



8Gb DDR4 SDRAM Datasheet

CXDQ3A8AM-WQ-A

ChangXin Memory Technologies, Inc.

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Revision History

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1. Core Specifications

This chapter is an index to help you quickly know the key features of DDR4 component and available product options.

- [Speed Bins on Page 8](#)
- [Key Features on Page 8](#)
- [Ordering Options on Page 10](#)
- [Part Number Decoding on Page 10](#)
- [Address Table on Page 10](#)

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1.1 Key Features

| Speed | DDR4-2666 | Unit |
|-------------|-----------|------|
| | 19-19-19 | |
| tCK (min) | 0.75 | ns |
| CAS Latency | 19 | nCK |
| tRCD (min) | 14.25 | ns |
| tRP (min) | 14.25 | ns |
| tRAS (min) | 32 | ns |
| tRC (min) | 46.25 | ns |

- Power supply : VDD = VDDQ = 1.2V (1.14V to 1.26V); VPP = 2.5V (2.375V to 2.75V)
- JEDEC standard package: x8 78-ball FBGA
- Array Configuration : 16 banks (x8) 4 groups of 4 banks
- 8n-bit prefetch architecture
- Burst Length (BL) : 8 and 4 with Burst Chop (BC)
- Programmable CAS Latency (CL)
- Programmable CAS Write Latency (CWL)
- Internal generated Vref for data inputs
- On-Die Termination (ODT) : support Nominal, Park and Dynamic ODT
- Differential clock and data strobe inputs (CK_t ,CK_c; DQS_t, DQS_c)
- Interface: 1.2V Pseudo Open Drain (POD) IO
- Per DRAM Addressability (PDA)
- Data Bus Inversion (DBI)
- Data Mask (DM) for write data
- Maximum Power Saving Mode (MPSM)
- LP ASR(Low Power Auto Self Refresh) mode is supported
- Asynchronous reset for power up
- Precharge: auto precharge option for each burst access
- Operating case temperature : $-40^{\circ}\text{C} \leq \text{TCase} \leq 95^{\circ}\text{C}$
- Support auto-refresh and self-refresh mode

- Average Refresh Period: 7.8 μ s at $-40^{\circ}\text{C} \leq \text{TCase} \leq 85^{\circ}\text{C}$; 3.9 μ s at $85^{\circ}\text{C} < \text{TCase} \leq 95^{\circ}\text{C}$
- Fine granularity refresh 2x, 4x mode for smaller tRFC
- Programmable data strobe preambles
- Command Address (CA) Parity is supported
- Write Cyclic Redundancy Code (CRC) is supported
- hPPR and sPPR are supported
- Connectivity test mode (TEN) is supported
- Gear Down Mode
- Output driver calibration through ZQ pin (RZQ: 240ohm \pm 1%)
- JEDEC JESD-79-4 compliant
- RoHS compliant

Note:

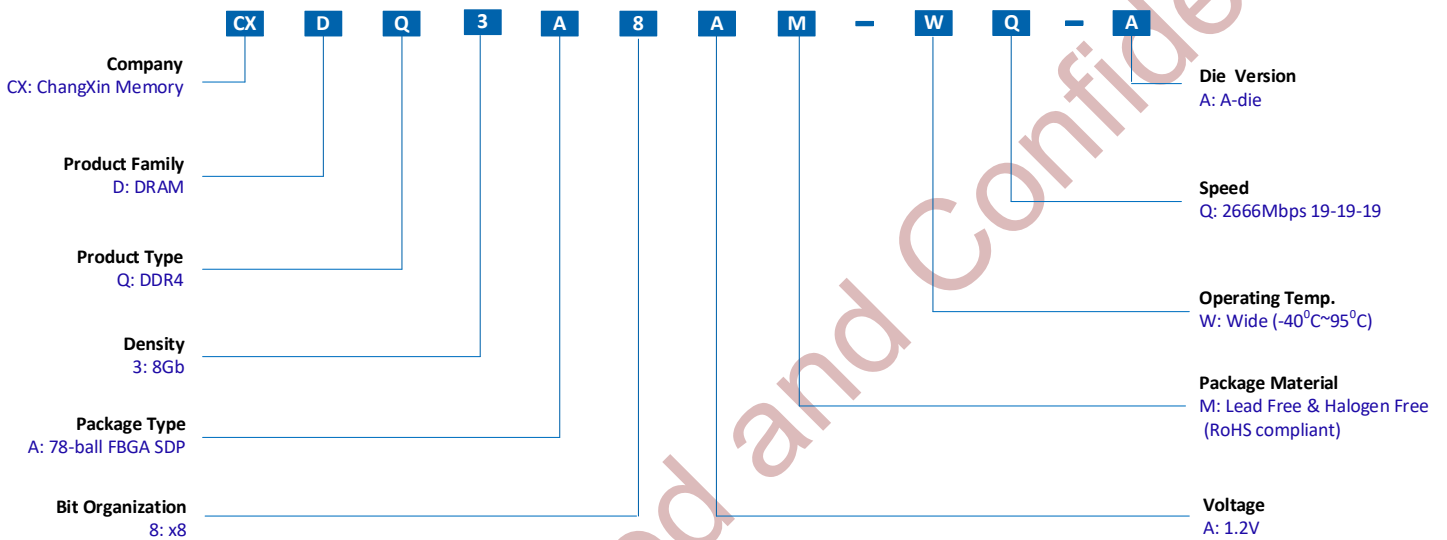
The functionality described and the timing specifications included in this datasheet are for the DLL Enabled mode of operation (normal operation), unless specifically stated otherwise.

1.2 Ordering Options

Table 1-1 Device Ordering Information

| Part Number | Organization | Data Rate |
|----------------|--------------|-----------|
| CXDQ3A8AM-WQ-A | 1G x 8 | 2666 Mbps |

1.3 Part Number Decoding



1.4 Address Table

Table 1-2 8Gb Addressing Table

| Parameter | 1G x 8 |
|--------------------------------|---------|
| Number of Bank Groups | 4 |
| Number of Banks per Bank Group | 4 |
| Bank Group Address | BG0~BG1 |
| Bank Address per Bank Group | BA0~BA1 |
| Row Address | A0~A15 |
| Column Address | A0~A9 |
| Page Size | 1KB |

2. DDR4 SDRAM Package Specifications

This chapter will mainly introduce the package dimension and ballout in x8 configurations which may help to match your device.

