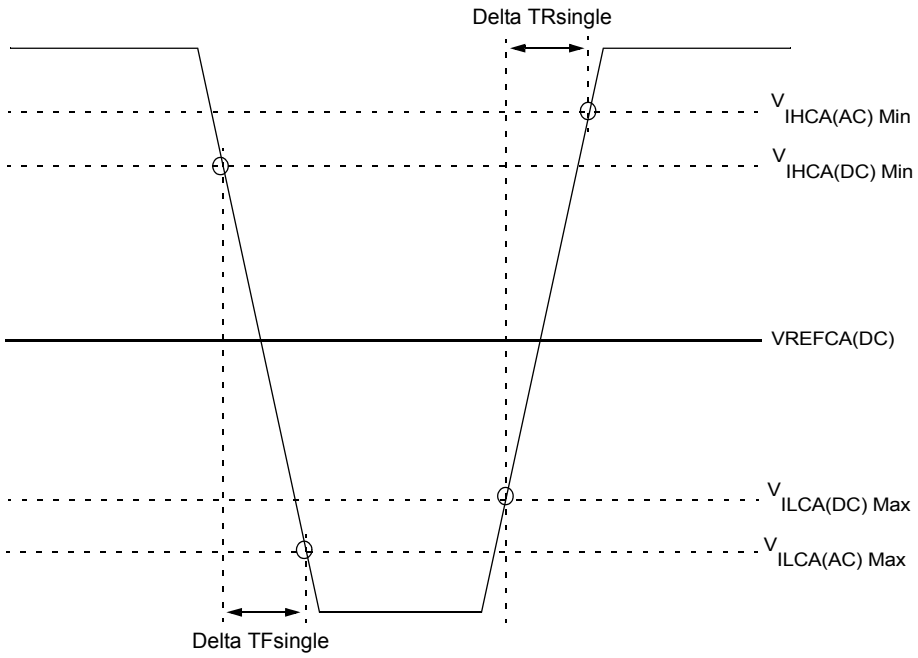


Figure 8. Single-ended Input Slew Rate definition for CMD and ADD

NOTE :
1) Single-ended input slew rate for rising edge = {VIHCA(AC)Min - VILCA(DC)Max} / Delta TR single.
2) Single-ended input slew rate for falling edge = {VIHCA(DC)Min - VILCA(AC)Max} / Delta TF single.
3) Single-ended signal rising edge from VILCA(DC)Max to VIHCA(DC)Min must be monotonic slope.
4) Single-ended signal falling edge from VIHCA(DC)Min to VILCA(DC)Max must be monotonic slope.

10.5 Differential Input Cross Point Voltage

To guarantee tight setup and hold times as well as output skew parameters with respect to clock, each cross point voltage of differential input signals (CK_t, CK_c) must meet the requirements in Table 15. The differential input cross point voltage VIX is measured from the actual cross point of true and complement signals to the midlevel between of VDD and VSS.

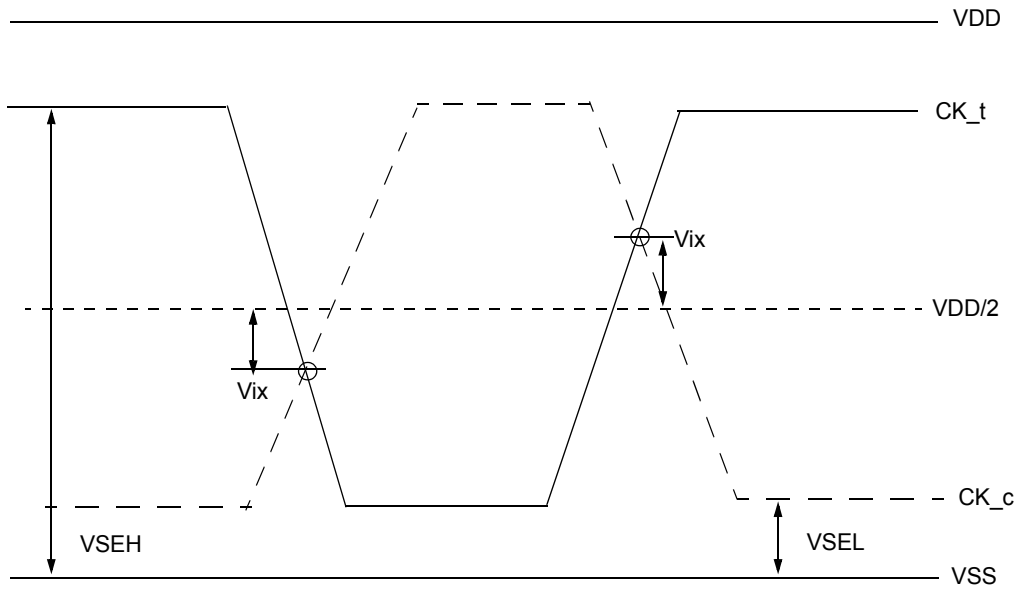


Figure 9. Vix Definition (CK)

[Table 15] Cross Point Voltage for Differential Input Signals (CK)

Symbol	Parameter	DDR4-1600/1866/2133			
		min		max	
-	Area of VSEH, VSEL	VSEL < VDD/2 - 145mV	VDD/2 - 145mV =< VSEL =< VDD/2 - 100mV	VDD/2 + 100mV =< VSEH =< VDD/2 + 145mV	VDD/2 + 145mV < VSEH
VIX(CK)	Differential Input Cross Point Voltage relative to VDD/2 for CK_t, CK_c	-120mV	-(VDD/2 - VSEL) + 25mV	(VSEH - VDD/2) - 25mV	120mV

Symbol	Parameter	DDR4-2400			
		min		max	
-	Area of VSEH, VSEL	VSEL < VDD/2 - 145 mV	VDD/2 - 145 mV =< VSEL =< VDD/2 - 100 mV	VDD/2 + 100 mV =< VSEH =< VDD/2 + 145 mV	VDD/2 + 145 mV < VSEH
VIX(CK)	Differential Input Cross Point Voltage relative to VDD/2 for CK_t, CK_c	-120mV	- (VDD/2 - VSEL) + 25 mV	(VSEH - VDD/2) - 25 mV	120mV

Symbol	Parameter	DDR4-2666			
		min		max	
-	Area of VSEH, VSEL	VSEL < VDD/2 - 145 mV	VDD/2 - 145 mV =< VSEL =< VDD/2 - 100 mV	VDD/2 + 100 mV =< VSEH =< VDD/2 + 145 mV	VDD/2 + 145 mV < VSEH
VIX(CK)	Differential Input Cross Point Voltage relative to VDD/2 for CK_t, CK_c	-110 mV	- (VDD/2 - VSEL) + 30 mV	(VSEH - VDD/2) - 30 mV	110mV

10.6 CMOS rail to rail Input Levels

10.6.1 CMOS rail to rail Input Levels for RESET_n

[Table 16] CMOS rail to rail Input Levels for RESET_n

Parameter	Symbol	Min	Max	Unit	NOTE
AC Input High Voltage	VIH(AC)_RESET	0.8*VDD	VDD	V	6
DC Input High Voltage	VIH(DC)_RESET	0.7*VDD	VDD	V	2
DC Input Low Voltage	VIL(DC)_RESET	VSS	0.3*VDD	V	1
AC Input Low Voltage	VIL(AC)_RESET	VSS	0.2*VDD	V	7
Rising time	TR_RESET	-	1.0	us	4
RESET pulse width	tPW_RESET	1.0	-	us	3,5

NOTE :
1) After RESET_n is registered LOW, RESET_n level shall be maintained below VIL(DC)_RESET during tPW_RESET, otherwise, SDRAM may not be reset.
2) Once RESET_n is registered HIGH, RESET_n level must be maintained above VIH(DC)_RESET, otherwise, SDRAM operation will not be guaranteed until it is reset asserting RESET_n signal LOW.
3) RESET is destructive to data contents.
4) No slope reversal(ringback) requirement during its level transition from Low to High.
5) This definition is applied only “Reset Procedure at Power Stable”.
6) Overshoot might occur. It should be limited by the Absolute Maximum DC Ratings.
7) Undershoot might occur. It should be limited by Absolute Maximum DC Ratings.

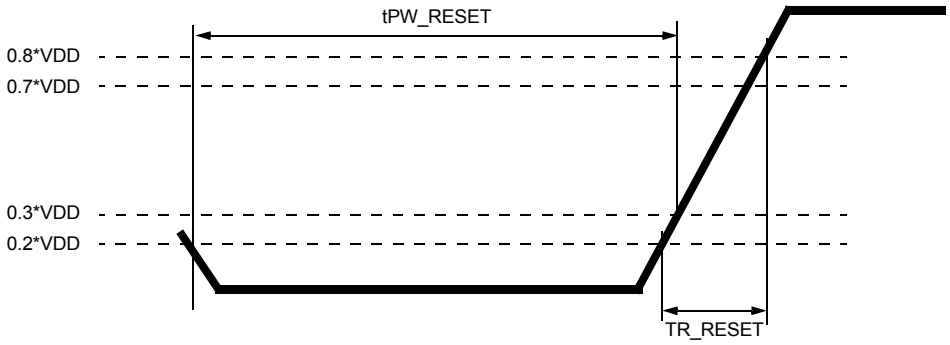


Figure 10. RESET_n Input Slew Rate Definition

10.7 AC and DC Logic Input Levels for DQS Signals

10.7.1 Differential signal definition

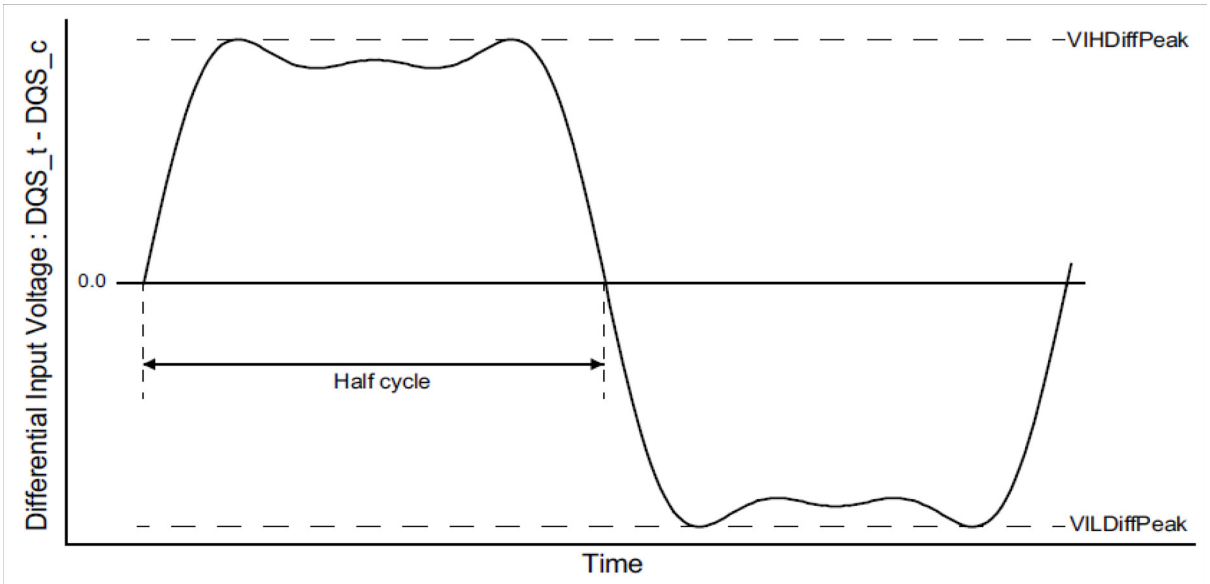


Figure 11. Definition of differential DQS Signal AC-swing Level

10.7.2 Differential swing requirements for DQS (DQS_t - DQS_c)

[Table 17] Differential AC and DC Input Levels for DQS

Symbol	Parameter	DDR4-1600, 1866, 2133		DDR4-2400		DDR4-2666		Unit	Note
		Min	Max	Min	Max	Min	Max		
VIHDiffPeak	VIH.DIFF.Peak Voltage	186	Note2	160	Note2	150	Note2	mV	1
VILDiffPeak	VIL.DIFF.Peak Voltage	Note2	-186	Note2	-160	Note2	-150	mV	1

NOTE :

1) Used to define a differential signal slew-rate.
2) These values are not defined; however, the differential signals DQS_t - DQS_c, need to be within the respective limits Overshoot, Undershoot Specification for single-ended signals.

10.7.3 Peak voltage calculation method

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

VIH.DIFF.Peak Voltage = Max(f(t))

VIL.DIFF.Peak Voltage = Min(f(t))

f(t) = VDQS_t - VDQS_c

The Max(f(t)) or Min(f(t)) used to determine the midpoint which to reference the +/-35% window of the exempt non-monotonic signaling shall be the smallest peak voltage observed in all ui's.

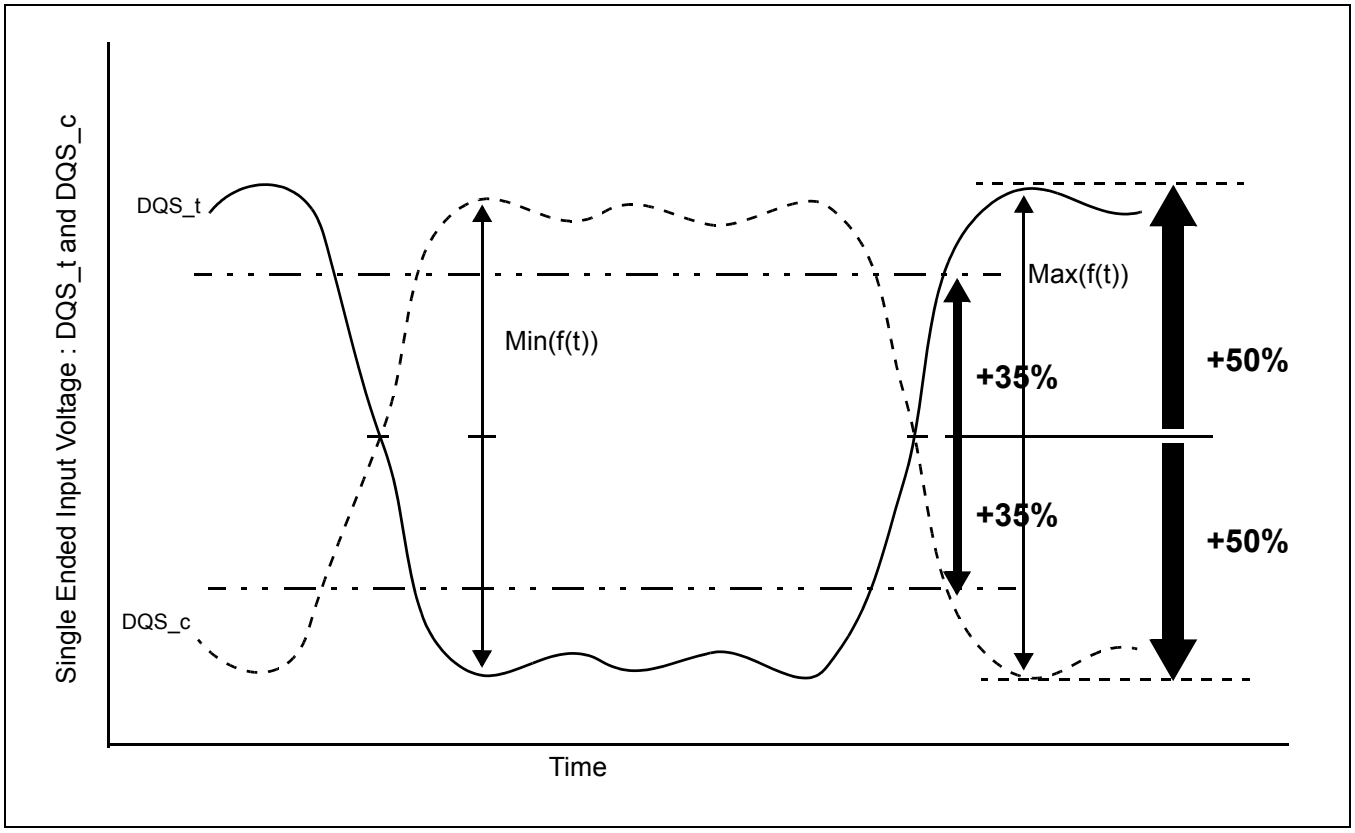


Figure 12. Definition of differential DQS Peak Voltage and rage of exempt non-monotonic signaling

10.7.4 Differential Input Cross Point Voltage

To achieve tight RxMask input requirements as well as output skew parameters with respect to strobe, the cross point voltage of differential input signals (DQS_t, DQS_c) must meet the requirements in Table 18. The differential input cross point voltage VIX_DQS (VIX_DQS_FR and VIX_DQS_RF) is measured from the actual cross point of DQS_t, DQS_c relative to the VDQSmid of the DQS_t and DQS_c signals.
VDQSmid is the midpoint of the minimum levels achieved by the transitioning DQS_t and DQS_c signals, and noted by VDQS_trans. VDQS_trans is the difference between the lowest horizontal tangent above VDQSmid of the transitioning DQS signals and the highest horizontal tangent below VDQSmid of the transitioning DQS signals.
A non-monotonic transitioning signal's ledge is exempt or not used in determination of a horizontal tangent provided the said ledge occurs within +/- 35% of the midpoint of either VIH.DIFF.Peak Voltage (DQS_t rising) or VIL.DIFF.Peak Voltage (DQS_c rising), refer to Figure 12. A secondary horizontal tangent resulting from a ring-back transition is also exempt in determination of a horizontal tangent. That is, a falling transition's horizontal tangent is derived from its negative slope to zero slope transition (point A in Figure 13) and a ring-back's horizontal tangent derived from its positive slope to zero slope transition (point B in Figure 13) is not a valid horizontal tangent; and a rising transition's horizontal tangent is derived from its positive slope to zero slope transition (point C in Figure 13) and a ring-back's horizontal tangent derived from its negative slope to zero slope transition (point D in Figure 13) is not a valid horizontal tangent

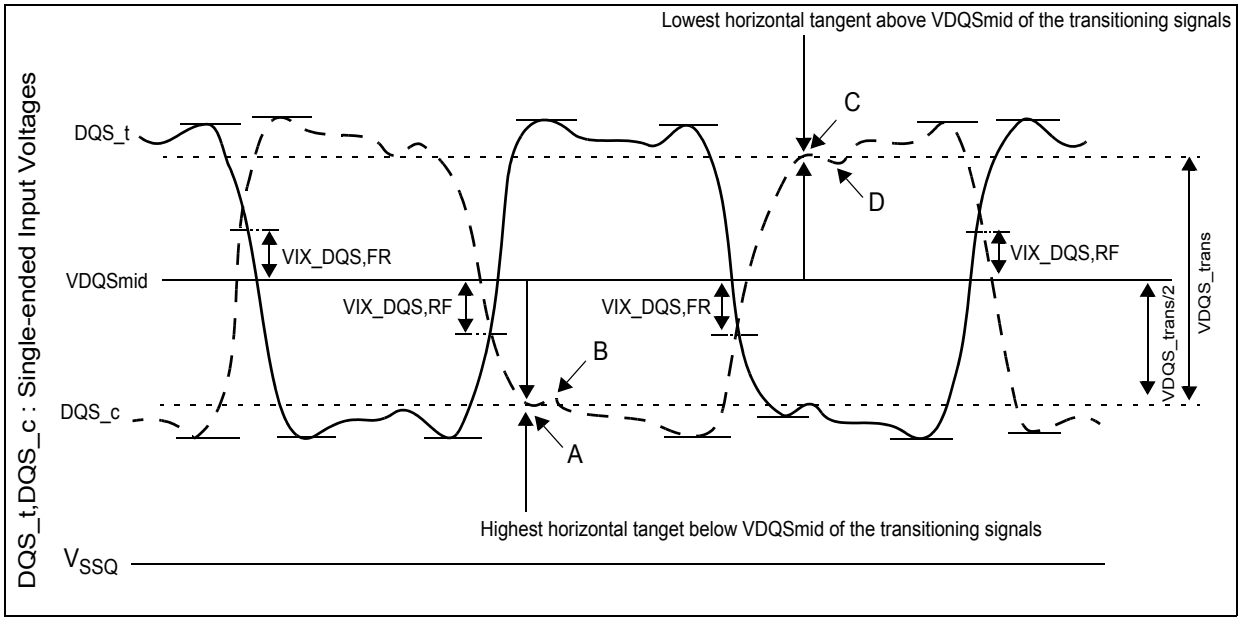


Figure 13. Vix Definition (DQS)

[Table 18] Cross point voltage for DQS differential input signals

Symbol	Parameter	DDR4-1600/1866/2133/		DDR4-2666		Unit	Note
		Min	Max	Min	Max		
Vix_DQS_ratio	DQS_t and DQS_c crossing relative to the midpoint of the DQS_t and DQS_c signal swings	-	25	-	25	%	1, 2
VDQSmid_to_Vcent	VDQSmid offset relative to Vcent_DQ(midpoint)	-	min (VIHdiff,50)	-	min (VIHdiff,50)	mV	3, 4, 5

NOTE :
1) Vix_DQS_Ratio is DQS VIX crossing (Vix_DQS_FR or Vix_DQS_RF) divided by VDQS_trans. VDQS_trans is the difference between the lowest horizontal tangent above VDQSmid of the transitioning DQS signals and the highest horizontal tangent below VDQSmid of the transitioning DQS signals.
2) VDQSmid will be similar to the VREFDQ internal setting value obtained during Vref Training if the DQS and DQs drivers and paths are matched.
3) The maximum limit shall not exceed the smaller of VIHdiff minimum limit or 50mV.
4) VIX measurements are only applicable for transitioning DQS_t and DQS_c signals when toggling data, preamble and high-z states are not applicable conditions.
5) The parameter VDQSmid is defined for simulation and ATE testing purposes, it is not expected to be tested in a system.

10.7.5 Differential Input Slew Rate Definition

Input slew rate for differential signals (DQS_t, DQS_c) are defined and measured as shown in Figure 13 and Figure 14.

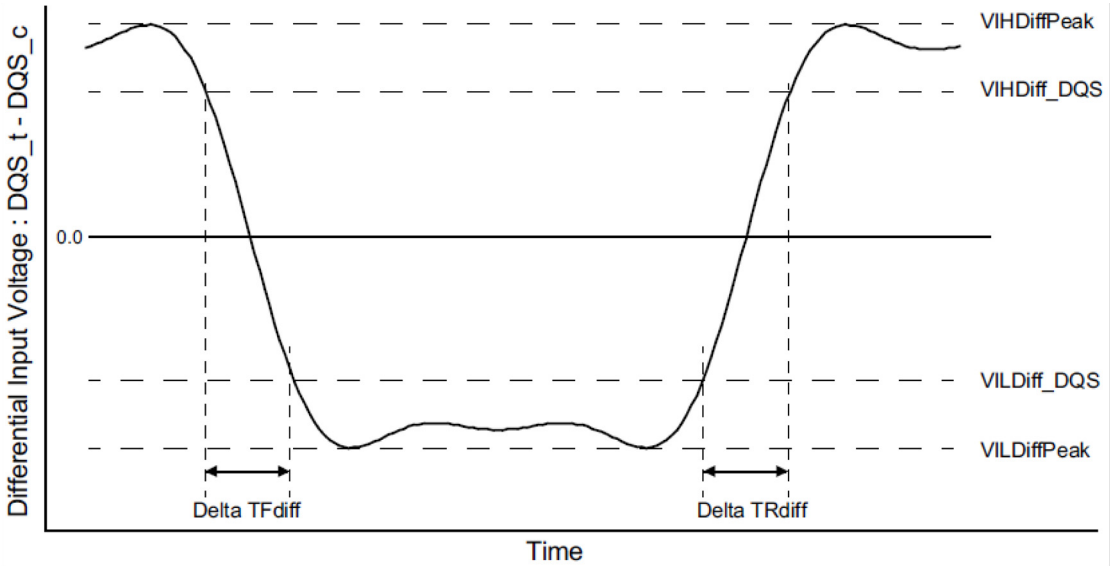


Figure 14. Differential Input Slew Rate Definition for DQS_t, DQS_c

NOTE :

1) Differential signal rising edge from VILDiff_DQS to VIHDiff_DQS must be monotonic slope.
2) Differential signal falling edge from VIHDiff_DQS to VILDiff_DQS must be monotonic slope.

[Table 19] Differential Input Slew Rate Definition for DQS_t, DQS_c

Description	Measured		Defined by
	From	To	
Differential input slew rate for rising edge (DQS_t - DQS_c)	VILDiff_DQS	VIHDiff_DQS	|VILDiff_DQS - VIHDiff_DQS|/DeltaTRdiff
Differential input slew rate for falling edge (DQS_t - DQS_c)	VIHDiff_DQS	VILDiff_DQS	|VILDiff_DQS - VIHDiff_DQS|/DeltaTFdiff

[Table 20] Differential Input Level for DQS_t, DQS_c

Symbol	Parameter	DDR4-1600/1866/2133		DDR4-2400/2666		Unit	NOTE
		Min	Max	Min	Max		
VIHDiff_DQS	Differential Input High	136	-	130	-	mV	
VILDiff_DQS	Differential Input Low	-	-136	-	-130	mV	

[Table 21] Differential Input Slew Rate for DQS_t, DQS_c

Symbol	Parameter	DDR4-1600/1866/2133/2400		DDR4-2666		Unit	NOTE
		Min	Max	Min	Max		
SRIdiff	Differential Input Slew Rate	3	18	2.5	18	V/ns	

11. AC AND DC OUTPUT MEASUREMENT LEVELS

11.1 Output Driver DC Electrical Characteristics

The DDR4 driver supports two different Ron values. These Ron values are referred as strong(low Ron) and weak mode(high Ron). A functional representation of the output buffer is shown in the figure below. Output driver impedance RON is defined as follows:

The individual pull-up and pull-down resistors (RON_{Pu} and RON_{Pd}) are defined as follows:

$$RON_{Pu} = \frac{VDDQ - Vout}{|I\ out|}$$ under the condition that RON_{Pd} is off

$$RON_{Pd} = \frac{Vout}{|I\ out|}$$ under the condition that RON_{Pu} is off

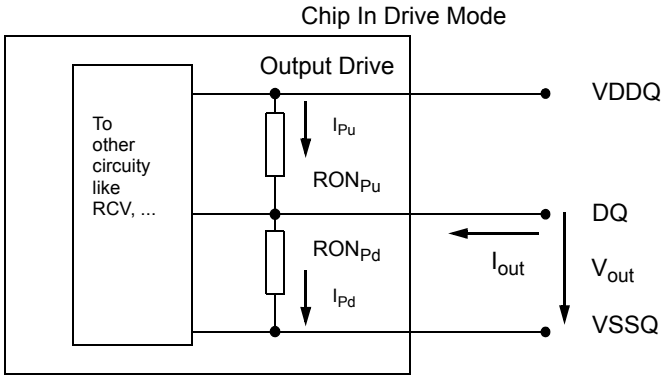


Figure 15. Output driver

[Table 22] Output Driver DC Electrical Characteristics, assuming RZQ=240ohm; entire operating temperature range; after proper ZQ calibration

RON_{NOM}	Resistor	Vout	Min	Nom	Max	Unit	NOTE
34Ω	RON34Pd	VOLdc= 0.5*VDDQ	0.73	1	1.1	RZQ/7	1,2
		VOMdc= 0.8* VDDQ	0.83	1	1.1	RZQ/7	1,2
		VOHdc= 1.1* VDDQ	0.83	1	1.25	RZQ/7	1,2
	RON34Pu	VOLdc= 0.5* VDDQ	0.9	1	1.25	RZQ/7	1,2
		VOMdc= 0.8* VDDQ	0.9	1	1.1	RZQ/7	1,2
		VOHdc= 1.1* VDDQ	0.8	1	1.1	RZQ/7	1,2
48Ω	RON48Pd	VOLdc= 0.5*VDDQ	0.73	1	1.1	RZQ/5	1,2
		VOMdc= 0.8* VDDQ	0.83	1	1.1	RZQ/5	1,2
		VOHdc= 1.1* VDDQ	0.83	1	1.25	RZQ/5	1,2
	RON48Pu	VOLdc= 0.5* VDDQ	0.9	1	1.25	RZQ/5	1,2
		VOMdc= 0.8* VDDQ	0.9	1	1.1	RZQ/5	1,2
		VOHdc= 1.1* VDDQ	0.8	1	1.1	RZQ/5	1,2
Mismatch between pull-up and pull-down, MMPuPd		VOMdc= 0.8* VDDQ	-10	-	17	%	1,2,3,4
Mismatch DQ-DQ within byte variation pull-up, MMPudd		VOMdc= 0.8* VDDQ	-	-	10	%	1,2,4
Mismatch DQ-DQ within byte variation pull-dn, MMPddd		VOMdc= 0.8* VDDQ	-	-	10	%	1,2,4

NOTE :

1) The tolerance limits are specified after calibration with stable voltage and temperature. For the behavior of the tolerance limits if temperature or voltage changes after calibration, see following section on voltage and temperature sensitivity (TBD).
2) Pull-up and pull-dn output driver impedances are recommended to be calibrated at 0.8 * VDDQ. Other calibration schemes may be used to achieve the linearity spec shown above, e.g. calibration at 0.5 * VDDQ and 1.1 * VDDQ.
3) Measurement definition for mismatch between pull-up and pull-down, MMPuPd : Measure RONPu and RONPD both at 0.8*VDD separately; Ronnom is the nominal Ron value

$$MMPuPd = \frac{RONPu - RONPd}{RONNOM} * 100$$

4) RON variance range ratio to RON Nominal value in a given component, including DQS_t and DQS_c.

$$MMPudd = \frac{RONPuMax - RONPuMin}{RONNOM} * 100$$

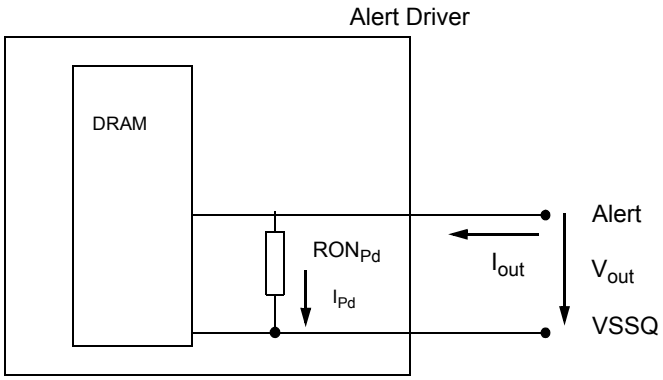
$$MMPddd = \frac{RONPdMax - RONPdMin}{RONNOM} * 100$$

5) This parameter of x16 device is specified for Uper byte and Lower byte.

11.1.1 Alert_n output Drive Characteristic

A functional representation of the output buffer is shown in the figure below. Output driver impedance RON is defined as follows:

$$RON_{Pd} = \frac{Vout}{|\ Iout\ |}$$ under the condition that RON_{Pu} is off



Resistor	Vout	Min	Max	Unit	NOTE
RON_{Pd}	VOLdc= 0.1* VDDQ	0.3	1.2	34Ω	1
	V_{OMdc} = 0.8* VDDQ	0.4	1.2	34Ω	1
	V_{OHdc} = 1.1* VDDQ	0.4	1.4	34Ω	1

NOTE:
1) VDDQ voltage is at VDDQ DC. VDDQ DC definition is TBD.

11.1.2 Output Driver Characteristic of Connectivity Test (CT) Mode

Following Output driver impedance RON will be applied Test Output Pin during Connectivity Test (CT) Mode.
The individual pull-up and pull-down resistors (RONPu_CT and RONPd_CT) are defined as follows:

$$RON_{Pu\_CT} = \frac{V_{DDQ}-V_{OUT}}{|Iout|}$$

$$RON_{Pd\_CT} = \frac{V_{OUT}}{|Iout|}$$

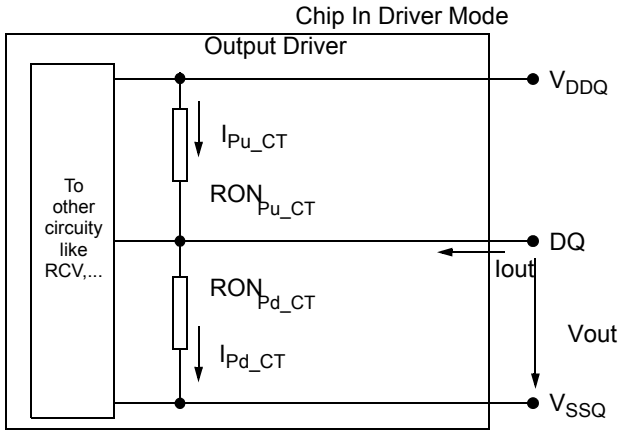


Figure 16. Output Driver

RON_{NOM_CT}	Resistor	Vout	Max	Units	NOTE
34Ω	RON_{Pd_CT}	VOB_{dc} = 0.2 x V_{DDQ}	1.9	34Ω	1
		VOL_{dc} = 0.5 x V_{DDQ}	2.0	34Ω	1
		VOM_{dc} = 0.8 x V_{DDQ}	2.2	34Ω	1
		VOH_{dc} = 1.1 x V_{DDQ}	2.5	34Ω	1
	RON_{Pu_CT}	VOB_{dc} = 0.2 x V_{DDQ}	2.5	34Ω	1
		VOL_{dc} = 0.5 x V_{DDQ}	2.2	34Ω	1
		VOM_{dc} = 0.8 x V_{DDQ}	2.0	34Ω	1
		VOH_{dc} = 1.1 x V_{DDQ}	1.9	34Ω	1

NOTE :
1) Connectivity test mode uses un-calibrated drivers, showing the full range over PVT. No mismatch between pull up and pull down is defined.

11.2 Single-ended AC & DC Output Levels

[Table 23] Single-ended AC & DC Output Levels

Symbol	Parameter	DDR4-1600/1866/2133/2400/2666	Units	NOTE
V_{OH}(DC)	DC output high measurement level (for IV curve linearity)	1.1 x V_{DDQ}	V	
V_{OM}(DC)	DC output mid measurement level (for IV curve linearity)	0.8 x V_{DDQ}	V	
V_{OL}(DC)	DC output low measurement level (for IV curve linearity)	0.5 x V_{DDQ}	V	
V_{OH}(AC)	AC output high measurement level (for output SR)	(0.7 + 0.15) x V_{DDQ}	V	1
V_{OL}(AC)	AC output low measurement level (for output SR)	(0.7 - 0.15) x V_{DDQ}	V	1

NOTE :
1) The swing of ± 0.15 × V_{DDQ} is based on approximately 50% of the static single-ended output peak-to-peak swing with a driver impedance of RZQ/7Ω and an effective test load of 50Ω to V_{TT} = V_{DDQ}.

11.3 Differential AC & DC Output Levels

[Table 24] Differential AC & DC Output Levels

Symbol	Parameter	DDR4-1600/1866/2133/2400/2666	Units	NOTE
V_{OHdiff}(AC)	AC differential output high measurement level (for output SR)	+0.3 x V_{DDQ}	V	1
V_{OLdiff}(AC)	AC differential output low measurement level (for output SR)	-0.3 x V_{DDQ}	V	1

NOTE :
1) The swing of ± 0.3 × V_{DDQ} is based on approximately 50% of the static differential output peak-to-peak swing with a driver impedance of RZQ/7Ω and an effective test load of 50Ω to V_{TT} = V_{DDQ} at each of the differential outputs.

11.4 Single-ended Output Slew Rate

With the reference load for timing measurements, output slew rate for falling and rising edges is defined and measured between $V_{OL(AC)}$ and $V_{OH(AC)}$ for single ended signals as shown in Table 25 and Figure 17.

[Table 25] Single-ended Output Slew Rate Definition

Description	Measured		Defined by
	From	To	
Single ended output slew rate for rising edge	V_{OL}(AC)	V_{OH}(AC)	[V_{OH}(AC)-V_{OL}(AC)] / Delta TRse
Single ended output slew rate for falling edge	V_{OH}(AC)	V_{OL}(AC)	[V_{OH}(AC)-V_{OL}(AC)] / Delta TFse

NOTE :
1) Output slew rate is verified by design and characterization, and may not be subject to production test.

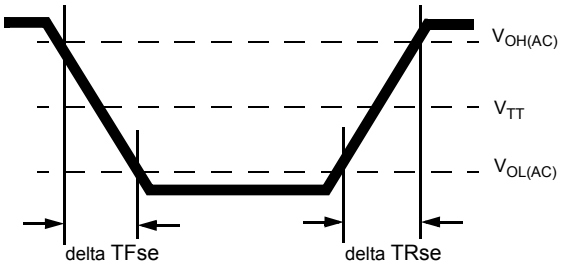


Figure 17. Single-ended Output Slew Rate Definition

[Table 26] Single-ended Output Slew Rate

Parameter	Symbol	DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Single ended output slew rate	SRQse	4	9	4	9	4	9	4	9	4	9	V/ns

Description: SR: Slew Rate
Q: Query Output (like in DQ, which stands for Data-in, Query-Output)
se: Single-ended Signals
For Ron = RZQ/7 setting

NOTE :
1. In two cases, a maximum slew rate of 12 V/ns applies for a single DQ signal within a byte lane.
-Case 1 is defined for a single DQ signal within a byte lane which is switching into a certain direction (either from high to low or low to high) while all remaining DQ signals in the same byte lane are static (i.e. they stay at either high or low).
-Case 2 is defined for a single DQ signal within a byte lane which is switching into a certain direction (either from high to low or low to high) while all remaining DQ signals in the same byte lane are switching into the opposite direction (i.e. from low to high or high to low respectively). For the remaining DQ signal switching into the opposite direction, the regular maximum limit of 9 V/ns applies

11.5 Differential Output Slew Rate

With the reference load for timing measurements, output slew rate for falling and rising edges is defined and measured between VOLdiff(AC) and VOHdiff(AC) for differential signals as shown in Table 27 and Figure 18.

[Table 27] Differential Output Slew Rate Definition

Description	Measured		Defined by
	From	To	
Differential output slew rate for rising edge	$V_{OLdiff}(AC)$	$V_{OHdiff}(AC)$	$[V_{OHdiff}(AC)-V_{OLdiff}(AC)]$ / Delta TRdiff
Differential output slew rate for falling edge	$V_{OHdiff}(AC)$	$V_{OLdiff}(AC)$	$[V_{OHdiff}(AC)-V_{OLdiff}(AC)]$ / Delta TFdiff

NOTE:
1) Output slew rate is verified by design and characterization, and may not be subject to production test.

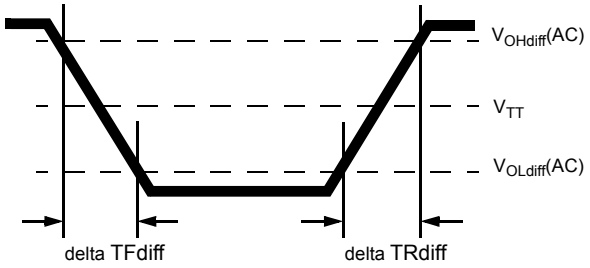


Figure 18. Differential Output Slew Rate Definition

[Table 28] Differential Output Slew Rate

Parameter	Symbol	DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Differential output slew rate	SRQdiff	8	18	8	18	8	18	8	18	8	18	V/ns

Description:
SR: Slew Rate
Q: Query Output (like in DQ, which stands for Data-in, Query-Output)
diff: Differential Signals
For Ron = RZQ/7 setting

11.6 Single-ended AC & DC Output Levels of Connectivity Test Mode

Following output parameters will be applied for DDR4 SDRAM Output Signal during Connectivity Test Mode.

[Table 29] Single-ended AC & DC Output Levels of Connectivity Test Mode

Symbol	Parameter	DDR4-1600/1866/2133/2400/2666	Unit	Notes
$V_{OH(DC)}$	DC output high measurement level (for IV curve linearity)	1.1 x VDDQ	V	
$V_{OM(DC)}$	DC output mid measurement level (for IV curve linearity)	0.8 x VDDQ	V	
$V_{OL(DC)}$	DC output low measurement level (for IV curve linearity)	0.5 x VDDQ	V	
$V_{OB(DC)}$	DC output below measurement level (for IV curve linearity)	0.2 x VDDQ	V	
$V_{OH(AC)}$	AC output high measurement level (for output SR)	VTT + (0.1 x VDDQ)	V	1
$V_{OL(AC)}$	AC output below measurement level (for output SR)	VTT - (0.1 x VDDQ)	V	1

NOTE :

1) The effective test load is 50Ω terminated by VTT = 0.5 * VDDQ.

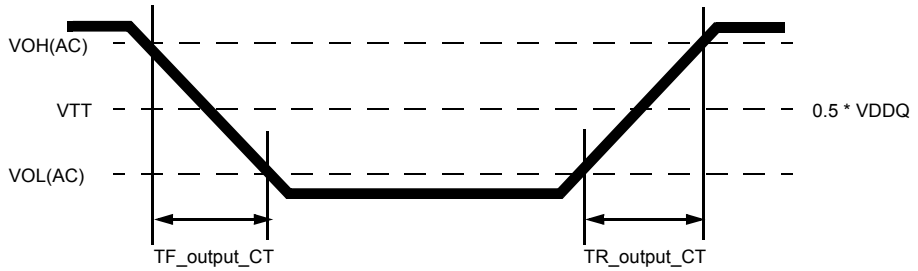


Figure 19. Output Slew Rate Definition of Connectivity Test Mode

[Table 30] Single-ended Output Slew Rate of Connectivity Test Mode

Parameter	Symbol	DDR4-1600/1866/2133/2400/2666		Unit	Notes
		Min	Max		
Output signal Falling time	TF_output_CT	-	10	ns/V	
Output signal Rising time	TR_output_CT	-	10	ns/V	

11.7 Test Load for Connectivity Test Mode Timing

The reference load for ODT timings is defined in Figure 20.