- [DDR4 SDRAM Package Dimension on Page 12](#)
- [DDR4 SDRAM x8 Ballout Using MO-207 on Page 16](#)
- [Pinout Description on Page 15](#)

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2.1 DDR4 SDRAM Package Dimensi

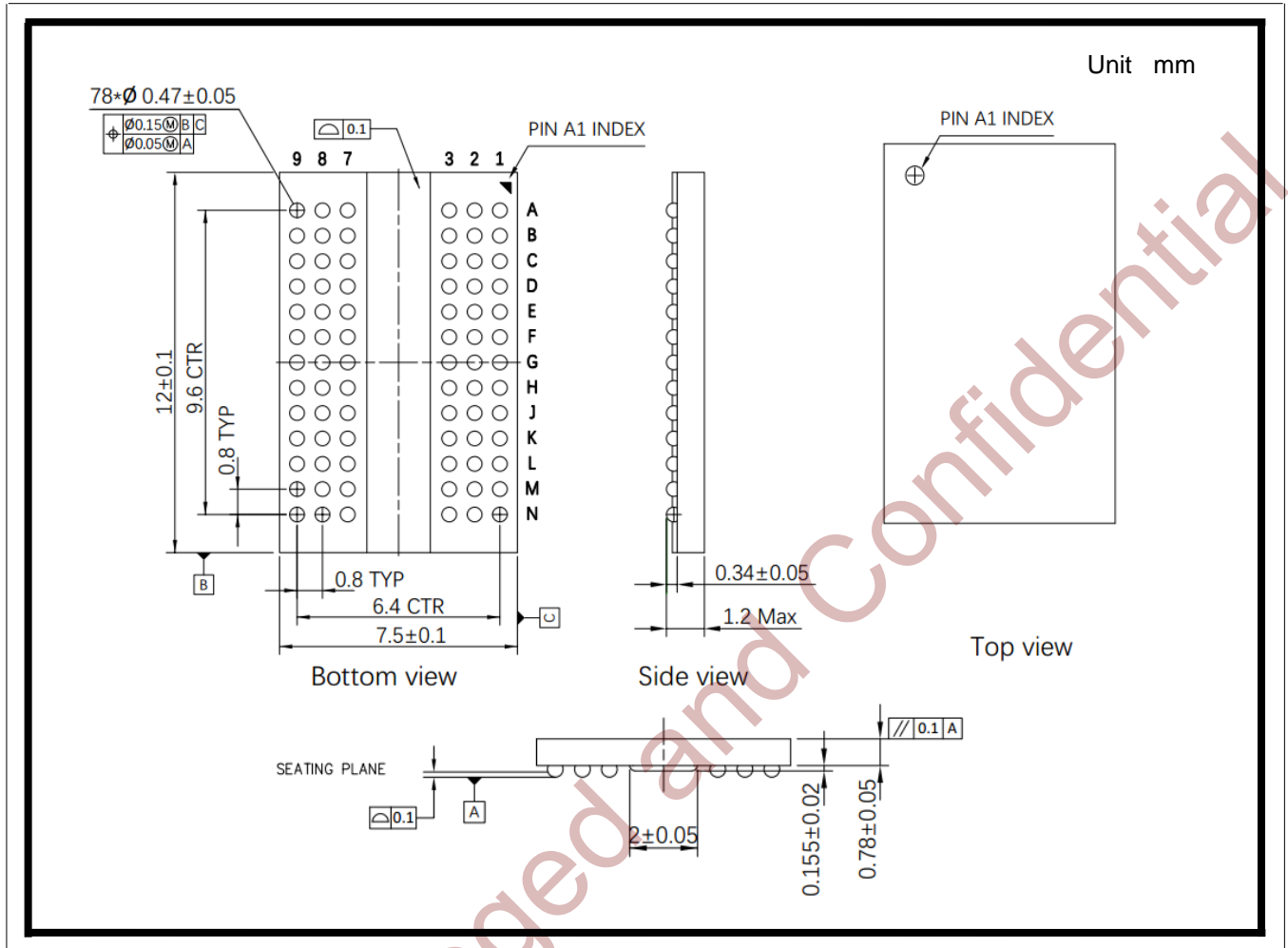


Figure 2-1 78-Ball FBGA – x8 Component

Note:

- 1 These pins are not connected for the x4 configuration.
- 2 TDQS_t is not valid for the x4 configuration.
- 3 TDQS_c is not valid for the x4 configuration.
- 4 A17 is only defined for the x4 configuration.
- 5 These pins are for stacked component such as 3DS. For mono package, these pins are NC.
- 6 ODT1 / CKE1 /CS1_n are used together only for DDP.
- 7 TEN is optional for 8Gb and above. This pin is not connected if TEN is not supported.

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2.2 DDR4 SDRAM x8 Ballout Using MO-207