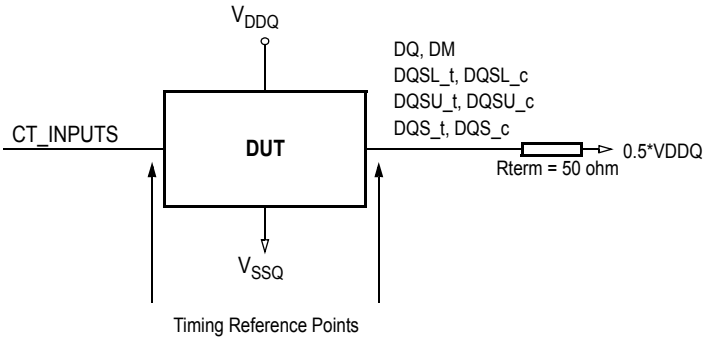


Figure 20. Connectivity Test Mode Timing Reference Load

12. SPEED BIN

[Table 31] DDR4-1600 Speed Bins and Operations

Speed Bin				DDR4-1600		Unit	NOTE
CL-nRCD-nRP				11-11-11			
Parameter			Symbol	min	max		
Internal read command to first data			tAA	13.75[13] (13.50)[5),10)]	18.00	ns	11
Internal read command to first data with read DBI enabled			tAA_DBI	tAA(min) + 2nCK	tAA(max) +2nCK	ns	11
ACT to internal read or write delay time			tRCD	13.75 (13.50)[5),10)]	-	ns	11
PRE command period			tRP	13.75 (13.50)[5),10)]	-	ns	11
ACT to PRE command period			tRAS	35	9 x tREFI	ns	11
ACT to ACT or REF command period			tRC	48.75 (48.50)[5),10)]	-	ns	11
	Normal	Read DBI					
CWL = 9	CL = 9	CL = 11 (Optional) [5)]	tCK(AVG)	1.5 (Optional)[5),10]	1.6	ns	1,2,3,4,10,13
	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	1,2,3,4,10
CWL = 9,11	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 11	CL = 13	tCK(AVG)	1.25	<1.5	ns	1,2,3,4
	CL = 12	CL = 14	tCK(AVG)	1.25	<1.5	ns	1,2,3
Supported CL Settings				(9),11,12		nCK	12,13
Supported CL Settings with read DBI				(11),13,14		nCK	12
Supported CWL Settings				9,11		nCK	

[Table 32] DDR4-1866 Speed Bins and Operations

Speed Bin				DDR4-1866		Unit	NOTE
CL-nRCD-nRP				13-13-13			
Parameter			Symbol	min	max		
Internal read command to first data			tAA	13.92[13)] (13.50)[5),11)]	18.00	ns	11
Internal read command to first data with read DBI enabled			tAA_DBI	tAA(min) + 2nCK	tAA(max) +2nCK	ns	11
ACT to internal read or write delay time			tRCD	13.92 (13.50)[5),11)]	-	ns	11
PRE command period			tRP	13.92 (13.50)[5),11)]	-	ns	11
ACT to PRE command period			tRAS	34	9 x tREFI	ns	11
ACT to ACT or REF command period			tRC	47.92 (47.50)[5),11)]	-	ns	11
	Normal	Read DBI					
CWL = 9	CL = 9	CL = 11 (Optional) [5)]	tCK(AVG)	1.5 (Optional)[5),11)]	1.6	ns	1,2,3,4,10,13
	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	1,2,3,4,10
CWL = 9,11	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	4
	CL = 11	CL = 13	tCK(AVG)	1.25 (Optional)[5),11)]	<1.5	ns	1,2,3,4,6
	CL = 12	CL = 14	tCK(AVG)	1.25	<1.5	ns	1,2,3,6
CWL = 10,12	CL = 12	CL = 14	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 13	CL = 15	tCK(AVG)	1.071	<1.25	ns	1,2,3,4
	CL = 14	CL = 16	tCK(AVG)	1.071	<1.25	ns	1,2,3
Supported CL Settings				9,11,12,13,14		nCK	12,13
Supported CL Settings with read DBI				11,13,14,15,16		nCK	12
Supported CWL Settings				9,10,11,12		nCK	

[Table 33] DDR4-2133 Speed Bins and Operations

Speed Bin				DDR4-2133		Unit	NOTE
CL-nRCD-nRP				15-15-15			
Parameter			Symbol	min	max		
Internal read command to first data			tAA	14.06[13] (13.50)[5),11)]	18.00	ns	11
Internal read command to first data with read DBI enabled			tAA_DBI	tAA(min) + 3nCK	tAA(max) + 3nCK	ns	11
ACT to internal read or write delay time			tRCD	14.06 (13.50)[5),11)]	-	ns	11
PRE command period			tRP	14.06 (13.50)[5),11)]	-	ns	11
ACT to PRE command period			tRAS	33	9 x tREFI	ns	11
ACT to ACT or REF command period			tRC	47.06 (46.50)[5),11)]	-	ns	11
	Normal	Read DBI					
CWL = 9	CL = 9	CL = 11 (Optional) [5]	tCK(AVG)	1.5 (Optional)[5),11)]	1.6	ns	1,2,3,4,10,13
	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	1,2,3,10
CWL = 9,11	CL = 11	CL = 13	tCK(AVG)	1.25 (Optional)[5),11)]	<1.5	ns	1,2,3,4,7
	CL = 12	CL = 14	tCK(AVG)	1.25	<1.5	ns	1,2,3,7
CWL = 10,12	CL = 13	CL = 15	tCK(AVG)	1.071 (Optional)[5),11)]	<1.25	ns	1,2,3,4,7
	CL = 14	CL = 16	tCK(AVG)	1.071	<1.25	ns	1,2,3,7
CWL = 11,14	CL = 14	CL = 17	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 15	CL = 18	tCK(AVG)	0.937	<1.071	ns	1,2,3,4
	CL = 16	CL = 19	tCK(AVG)	0.937	<1.071	ns	1,2,3
Supported CL Settings				(9),(11), 12,(13),14,15,16		nCK	12,13
Supported CL Settings with read DBI				(11),(13),14,(15),16,18,19		nCK	
Supported CWL Settings				9,10,11,12,14		nCK	

[Table 34] DDR4-2400 Speed Bins and Operations

Speed Bin				DDR4-2400		Unit	NOTE
CL-nRCD-nRP				17-17-17			
Parameter			Symbol	min	max		
Internal read command to first data			tAA	14.16 (13.75)[5),11)]	18.00	ns	11
Internal read command to first data with read DBI enabled			tAA_DBI	tAA(min) + 3nCK	tAA(max) + 3nCK	ns	11
ACT to internal read or write delay time			tRCD	14.16 (13.75)[5),11)]	-	ns	11
PRE command period			tRP	14.16 (13.75)[5),11)]	-	ns	11
ACT to PRE command period			tRAS	32	9 x tREFI	ns	11
ACT to ACT or REF command period			tRC	46.16 (45.75)[5),11)]	-	ns	11
	Normal	Read DBI					
CWL = 9	CL = 9	CL = 11 (Optional) [5)]	tCK(AVG)	Reserved		ns	1,2,3,4,10
	CL = 10	CL = 12	tCK(AVG)	1.5	1.6	ns	1,2,3,4,10
CWL = 9,11	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	4
	CL = 11	CL = 13	tCK(AVG)	1.25	<1.5	ns	1,2,3,4,8
				(Optional)[5),11)]			
	CL = 12	CL = 14	tCK(AVG)	1.25	<1.5	ns	1,2,3,8
CWL = 10,12	CL = 12	CL = 14	tCK(AVG)	Reserved		ns	4
	CL = 13	CL = 15	tCK(AVG)	1.071	<1.25	ns	1,2,3,4,8
				(Optional)[5),11)]			
	CL = 14	CL = 16	tCK(AVG)	1.071	<1.25	ns	1,2,3,8
CWL = 11,14	CL = 14	CL = 17	tCK(AVG)	Reserved		ns	4
	CL = 15	CL = 18	tCK(AVG)	0.937	<1.071	ns	1,2,3,4,8
				(Optional)[5),11)]			
	CL = 16	CL = 19	tCK(AVG)	0.937	<1.071	ns	1,2,3,8
CWL = 12,16	CL = 15	CL = 18	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 16	CL = 19	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 17	CL = 20	tCK(AVG)	0.833	<0.937	ns	
	CL = 18	CL = 21	tCK(AVG)	0.833	<0.937	ns	1,2,3
Supported CL Settings				10,11,12,13,14,15,16,17,18		nCK	12
Supported CL Settings with read DBI				12,13,14,15,16,18,19,20,21		nCK	
Supported CWL Settings				9,10,11,12,14,16		nCK	

[Table 35] DDR4-2666 Speed Bins and Operations

Speed Bin				DDR4-2666		Unit	NOTE
CL-nRCD-nRP				19-19-19			
Parameter			Symbol	min	max		
Internal read command to first data			tAA	14.25[13] (13.75)[5),11)]	18.00	ns	11
Internal read command to first data with read DBI enabled			tAA_DBI	tAA(min) + 3nCK	tAA(max) + 3nCK	ns	11
ACT to internal read or write delay time			tRCD	14.25 (13.75)[5),11)]	-	ns	11
PRE command period			tRP	14.25[13] (13.75)[5),11)]	-	ns	11
ACT to PRE command period			tRAS	32	9 x tREFI	ns	11
ACT to ACT or REF command period			tRC	46.25 (45.75)[5),11)]	-	ns	11
	Normal	Read DBI					
CWL = 9	CL = 9	CL = 11	tCK(AVG)	Reserved		ns	1,2,3,4,10
	CL = 10	CL = 12	tCK(AVG)	1.5	1.6	ns	1,2,3,10
CWL = 9,11	CL = 10	CL = 12	tCK(AVG)	Reserved		ns	4
	CL = 11	CL = 13	tCK(AVG)	1.25	<1.5	ns	1,2,3,4,9
				(Optional)[5),11)]			
	CL = 12	CL = 14	tCK(AVG)	1.25	<1.5	ns	1,2,3,9
CWL = 10,12	CL = 12	CL = 14	tCK(AVG)	Reserved		ns	4
	CL = 13	CL = 15	tCK(AVG)	1.071	<1.25	ns	1,2,3,4,9
				(Optional)[5),11)]			
	CL = 14	CL = 16	tCK(AVG)	1.071	<1.25	ns	1,2,3,9
CWL = 11,14	CL = 14	CL = 17	tCK(AVG)	Reserved		ns	4
	CL = 15	CL = 18	tCK(AVG)	0.937	<1.071	ns	1,2,3,4,9
				(Optional)[5),11)]			
	CL = 16	CL = 19	tCK(AVG)	0.937	<1.071	ns	1,2,3,9
CWL = 12,16	CL = 15	CL = 18	tCK(AVG)	Reserved		ns	4
	CL = 16	CL = 19	tCK(AVG)	Reserved		ns	1,2,3,4,9
	CL = 17	CL = 20	tCK(AVG)	0.833	<0.937	ns	1,2,3,4,9
				(Optional)[5),11)]			1,2,3,4,9
	CL = 18	CL = 21	tCK(AVG)	0.833	<0.937	ns	1,2,3
CWL = 14.18	CL = 17	CL = 20	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 18	CL = 21	tCK(AVG)	Reserved		ns	1,2,3,4
	CL = 19	CL = 22	tCK(AVG)	0.75	<0.833	ns	1,2,3,4
	CL = 20	CL = 23	tCK(AVG)	0.75	<0.833	ns	1,2,3
Supported CL Settings				10,(11),12,(13),14,(15),16,(17),18,19,20		nCK	12
Supported CL Settings with read DBI				12,(13),14,(15),17,(18),19,(20),21,22,23		nCK	
Supported CWL Settings				9,10,11,12,14,16,18		nCK	

12.1 Speed Bin Table Note

Absolute Specification
- VDDQ = VDD = 1.20V +/- 0.06 V
- VPP = 2.5V +0.25/-0.125 V
- The values defined with above-mentioned table are DLL ON case.
- DDR4-1600, 1866, 2133, 2400 and 2666 Speed Bin Tables are valid only when Geardown Mode is disabled.

1) The CL setting and CWL setting result in tCK(avg).MIN and tCK(avg).MAX requirements. When making a selection of tCK(avg), both need to be fulfilled: Requirements from CL setting as well as requirements from CWL setting.
2) tCK(avg).MIN limits: Since CAS Latency is not purely analog - data and strobe output are synchronized by the DLL - all possible intermediate frequencies may not be guaranteed. CL in clock cycle is calculated from tAA following rounding algorithm defined in Section 13.5.
3) tCK(avg).MAX limits: Calculate tCK(avg) = tAA.MAX / CL SELECTED and round the resulting tCK(avg) down to the next valid speed bin (i.e. 1.5ns or 1.25ns or 1.071ns or 0.937ns or 0.833ns). This result is tCK(avg).MAX corresponding to CL SELECTED.
4) 'Reserved' settings are not allowed. User must program a different value.
5) 'Optional' settings allow certain devices in the industry to support this setting, however, it is not a mandatory feature. Refer to supplier's data sheet and/or the DIMM SPD information if and how this setting is supported.
6) Any DDR4-1866 speed bin also supports functional operation at lower frequencies as shown in the table which are not subject to Production Tests but verified by Design/ Characterization.
7) Any DDR4-2133 speed bin also supports functional operation at lower frequencies as shown in the table which are not subject to Production Tests but verified by Design/ Characterization.
8) Any DDR4-2400 speed bin also supports functional operation at lower frequencies as shown in the table which are not subject to Production Tests but verified by Design/ Characterization.
9) Any DDR4-2666 speed bin also supports functional operation at lower frequencies as shown in the table which are not subject to Production Tests but verified by Design/ Characterization.
10) DDR4-1600 AC timing apply if DRAM operates at lower than 1600 MT/s data rate.
11) Parameters apply from tCK(avg) min to tCK(avg) max at all standard JEDEC clock period values as stated in the Speed Bin Tables.
12) CL number in parentheses, it means that these numbers are optional.
13) DDR4 SDRAM supports CL=9 as long as a system meets tAA(min).
14) Each speed bin lists the timing requirements that need to be supported in order for a given DRAM to be JEDEC compliant. JEDEC compliance does not require support for all speed bins within a given speed. JEDEC compliance requires meeting the parameters for a least one of the listed speed bins.

13. IDD AND IDDQ SPECIFICATION PARAMETERS AND TEST CONDITIONS

13.1 IDD, IPP and IDDQ Measurement Conditions

In this chapter, IDD, IPP and IDDQ measurement conditions such as test load and patterns are defined. Figure 21 shows the setup and test load for IDD, IPP and IDDQ measurements.

- IDD currents (such as IDD0, IDD0A, IDD1, IDD1A, IDD2N, IDD2NA, IDD2NL, IDD2NT, IDD2P, IDD2Q, IDD3N, IDD3NA, IDD3P, IDD4R, IDD4RA, IDD4W, IDD4WA, IDD5B, IDD5F2, IDD5F4, IDD6N, IDD6E, IDD6R, IDD6A, IDD7 and IDD8) are measured as time-averaged currents with all VDD balls of the DDR4 SDRAM under test tied together. Any IPP or IDDQ current is not included in IDD currents.
- IPP currents have the same definition as IDD except that the current on the VPP supply is measured.
- IDDQ currents (such as IDDQ2NT and IDDQ4R) are measured as time-averaged currents with all VDDQ balls of the DDR4 SDRAM under test tied together. Any IDD current is not included in IDDQ currents.
  Attention: IDDQ values cannot be directly used to calculate IO power of the DDR4 SDRAM. They can be used to support correlation of simulated IO power to actual IO power as outlined in Figure 22. In DRAM module application, IDDQ cannot be measured separately since VDD and VDDQ are using one merged-power layer in Module PCB.

For IDD, IPP and IDDQ measurements, the following definitions apply:

- "0" and "LOW" is defined as VIN <= VILAC(max).
- "1" and "HIGH" is defined as VIN >= VIHAC(min).
- "MID-LEVEL" is defined as inputs are VREF = VDD / 2.
- Timings used for IDD, IPP and IDDQ Measurement-Loop Patterns are provided in Table 36.
- Basic IDD, IPP and IDDQ Measurement Conditions are described in Table 38.
- Detailed IDD, IPP and IDDQ Measurement-Loop Patterns are described in Table 39 through Table 46.
- IDD Measurements are done after properly initializing the DDR4 SDRAM. This includes but is not limited to setting
  RON = RZQ/7 (34 Ohm in MR1);
  RTT_NOM = RZQ/6 (40 Ohm in MR1);
  RTT_WR = RZQ/2 (120 Ohm in MR2);
  RTT_PARK = Disable;
  Qoff = 0_B (Output Buffer enabled) in MR1;
  TDQS_t disabled in MR1;
  CRC disabled in MR2;
  CA parity feature disabled in MR5;
  Gear down mode disabled in MR3
  Read/Write DBI disabled in MR5;
  DM disabled in MR5
- Attention: The IDD, IPP and IDDQ Measurement-Loop Patterns need to be executed at least one time before actual IDD or IDDQ measurement is started.
- Define D = {CS_n, ACT_n, RAS_n, CAS_n, WE_n} := {HIGH, LOW, LOW, LOW, LOW} ; apply BG/BA changes when directed.
- Define D# = {CS_n, ACT_n, RAS_n, CAS_n, WE_n} := {HIGH, HIGH, HIGH, HIGH, HIGH} ;apply invert of BG/BA changes when directed above.

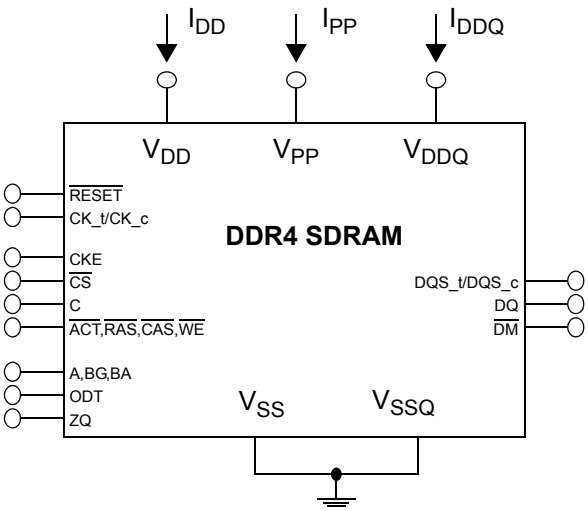


Figure 21. Measurement Setup and Test Load for IDD, IPP and IDDQ Measurements

NOTE :
1) DIMM level Output test load condition may be different from above.

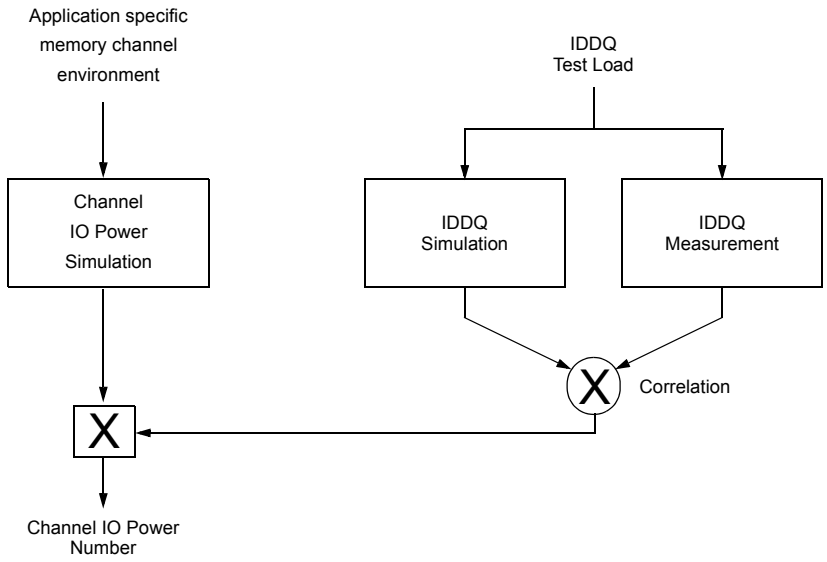


Figure 22. Correlation from simulated Channel IO Power to actual Channel IO Power supported by IDDQ Measurement.

[Table 36] Timings used for IDD, IPP and IDDQ Measurement-Loop Patterns

Symbol		DDR4-1600	DDR4-1866	DDR4-2133	DDR4-2400	DDR4-2666	Unit
		11-11-11	13-13-13	15-15-15	17-17-17	19-19-19	
tCK		1.25	1.071	0.937	0.833	0.75	ns
CL		11	13	15	17	19	nCK
CWL		11	12	14	16	18	nCK
nRCD		11	13	15	17	19	nCK
nRC		39	45	51	56	62	nCK
nRAS		28	32	36	39	43	nCK
nRP		11	13	15	17	19	nCK
nFAW	x4	16	16	16	16	16	nCK
	x8	20	22	23	26	28	nCK
nRRDS	x4	4	4	4	4	4	nCK
	x8	4	4	4	4	4	nCK
nRRDL	x4	5	5	6	6	7	nCK
	x8	5	5	6	6	7	nCK
tCCD_S		4	4	4	4	4	nCK
tCCD_L		5	5	6	6	7	nCK
tWTR_S		2	3	3	3	4	nCK
tWTR_L		6	7	8	9	10	nCK
nRFC 2Gb		128	150	171	193	214	nCK
nRFC 4Gb		208	243	278	313	347	nCK
nRFC 8Gb		280	327	374	421	467	nCK
nRFC 16Gb		440	514	587	661	734	nCK

[Table 37] Basic IDD, IPP and IDDQ Measurement Conditions

Symbol	Description
IDD0	**Operating One Bank Active-Precharge Current (AL=0)** **CKE:** High; **External clock:** On; **tCK, nRC, nRAS, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n:** High between ACT and PRE; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 38; **Data IO:** VDDQ; **DM_n:** stable at 1; **Bank Activity:** Cycling with one bank active at a time: 0,0,1,1,2,2,... (see Table 38); **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 38
IDD0A	**Operating One Bank Active-Precharge Current (AL=CL-1)** **AL = CL-1, Other conditions:** see IDD0
IPP0	**Operating One Bank Active-Precharge IPP Current** **Same condition with IDD0**
IDD1	**Operating One Bank Active-Read-Precharge Current (AL=0)** **CKE:** High; **External clock:** On; **tCK, nRC, nRAS, nRCD, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: High between ACT, RD and PRE; **Command, Address, Bank Group Address, Bank Address Inputs, Data IO:** partially toggling according to Table 39; **DM_n:** stable at 1; **Bank Activity:** Cycling with one bank active at a time: 0,0,1,1,2,2,... (see Table 39); **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 39
IDD1A	**Operating One Bank Active-Read-Precharge Current (AL=CL-1)** **AL = CL-1, Other conditions:** see IDD1
IPP1	**Operating One Bank Active-Read-Precharge IPP Current** **Same condition with IDD1**
IDD2N	**Precharge Standby Current (AL=0)** **CKE**: High; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: stable at 1; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 40; **Data IO:** VDDQ; **DM_n:** stable at 1; **Bank Activity:** all banks closed; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 40
IDD2NA	**Precharge Standby Current (AL=CL-1)** **AL = CL-1, Other conditions:** see IDD2N
IPP2N	**Precharge Standby IPP Current** **Same condition with IDD2N**
IDD2NT	**Precharge Standby ODT Current** **CKE**: High; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: stable at 1; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 41; **Data IO: VSSQ**; **DM_n:** stable at 1; **Bank Activity:** all banks closed; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** toggling according to Table 41; **Pattern Details:** see Table 41
IDDQ2NT (Optional)	**Precharge Standby ODT IDDQ Current** Same definition like for IDD2NT, however measuring IDDQ current instead of IDD current
IDD2NL	**Precharge Standby Current with CAL enabled** Same definition like for IDD2N, CAL enabled[3]
IDD2NG	**Precharge Standby Current with Gear Down mode enabled** Same definition like for IDD2N, Gear Down mode enabled[3],[5]
IDD2ND	**Precharge Standby Current with DLL disabled** Same definition like for IDD2N, DLL disabled[3]
IDD2N_par	**Precharge Standby Current with CA parity enabled** Same definition like for IDD2N, CA parity enabled[3]
IDD2P	**Precharge Power-Down Current CKE:** Low; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: stable at 1; **Command, Address, Bank Group Address, Bank Address Inputs:** stable at 0; **Data IO:** VDDQ; **DM_n:** stable at 1; **Bank Activity:** all banks closed; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0
IPP2P	**Precharge Power-Down IPP Current** **Same condition with IDD2P**
IDD2Q	**Precharge Quiet Standby Current** **CKE**: High; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: stable at 1; **Command, Address, Bank Group Address, Bank Address Inputs:** stable at 0; **Data IO:** VDDQ; **DM_n:** stable at 1;**Bank Activity:** all banks closed; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0
IDD3N	**Active Standby Current** **CKE**: High; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: stable at 1; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 40; **Data IO:** VDDQ; **DM_n:** stable at 1;**Bank Activity:** all banks open; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 40

[Table 37] Basic IDD, IPP and IDDQ Measurement Conditions

Symbol	Description
IDD3NA	**Active Standby Current (AL=CL-1)** **AL = CL-1, Other conditions:** see IDD3N
IPP3N	**Active Standby IPP Current** **Same condition with IDD3N**
IDD3P	**Active Power-Down Current** **CKE:** Low; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: stable at 1; **Command, Address, Bank Group Address, Bank Address Inputs:** stable at 0; **Data IO:** VDDQ; **DM_n:** stable at 1; **Bank Activity:** all banks open; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0
IPP3P	**Active Power-Down IPP Current** **Same condition with IDD3P**
IDD4R	**Operating Burst Read Current** **CKE:** High; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[2]; **AL:** 0; **CS_n**: High between RD; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 42; **Data IO:** seamless read data burst with different data between one burst and the next one according to Table 42; **DM_n**: stable at 1; **Bank Activity:** all banks open, RD commands cycling through banks: 0,0,1,1,2,2,... (see Table 42); **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 42
IDD4RA	**Operating Burst Read Current (AL=CL-1)** **AL = CL-1, Other conditions:** see IDD4R
IDD4RB	**Operating Burst Read Current with Read DBI** **Read DBI enabled[3], Other conditions:** see IDD4R
IPP4R	**Operating Burst Read IPP Current** **Same condition with IDD4R**
IDDQ4R (Optional)	**Operating Burst Read IDDQ Current** Same definition like for IDD4R, however measuring IDDQ current instead of IDD current
IDDQ4RB (Optional)	**Operating Burst Read IDDQ Current with Read DBI** Same definition like for IDD4RB, however measuring IDDQ current instead of IDD current
IDD4W	**Operating Burst Write Current** **CKE:** High; **External clock:** On; **tCK, CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: High between WR; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 43; **Data IO:** seamless write data burst with different data between one burst and the next one according to Table 43; **DM_n:** stable at 1; **Bank Activity:** all banks open, WR commands cycling through banks: 0,0,1,1,2,2,... (see Table 43); **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at HIGH; **Pattern Details:** see Table 43
IDD4WA	**Operating Burst Write Current (AL=CL-1)** **AL = CL-1, Other conditions:** see IDD4W
IDD4WB	**Operating Burst Write Current with Write DBI** **Write DBI enabled[3], Other conditions:** see IDD4W
IDD4WC	**Operating Burst Write Current with Write CRC** **Write CRC enabled[3], Other conditions:** see IDD4W
IDD4W_par	**Operating Burst Write Current with CA Parity** **CA Parity enabled[3], Other conditions:** see IDD4W
IPP4W	**Operating Burst Write IPP Current** **Same condition with IDD4W**
IDD5B	**Burst Refresh Current (1X REF)** **CKE:** High; **External clock:** On; **tCK, CL, nRFC**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n**: High between REF; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 45; **Data IO:** VDDQ; **DM_n:** stable at 1; **Bank Activity:** REF command every nRFC (see Table 45); **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 45
IPP5B	**Burst Refresh Write IPP Current (1X REF)** **Same condition with IDD5B**
IDD5F2	**Burst Refresh Current (2X REF)** **tRFC=tRFC_x2, Other conditions:** see IDD5B
IPP5F2	**Burst Refresh Write IPP Current (2X REF)** **Same condition with IDD5F2**
IDD5F4	**Burst Refresh Current (4X REF)** **tRFC=tRFC_x4, Other conditions:** see IDD5B
IPP5F4	**Burst Refresh Write IPP Current (4X REF)** **Same condition with IDD5F4**

[Table 37] Basic IDD, IPP and IDDQ Measurement Conditions

Symbol	Description
IDD6N	**Self Refresh Current: Normal Temperature Range** **T_{CASE}:** 0 - 85°C; **Low Power Auto Self Refresh (LP ASR)** : Normal[4]; **CKE:** Low; **External clock:** Off; CK_t and CK_c#: LOW; **CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n#, Command, Address, Bank Group Address, Bank Address, Data IO:** High; **DM_n:** stable at 1; **Bank Activity:** Self-Refresh operation; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** MID-LEVEL
IPP6N	**Self Refresh IPP Current: Normal Temperature Range** **Same condition with IDD6N**
IDD6E	**Self-Refresh Current: Extended Temperature Range**[)] **T_{CASE}:** 0 - 95°C; **Low Power Auto Self Refresh (LP ASR)** : Extended[4]; **CKE:** Low; **External clock:** Off; CK_t and CK_c: LOW; **CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n, Command, Address, Bank Group Address, Bank Address, Data IO:** High; **DM_n**: stable at 1; **Bank Activity:** Extended Temperature Self-Refresh operation; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** MID-LE**VEL**
IPP6E	**Self Refresh IPP Current: Extended Temperature Range** **Same condition with IDD6E**
IDD6R	**Self-Refresh Current: Reduced Temperature Range** **T_{CASE}:** 0 - 45°C; **Low Power Auto Self Refresh (LP ASR)** : Reduced[4]; **CKE:** Low; **External clock:** Off; CK_t and CK_c#: LOW; **CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n#, Command, Address, Bank Group Address, Bank Address, Data IO:** High; **DM_n**: stable at 1; **Bank Activity:** Extended Temperature Self-Refresh operation; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** MID-LEVEL
IPP6R	**Self Refresh IPP Current: Reduced Temperature Range** **Same condition with IDD6R**
IDD6A	**Auto Self-Refresh Current** **T_{CASE}:** 0 - 95°C; **Low Power Auto Self Refresh (LP ASR)** : Auto[4];**CKE:** Low; **External clock:** Off; CK_t and CK_c#: LOW; **CL**: see Table 36; **BL:** 8[1]; **AL:** 0; **CS_n#, Command, Address, Bank Group Address, Bank Address, Data IO:** High; **DM_n**: stable at 1; **Bank Activity:** Auto Self-Refresh operation; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** MID-LEVEL
IPP6A	**Auto Self-Refresh IPP Current** **Same condition with IDD6A**
IDD7	**Operating Bank Interleave Read Current** **CKE:** High; **External clock:** On; **tCK, nRC, nRAS, nRCD, nRRD, nFAW, CL**: see Table 36; **BL:** 8[1]; **AL:** CL-1; **CS_n**: High between ACT and RDA; **Command, Address, Bank Group Address, Bank Address Inputs:** partially toggling according to Table 46; **Data IO:** read data bursts with different data between one burst and the next one according to Table 46; **DM_n:** stable at 1; **Bank Activity:** two times interleaved cycling through banks (0, 1, ...7) with different addressing, see Table 46; **Output Buffer and RTT:** Enabled in Mode Registers[2]; **ODT Signal:** stable at 0; **Pattern Details:** see Table 46
IPP7	**Operating Bank Interleave Read IPP Current** **Same condition with IDD7**
IDD8	**Maximum Power Down Current** **TBD**
IPP8	**Maximum Power Down IPP Current** **Same condition with IDD8**

NOTE:
1) Burst Length: BL8 fixed by MRS: set MR0 [A1:0=00].
2) Output Buffer Enable
- set MR1 [A12 = 0]: Qoff = Output buffer enabled
- set MR1 [A2:1 = 00]: Output Driver Impedance Control = RZQ/7

RTT_Nom enable
- set MR1 [A10:8 = 011]: RTT_NOM = RZQ/6

RTT_WR enable
- set MR2 [A10:9 = 01]: RTT_WR = RZQ/2

RTT_PARK disable
- set MR5 [A8:6 = 000]

3) CAL enabled: set MR4 [A8:6 = 001]: 1600MT/s
010]: 1866MT/s, 2133MT/s
011]: 2400MT/s, 2666MT/s

Gear Down mode enabled: set MR3 [A3 = 1]: 1/4 Rate
DLL disabled: set MR1 [A0 = 0]
CA parity enabled: set MR5 [A2:0 = 001]: 1600MT/s,1866MT/s, 2133MT/s
010]: 2400MT/s, 2666MT/s
Read DBI enabled: set MR5 [A12 = 1]
Write DBI enabled: set MR5 [A11 = 1]
4) Low Power Array Self Refresh (LP ASR): set MR2 [A7:6 = 00]: Normal
01]: Reduced Temperature range
10]: Extended Temperature range
11]: Auto Self Refresh
5) IDD2NG should be measured after sync pules (NOP) input.

[Table 38] IDD0, IDD0A and IPP0 Measurement-Loop Pattern [1)]

CK_t /CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/ A15	WE_n/ A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**ACT**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
			1,2	D, D	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
			3,4	D_#, D_#	1	1	1	1	1	0	0	3[2)]	3	0	0	0	7	F	0	-
			...	repeat pattern 1...4 until nRAS - 1, truncate if necessary																
			nRAS	PRE	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	-
			...	repeat pattern 1...4 until nRC - 1, truncate if necessary																
		1	1*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 1, BA[1:0] = 1** instead																
		2	2*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 2** instead																
		3	3*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 1, BA[1:0] = 3** instead																
		4	4*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 1** instead																
		5	5*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 1, BA[1:0] = 2** instead																
		6	6*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 3** instead																
		7	7*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 1, BA[1:0] = 0** instead																
		8	8*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 0** instead																For x4 and x8 only
		9	9*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] = 1** instead																
		10	10*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 2** instead																
		11	11*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] = 3** instead																
		12	12*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 1** instead																
		13	13*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] = 2** instead																
		14	14*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 3** instead																
		15	15*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] = 0** instead																

NOTE :
1) DQS_t, DQS_c are VDDQ.
2) BG1 is don't care for x16 device
3) C[2:0] are used only for 3DS device
4) DQ signals are VDDQ.

[Table 39] IDD1, IDD1A and IPP1 Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**ACT**	0	0	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	-
			1, 2	D, D	1	0	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	-
			3, 4	D#, D#	1	1	1	1	1	0	0	3[b)]	**3**	**0**	0	0	7	F	0	-
			...	repeat pattern 1...4 until nRCD - AL - 1, truncate if necessary																
			nRCD -AL	**RD**	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	**D0=00, D1=FF D2=FF, D3=00 D4=FF, D5=00 D6=00, D7=FF**
			...	repeat pattern 1...4 until nRAS - 1, truncate if necessary																
			nRAS	**PRE**	0	1	0	1	0	0	0	0	**0**	**0**	0	0	0	0	0	-
			...	repeat pattern 1...4 until nRC - 1, truncate if necessary																
		1	1*nRC + 0	**ACT**	0	0	0	1	1	0	0	1	**1**	**0**	0	0	0	0	0	-
			1*nRC + 1, 2	D, D	1	0	0	0	0	0	**0**	**0**	0	0	0	0	0	0	0	-
			1*nRC + 3, 4	D#, D#	1	1	1	1	1	0	**0**	3[b)]	**3**	**0**	0	0	7	F	0	-
			...	repeat pattern nRC + 1...4 until 1*nRC + nRAS - 1, truncate if necessary																
			1*nRC + nRCD - AL	**RD**	0	1	1	0	1	0	**0**	**1**	1	0	0	0	0	**0**	**0**	**D0=FF, D1=00 D2=00, D3=FF D4=00, D5=FF D6=FF, D7=00**
			...	repeat pattern 1...4 until nRAS - 1, truncate if necessary																
			1*nRC + nRAS	**PRE**	0	1	0	1	0	0	1	1	**0**	**0**	0	0	0	0	0	-
			...	repeat nRC + 1...4 until 2*nRC - 1, truncate if necessary																
		2	2*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 2** instead																
		3	3*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 3** instead																
		4	4*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 1** instead																
		5	5*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 2** instead																
		6	6*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 3** instead																
		8	7*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 0** instead																
		9	9*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 2, BA[1:0] = 0** instead																For x4 and x8 only
		10	10*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] = 1** instead																
		11	11*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 2, BA[1:0] = 2** instead																
		12	12*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] = 3** instead																
		13	13*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 2, BA[1:0] = 1** instead																
		14	14*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] =** 2 instead																
		15	15*nRC	repeat Sub-Loop 1, use **BG[1:0][2)] = 2, BA[1:0] =** 3 instead																
		16	16*nRC	repeat Sub-Loop 0, use **BG[1:0][2)] = 3, BA[1:0] =** 0 instead																

NOTE :

1) DQS_t, DQS_c are used according to RD Commands, otherwise VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) Burst Sequence driven on each DQ signal by Read Command. Outside burst operation, DQ signals are VDDQ.

[Table 40] IDD2N, IDD2NA, IDD2NL, IDD2NG, IDD2ND, IDD2N_par, IPP2,IDD3N, IDD3NA and IDD3P Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	D, D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	0
			1	D, D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	0
			2	D#, D#	1	1	1	1	1	0	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	0
			3	D#, D#	1	1	1	1	1	0	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	0
		1	4-7	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 1, BA[1:0] = 1** instead																
		2	8-11	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 2** instead																
		3	12-15	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 1, BA[1:0] = 3** instead																
		4	16-19	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 1** instead																
		5	20-23	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 1, BA[1:0] = 2** instead																
		6	24-27	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 3** instead																
		7	28-31	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 1, BA[1:0] = 0** instead																
		8	32-35	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 0** instead																
		9	36-39	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 3, BA[1:0] = 1** instead																
		10	40-43	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 2** instead																
		11	44-47	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 3, BA[1:0] = 3** instead																
		12	48-51	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 1** instead																
		13	52-55	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 3, BA[1:0] = 2** instead																
		14	56-59	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 3** instead																
		15	60-63	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 3, BA[1:0] = 0** instead																

NOTE :
1) DQS_t, DQS_c are VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) DQ signals are VDDQ.

[Table 41] IDD2NT and IDDQ2NT Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	D, D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			1	D, D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			2	D#, D#	1	1	1	1	1	0	0	**3**[2]	**3**	0	0	0	**7**	**F**	0	-
			3	D#, D#	1	1	1	1	1	0	0	**3**[2]	**3**	0	0	0	**7**	**F**	0	-
		1	4-7	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 1, BA[1:0] = 1** instead																	
		2	8-11	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 0, BA[1:0] = 2** instead																	
		3	12-15	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 1, BA[1:0] = 3** instead																	
		4	16-19	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 0, BA[1:0] = 1** instead																	
		5	20-23	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 1, BA[1:0] = 2** instead																	
		6	24-27	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 0, BA[1:0] = 3** instead																	
		7	28-31	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 1, BA[1:0] = 0** instead																	
		8	32-35	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 2, BA[1:0] = 0** instead																	For x4 and x8 only
		9	36-39	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 3, BA[1:0] = 1** instead																	
		10	40-43	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 2, BA[1:0] = 2** instead																	
		11	44-47	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 3, BA[1:0] = 3** instead																	
		12	48-51	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 2, BA[1:0] = 1** instead																	
		13	52-55	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 3, BA[1:0] = 2** instead																	
		14	56-59	repeat Sub-Loop 0, but ODT = 0 and **BG[1:0]**[2)] **= 2, BA[1:0] = 3** instead																	
		15	60-63	repeat Sub-Loop 0, but ODT = 1 and **BG[1:0]**[2)] **= 3, BA[1:0] = 0** instead																	

NOTE :
1) DQS_t, DQS_c are VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) DQ signals are VDDQ.

[Table 42] IDD4R, IDDR4RA, IDD4RB and IDDQ4R Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**RD**	0	1	1	0	1	0	0	**0**	**0**	0	0	0	**0**	**0**	0	**D0=00, D1=FF D2=FF, D3=00 D4=FF, D5=00 D6=00, D7=FF**
			1	D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			2,3	D#, D#	1	1	1	1	1	0	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
		1	4	**RD**	0	1	1	0	1	0	0	**1**	**1**	0	0	0	**7**	**F**	0	**D0=FF, D1=00 D2=00, D3=FF D4=00, D5=FF D6=FF, D7=00**
			5	D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			6,7	D#, D#	1	1	1	1	1	0	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
		2	8-11	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 2** instead															
		3	12-15	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 3** instead															
		4	16-19	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 1** instead															
		5	20-23	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 2** instead															
		6	24-27	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 3** instead															
		7	28-31	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 0** instead															
		8	32-35	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 0** instead															For x4 and x8 only
		9	36-39	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 1** instead															
		10	40-43	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 2** instead															
		11	44-47	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 3** instead															
		12	48-51	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 1** instead															
		13	52-55	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 2** instead															
		14	56-59	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 3** instead															
		15	60-63	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 0** instead															

NOTE :
1) DQS_t, DQS_c are used according to RD Commands, otherwise VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) Burst Sequence driven on each DQ signal by Read Command.

[Table 43] IDD4W, IDD4WA, IDD4WB and IDD4W_par Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**WR**	0	1	1	0	0	1	0	**0**	**0**	0	0	0	**0**	**0**	0	**D0=00, D1=FF D2=FF, D3=00 D4=FF, D5=00 D6=00, D7=FF**
			1	D	1	0	0	0	0	1	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			2,3	D#, D#	1	1	1	1	1	1	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
		1	4	**WR**	0	1	1	0	0	1	0	**1**	**1**	0	0	0	**7**	**F**	0	**D0=FF, D1=00 D2=00, D3=FF D4=00, D5=FF D6=FF, D7=00**
			5	D	1	0	0	0	0	1	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			6,7	D#, D#	1	1	1	1	1	1	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
		2	8-11	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 2** instead																
		3	12-15	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 1, BA[1:0] = 3** instead																
		4	16-19	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 1** instead																
		5	20-23	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 1, BA[1:0] = 2** instead																
		6	24-27	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 3** instead																
		7	28-31	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 1, BA[1:0] = 0** instead																
		8	32-35	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 0** instead																For x4 and x8 only
		9	36-39	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 1** instead																
		10	40-43	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 2** instead																
		11	44-47	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 3** instead																
		12	48-51	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 1** instead																
		13	52-55	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 2** instead																
		14	56-59	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 3** instead																
		15	60-63	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 0** instead																

NOTE :
1) DQS_t, DQS_c are used according to WR Commands, otherwise VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) Burst Sequence driven on each DQ signal by Write Command.

[Table 44] IDD4WC Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**WR**	0	1	1	0	0	1	0	**0**	**0**	0	0	0	**0**	**0**	0	**D0=00, D1=FF D2=FF, D3=00 D4=FF, D5=00 D6=00, D7=FF D8=CRC**
			1,2	D, D	1	0	0	0	0	1	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			3,4	D#, D#	1	1	1	1	1	1	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
			5	**WR**	0	1	1	0	0	1	0	**1**	**1**	0	0	0	**7**	**F**	0	**D0=FF, D1=00 D2=00, D3=FF D4=00, D5=FF D6=FF, D7=00 D8=CRC**
			6,7	D, D	1	0	0	0	0	1	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			8,9	D#, D#	1	1	1	1	1	1	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
		2	10-14	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 2** instead																
		3	15-19	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 1, BA[1:0] = 3** instead																
		4	20-24	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 1** instead																
		5	25-29	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 1, BA[1:0] = 2** instead																
		6	30-34	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 0, BA[1:0] = 3** instead																
		7	35-39	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 1, BA[1:0] = 0** instead																
		8	40-44	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 0** instead																For x4 and x8 only
		9	45-49	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 1** instead																
		10	50-54	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 2** instead																
		11	55-59	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 3** instead																
		12	60-64	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 1** instead																
		13	65-69	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 2** instead																
		14	70-74	repeat Sub-Loop 0, use **BG[1:0]**[2)] **= 2, BA[1:0] = 3** instead																
		15	75-79	repeat Sub-Loop 1, use **BG[1:0]**[2)] **= 3, BA[1:0] = 0** instead																

NOTE :
1) DQS_t, DQS_c are VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) Burst Sequence driven on each DQ signal by Write Command.

[Table 45] IDD5B Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**REF**	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
		1	1	D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			2	D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			3	D#, D#	1	1	1	1	1	0	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
			4	D#, D#	1	1	1	1	1	0	0	**3**[2)]	**3**	0	0	0	**7**	**F**	0	-
			4-7	repeat pattern 1...4, use **BG[1:0]**[2)] **= 1, BA[1:0] = 1** instead																
			8-11	repeat pattern 1...4, use **BG[1:0]**[2)] **= 0, BA[1:0] = 2** instead																
			12-15	repeat pattern 1...4, use **BG[1:0]**[2)] **= 1, BA[1:0] = 3** instead																
			16-19	repeat pattern 1...4, use **BG[1:0]**[2)] **= 0, BA[1:0] = 1** instead																
			20-23	repeat pattern 1...4, use **BG[1:0]**[2)] **= 1, BA[1:0] = 2** instead																
			24-27	repeat pattern 1...4, use **BG[1:0]**[2)] **= 0, BA[1:0] = 3** instead																
			28-31	repeat pattern 1...4, use **BG[1:0]**[2)] **= 1, BA[1:0] = 0** instead																
			32-35	repeat pattern 1...4, use **BG[1:0]**[2)] **= 2, BA[1:0] = 0** instead																For x4 and x8 only
			36-39	repeat pattern 1...4, use **BG[1:0]**[2)] **= 3, BA[1:0] = 1** instead																
			40-43	repeat pattern 1...4, use **BG[1:0]**[2)] **= 2, BA[1:0] = 2** instead																
			44-47	repeat pattern 1...4, use **BG[1:0]**[2)] **= 3, BA[1:0] = 3** instead																
			48-51	repeat pattern 1...4, use **BG[1:0]**[2)] **= 2, BA[1:0] = 1** instead																
			52-55	repeat pattern 1...4, use **BG[1:0]**[2)] **= 3, BA[1:0] = 2** instead																
			56-59	repeat pattern 1...4, use **BG[1:0]**[2)] **= 2, BA[1:0] = 3** instead																
			60-63	repeat pattern 1...4, use **BG[1:0]**[2)] **= 3, BA[1:0] = 0** instead																
		2	64 ... nRFC - 1	repeat Sub-Loop 1, Truncate, if necessary																

NOTE :
1) DQS_t, DQS_c are VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) DQ signals are VDDQ.