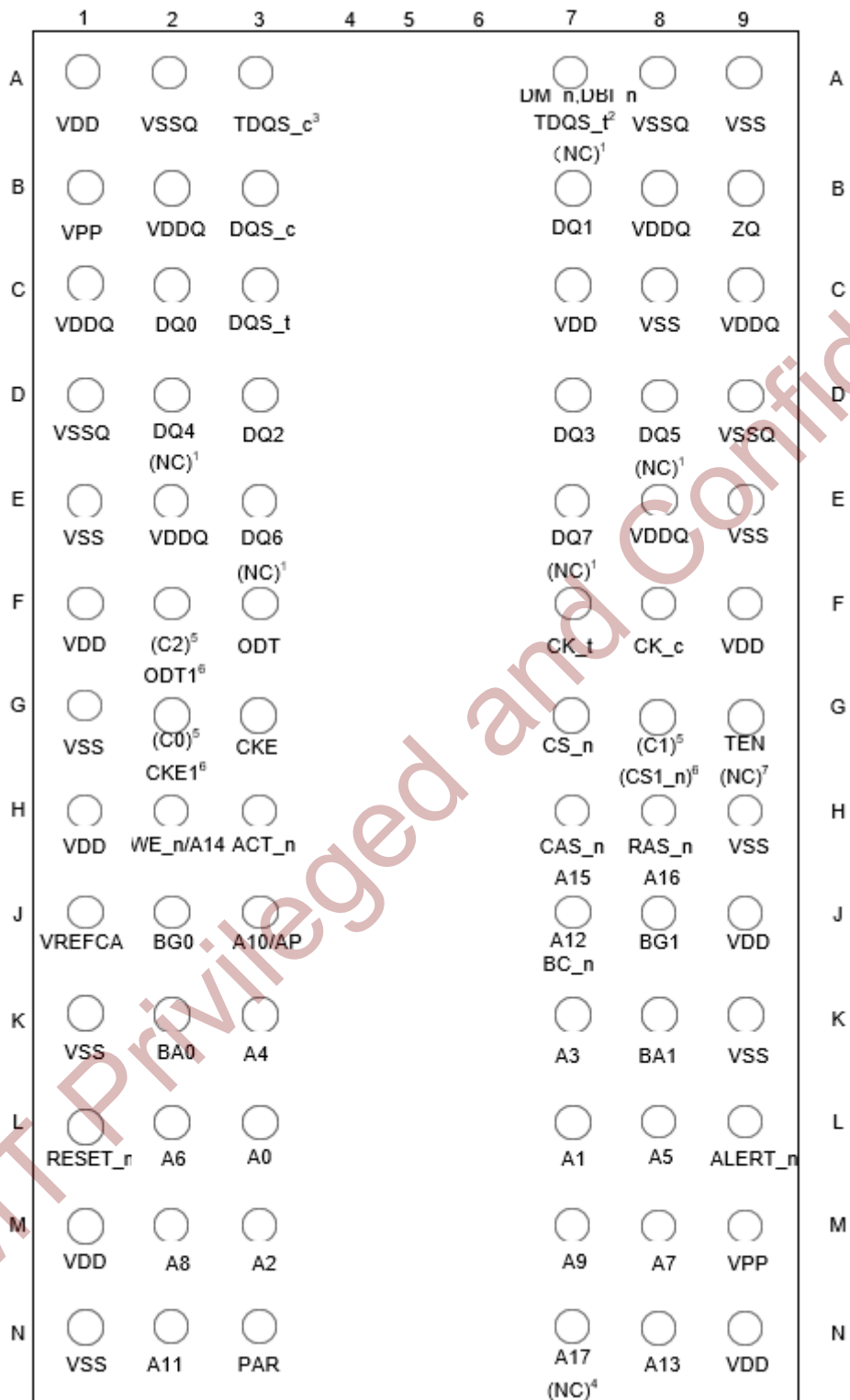


Figure 2-2 DDR4 Ball Assignments for the x8 Component

2.3 Pinout 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 | 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 | 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 |
| ODT | 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 commands 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 identifying 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 |

| Symbol | Type | Function |
|--|---------------|--|
| 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/x8 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 - A16 | 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 corresponding entries in this table. The address inputs also provide the op-code during Mode Register Set commands. |
| 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" of Operation Guide 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 VDD |
| 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 data sheets to determine which DQ is used. |
| 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-aligned with 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. |

| Symbol | Type | Function |
|----------------|--------------|--|
| 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, A12, A10 and 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 DRAMs with MR setting. Once it is 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. Input parity should maintain at the rising edge of the clock and at the same time with command & address with CS_n 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 an 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 |

3. Absolute Maximum Ratings

3.1 Absolute Maximum DC Ratings

| Symbol | Parameter | Min | Max | Unit | 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 | 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 300 mV of each other at all times; and VREFCA must be not greater than 0.6*VDDQ, When VDD and VDDQ are less than 500 mV; VREF may be equal to or less than 300 mV.
- 4 VPP must be equal or greater than VDD/VDDQ at all times.
- 5 Overshoot area above 1.5V is specified in [Section 4.3.5](#) and [Section 4.3.6](#).

3.2 Recommended DC Operating Conditions

Table 3-1 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 | Wordline supply voltage | 2.375 | 2.5 | 2.75 | V | 3 |

Note:

- 1 Under all conditions VDDQ must be less than or equal to VDD.
- 2 VDDQ tracks with VDD. AC parameters are measured with VDD and VDDQ tied together.
- 3 DC bandwidth is limited to 20MHz.

3.3 DRAM Component Operating Temperature Range

Table 3-2 Operating Temperature Range

| Symbol | Parameter | Rating | Unit | Note |
|------------|----------------------------|---------|------|------|
| T_{OPER} | Normal Temperature Range | 0 ~ 85 | °C | 1,2 |
| | Extended Temperature Range | 85 ~ 95 | °C | 1,3 |

Note:

- 1 Operating Temperature T_{OPER} is the case surface temperature on the center / top side of the DRAM. For measurement conditions, please refer to the JEDEC document JESD51-2.
- 2 The Normal Temperature Range specifies the temperatures where all DRAM specifications will be supported. During operation, the DRAM case temperature must be maintained between 0 - 85°C under all operating conditions.
- 3 Some applications require operation of the DRAM in the Extended Temperature Range between 85 °C and 95 °C case temperature. Full specifications are guaranteed in this range, but the following additional conditions apply:
 - Refresh commands must be doubled in frequency, therefore reducing the Refresh interval t_{REFI} to 3.9 μ s. It is also possible to specify a component with 1X refresh (t_{REFI} to 7.8 μ s) in the Extended Temperature Range. Please refer to the DIMM SPD for option availability.
 - If Self-Refresh operation is required in the Extended Temperature Range, then it is mandatory to either use the Manual Self-Refresh mode with Extended Temperature Range capability (MR2 A6 = 0 and MR2 A7 = 1) or enable the optional Auto Self-Refresh mode (MR2 A6 = 1 and MR2 A7 = 1).