[Table 46] IDD7 Measurement-Loop Pattern[1)]

CK_t, CK_c	CKE	Sub-Loop	Cycle Number	Command	CS_n	ACT_n	RAS_n/A16	CAS_n/A15	WE_n/A14	ODT	C[2:0][3)]	BG[1:0][2)]	BA[1:0]	A12/BC_n	A[17,13,11]	A[10]/AP	A[9:7]	A[6:3]	A[2:0]	Data[4)]
toggling	Static High	0	0	**ACT**	0	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	**-**
			1	**RDA**	0	1	1	0	1	0		**0**	**0**	0	0	1	**0**	**0**	0	**D0=00, D1=FF D2=FF, D3=00 D4=FF, D5=00 D6=00, D7=FF**
			2	D	1	0	0	0	0	0	0	**0**	**0**	0	0	0	**0**	**0**	0	-
			3	D#	1	1	1	1	1	0	0	**3**[2]	**3**	0	0	0	**7**	**F**	0	-
			...	repeat pattern 2...3 until nRRD - 1, if nRRD > 4. Truncate if necessary																
		1	nRRD	**ACT**	0	0	0	0	0	0	0	**1**	**1**	0	0	0	**0**	**0**	0	**-**
			nRRD + 1	**RDA**	0	1	1	0	1	0		**1**	**1**	0	0	1	**0**	**0**	0	**D0=FF, D1=00 D2=00, D3=FF D4=00, D5=FF D6=FF, D7=00**
			...	repeat pattern 2 ... 3 until 2*nRRD - 1, if nRRD > 4. Truncate if necessary																
		2	2*nRRD	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 2** instead																
		3	3*nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 3** instead																
		4	4*nRRD	repeat pattern 2 ... 3 until nFAW - 1, if nFAW > 4*nRRD. Truncate if necessary																
		5	nFAW	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 1** instead																
		6	nFAW + nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 2** instead																
		7	nFAW + 2*nRRD	repeat Sub-Loop 0, use **BG[1:0][2)] = 0, BA[1:0] = 3** instead																
		8	nFAW + 3*nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 1, BA[1:0] = 0** instead																
		9	nFAW + 4*nRRD	repeat Sub-Loop 4																
		10	2*nFAW	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 0** instead																For x4 and x8 only
		11	2*nFAW + nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 1** instead																
		12	2*nFAW + 2*nRRD	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 2** instead																
		13	2*nFAW + 3*nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 3** instead																
		14	2*nFAW + 4*nRRD	repeat Sub-Loop 4																
		15	3*nFAW	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 1** instead																
		16	3*nFAW + nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 2** instead																
		17	3*nFAW + 2*nRRD	repeat Sub-Loop 0, use **BG[1:0][2)] = 2, BA[1:0] = 3** instead																
		18	3*nFAW + 3*nRRD	repeat Sub-Loop 1, use **BG[1:0][2)] = 3, BA[1:0] = 0** instead																
		19	3*nFAW + 4*nRRD	repeat Sub-Loop 4																
		20	4*nFAW	repeat pattern 2 ... 3 until nRC - 1, if nRC > 4*nFAW. Truncate if necessary																

NOTE:
1) DQS_t, DQS_c are VDDQ.
2) BG1 is don't care for x16 device.
3) C[2:0] are used only for 3DS device.
4) Burst Sequence driven on each DQ signal by Read Command. Outside burst operation, DQ signals are VDDQ.

14. IDD SPEC TABLE

IDD and IPP values are for typical operating range of voltage and temperature unless otherwise noted.

[Table 47] I_{DD} and I_{DDQ} Specification for M471A5244CB0

Symbol	M471A5244CB0 4GB(512Mx64) Module						Unit	NOTE
	DDR4-2133		DDR4-2400		DDR4-2666			
	15-15-15		17-17-17		19-19-19			
	VDD 1.2V	VPP 2.5V	VDD 1.2V	VPP 2.5V	VDD 1.2V	VPP 2.5V		
	IDD Max.	IPP Max.	IDD Max.	IPP Max.	IDD Max.	IPP Max.		
I_{DD0}	152	16	152	16	160	16	mA	
I_{DD0A}	160	16	160	16	172	16	mA	
I_{DD1}	176	16	176	16	176	16	mA	
I_{DD1A}	188	16	188	16	208	16	mA	
I_{DD2N}	68	12	72	12	72	12	mA	
I_{DD2NA}	68	12	68	12	84	12	mA	
I_{DD2NT}	68	12	68	12	84	12	mA	
I_{DD2NL}	52	12	52	12	48	12	mA	
I_{DD2NG}	64	12	64	12	68	12	mA	
I_{DD2ND}	64	12	64	12	64	12	mA	
I_{DD2N_par}	72	12	72	12	76	12	mA	
I_{DD2P}	44	12	44	12	44	12	mA	
I_{DD2Q}	64	12	68	12	68	12	mA	
I_{DD3N}	108	16	108	16	108	16	mA	
I_{DD3NA}	112	16	112	16	116	16	mA	
I_{DD3P}	76	16	76	16	76	16	mA	
I_{DD4R}	512	16	548	16	664	16	mA	
I_{DD4RA}	524	16	564	16	684	16	mA	
I_{DD4RB}	532	16	576	16	660	16	mA	
I_{DD4W}	404	12	444	12	512	12	mA	
I_{DD4WA}	420	12	464	12	528	12	mA	
I_{DD4WB}	404	12	444	12	512	12	mA	
I_{DD4WC}	368	12	384	12	484	12	mA	
I_{DD4W_par}	432	12	464	12	568	12	mA	
I_{DD5B}	816	72	816	72	816	72	mA	
I_{DD5F2}	572	60	576	60	576	60	mA	
I_{DD5F4}	476	56	480	56	480	56	mA	
I_{DD6N}	88	16	88	16	88	16	mA	
I_{DD6E}	136	20	136	20	132	20	mA	
I_{DD6R}	60	14	60	14	60	14	mA	
I_{DD6A}	84	16	84	16	84	16	mA	
I_{DD7}	712	52	720	56	784	64	mA	
I_{DD8}	36	12	36	12	40	12	mA	

NOTE :

1) DIMM IDD SPEC is based on the condition that de-actived rank (IDLE) is IDD2N. Please refer to Table20.
2) IDD current measure method and detail patterns are described on DDR4 component datasheet.
3) VDD and VDDQ are merged on module PCB (IDDQ values are not considered by Qoff condition)
4) DIMM IDD Values are calculated based on the component IDD spec and Register power.

[Table 48] I_{DD} and I_{DDQ} Specification for M471A1K43CB1

Symbol	M471A1K43CB1 8GB(1Gx64) Module						Unit	NOTE
	DDR4-2133		DDR4-2400		DDR4-2666			
	15-15-15		17-17-17		19-19-19			
	VDD 1.2V	VPP 2.5V	VDD 1.2V	VPP 2.5V	VDD 1.2V	VPP 2.5V		
	IDD Max.	IPP Max.	IDD Max.	IPP Max.	IDD Max.	IPP Max.		
I_{DD0}	216	32	216	32	224	32	mA	
I_{DD0A}	232	32	232	32	248	32	mA	
I_{DD1}	256	32	256	32	256	32	mA	
I_{DD1A}	264	32	272	32	304	32	mA	
I_{DD2N}	136	24	144	24	144	24	mA	
I_{DD2NA}	136	24	144	24	168	24	mA	
I_{DD2NT}	136	24	144	24	168	24	mA	
I_{DD2NL}	104	24	112	24	112	24	mA	
I_{DD2NG}	128	24	136	24	144	24	mA	
I_{DD2ND}	128	24	136	24	136	24	mA	
I_{DD2N_par}	144	24	152	24	152	24	mA	
I_{DD2P}	88	24	88	24	88	24	mA	
I_{DD2Q}	128	24	136	24	136	24	mA	
I_{DD3N}	216	24	216	24	216	32	mA	
I_{DD3NA}	224	24	224	24	232	32	mA	
I_{DD3P}	152	24	152	24	152	32	mA	
I_{DD4R}	608	24	656	24	792	32	mA	
I_{DD4RA}	632	24	688	24	840	32	mA	
I_{DD4RB}	632	24	680	24	800	32	mA	
I_{DD4W}	592	24	640	24	736	24	mA	
I_{DD4WA}	624	24	680	24	776	24	mA	
I_{DD4WB}	592	24	640	24	744	24	mA	
I_{DD4WC}	536	24	568	24	680	24	mA	
I_{DD4W_par}	648	24	712	24	824	24	mA	
I_{DD5B}	1480	144	1480	144	1480	144	mA	
I_{DD5F2}	1040	120	1040	120	1040	120	mA	
I_{DD5F4}	864	112	864	112	864	112	mA	
I_{DD6N}	168	32	168	32	168	32	mA	
I_{DD6E}	272	40	272	40	272	40	mA	
I_{DD6R}	120	28	120	28	120	28	mA	
I_{DD6A}	168	32	168	32	168	32	mA	
I_{DD7}	1056	80	1080	80	1176	88	mA	
I_{DD8}	72	24	72	24	80	24	mA	

NOTE :

1) DIMM IDD SPEC is based on the condition that de-actived rank (IDLE) is IDD2N. Please refer to Table20.
2) IDD current measure method and detail patterns are described on DDR4 component datasheet.
3) VDD and VDDQ are merged on module PCB (IDDQ values are not considered by Qoff condition)
4) DIMM IDD Values are calculated based on the component IDD spec and Register power.

[Table 49] I_{DD} and I_{DDQ} Specification for M471A2K43CB1

Symbol	M471A2K43CB1 16GB(2Gx64) Module						Unit	NOTE
	DDR4-2133		DDR4-2400		DDR4-2666			
	15-15-15		17-17-17		19-19-19			
	VDD 1.2V	VPP 2.5V	VDD 1.2V	VPP 2.5V	VDD 1.2V	VPP 2.5V		
	IDD Max.	IPP Max.	IDD Max.	IPP Max.	IDD Max.	IPP Max.		
I_{DD0}	352	56	360	56	368	56	mA	
I_{DD0A}	368	56	376	56	392	56	mA	
I_{DD1}	392	56	400	56	400	56	mA	
I_{DD1A}	400	56	416	56	448	56	mA	
I_{DD2N}	272	48	288	48	288	48	mA	
I_{DD2NA}	272	48	288	48	336	48	mA	
I_{DD2NT}	272	48	288	48	336	48	mA	
I_{DD2NL}	208	48	224	48	224	48	mA	
I_{DD2NG}	256	48	272	48	288	48	mA	
I_{DD2ND}	256	48	272	48	272	48	mA	
I_{DD2N_par}	288	48	304	48	304	48	mA	
I_{DD2P}	176	48	176	48	176	48	mA	
I_{DD2Q}	256	48	272	48	272	48	mA	
I_{DD3N}	432	48	432	48	432	64	mA	
I_{DD3NA}	448	48	448	48	464	64	mA	
I_{DD3P}	304	48	304	48	304	64	mA	
I_{DD4R}	744	48	800	48	936	56	mA	
I_{DD4RA}	768	48	832	48	984	56	mA	
I_{DD4RB}	768	48	824	48	944	56	mA	
I_{DD4W}	728	48	784	48	880	48	mA	
I_{DD4WA}	760	48	824	48	920	48	mA	
I_{DD4WB}	728	48	784	48	888	48	mA	
I_{DD4WC}	672	48	712	48	824	48	mA	
I_{DD4W_par}	784	48	856	48	968	48	mA	
I_{DD5B}	1616	168	1624	168	1624	168	mA	
I_{DD5F2}	1176	144	1184	144	1184	144	mA	
I_{DD5F4}	1000	136	1008	136	1008	136	mA	
I_{DD6N}	336	64	336	64	336	64	mA	
I_{DD6E}	544	80	544	80	544	80	mA	
I_{DD6R}	240	56	240	56	240	56	mA	
I_{DD6A}	336	64	336	64	336	64	mA	
I_{DD7}	1192	88	1224	104	1320	112	mA	
I_{DD8}	144	48	144	48	160	48	mA	

NOTE :

1) DIMM IDD SPEC is based on the condition that de-actived rank (IDLE) is IDD2N. Please refer to Table20.
2) IDD current measure method and detail patterns are described on DDR4 component datasheet.
3) VDD and VDDQ are merged on module PCB (IDDQ values are not considered by Qoff condition)
4) DIMM IDD Values are calculated based on the component IDD spec and Register power.

[Table 50] DIMM Rank Status

SEC DIMM	Operating Rank	The other Rank
I_{DD0}	I_{DD0}	I_{DD2N}
I_{DD1}	I_{DD1}	I_{DD2N}
I_{DD2P}	I_{DD2P}	I_{DD2P}
I_{DD2N}	I_{DD2N}	I_{DD2N}
I_{DD2Q}	I_{DD2Q}	I_{DD2Q}
I_{DD3P}	I_{DD3P}	I_{DD3P}
I_{DD3N}	I_{DD3N}	I_{DD3N}
I_{DD4R}	I_{DD4R}	I_{DD2N}
I_{DD4W}	I_{DD4W}	I_{DD2N}
I_{DD5B}	I_{DD5B}	I_{DD2N}
I_{DD6}	I_{DD6}	I_{DD6}
I_{DD7}	I_{DD7}	I_{DD2N}
I_{DD8}	I_{DD8}	I_{DD8}

15. INPUT/OUTPUT CAPACITANCE

[Table 51] Silicon Pad I/O Capacitance

Symbol	Parameter	DDR4-1600/1866/2133		DDR4-2400/2666		Unit	NOTE
		min	max	min	max		
C_{IO}	Input/output capacitance	0.55	1.4	0.55	1.15	pF	1,2,3
C_{DIO}	Input/output capacitance delta	-0.1	0.1	-0.1	0.1	pF	1,2,3,11
C_{DDQS}	Input/output capacitance delta DQS_t and DQS_c	-	0.05	-	0.05	pF	1,2,3,5
C_{CK}	Input capacitance, CK_t and CK_c	0.2	0.8	0.2	0.7	pF	1,3
C_{DCK}	Input capacitance delta CK_t and CK_c	-	0.05	-	0.05	pF	1,3,4
C_{I}	Input capacitance (CTRL, ADD, CMD pins only)	0.2	0.8	0.2	0.7	pF	1,3,6
C_{DI_CTRL}	Input capacitance delta (All CTRL pins only)	-0.1	0.1	-0.1	0.1	pF	1,3,7,8
$C_{DI\_ADD\_CMD}$	Input capacitance delta (All ADD/CMD pins only)	-0.1	0.1	-0.1	0.1	pF	1,2,9,10
C_{ALERT}	Input/output capacitance of ALERT	0.5	1.5	0.5	1.5	pF	1,3
C_{ZQ}	Input/output capacitance of ZQ	-	2.3	-	2.3	pF	1,3,12
C_{TEN}	Input capacitance of TEN	0.2	2.3	0.2	2.3	pF	1,3,13

NOTE :

1) This parameter is not subject to production test. It is verified by design and characterization. The silicon only capacitance is validated by de-embedding the package L & C parasitic. The capacitance is measured with VDD, VDDQ, VSS, VSSQ applied with all other signal pins floating. Measurement procedure tbd.
2) DQ, DM_n, DQS_T, DQS_c, TDQS_T, TDQS_C. Although the DM, TDQS_T and TDQS_C pins have different functions, the loading matches DQ and DQS
3) This parameter applies to monolithic devices only; stacked/dual-die devices are not covered here
4) Absolute value CK_T-CK_C
5) Absolute value of CIO(DQS_T)-CIO (DQS_c)
6) CI applies to ODT, CS_n, CKE, A0-A17, BA0-BA1, BG0-BG1, RAS_n/A16, CAS_n/A15, WE_n/A14, ACT_n and PAR.
7) CDI CTRL applies to ODT, CS_n and CKE
8) CDI_CTRL = CI(CTRL)-0.5*(CI(CLK_T)+CI(CLK_C))
9) CDI_ADD_ CMD applies to, A0-A17, BA0-BA1, BG0-BG1,RAS_n/A16, CAS_n/A15, WE_n/A14, ACT_n and PAR.
10) CDI_ADD_CMD = CI(ADD_CMD)-0.5*(CI(CLK_T)+CI(CLK_C))
11) CDIO = CIO(DQ,DM)-0.5*(CIO(DQS_T)+CIO(DQS_c))
12) Maximum external load capacitance on ZQ pin: tbd pF.
13) TEN pin may be DRAM internally pulled low through a weak pull-down resistor to VSS. In this case C_{TEN} might not be valid and system shall verify TEN signal with Vendor specific information.

16. ELECTRICAL CHARACTERISTICS & AC TIMING

16.1 Reference Load for AC Timing and Output Slew Rate

Figure 23 represents the effective reference load of 50 ohms used in defining the relevant AC timing parameters of the device as well as output slew rate measurements.

Ron nominal of DQ, DQS_t and DQS_c drivers uses 34 ohms to specify the relevant AC timing parameter values of the device.

The maximum DC High level of Output signal = 1.0 * VDDQ,

The minimum DC Low level of Output signal = {34 /(34 + 50)} *VDDQ = 0.4* VDDQ

The nominal reference level of an Output signal can be approximated by the following:

The center of maximum DC High and minimum DC Low = {(1 + 0.4) / 2} * VDDQ = 0.7 * VDDQ

The actual reference level of Output signal might vary with driver Ron and reference load tolerances. Thus, the actual reference level or midpoint of an output signal is at the widest part of the output signal's eye. Prior to measuring AC parameters, the reference level of the verification tool should be set to an appropriate level.

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

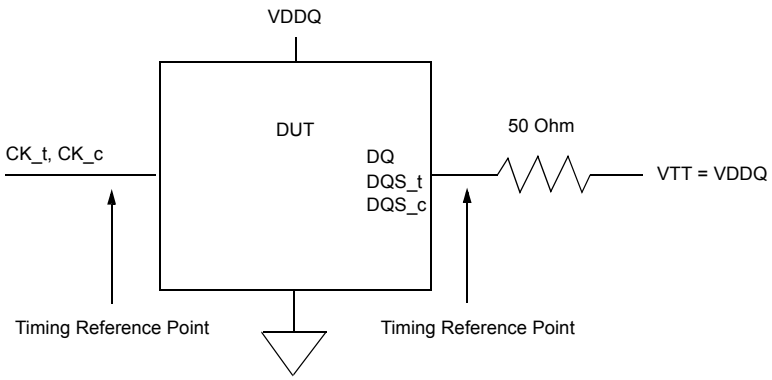


Figure 23. Reference Load for AC Timing and Output Slew Rate

16.2 tREFI

Average periodic Refresh interval (tREFI) of DDR4 SDRAM is defined as shown in the table.

[Table 52] tREFI by device density

Parameter	Symbol		2Gb	4Gb	8Gb	16Gb	Units	NOTE
All Bank Refresh to active/refresh cmd time	tRFC		160	260	350	550	ns	
Average periodic refresh interval	tREFI	0 °C ≤ T_{CASE} ≤ 85°C	7.8	7.8	7.8	7.8	µs	
		-40 °C ≤ T_{CASE} ≤ 85°C	7.8	7.8	7.8	7.8	µs	2
		85 °C < T_{CASE} ≤ 95°C	3.9	3.9	3.9	3.9	µs	1

NOTE :

1) Users should refer to the DRAM supplier data sheet and/or the DIMM SPD to determine if DDR4 SDRAM devices support the following options or requirements referred to in this material.

2) Supported only for Industrial Temperature.

16.3 Clock Specification

The jitter specified is a random jitter meeting a Gaussian distribution. Input clocks violating the min/max values may result in malfunction of the DDR4 SDRAM device.

16.3.1 Definition for tCK(abs)

tCK(abs) is defined as the absolute clock period, as measured from one rising edge to the next consecutive rising edge. tCK(abs) is not subject t o production test.

16.3.2 Definition for tCK(avg)

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

$$tCK(avg) = \left(\sum_{j=1}^{N} tCK(abs)j \right) / N \qquad N = 200$$

16.3.3 Definition for tCH(avg) and tCL(avg)

tCH(avg) is defined as the average high pulse width, as calculated across any consecutive 200 high pulses.

$$tCH(avg) = \left(\sum_{j=1}^{N} tCHj \right) / \{ N \times tCK(avg) \} \quad N = 200$$

tCL(avg) is defined as the average low pulse width, as calculated across any consecutive 200 low pulses.

$$tCL(avg) = \left(\sum_{j=1}^{N} tCLj \right) / \{ N \times tCK(avg) \} \quad N = 200$$

16.3.4 Definition for tERR(nper)

tERR is defined as the cumulative error across n consecutive cycles of n x tCK(avg). tERR is not subject to production test.

17. TIMING PARAMETERS BY SPEED GRADE

[Table 53] Timing Parameters by Speed Bin for DDR4-1600 to DDR4-2666

Speed		DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units	NOTE
Parameter	Symbol	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX		
Clock Timing													
Minimum Clock Cycle Time (DLL off mode)	tCK (DLL_OFF)	8	20	8	20	8	20	8	20	8	20	ns	
Average Clock Period	tCK(avg)	1.25	<1.5	1.071	<1.25	0.937	<1.071	0.833	<0.937	0.750	<0.833	ns	35,36
Average high pulse width	tCH(avg)	0.48	0.52	0.48	0.52	0.48	0.52	0.48	0.52	0.48	0.52	tCK(avg)	
Average low pulse width	tCL(avg)	0.48	0.52	0.48	0.52	0.48	0.52	0.48	0.52	0.48	0.52	tCK(avg)	
Absolute Clock Period	tCK(abs)	MIN : tCK(avg)min + tJIT(per)min_tot MAX : tCK(avg)max + tJIT(per)max_tot										tCK(avg)	
Absolute clock HIGH pulse width	tCH(abs)	0.45	-	0.45	-	0.45	-	0.45	-	0.45	-	tCK(avg)	23
Absolute clock LOW pulse width	tCL(abs)	0.45	-	0.45	-	0.45	-	0.45	-	0.45	-	tCK(avg)	24
Clock Period Jitter- total	JIT(per)_tot	-63	63	-54	54	-47	47	-42	42	-38	38	ps	23
Clock Period Jitter- deterministic	JIT(per)_dj	-31	31	-27	27	-23	23	-21	21	-19	19	ps	26
Clock Period Jitter during DLL locking period	tJIT(per, lck)	-50	50	-43	43	-38	38	-33	33	-30	30	ps	
Cycle to Cycle Period Jitter	tJIT(cc)	-	125	-	107	-	94	-	83	-	75	ps	
Cycle to Cycle Period Jitter during DLL locking period	tJIT(cc, lck)	-	100	-	86	-	75	-	67	-	60	ps	
Duty Cycle Jitter	tJIT(duty)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	ps	
Cumulative error across 2 cycles	tERR(2per)	-92	92	-79	79	-69	69	-61	61	-55	55	ps	
Cumulative error across 3 cycles	tERR(3per)	-109	109	-94	94	-82	82	-73	73	-66	66	ps	
Cumulative error across 4 cycles	tERR(4per)	-121	121	-104	104	-91	91	-81	81	-73	73	ps	
Cumulative error across 5 cycles	tERR(5per)	-131	131	-112	112	-98	98	-87	87	-78	78	ps	
Cumulative error across 6 cycles	tERR(6per)	-139	139	-119	119	-104	104	-92	92	-83	83	ps	
Cumulative error across 7 cycles	tERR(7per)	-145	145	-124	124	-109	109	-97	97	-87	87	ps	
Cumulative error across 8 cycles	tERR(8per)	-151	151	-129	129	-113	113	-101	101	-91	91	ps	
Cumulative error across 9 cycles	tERR(9per)	-156	156	-134	134	-117	117	-104	104	-94	94	ps	
Cumulative error across 10 cycles	tERR(10per)	-160	160	-137	137	-120	120	-107	107	-96	96	ps	
Cumulative error across 11 cycles	tERR(11per)	-164	164	-141	141	-123	123	-110	110	-99	99	ps	
Cumulative error across 12 cycles	tERR(12per)	-168	168	-144	144	-126	126	-112	112	-101	101	ps	
Cumulative error across 13 cycles	tERR(13per)	-172	172	-147	147	-129	129	-114	114	-103	103	ps	
Cumulative error across 14 cycles	tERR(14per)	-175	175	-150	150	-131	131	-116	116	-104	104	ps	
Cumulative error across 15 cycles	tERR(15per)	-178	178	-152	152	-133	133	-118	118	-106	106	ps	
Cumulative error across 16 cycles	tERR(16per)	-180	189	-155	155	-135	135	-120	120	-108	108	ps	
Cumulative error across 17 cycles	tERR(17per)	-183	183	-157	157	-137	137	-122	122	-110	110	ps	
Cumulative error across 18 cycles	tERR(18per)	-185	185	-159	159	-139	139	-124	124	-112	112	ps	
Cumulative error across n = 13, 14 . . . 49, 50 cycles	tERR(nper)	MIN : tERR(nper)min = ((1 + 0.68ln(n)) * tJIT(per)_total min) MAX : tERR(nper)max = ((1 + 0.68ln(n)) * tJIT(per)_total max)										ps	
Command and Address setup time to CK_t, CK_c referenced to Vih(ac) / Vil(ac) levels	tIS(base)	115	-	100	-	80	-	62	-	55	-	ps	
Command and Address setup time to CK_t, CK_c referenced to Vref levels	tIS(Vref)	215	-	200	-	180	-	162	-	145	-	ps	
Command and Address hold time to CK_t, CK_c referenced to Vih(dc) / Vil(dc) levels	tIH(base)	140	-	125	-	105	-	87	-	80	-	ps	
Command and Address hold time to CK_t, CK_c referenced to Vref levels	tIH(Vref)	215	-	200	-	180	-	162	-	145	-	ps	
Control and Address Input pulse width for each input	tIPW	600	-	525	-	460	-	410	-	385	-	ps	
Command and Address Timing													
CAS_n to CAS_n command delay for same bank group	tCCD_L	max(5 nCK, 6.250 ns)	-	max(5 nCK, 5.355 ns)	-	max(5 nCK, 5.355 ns)	-	max(5 nCK, 5 ns)	-	max(5 nCK, 5 ns)	-	nCK	34
CAS_n to CAS_n command delay for different bank group	tCCD_S	4	-	4	-	4	-	4	-	4	-	nCK	34
ACTIVATE to ACTIVATE Command delay to different bank group for 2KB page size	tRRD_S(2K)	Max(4nCK,6 ns)	-	Max(4nCK,5 .3ns)	-	Max(4nCK,5 .3ns)	-	Max(4nCK,5 .3ns)	-	Max(4nCK,5 .3ns)	-	nCK	34
ACTIVATE to ACTIVATE Command delay to different bank group for 2KB page size	tRRD_S(1K)	Max(4nCK,5 ns)		Max(4nCK,4 .2ns)		Max(4nCK,3 .7ns)		Max(4nCK,3 .3ns)	-	Max(4nCK,3 ns)	-	nCK	34
ACTIVATE to ACTIVATE Command delay to different bank group for 1/2KB page size	tRRD_S(1/2K)	Max(4nCK,5 ns)		Max(4nCK,4 .2ns)		Max(4nCK,3 .7ns)		Max(4nCK,3 .3ns)	-	Max(4nCK,3 ns)	-	nCK	34
ACTIVATE to ACTIVATE Command delay to same bank group for 2KB page size	tRRD_L(2K)	Max(4nCK,7 .5ns)		Max(4nCK,6 .4ns)		Max(4nCK,6 .4ns)		Max(4nCK,6 .4ns)	-	Max(4nCK,6 .4ns)	-	nCK	34
ACTIVATE to ACTIVATE Command delay to same bank group for 1KB page size	tRRD_L(1K)	Max(4nCK,6 ns)		Max(4nCK,5 .3ns)		Max(4nCK,5 .3ns)		Max(4nCK,4 .9ns)	-	Max(4nCK,4 .9ns)	-	nCK	34

[Table 53] Timing Parameters by Speed Bin for DDR4-1600 to DDR4-2666

Speed		DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units	NOTE
Parameter	Symbol	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX		
ACTIVATE to ACTIVATE Command delay to same bank group for 1/2KB page size	tRRD_L(1/2K)	Max(4nCK,6 ns)		Max(4nCK,5 .3ns)		Max(4nCK,5 .3ns)		Max(4nCK,4 .9ns)	-	Max(4nCK,4 .9ns)	-	nCK	34
Four activate window for 2KB page size	tFAW_2K	Max(28nCK, 35ns)		Max(28nCK, 30ns)		Max(28nCK, 30ns)		Max(28nCK, 30ns)	-	Max(28nCK, 30ns)	-	ns	34
Four activate window for 1KB page size	tFAW_1K	Max(20nCK, 25ns)		Max(20nCK, 23ns)		Max(20nCK, 21ns)		Max(20nCK, 21ns)	-	Max(20nCK, 21ns)	-	ns	34
Four activate window for 1/2KB page size	tFAW_1/2K	Max(16nCK, 20ns)		Max(16nCK, 17ns)		Max(16nCK, 15ns)		Max(16nCK, 13ns)	-	Max(16nCK, 12ns)	-	ns	34
Delay from start of internal write transaction to internal read command for different bank group	tWTR_S	max(2nCK,2 .5ns)	-	max(2nCK,2 .5ns)	-	max(2nCK,2 .5ns)	-	Max (2nCK, 2.5ns)	-	Max (2nCK, 2.5ns)	-	ns	1,2,e,34
Delay from start of internal write transaction to internal read command for same bank group	tWTR_L	max(4nCK,7 .5ns)	-	max(4nCK,7 .5ns)	-	max(4nCK,7 .5ns)	-	max (4nCK,7.5ns)	-	max (4nCK,7.5ns)	-		1,34
Internal READ Command to PRECHARGE Command delay	tRTP	max(4nCK,7 .5ns)	-	max(4nCK,7 .5ns)	-	max(4nCK,7 .5ns)	-	max (4nCK,7.5ns)	-	max (4nCK,7.5ns)	-		
WRITE recovery time	tWR	15	-	15	-	15	-	15	-	15	-	ns	1
Write recovery time when CRC and DM are enabled	tWR_CRC_DM	tWR+max (4nCK,3.75n s)	-	tWR+max (5nCK,3.75n s)	-	tWR+max (5nCK,3.75n s)	-	tWR+max (5nCK,3.75n s)	-	tWR+max (5nCK,3.75n s)	-	ns	1, 28
Delay from start of internal write transaction to internal read command for different bank group with both CRC and DM enabled	tWTR_S_CRC_DM	tWTR_S+max (4nCK,3.75n s)	-	tWTR_S+max (5nCK,3.75n s)	-	tWTR_S+max (5nCK,3.75n s)	-	tWTR_S+max (5nCK,3.75n s)	-	tWTR_S+max (5nCK,3.75n s)	-	ns	2, 29, 34
Delay from start of internal write transaction to internal read command for same bank group with both CRC and DM enabled	tWTR_L_CRC_DM	tWTR_L+max (4nCK,3.75n s)	-	tWTR_L+max (5nCK,3.75n s)	-	tWTR_L+max (5nCK,3.75n s)	-	tWTR_L+max (5nCK,3.75n s)	-	tWTR_L+max (5nCK,3.75n s)	-	ns	3,30, 34
DLL locking time	tDLLK	597	-	597	-	768	-	768	-	1024	-	nCK	
Mode Register Set command cycle time	tMRD	8	-	8	-	8	-	8	-	8	-	nCK	
Mode Register Set command update delay	tMOD	max(24nCK, 15ns)	-	max(24nCK, 15ns)	-	max(24nCK, 15ns)	-	max(24nCK, 15ns)	-	max(24nCK, 15ns)	-	nCK	50
Multi-Purpose Register Recovery Time	tMPRR	1	-	1	-	1	-	1	-	1	-	nCK	33
Multi Purpose Register Write Recovery Time	tWR_MPR	tMOD (min) + AL + PL	-	tMOD (min) + AL + PL	-	tMOD (min) + AL + PL	-	tMOD (min) + AL + PL	-	tMOD (min) + AL + PL	-		
Auto precharge write recovery + precharge time	tDAL(min)	Programmed WR + roundup (tRP / tCK(avg))										nCK	
DQ0 or DQL0 driven to 0 set-up time to first DQS rising edge	tPDA_S	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	UI	45,47
DQ0 or DQL0 driven to 0 hold time from last DQS falling edge	tPDA_H	0.5	-	0.5	-	0.5	-	0.5	-	0.5	-	UI	46,47
CS_n to Command Address Latency													
CS_n to Command Address Latency	tCAL	max(3 nCK, 3.748 ns)	-	max(3 nCK, 3.748 ns)	-	max(3 nCK, 3.748 ns)	-	max(3 nCK, 3.748 ns)	-	max(3 nCK, 3.748 ns)	-	nCK	
Mode Register Set command cycle time in CAL mode	tMRD_tCAL	tMOD+ tCAL	-	tMOD+ tCAL	-	tMOD+ tCAL	-	tMOD+ tCAL	-	tMOD+ tCAL	-	nCK	
Mode Register Set update delay in CAL mode	tMOD_tCAL	tMOD+ tCAL	-	tMOD+ tCAL	-	tMOD+ tCAL	-	tMOD+ tCAL	-	tMOD+ tCAL	-	nCK	
DRAM Data Timing													
DQS_t, DQS_c to DQ skew, per group, per access	tDQSQ	-	0.16	-	0.16	-	0.16	-	0.17	-	0.18	tCK(avg)/2	13,18,39 ,49
DQ output hold time per group, per access from DQS_t, DQS_c	tQH	0.76	-	0.76	-	0.76	-	0.74	-	0.74	-	tCK(avg)/2	13,17,18 ,39,49
Data Valid Window per device, per UI: (tQH - tDQSQ) of each UI on a given DRAM	tDVWd	0.63	-	0.63	-	0.64	-	0.64	-	TBD	-	UI	17,18,39 ,49
Data Valid Window, per pin, per UI: (tQH - tDQSQ) each UI on a pin of a given DRAM	tDVWp	0.66	-	0.66	-	0.69	-	0.72	-	0.72	-	UI	17,18,39 ,49
DQ low impedance time from CK_t, CK_c	tLZ(DQ)	-450	225	-390	195	-360	180	-330	175	-310	170	ps	39
DQ high impedance time from CK_t, CK_c	tHZ(DQ)	-	225	-	195	-	180	-	175	-	170	ps	39
Data Strobe Timing													
DQS_t, DQS_c differential READ Preamble (1 clock preamble)	tRPRE	0.9	NOTE44	0.9	NOTE44	0.9	NOTE44	0.9	NOTE 44	0.9	NOTE 44	tCK	40
DQS_t, DQS_c differential READ Preamble (2 clock preamble)	tRPRE2	NA	NA	NA	NA	NA	NA	1.8	NOTE 44	1.8	NOTE 44	tCK	41
DQS_t, DQS_c differential READ Postamble	tRPST	0.33	NOTE 45	0.33	NOTE 45	0.33	NOTE 45	0.33	NOTE 45	0.33	NOTE 45	tCK	
DQS_t, DQS_c differential output high time	tQSH	0.4	-	0.4	-	0.4	-	0.4	-	0.4	-	tCK	21
DQS_t, DQS_c differential output low time	tQSL	0.4	-	0.4	-	0.4	-	0.4	-	0.4	-	tCK	20

[Table 53] Timing Parameters by Speed Bin for DDR4-1600 to DDR4-2666

Speed		DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units	NOTE
Parameter	Symbol	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX		
DQS_t, DQS_c differential WRITE Preamble (1 clock preamble)	tWPRE	0.9	-	0.9	-	0.9	-	0.9	-	0.9	-	tCK	42
DQS_t, DQS_c differential WRITE Preamble (2 clock preamble)	tWPRE2	NA		NA		NA		1.8	-	1.8	-	tCK	43
DQS_t, DQS_c differential WRITE Postamble	tWPST	0.33	-	0.33	-	0.33	-	0.33	-	0.33	-	tCK	
DQS_t and DQS_c low-impedance time (Referenced from RL-1)	tLZ(DQS)	-450	225	-390	195	-360	180	-330	175	-310	170	ps	
DQS_t and DQS_c high-impedance time (Referenced from RL+BL/2)	tHZ(DQS)	-	225	-	195	-	180	-	175	-	170	ps	
DQS_t, DQS_c differential input low pulse width	tDQSL	0.46	0.54	0.46	0.54	0.46	0.54	0.46	0.54	0.46	0.54	tCK	
DQS_t, DQS_c differential input high pulse width	tDQSH	0.46	0.54	0.46	0.54	0.46	0.54	0.46	0.54	0.46	0.54	tCK	
DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (1 clock preamble)	tDQSS	-0.27	0.27	-0.27	0.27	-0.27	0.27	-0.27	0.27	-0.27	0.27	tCK	42
DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (2 clock preamble)	tDQSS2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	tCK	43
DQS_t, DQS_c falling edge setup time to CK_t, CK_c rising edge	tDSS	0.18	-	0.18	-	0.18	-	0.18	-	0.18	-	tCK	
DQS_t, DQS_c falling edge hold time from CK_t, CK_c rising edge	tDSH	0.18	-	0.18	-	0.18	-	0.18	-	0.18	-	tCK	
DQS_t, DQS_c rising edge output timing location from rising CK_t, CK_c with DLL On mode	tDQSCK (DLL On)	-225	225	-195	195	-180	180	-175	175	-170	170	ps	37,38,39
DQS_t, DQS_c rising edge output variance window per DRAM	tDQSCKI (DLL On)	-	370	-	330	-	310	-	290	-	270	ps	37,38,39
MPSM Timing													
Command path disable delay upon MPSM entry	tMPED	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-		
Valid clock requirement after MPSM entry	tCKMPE	tMOD(min) +tCPDED(min)	-	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-	tMOD(min) + tCPDED(min)	-		
Valid clock requirement before MPSM exit	tCKMPX	tCKSRX(min)	-	tCKSRX(min)	-	tCKSRX(min)	-	tCKSRX(min)	-	tCKSRX(min)	-		
Exit MPSM to commands not requiring a locked DLL	tXMP	tXS(min)	-	tXS(min)	-	tXS(min)	-	tXS(min)	-	tXS(min)	-		
Exit MPSM to commands requiring a locked DLL	tXMPDLL	tXMP(min) + tXSDLL(min)	-	tXMP(min) + tXSDLL(min)	-	tXMP(min) +tXSDLL(min)	-	tXMP(min) + tXSDLL(min)	-	tXMP(min) + tXSDLL(min)	-		
CS setup time to CKE	tMPX_S	tIS(min) + tIH(min)	-	tIS(min) + tIH(min)	-	tIS(min) + tIH(min)	-	tIS(min) + tIH(min)	-	tIS(min) + tIH(min)	-		
CS_n High hold time to CKE rising edge	tMPX_HH	tXP(min)	-	tXP(min)	-	tXP(min)	-	tXP(min)	-	tXP(min)	-		
CS_n Low hold time to CKE rising edge	tMPX_LH	12	tXMP-10ns	12	tXMP-10ns	12	tXMP-10ns	12	tXMP-10ns	12	tXMP-10ns	ns	51
Calibration Timing													
Power-up and RESET calibration time	tZQinit	1024	-	1024	-	1024	-	1024	-	1024	-	nCK	
Normal operation Full calibration time	tZQoper	512	-	512	-	512	-	512	-	512	-	nCK	
Normal operation Short calibration time	tZQCS	128	-	128	-	128	-	128	-	128	-	nCK	
Reset/Self Refresh Timing													
Exit Reset from CKE HIGH to a valid command	tXPR	max (5nCK,tRFC(min)+ 10ns)	-	max (5nCK,tRFC(min)+ 10ns)	-	max (5nCK,tRFC(min)+ 10ns)	-	max (5nCK,tRFC(min)+10ns)	-	max (5nCK,tRFC(min)+10ns)	-	nCK	
Exit Self Refresh to commands not requiring a locked DLL	tXS	tRFC(min)+10ns	-	tRFC(min)+10ns	-	tRFC(min)+10ns	-	tRFC(min)+10ns	-	tRFC(min)+10ns	-	nCK	
SRX to commands not requiring a locked DLL in Self Refresh ABORT	tXS_ABORT(min)	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	nCK	
Exit Self Refresh to ZQCL,ZQCS and MRS (CL,CWL,WR,RTP and Gear Down)	tXS_FAST (min)	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	tRFC4(min)+ 10ns	-	nCK	
Exit Self Refresh to commands requiring a locked DLL	tXSDLL	tDLLK(min)	-	tDLLK(min)	-	tDLLK(min)	-	tDLLK(min)	-	tDLLK(min)	-	nCK	
Minimum CKE low width for Self refresh entry to exit timing	tCKESR	tCKE(min)+1 nCK	-	tCKE(min)+1 nCK	-	tCKE(min)+1 nCK	-	tCKE(min)+1 nCK	-	tCKE(min)+1 nCK	-	nCK	
Minimum CKE low width for Self refresh entry to exit timing with CA Parity enabled	tCKESR_ PAR	tCKE(min)+ 1nCK+PL	-	tCKE(min)+ 1nCK+PL	-	tCKE(min)+ 1nCK+PL	-	tCKE(min)+ 1nCK+PL	-	tCKE(min)+ 1nCK+PL	-	nCK	
Valid Clock Requirement after Self Refresh Entry (SRE) or Power-Down Entry (PDE)	tCKSRE	max(5nCK,10ns)	-	max(5nCK,10ns)	-	max(5nCK,10ns)	-	max (5nCK,10ns)	-	max (5nCK,10ns)	-	nCK	

[Table 53] Timing Parameters by Speed Bin for DDR4-1600 to DDR4-2666

Speed		DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units	NOTE
Parameter	Symbol	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX		
Valid Clock Requirement after Self Refresh Entry (SRE) or Power-Down when CA Parity is enabled	tCKSRE_PAR	max (5nCK,10ns) +PL	-	max (5nCK,10ns) +PL	-	max (5nCK,10ns) +PL	-	max (5nCK,10ns) +PL	-	max (5nCK,10ns) +PL	-	nCK	
Valid Clock Requirement before Self Refresh Exit (SRX) or Power-Down Exit (PDX) or Reset Exit	tCKSRX	max(5nCK,10ns)	-	max(5nCK,10ns)	-	max(5nCK,10ns)	-	max (5nCK,10ns)	-	max (5nCK,10ns)	-	nCK	
Power Down Timing													
Exit Power Down with DLL on to any valid command; Exit Precharge Power Down with DLL frozen to commands not requiring a locked DLL	tXP	max (4nCK,6ns)	-	max (4nCK,6ns)	-	max (4nCK,6ns)	-	max (4nCK,6ns)	-	max (4nCK,6ns)	-	nCK	
CKE minimum pulse width	tCKE	max (3nCK, 5ns)	-	max (3nCK, 5ns)	-	max (3nCK, 5ns)	-	max (3nCK, 5ns)	-	max (3nCK, 5ns)	-	nCK	31,32
Command pass disable delay	tCPDED	4	-	4	-	4	-	4	-	4	-	nCK	
Power Down Entry to Exit Timing	tPD	tCKE(min)	9*tREFI	tCKE(min)	9*tREFI	tCKE(min)	9*tREFI	tCKE(min)	9*tREFI	tCKE(min)	9*tREFI	nCK	6
Timing of ACT command to Power Down entry	tACTPDEN	1	-	1	-	2	-	2	-	2	-	nCK	7
Timing of PRE or PREA command to Power Down entry	tPRPDEN	1	-	1	-	2	-	2	-	2	-	nCK	7
Timing of RD/RDA command to Power Down entry	tRDPDEN	RL+4+1	-	RL+4+1	-	RL+4+1	-	RL+4+1	-	RL+4+1	-	nCK	
Timing of WR command to Power Down entry (BL8OTF, BL8MRS, BC4OTF)	tWRPDEN	WL+4+(tWR /tCK(avg))	-	WL+4+(tWR /tCK(avg))	-	WL+4+(tWR /tCK(avg))	-	WL+4+(tWR /tCK(avg))	-	WL+4+(tWR /tCK(avg))	-	nCK	4
Timing of WRA command to Power Down entry (BL8OTF, BL8MRS, BC4OTF)	tWRAPDEN	WL+4+WR+1	-	WL+4+WR+1	-	WL+4+WR+1	-	WL+4+WR+1	-	WL+4+WR+1	-	nCK	5
Timing of WR command to Power Down entry (BC4MRS)	tWRPBC4DEN	WL+2+(tWR /tCK(avg))	-	WL+2+(tWR /tCK(avg))	-	WL+2+(tWR /tCK(avg))	-	WL+2+(tWR /tCK(avg))	-	WL+2+(tWR /tCK(avg))	-	nCK	4
Timing of WRA command to Power Down entry (BC4MRS)	tWRAP-BC4DEN	WL+2+WR+1	-	WL+2+WR+1	-	WL+2+WR+1	-	WL+2+WR+1	-	WL+2+WR+1	-	nCK	5
Timing of REF command to Power Down entry	tREFPDEN	1	-	1	-	2	-	2	-	2	-	nCK	7
Timing of MRS command to Power Down entry	tMRSPDEN	tMOD(min)	-	tMOD(min)	-	tMOD(min)	-	tMOD(min)	-	tMOD(min)	-		
PDA Timing													
Mode Register Set command cycle time in PDA mode	tMRD_PDA	max(16nCK, 10ns)	-	max(16nCK, 10ns)	-	max(16nCK, 10ns)	-	max(16nCK, 10ns)	-	max(16nCK, 10ns)	-	nCK	
Mode Register Set command update delay in PDA mode	tMOD_PDA	tMOD		tMOD		tMOD		tMOD		tMOD			
ODT Timing													
Asynchronous RTT turn-on delay (Power-Down with DLL frozen)	tAONAS	1.0	9.0	1.0	9.0	1.0	9.0	1.0	9.0	1.0	9.0	ns	
Asynchronous RTT turn-off delay (Power-Down with DLL frozen)	tAOFAS	1.0	9.0	1.0	9.0	1.0	9.0	1.0	9.0	1.0	9.0	ns	
RTT dynamic change skew	tADC	0.3	0.7	0.3	0.7	0.3	0.7	0.3	0.7	0.28	0.72	tCK(avg)	
Write Leveling Timing													
First DQS_t/DQS_c rising edge after write leveling mode is programmed	tWLMRD	40	-	40	-	40	-	40	-	40	-	nCK	12
DQS_t/DQS_c delay after write leveling mode is programmed	tWLDQSEN	25	-	25	-	25	-	25	-	25	-	nCK	12
Write leveling setup time from rising CK_t, CK_c crossing to rising DQS_t/DQS_c crossing	tWLS	0.13	-	0.13	-	0.13	-	0.13	-	0.13	-	tCK(avg)	
Write leveling hold time from rising DQS_t/DQS_c crossing to rising CK_t, CK_c crossing	tWLH	0.13	-	0.13	-	0.13	-	0.13	-	0.13	-	tCK(avg)	
Write leveling output delay	tWLO	0	9.5	0	9.5	0	9.5	0	9.5	0	9.5	ns	
Write leveling output error	tWLOE	0	2	0	2	0	2	0	2	0	2	ns	
CA Parity Timing													
Commands not guaranteed to be executed during this time	tPAR_UNKNOWN	-	PL	-	PL	-	PL	-	PL	-	PL		
Delay from errant command to ALERT_n assertion	tPAR_ALERT_ON	-	PL+6ns	-	PL+6ns	-	PL+6ns	-	PL+6ns	-	PL+6ns		
Pulse width of ALERT_n signal when asserted	tPAR_ALERT_PW	48	96	56	112	64	128	72	144	80	160	nCK	
Time from when Alert is asserted till controller must start providing DES commands in Persistent CA parity mode	tPAR_ALERT_RSP	-	43	-	50	-	57	-	64	-	71	nCK	
Parity Latency	PL	4		4		4		5		5		nCK	
CRC Error Reporting													
CRC error to ALERT_n latency	tCRC_ALERT	3	13	3	13	3	13	3	13	3	13	ns	
CRC ALERT_n pulse width	CRC_ALERT_PW	6	10	6	10	6	10	6	10	6	10	nCK	