4. AC & DC Input Measurement Levels

This chapter mainly defines voltage tolerance limits and AC&DC logic input levels for input signals to ensure the normal operation of DDR4 SDRAM.

- AC and DC Logic Input Levels for Single-ended Signals on [Page 24](#)
- AC and DC Input Measurement Levels: Vref Tolerances on [Page 25](#)
- AC and DC Logic Input Levels for CK Differential Signals on [Page 26](#)
- Slew Rate Definitions for CK Differential Input Signals on [Page 33](#)
- CK Differential Input Cross Point Voltage on [Page 36](#)
- CMOS rail to rail Input Levels on [Page 38](#)
- AC&DC Logic input levels for DQS Signals on [Page 39](#)

4.1 AC and DC Logic Input Levels for Single-ended Signals

Table 4-1 Single-ended AC and DC Input Levels for Command and Address

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|---------------|---------------------------------------|----------------|----------------|------|------|
| | | Min | Max | | |
| VIH.CA(DC75) | DC input logic high | - | - | V | |
| VIL.CA(DC75) | DC input logic low | - | - | V | |
| VIH.CA(DC65) | DC input logic high | VREFCA + 0.065 | VDD | V | |
| VIL.CA(DC65) | DC input logic low | VSS | VREFCA - 0.065 | V | |
| VIH.CA(AC100) | AC input logic high | - | - | V | 1 |
| VIL.CA(AC100) | AC input logic low | - | - | V | 1 |
| VIH.CA(AC90) | AC input logic high | VREF + 0.09 | Note 2 | V | 1 |
| VIL.CA(AC90) | AC input logic low | Note 2 | VREF - 0.09 | V | 1 |
| VREFCA(DC) | Reference voltage for ADD, CMD inputs | 0.49*VDD | 0.51*VDD | V | 2,3 |

Note:

- 1 See "Overshoot and Undershoot Specifications"
- 2 The AC peak noise on VREFCA may not allow VREFCA to deviate from VREFCA(DC) by more than $\pm 1\%$ VDD (for reference : approx. $\pm 12\text{mV}$)
- 3 For reference : approx. $VDD/2 \pm 12\text{ mV}$

4.2 AC and DC Input Measurement Levels: Vref Tolerances

The DC-tolerance limits and AC-noise limits for the reference voltages VrefCA is illustrated in Figure 4-1 below. It shows a valid reference voltage Vref(t) as a function of time. (Vref stands for VrefCA).

Vref(DC) is the linear average of Vref(t) over a very long period of time (for example, 1 second). This average has to meet the min/max requirement in Table 4-1. Furthermore Vref(t) may temporarily deviate from Vref(DC) by no more than $\pm 1\%$ VDD.

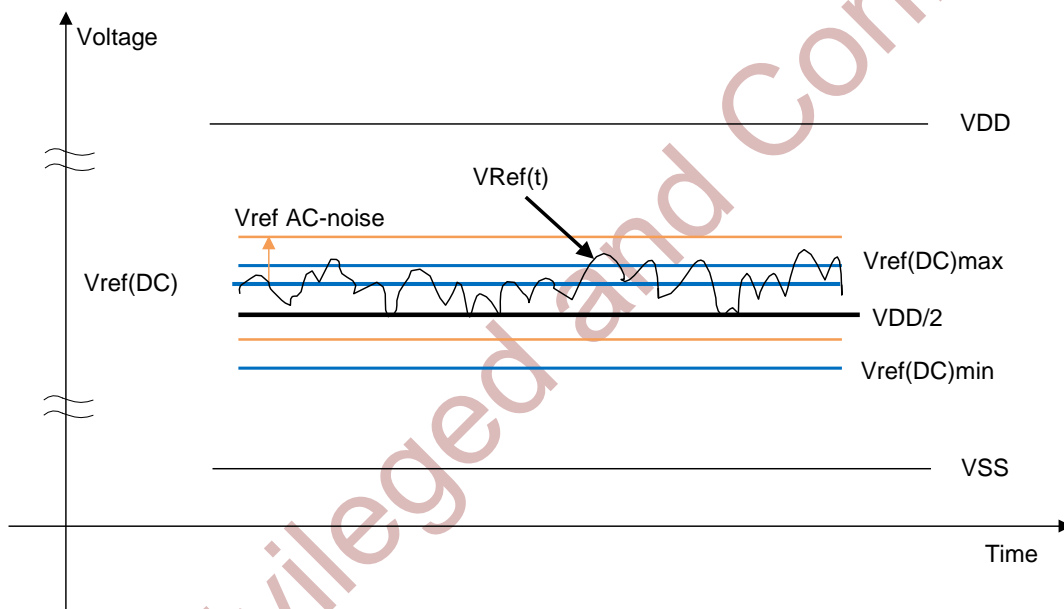


Figure 4-1 Illustration of Vref(DC) Tolerance and Vref AC-noise Limits

The voltage levels for setup and hold time measurements VIH(AC), VIH(DC), VIL(AC) and VIL(DC) are dependent on Vref.

“Vref” should be understood as Vref(DC).

This clarifies that DC-variations of Vref 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 Vref(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 Vref AC-noise. Timing and voltage effects due to AC-noise on Vref up to the specified limit ($\pm 1\%$ of VDD) are included in DRAM timings and their associated deratings.