[Table 53] Timing Parameters by Speed Bin for DDR4-1600 to DDR4-2666

Speed		DDR4-1600		DDR4-1866		DDR4-2133		DDR4-2400		DDR4-2666		Units	NOTE
Parameter	Symbol	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX		
Geardown timing													
Exit RESET from CKE HIGH to a valid MRS geardown (T2/Reset)	tXPR_GEAR	-	-	-	-	-	-	-	-	tXPR	-		
CKE High Assert to Gear Down Enable time(T2/CKE)	tXS_GEAR	-	-	-	-	-	-	-	-	tXS	-		
MRS command to Sync pulse time(T3)	tSYNC_GEA R	-	-	-	-	-	-	-	-	tMOD + 4tCK	-		27
Sync pulse to First valid command(T4)	tCMD_GEAR	-	-	-	-	-	-	-	-	tMOD	-		27
Geardown setup time	tGEAR_setup	-	-	-	-	-	-	-	-	2	-	nCK	
Geardown hold time	tGEAR_hold	-	-	-	-	-	-	-	-	2	-	nCK	
tREFI													
tRFC1 (min)	2Gb	160	-	160	-	160	-	160	-	160	-	ns	34
	4Gb	260	-	260	-	260	-	260	-	260	-	ns	34
	8Gb	350	-	350	-	350	-	350	-	350	-	ns	34
	16Gb	550	-	550	-	550	-	550	-	550	-	ns	34
tRFC2 (min)	2Gb	110	-	110	-	110	-	110	-	110	-	ns	34
	4Gb	160	-	160	-	160	-	160	-	160	-	ns	34
	8Gb	260	-	260	-	260	-	260	-	260	-	ns	34
	16Gb	350	-	350	-	350	-	350	-	350	-	ns	34
tRFC4 (min)	2Gb	90	-	90	-	90	-	90	-	90	-	ns	34
	4Gb	110	-	110	-	110	-	110	-	110	-	ns	34
	8Gb	160	-	160	-	160	-	160	-	160	-	ns	34
	16Gb	260	-	260	-	260	-	260	-	260	-	ns	34

NOTE :

1) Start of internal write transaction is defined as follows :
   For BL8 (Fixed by MRS and on-the-fly) : Rising clock edge 4 clock cycles after WL.
   For BC4 (on-the-fly) : Rising clock edge 4 clock cycles after WL.
   For BC4 (fixed by MRS) : Rising clock edge 2 clock cycles after WL.
2) A separate timing parameter will cover the delay from write to read when CRC and DM are simultaneously enabled
3) Commands requiring a locked DLL are: READ (and RAP) and synchronous ODT commands.
4) tWR is defined in ns, for calculation of tWRPDEN it is necessary to round up tWR/tCK following rounding algorithm defined in "17.1 Rounding Algorithms".
5) WR in clock cycles as programmed in MR0.
6) tREFI depends on TOPER.
7) CKE is allowed to be registered low while operations such as row activation, precharge, autoprecharge or refresh are in progress, but power-down IDD spec will not be applied until finishing those operations.
8) For these parameters, the DDR4 SDRAM device supports tnPARAM[nCK]=RU{tPARAM[ns]/tCK(avg)[ns]}, which is in clock cycles assuming all input clock jitter specifications are satisfied.
9) When CRC and DM are both enabled, tWR_CRC_DM is used in place of tWR.
10) When CRC and DM are both enabled tWTR_S_CRC_DM is used in place of tWTR_S.
11) When CRC and DM are both enabled tWTR_L_CRC_DM is used in place of tWTR_L.
12) The max values are system dependent.
13) DQ to DQS total timing per group where the total includes the sum of deterministic and random timing terms for a specified BER. BER spec and measurement method are tbd.
14) The deterministic component of the total timing. Measurement method tbd.
15) DQ to DQ static offset relative to strobe per group. Measurement method tbd.
16) This parameter will be characterized and guaranteed by design.
17) When the device is operated with the input clock jitter, this parameter needs to be derated by the actual tjit(per)_total of the input clock. (output deratings are relative to the SDRAM input clock). Example tbd.
18) DRAM DBI mode is off.
19) DRAM DBI mode is enabled. Applicable to x8 and x16 DRAM only.
20) tQSL describes the instantaneous differential output low pulse width on DQS_t - DQS_c, as measured from on falling edge to the next consecutive rising edge
21) tQSH describes the instantaneous differential output high pulse width on DQS_t - DQS_c, as measured from on falling edge to the next consecutive rising edge
22) There is no maximum cycle time limit besides the need to satisfy the refresh interval tREFI
23) tCH(abs) is the absolute instantaneous clock high pulse width, as measured from one rising edge to the following falling edge
24) tCL(abs) is the absolute instantaneous clock low pulse width, as measured from one falling edge to the following rising edge
25) Total jitter includes the sum of deterministic and random jitter terms for a specified BER. BER target and measurement method are tbd.
26) The deterministic jitter component out of the total jitter. This parameter is characterized and guaranteed by design.
27) This parameter has to be even number of clocks
28) When CRC and DM are both enabled, tWR_CRC_DM is used in place of tWR.
29) When CRC and DM are both enabled tWTR_S_CRC_DM is used in place of tWTR_S.
30) When CRC and DM are both enabled tWTR_L_CRC_DM is used in place of tWTR_L.
31) After CKE is registered LOW, CKE signal level shall be maintained below VILDC for tCKE specification (Low pulse width).
32) After CKE is registered HIGH, CKE signal level shall be maintained above VIHDC for tCKE specification (HIGH pulse width).
33) Defined between end of MPR read burst and MRS which reloads MPR or disables MPR function.
34) Parameters apply from tCK(avg)min to tCK(avg)max at all standard JEDEC clock period values as stated in the Speed Bin Tables.
35) This parameter must keep consistency with Speed-Bin Tables shown in section 10.
36) DDR4-1600 AC timing apply if DRAM operates at lower than 1600 MT/s data rate. UI=tCK(avg).min/2.
37) applied when DRAM is in DLL ON mode.
38) Assume no jitter on input clock signals to the DRAM.
39) Value is only valid for RONNOM = 34 ohms.
40) 1tCK toggle mode with setting MR4:A11 to 0.
41) 2tCK toggle mode with setting MR4:A11 to 1, which is valid for DDR4-2400 and 2666 speed grade.
42) 1tCK mode with setting MR4:A12 to 0.
43) 2tCK mode with setting MR4:A12 to 1, which is valid for DDR4-2400 and 2666 speed grade.
44) The maximum read preamble is bounded by tLZ(DQS)min on the left side and tDQSCK(max) on the right side. See Figure “Clock to Data Strobe Relationship” in Operation datasheet. Boundary of DQS Low-Z occur one cycle earlier in 2tCK toggle mode which is illustrated in “Read Preamble” section.
45) DQ falling signal middle-point of transferring from High to Low to first rising edge of DQS diff-signal cross-point
46) last falling edge of DQS diff-signal cross-point to DQ rising signal middle-point of transferring from Low to High
47) VrefDQ value must be set to either its midpoint or Vcent_DQ(midpoint) in order to capture DQ0 or DQL0 low level for entering PDA mode.
48) The maximum read postamble is bound by tDQSCK(min) plus tQSH(min) on the left side and tHZ(DQS)max on the right side. See Figure “Clock to Data Strobe Relationship” in Operation datasheet.
49) Reference level of DQ output signal is specified with a midpoint as a widest part of Output signal eye which should be approximately 0.7 * VDDQ as a center level of the static single-ended output peak-to-peak swing with a driver impedance of 34 ohms and an effective test load of 50 ohms to VTT = VDDQ.
50) For MR7 commands, the minimum delay to a subsequent non-MRS command is 5nCK.
51) tMPX_LH(max) is defined with respect to actual tXMP in system as opposed to tXMP(min).

17.1 Rounding Algorithms

Software algorithms for calculation of timing parameters are subject to rounding errors from many sources. For example, a system may use a memory clock with a nominal frequency of 933.33... MHz, or a clock period of 1.0714... ns. Similarly, a system with a memory clock frequency of 1066.66... MHz yields mathematically a clock period of 0.9375... ns. In most cases, it is impossible to express all digits after the decimal point exactly, and rounding must be done because the DDR4 SDRAM specification establishes a minimum granularity for timing parameters of 1 ps.

Rules for rounding must be defined to allow optimization of device performance without violating device parameters. These algorithms rely on results that are within correction factors on device testing and specification to avoid losing performance due to rounding errors.

These rules are:

- Clock periods such as tCKAVGmin are defined to 1 ps of accuracy; for example, 0.9375... ns is defined as 937 ps and 1.0714... ns is defined as 1071 ps.
- Using real math, parameters like tAAmin, tRCDmin, etc. which are programmed in systems in numbers of clocks (nCK) but expressed in units of time (in ns) are divided by the clock period (in ns) yielding a unitless ratio, a correction factor of 2.5% is subtracted, then the result is set to the next higher integer number of clocks:

nCK = ceiling [(parameter_in_ns / application_tCK_in_ns) - 0.025]

- Alternatively, programmers may prefer to use integer math instead of real math by expressing timing in ps, scaling the desired parameter value by 1000, dividing by the application clock period, adding an inverse correction factor of 97.4%, dividing the result by 1000, then truncating down to the next lower integer value:

nCK = truncate [{(parameter_in_ps x 1000) / (application_tCK_in_ps) + 974} / 1000]

- Either algorithm yields identical results

17.2 The DQ input receiver compliance mask for voltage and timing

The DQ input receiver compliance mask for voltage and timing is shown in the figure below. The receiver mask (Rx Mask) defines area the input signal must not encroach in order for the DRAM input receiver to be expected to be able to successfully capture a valid input signal with BER of 1e-16; any input signal encroaching within the Rx Mask is subject to being invalid data. The Rx Mask is the receiver property for each DQ input pin and it is not the valid data-eye.

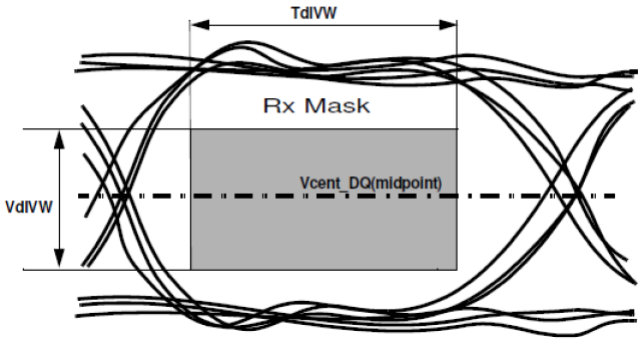


Figure 24. DQ Receiver(Rx) compliance mask

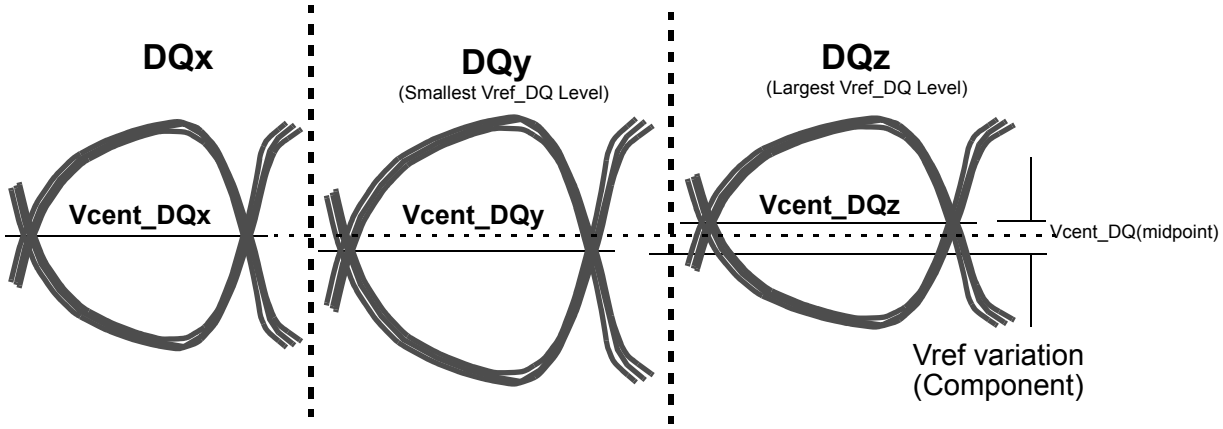
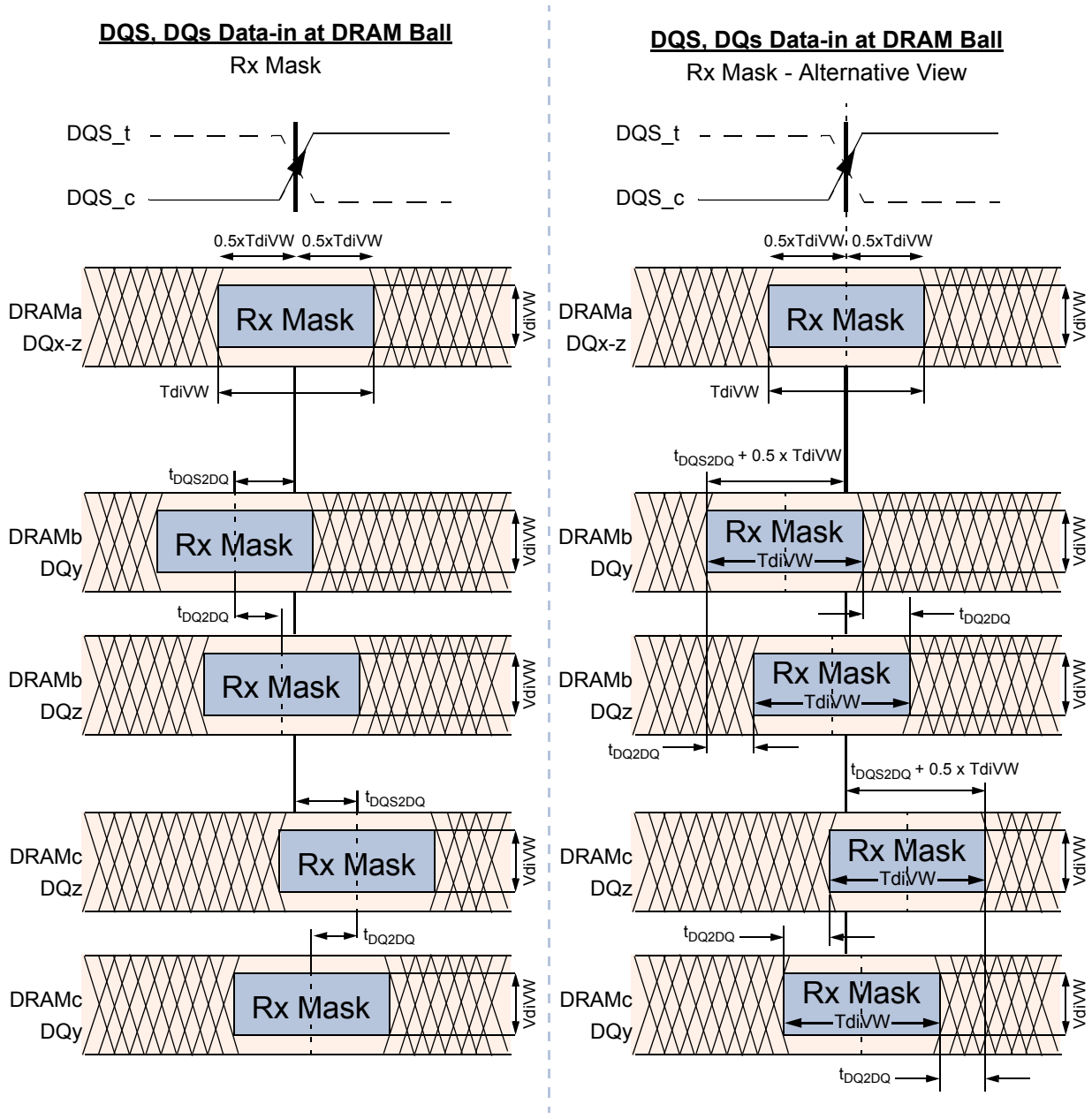


Figure 25. Vcent_DQ Variation to Vcent_DQ(midpoint)

The Vref_DQ voltage is an internal reference voltage level that shall be set to the properly trained setting, which is generally Vcent_DQ(midpoint), in order to have valid Rx Mask values.

Vcent_DQ is defined as the midpoint between the largest Vref_DQ voltage level and the smallest Vref_DQ voltage level across all DQ pins for a given DDR4 DRAM component. Each DQ pin Vref level is defined by the center, i.e. widest opening, of the cumulative data input eye as depicted in Figure 25. This clarifies that any DDR4 DRAM component level variation must be accounted for within the DDR4 DRAM Rx mask.The component level Vref will be set by the system to account for Ron and ODT settings.



NOTE : DQx represents an optimally centered mask.
DQy represents earliest valid mask.
DQz represents latest valid mask.

NOTE : DRAMa represents a DRAM without any DQS/DQ skews.
DRAMb represents a DRAM with early skews (negative t_{DQS2DQ}).
DRAMc represents a DRAM with delayed skews (positive t_{DQS2DQ}).

NOTE : Figures show skew allowed between DRAM to DRAM and DQ to DQ for a DRAM. Signals assume data centered aligned at DRAM Latch.
TdiPW is not shown; composite data-eyes shown would violate TdiPW.
VCENT DQ(midpoint) is not shown but is assummed to be midpoint of VdiVW..

Figure 26. DQS to DQ and DQ to DQ Timings at DRAM Balls

All of the timing terms in Figure 26 are measured at the VdIVW voltage levels centered around Vcent_DQ and are referenced to the DQS_t/DQS_c center aligned to the DQ per pin.

The rising edge slew rates are defined by srr1 and srr2. The slew rate measurement points for a rising edge are shown in Figure 27 below: A low to high transition tr1 is measured from 0.5*VdiVW(max) below Vcent_DQ(midpoint) to the last transition through 0.5*VdiVW(max) above Vcent_DQ(midpoint) while tr2 is measured from the last transition through 0.5*VdiVW(max) above Vcent_DQ(midpoint) to the first transition through the 0.5*VIHL_AC(min) above Vcent_DQ(midpoint).

Rising edge slew rate equations:

srr1 = VdIVW(max) / tr1

srr2 = (VIHL_AC(min) – VdIVW(max)) / (2*tr2)

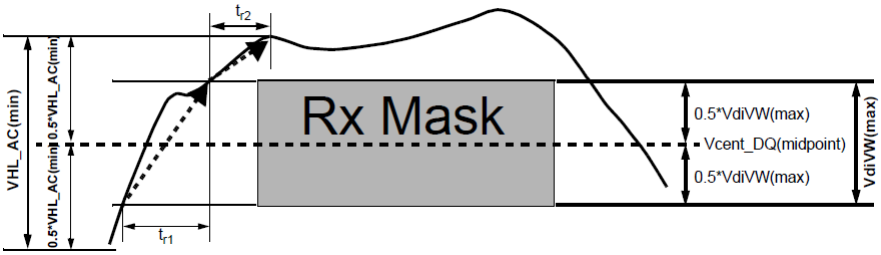


Figure 27. Slew Rate Conditions For Rising Transition

The falling edge slew rates are defined by srf1 and srf2. The slew rate measurement points for a falling edge are shown in Figure 28 below: A high to low transition tf1 is measured from 0.5*VdiVW(max) above Vcent_DQ(midpoint) to the last transition through 0.5*VdiVW(max) below Vcent_DQ(midpoint) while tf2 is measured from the last transition through 0.5*VdiVW(max) below Vcent_DQ(midpoint) to the first transition through the 0.5*VIHL_AC(min) below Vcent_DQ(pin mid).