4.3 AC and DC Logic Input Levels for Differential Signals

4.3.1 Differential Signal Definition

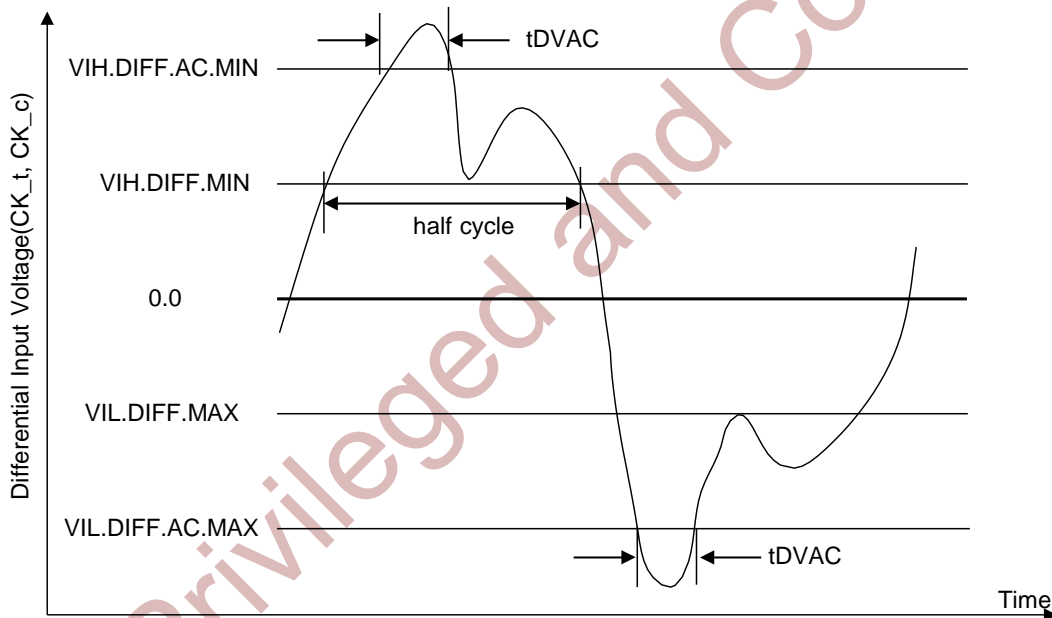


Figure 4-2 Definition of Differential AC-Swing and “Time above AC-Level” tDVAC

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.

4.3.2 Differential Swing Requirements for Clock (CK_t - CK_c)

Table 4-2 Differential Input Levels Requirements for CK_t - CK_c

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|-------------|----------------------------|----------------------|----------------------|------|------|
| | | Min | Max | | |
| VIHdiff | differential input high | + 0.135 | Note 3 | V | 1 |
| VILdiff | differential input low | Note 3 | - 0.135 | V | 1 |
| VIHdiff(AC) | differential input high ac | 2 x (VIH(AC) - VREF) | Note 3 | V | 2 |
| VILdiff(AC) | differential input low ac | Note 3 | 2 x (VIL(AC) - VREF) | V | 2 |

Note:

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

Table 4-3 Allowed Time before Ringback (tDVAC) for CK_t - CK_c

| Slew Rate [V/ns] | tDVAC [ps] @ VIH/Ldiff(AC) = 200mV | | tDVAC [ps] @ VIH/Ldiff(AC) = TBDmV | |
|------------------|--------------------------------------|-----|--------------------------------------|-----|
| | Min | Max | Min | Max |
| > 4.0 | 120 | - | TBD | - |
| 4.0 | 115 | - | TBD | - |
| 3.0 | 110 | - | TBD | - |
| 2.0 | 105 | - | TBD | - |
| 1.8 | 100 | - | TBD | - |
| 1.6 | 95 | - | TBD | - |
| 1.4 | 90 | - | TBD | - |
| 1.2 | 85 | - | TBD | - |
| 1.0 | 80 | - | TBD | - |
| <1.0 | 80 | - | TBD | - |

4.3.3 Single-ended Requirements for CK 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.

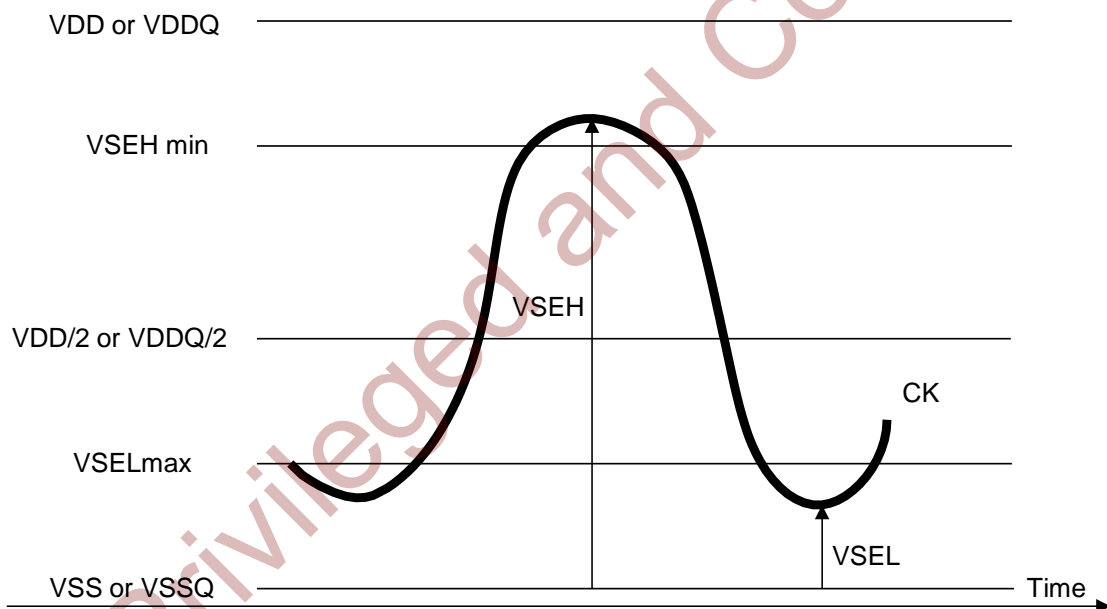


Figure 4-3 Single-ended Requirement for CK

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 4-4 Single-ended Levels Requirements for CK_t, CK_c

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|--------|---|-----------------|-----------------|------|------|
| | | Min | Max | | |
| VSEH | Single-ended high-level for CK_t / CK_c | $VDD/2 + 0.095$ | Note 3 | V | 1,2 |
| VSEL | Single-ended low-level for CK_t / CK_c | Note 3 | $VDD/2 - 0.095$ | V | 1,2 |

Note:

- 1 For CK_t-CK_c use VIH.CA/VIL.CA(AC) of ADD/CMD.
- 2 VIH(AC)/VIL(AC) for ADD/CMD is based on VREFCA.
- 3 These values are not defined, however the single-ended signals CK_t, CK_c need to be within the respective limits (VIH.CA(DC) max, VIL.CA(DC)min) for single-ended signals as well as the limitations for overshoot and undershoot.