Falling edge slew rate equations:

srf1 = VdIVW(max) / tf1

srf2 = (VIHL_AC(min) – VdIVW(max)) / (2*tf2)

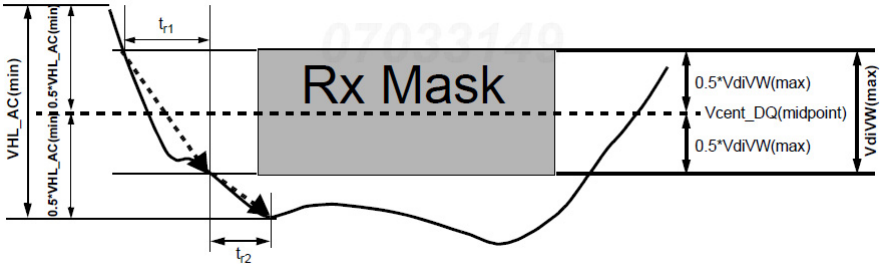


Figure 28. Slew Rate Conditions For Falling Transition

[Table 54] DRAM DQs In Receive Mode;

Symbol	Parameter	1600/1866/2133		2400		2666		Unit	NOTE
		min	max	min	max	min	max		
VdIVW	Rx Mask voltage - pk-pk	-	136	-	130	-	120	mV	1,2,10
TdIVW	Rx timing window	-	0.2	-	0.2	-	0.22	UI*	1,2,10
VIHL_AC	DQ AC input swing pk-pk	186	-	160	-	150	-	mV	3,4,10
TdIPW	DQ input pulse width	0.58	-	0.58	-	0.58	-	UI*	5,10
tDQS2DQ	Rx Mask DQS to DQ offset	-0.17	0.17	-0.17	0.17	-0.19	0.19	UI*	6, 10
tDQ2DQ	Rx Mask DQ to DQ offset	-	TBD	-	TBD	-	0.105	UI*	7
srr1, srf1	Input Slew Rate over VdIVW if tCK >0.937ns	1.0	9	1.0	9	1.0	9	V/ns	8,10
	Input Slew Rate over VdIVW if 0.937ns > tCK >= 0.625ns	-	-	1.25	9	1.25	9	V/ns	8,10
srr2	Rising Input Slew Rate over 1/2 VIHL_AC	0.2*srr1	9	0.2*srr1	9	0.2*srr1	9	V/ns	9,10
srf2	Falling Input Slew Rate over 1/2 VIHL_AC	0.2*srf1	9	0.2*srf1	9	0.2*srr1	9	V/ns	9,10

*** UI=tck(avg)min/2**

NOTE :

1) Data Rx mask voltage and timing total input valid window where VdIVW is centered around Vcent_DQ(midpoint) after VrefDQ training is completed. The data Rx mask is applied per bit and should include voltage and temperature drift terms. The input buffer design specification is to achieve at least a BER = e-16 when the RxMask is not violated. The BER will be characterized and extrapolated if necessary using a dual dirac method from a higher BER(tbd).
2) Defined over the DQ internal Vref range 1.
3) See Overshoot and Undershoot Specifications.
4) DQ input pulse signal swing into the receiver must meet or exceed VIHL AC(min). VIHL_AC(min) is to be achieved on an UI basis when a rising and falling edge occur in the same UI, i.e. a valid TdiPW.
5) DQ minimum input pulse width defined at the Vcent_DQ(midpoint).
6) DQS to DQ offset is skew between DQS and DQs within a nibble (x4) or word (x8, x16) at the DDR4 SDRAM balls over process, voltage, and temperature.
7) DQ to DQ offset is skew between DQs within a nibble (x4) or word (x8, x16) at the DDR4 SDRAM balls for a given component over process, voltage, and temperature.
8) Input slew rate over VdIVW Mask centered at Vcent_DQ(midpoint). Slowest DQ slew rate to fastest DQ slew rate per transition edge must be within 1.7 V/ns of each other.
9) Input slew rate between VdIVW Mask edge and VIHL_AC(min) points.
10) All Rx Mask specifications must be satisfied for each UI. For example, if the minimum input pulse width is violated when satisfying TdiVW(min), VdiVW(max), and minimum slew rate limits, then either TdiVW(min) or minimum slew rates would have to be increased to the point where the minimum input pulse width would no longer be violated.

17.3 Command, Control, and Address Setup, Hold, and Derating

The total tIS (setup time) and tIH (hold time) required is calculated to account for slew rate variation by adding the data sheet tIS (base) values, the VIL(AC)/VIH(AC) points, and tIH (base) values, the VIL(DC)/VIH(DC) points; to the ΔtIS and ΔtIH derating values, respectively. The base values are derived with single-end signals at 1V/ns and differential clock at 2V/ns. Example: tIS (total setup time) = tIS (base) + ΔtIS.

For a valid transition, the input signal has to remain above/below VIH(AC)/VIL(AC) for the time defined by tVAC.

Although the total setup time for slow slew rates might be negative (for example, a valid input signal will not have reached VIH(AC)/ VIL(AC) at the time of the rising clock transition), a valid input signal is still required to complete the transition and to reach VIH(AC)/ VIL(AC). For slew rates that fall between the values listed in derating tables, the derating values may be obtained by linear interpolation.

Setup (tIS) nominal slew rate for a rising signal is defined as the slew rate between the last crossing of VIL(DC)max and the first crossing of VIH(AC)min that does not ring back below VIH(DC)min. Setup (tIS) nominal slew rate for a falling signal is defined as the slew rate between the last crossing of VIH(DC)min and the first crossing of VIL(AC)max that does not ring back above VIL(DC)max. Hold (tIH) nominal slew rate for a rising signal is defined as the slew rate between the last crossing of VIL(DC)max and the first crossing of VIH(AC)min that does not ring back below VIH(DC)min. Hold (tIH) nominal slew rate for a falling signal is defined as the slew rate between the last crossing of VIH(DC)min and the first crossing of VIL(AC)minthat does not ring back above VIL(DC)max.

[Table 55] Command, Address, Control Setup and Hold Values

DDR4	1600	1866	2133	2400	2666	Unit	Reference
tIS(base, AC100)	115	100	80	62	-	ps	VIH/L(ac)
tIH(base, DC75)	140	125	105	87	-	ps	VIH/L(dc)
tIS(base, AC 90)	-	-	-	-	55	ps	VIH/L(ac)
tIH(base, DC 65)	-	-	-	-	80	ps	VIH/L(dc)
tIS/tIH @ VREF	215	200	180	162	145	ps	

NOTE :
1) Base ac/dc referenced for 1V/ns slew rate and 2 V/ns clock slew rate.
2) Values listed are referenced only; applicable limits are defined elsewhere.

[Table 56] Command, Address, Control Input Voltage Values

DDR4	1600	1866	2133	2400	2666	Unit	Reference
VIH.CA(AC)min	100	100	100	100	90	mV	VIH/L(ac)
VIH.CA(DC)min	75	75	75	75	65	mV	VIH/L(dc)
VIL.CA(DC)max	-75	-75	-75	-75	-65	mV	VIH/L(dc)
VIL.CA(AC)max	-100	-100	-100	-100	-90	mV	VIH/L(ac)

NOTE :
1) Command, Address, Control input levels relative to VREFCA.
2) Values listed are referenced only; applicable limits are defined elsewhere.

[Table 57] Derating values DDR4-1600/1866/2133/2400 tIS/tIH - ac/dc based

ΔtIS, ΔIH derating in [ps] AC/DC based [1]																
		CK_t, CK_c Differential Slew Rate														
		10V/ns		8V/ns		6V/ns		4V/ns		3.0V/ns		2.0V/ns		1.5V/ns		1V/ns	
		ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH
CMD, ADDR, CNTL Input Slew rate V/ns	7	76	54	76	55	77	56	79	58	82	60	86	64	94	73	111	89
	6	73	53	74	53	75	54	77	56	79	58	83	63	92	71	108	88
	5	70	50	71	51	72	52	74	54	76	56	80	60	88	68	105	85
	4	65	46	66	47	67	48	69	50	71	52	75	56	83	65	100	81
	3	57	40	57	41	58	42	60	44	63	46	67	50	75	58	92	75
	2	40	28	41	28	42	29	44	31	46	33	50	38	58	46	75	63
	1.5	23	15	24	16	25	17	27	19	29	21	33	25	42	33	58	50
	1	-10	-10	-9	-9	-8	-8	-6	-6	-4	-4	0	0	8	8	25	25
	0.9	-17	-14	-16	-14	-15	-13	-13	-10	-11	-8	-7	-4	1	4	18	21
	0.8	-26	-19	-25	-19	-24	-18	-22	-16	-20	-14	-16	-9	-7	-1	9	16
	0.7	-37	-26	-36	-25	-35	-24	-33	-22	-31	-20	-27	-16	-18	-8	-2	9
	0.6	-52	-35	-51	-34	-50	-33	-48	-31	-46	-29	-42	-25	-33	-17	-17	0
	0.5	-73	-48	-72	-47	-71	-46	-69	-44	-67	-42	-63	-38	-54	-29	-38	-13
	0.4	-104	-66	-103	-66	-102	-65	-100	-63	-98	-60	-94	-56	-85	-48	-69	-31

NOTE :
1) VIH/L(ac) = +/-100mV, VIH/L(dc) = +/-75mV; relative to VREFCA.

[Table 58] Derating values DDR4-2666 tIS/tIH - ac/dc based

ΔtIS, ΔIH derating in [ps] AC/DC based [1]																	
		CK_t, CK_c Differential Slew Rate															
		10V/ns		8V/ns		6V/ns		4V/ns		3.0V/ns		2.0V/ns		1.5V/ns		1V/ns	
		ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH	ΔtIS	ΔtIH
CMD, ADDR, CNTL Input Slew rate V/ns	7	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	6	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	4	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	3	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	2	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	1.5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	0.9	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	0.8	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	0.7	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	0.6	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	0.5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	0.4	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

NOTE :
1) VIH/L(ac) = +/-tbd mV, VIH/L(dc) = +/- tbd mV; relative to VREFCA

17.4 DDR4 Function Matrix

DDR4 SDRAM has several features supported by ORG and also by Speed. The following Table is the summary of the features.

[Table 59] Function Matrix (By ORG. V:Supported, Blank:Not supported)

Functions	x4	x8	NOTE
Write Leveling	V	V	
Temperature controlled Refresh	V	V	
Low Power Auto Self Refresh	V	V	
Fine Granularity Refresh	V	V	
Multi Purpose Register	V	V	
Data Mask		V	
Data Bus Inversion		V	
TDQS		V	
ZQ calibration	V	V	
DQ Vref Training	V	V	
Per DRAM Addressability	V	V	
Mode Register Readout	V	V	
CAL	V	V	
WRITE CRC	V	V	
CA Parity	V	V	
Control Gear Down Mode	V	V	
Programmable Preamble	V	V	
Maximum Power Down Mode	V	V	
Boundary Scan Mode			
Additive Latency	V	V	
3DS	V	V	

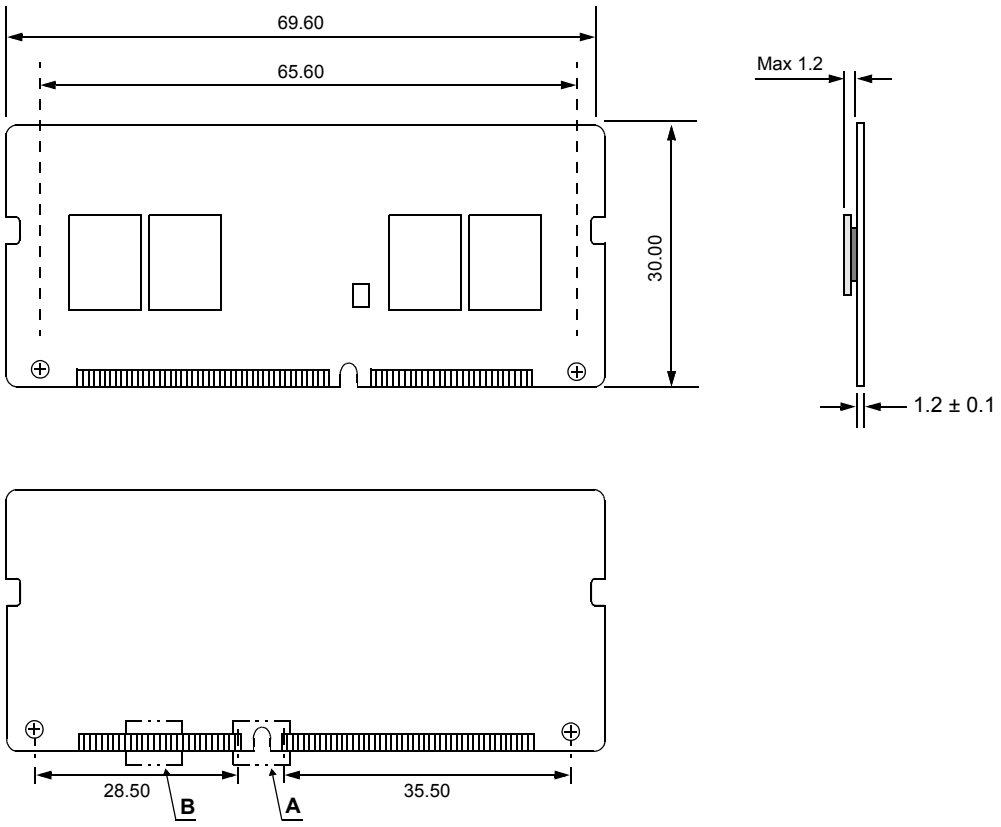
[Table 60] Function Matrix (By Speed. V:Supported, Blank:Not supported)

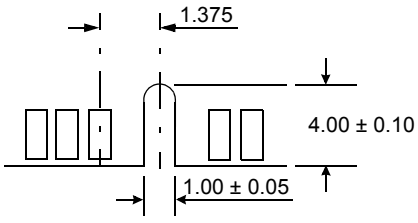
Functions	DLL Off mode	DLL On mode			NOTE
	equal or slower than 250Mbps	1600/1866/2133 Mbps	2400Mbps	2666Mbps	
Write Leveling	V	V	V	V	
Temperature controlled Refresh	V	V	V	V	
Low Power Auto Self Refresh	V	V	V	V	
Fine Granularity Refresh	V	V	V	V	
Multi Purpose Register	V	V	V	V	
Data Mask	V	V	V	V	
Data Bus Inversion	V	V	V	V	
TDQS		V	V	V	
ZQ calibration	V	V	V	V	
DQ Vref Training	V	V	V	V	
Per DRAM Addressability		V	V	V	
Mode Register Readout	V	V	V	V	
CAL		V	V	V	
WRITE CRC		V	V	V	
CA Parity		V	V	V	
Control Gear Down Mode				V	
Programmable Preamble (= 2tCK)			V	V	
Maximum Power Down Mode		V	V	V	
Boundary Scan Mode	V	V	V	V	
3DS	V	V	V	V	

18. PHYSICAL DIMENSIONS

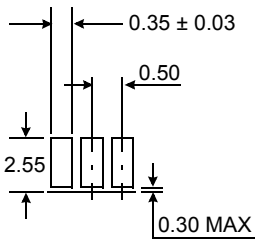
18.1 512Mx16 based 512Mx64 Module (1 Rank) - M471A5244CB0

Units: Millimeters





Detail A



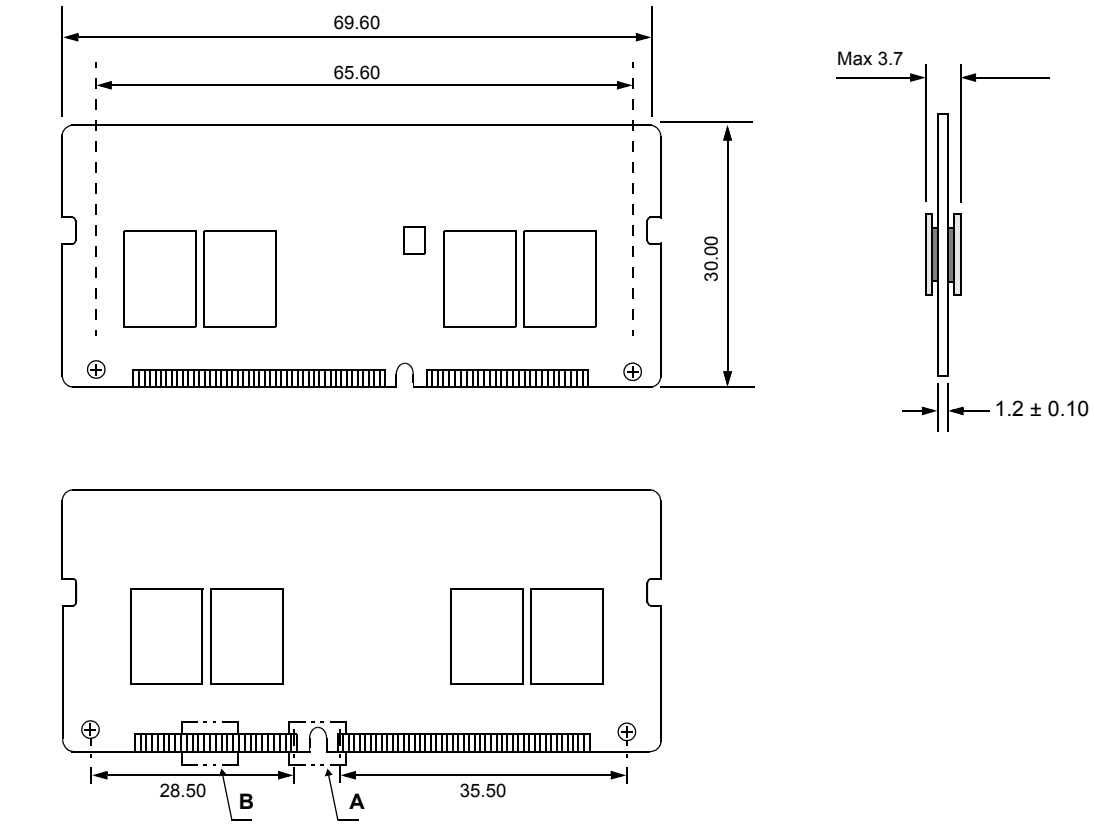
Detail B

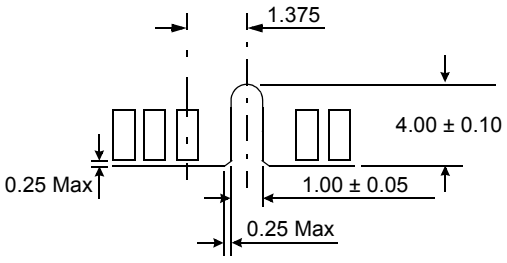
The used device is 512M x16 DDR4 SDRAM, Flip-Chip.
DDR4 SDRAM Part NO: K4A8G165WC- BC**

NOTE :
1) Tolerances on all dimensions ±0.15 unless otherwise specified.

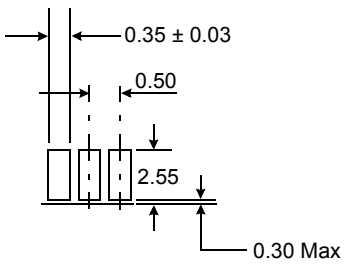
18.2 1Gx8 based 1Gx64 Module (1 Rank) - M471A1K43CB1

Units: Millimeters





Detail A



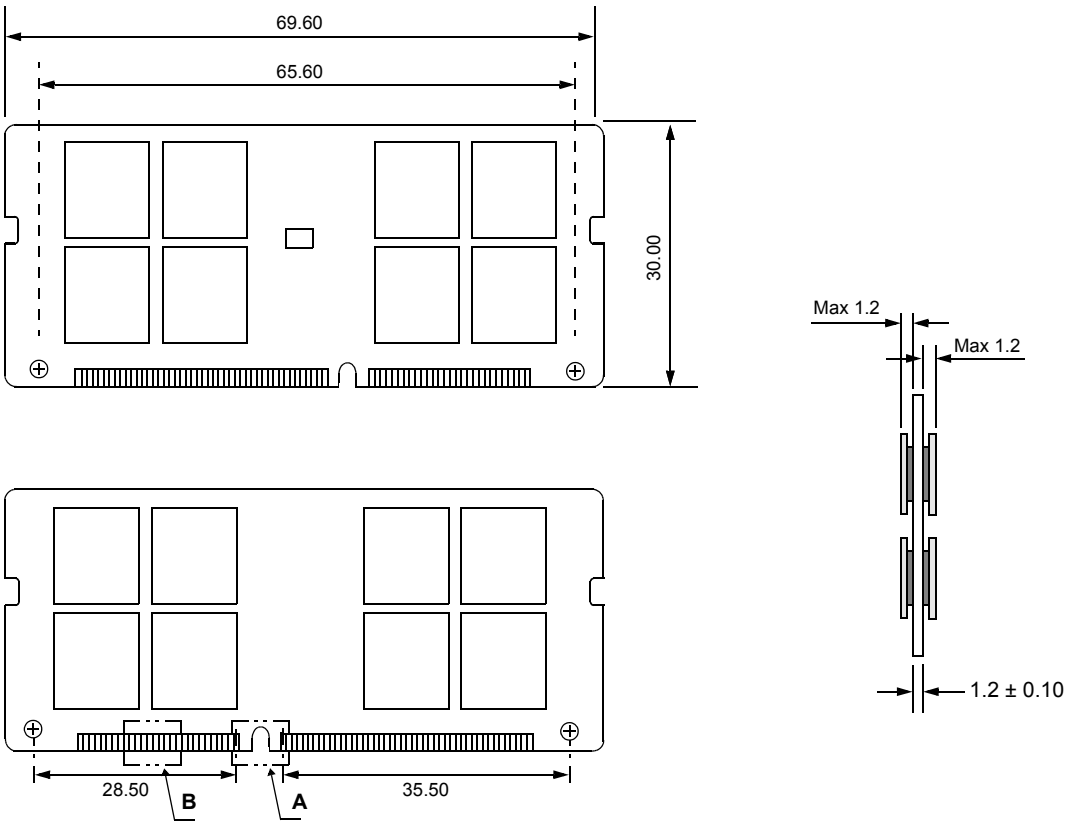
Detail B

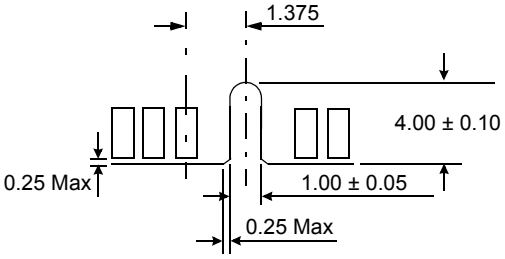
The used device is 1G x8 DDR4 SDRAM, Flip-Chip.
DDR4 SDRAM Part NO: K4A8G085WC - BC**

NOTE :
1) Tolerances on all dimensions ±0.15 unless otherwise specified.

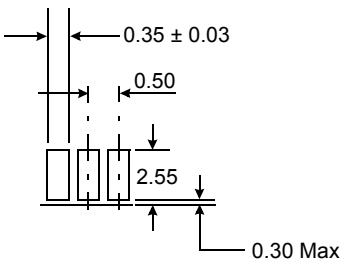
18.3 1Gx8 based 2Gx64 Module (2 Ranks) - M471A2K43CB1

Units: Millimeters





Detail A



Detail B

The used device is 1G x8 DDR4 SDRAM, Flip-Chip.
DDR4 SDRAM Part NO: K4A8G085WC - BC**

NOTE :
1) Tolerances on all dimensions ±0.15 unless otherwise specified.