4.3.4 Address, Command, and Control Overshoot and Undershoot Specifications

Table 4-5 AC Overshoot/Undershoot Specification for Address, Command, and Control Pins

| Parameter | Symbol | DDR4-2666 | Unit | Note |
|--|------------|--------------|------|------|
| Maximum peak amplitude above V_{AOS} | V_{AOSP} | 0.06 | V | |
| Upper boundary of overshoot area A_{AOS1} | V_{AOS} | $VDD + 0.24$ | V | 1 |
| Maximum peak amplitude allowed for undershoot | V_{AUS} | 0.3 | V | |
| Maximum overshoot area per 1tCK Above V_{AOS} | A_{AOS2} | 0.0055 | V-ns | |
| Maximum overshoot area per 1tCK Between VDD and V_{AOS} | A_{AOS1} | 0.1699 | V-ns | |
| Maximum undershoot area per 1tCK Below VSS | A_{AUS} | 0.1762 | 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:

The value of V_{AOS} matches VDD absolute max as defined in “Absolute Maximum DC Ratings” if VDD equals VDD max as defined in Table 3-1. If VDD is above the recommended operating conditions, V_{AOS} remains at VDD absolute max as defined in “Absolute Maximum DC Ratings” .

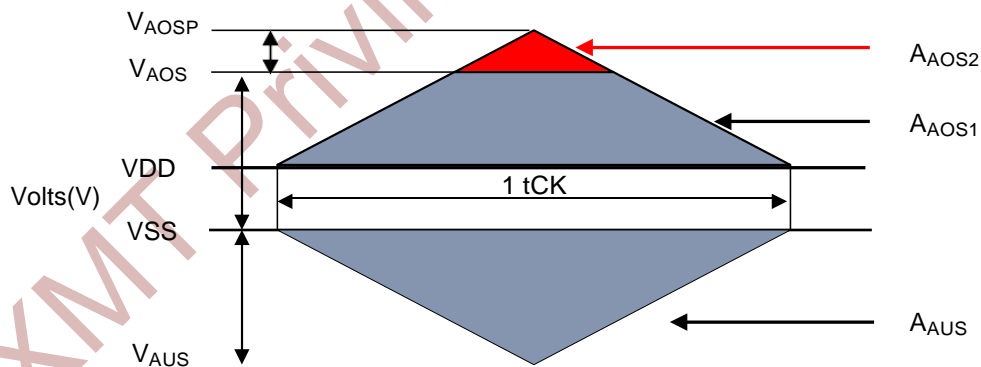


Figure 4-4 Address, Command, and Control Overshoot and Undershoot Definition

4.3.5 Clock Overshoot and Undershoot Specifications

Table 4-6 AC Overshoot/Undershoot Specification for Clock

| Parameter | Symbol | DDR4-2666 | Unit | Note |
|---|------------|--------------|------|------|
| Maximum peak amplitude above V_{COS} | V_{COSP} | 0.06 | V | |
| Upper boundary of overshoot area A_{COS1} | V_{COS} | $VDD + 0.24$ | V | 1 |
| Maximum peak amplitude allowed for undershoot | V_{CUS} | 0.3 | V | |
| Maximum overshoot area per UI Above V_{COS} | A_{COS2} | 0.0025 | V-ns | |
| Maximum overshoot area per 1tCK Between VDD and V_{COS} | A_{COS1} | 0.075 | V-ns | |
| Maximum undershoot area per UI Below VSS | A_{CUS} | 0.0762 | V-ns | |

(CK_t, CK_c)

Note:

The value of VAOS matches VDD absolute max as defined in “Absolute Maximum DC Ratings” if VDD equals VDD max as defined in Table 3-1. If VDD is above the recommended operating conditions, VAOS remains at VDD absolute max as defined in “Absolute Maximum DC Ratings” .

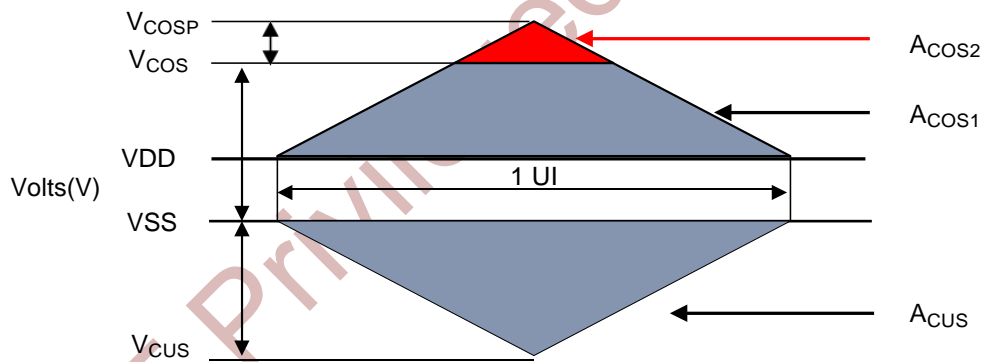


Figure 4-5 Clock Overshoot and Undershoot Definition

4.3.6 Data, Strobe and Mask Overshoot and Undershoot Specifications

Table 4-7 AC Overshoot/Undershoot Specification for Data, Strobe and Mask

| Parameter | Symbol | DDR4-2666 | Unit | Note |
|--|------------|--------------|------|------|
| Maximum peak amplitude above V_{DOS} | V_{DOSP} | 0.16 | V | |
| Upper boundary of overshoot area A_{DOS1} | V_{DOS} | $VDD + 0.24$ | V | 1 |
| Lower boundary of undershoot area A_{DUS1} | V_{DUS} | 0.3 | V | 2 |
| Maximum peak amplitude below V_{DUS} | A_{DUSP} | 0.1 | V-ns | |
| Maximum overshoot area per UI Above V_{DOS} | A_{DOS2} | 0.0100 | V-ns | |
| Maximum overshoot area per 1UI Between $VDDQ$ and V_{DOS} | A_{DOS1} | 0.0700 | V-ns | |
| Maximum undershoot area per UI Between $VSSQ$ and A_{DUS1} | A_{DUS1} | 0.0700 | V-ns | |
| Maximum undershoot area per 1 UI below V_{DUS} | A_{DUS2} | 0.0100 | V-ns | |

(DQ, DQS_t, DQS_c, DM_n, DBI_n, TDQS_t, TDQS_c)

Note:

- 1 The value of V_{DOS} matches (VIN, VOUT) max as defined in "Absolute Maximum DC Ratings" if $VDDQ$ equals $VDDQ$ max as defined Table 3-1. If $VDDQ$ is above the recommended operating conditions, V_{DOS} remains at (VIN, VOUT) max as defined in "Absolute Maximum DC Ratings"
- 2 The value of V_{DUS} matches (VIN, VOUT) min as defined in "Absolute Maximum DC Ratings" .

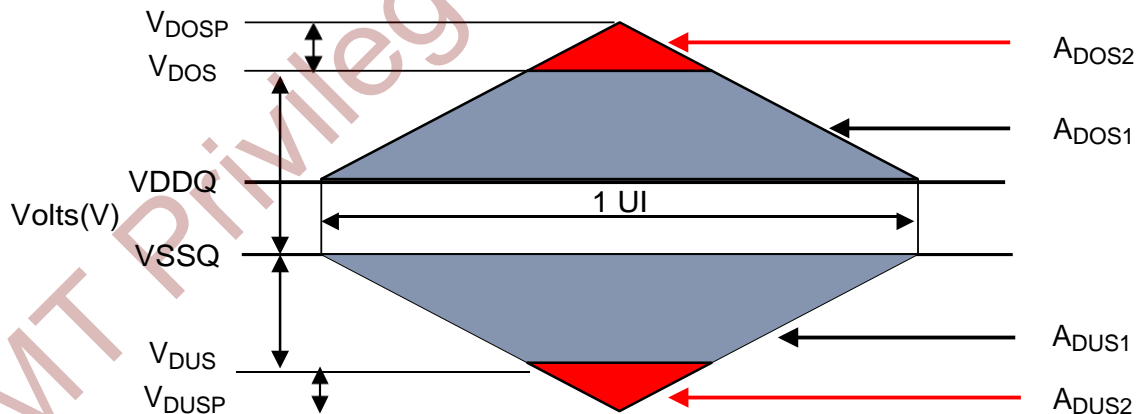


Figure 4-6 Data, Strobe and Mask Overshoot and Undershoot Definition

4.4 Slew Rate Definitions for Differential Input Signals

4.4.1 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 4-8 and Figure 4-7.

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Table 4-8 CK Differential Input Slew Rate Definition

| Description | From | To | Defined by |
|--|------------|------------|---|
| Differential input slew rate for rising edge(CK_t-CK_c) | VILdiffmax | VIHdiffmin | $[VIHdiffmin - VILdiffmax] / \Delta TRdiff$ |
| Differential input slew rate for falling edge(CK_t-CK_c) | VIHdiffmin | VILdiffmax | $[VIHdiffmin - VILdiffmax] / \Delta TFdiff$ |

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

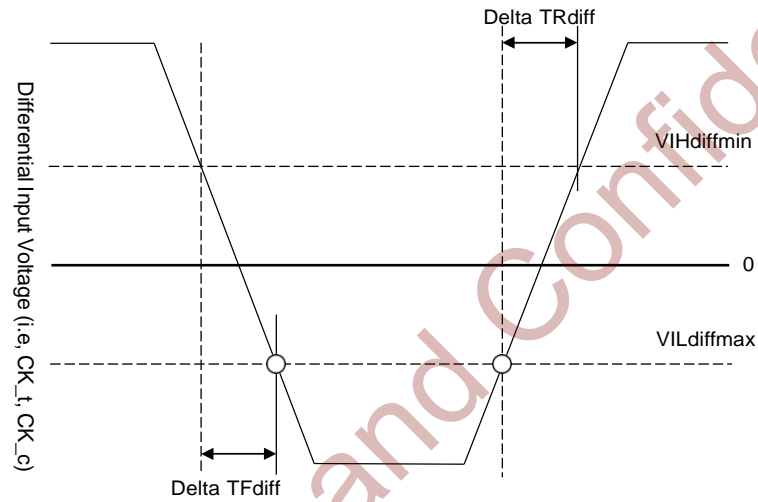


Figure 4-7 Differential Input Slew Rate Definition for CK_t, CK_c

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

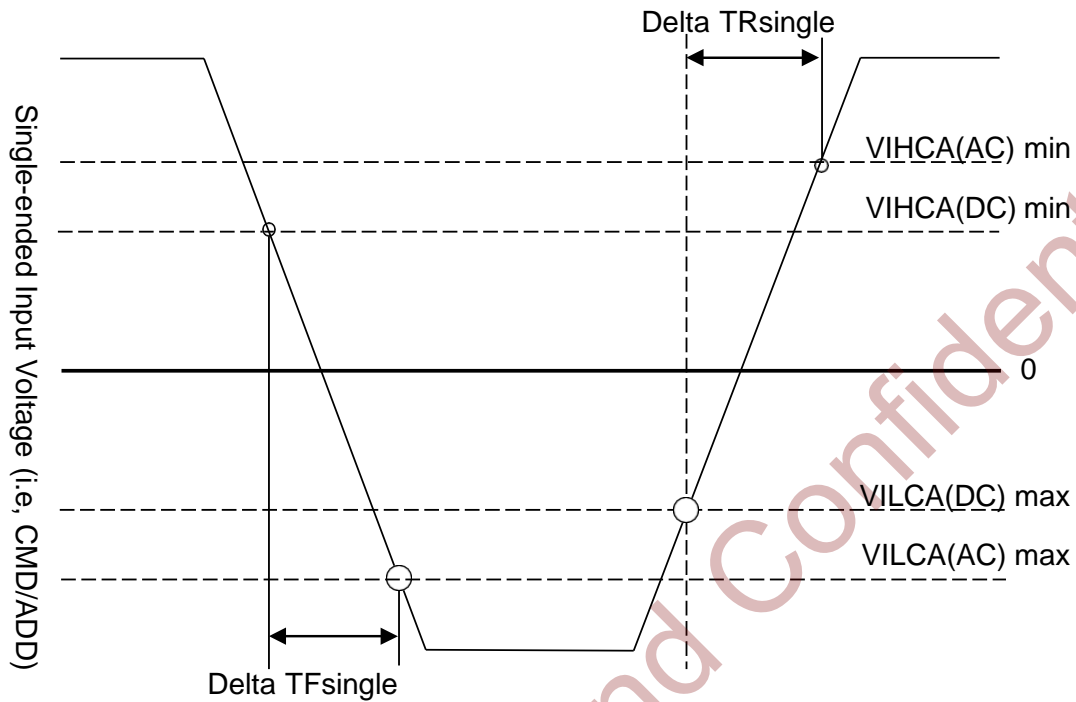


Figure 4-8 Single-ended Input Slew Rate Definition for CMD and ADD

Note:

- 1 Single-ended input slew rate for rising edge = { $V_{IHCA(AC)Min} - V_{ILCA(DC)Max}$ } / $\Delta T_{R\ single}$.
- 2 Single-ended input slew rate for falling edge = { $V_{IHCA(DC)Min} - V_{ILCA(AC)Max}$ } / $\Delta T_{F\ single}$.
- 3 Single-ended signal rising edge from $V_{ILCA(DC)Max}$ to $V_{IHCA(DC)Min}$ must be monotonic slope.
- 4 Single-ended signal falling edge from $V_{IHCA(DC)Min}$ to $V_{ILCA(DC)Max}$ must be monotonic slope.

4.5 CK 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 . The differential input cross point voltage V_{ix} is measured from the actual cross point of true and complement signals to the midlevel between of VDD and VSS.

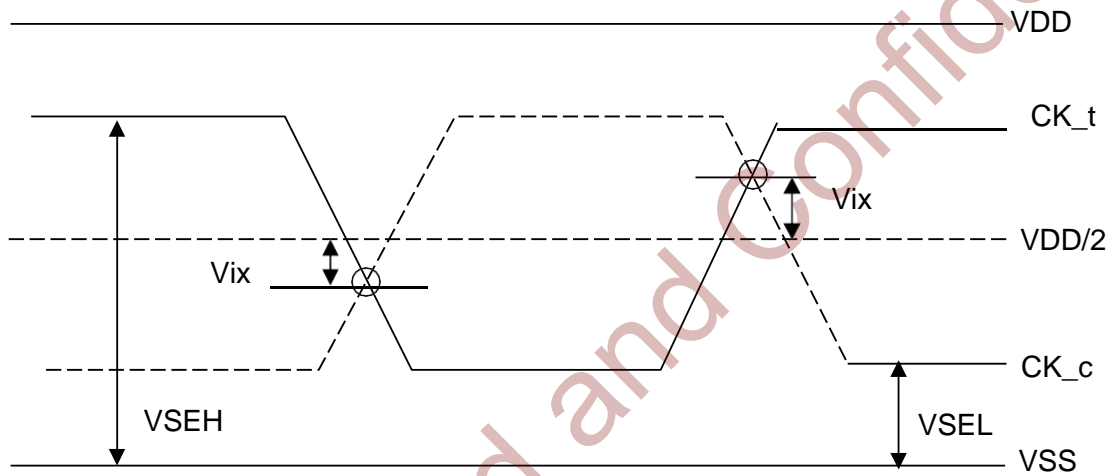


Figure 4-9 V_{ix} Definition (CK)

Table 4-9 Cross Point Voltage for CK Differential Input Signals

| Symbol | Parameter | DDR4 -2666 | | | |
|---------|---|-------------------------------|--|--|-------------------------------|
| | | Min | | Max | |
| | | VSEL | VSEH | VSEL | VSEH |
| - | Area of VSEH, VSEL | $VSEL < VDD/2 - 145\text{mV}$ | $VDD/2 - 145\text{mV} \leq VSEL \leq VDD/2 - 100\text{mV}$ | $VDD/2 + 100\text{mV} \leq VSEH \leq VDD/2 + 145\text{mV}$ | $VDD/2 + 145\text{mV} < VSEH$ |
| VIX(CK) | Differential Input Cross Point Voltage relative to VDD/2 for CK_t, CK_c | -110mV | $-(VDD/2 - VSEL) + 30\text{mV}$ | $(VSEH - VDD/2) - 30\text{mV}$ | 110 mV |

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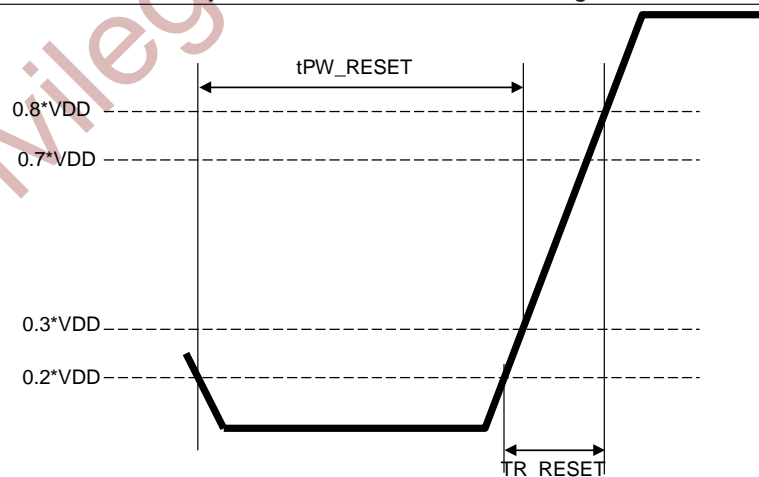
4.6 CMOS Rail to Rail Input Levels for RESET_n

 Table 4-10 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 4-10 RESET_n Input Slew Rate Definition

4.7 AC & DC Logic Input Levels for DQS Signals

4.7.1 Differential Signal Definition

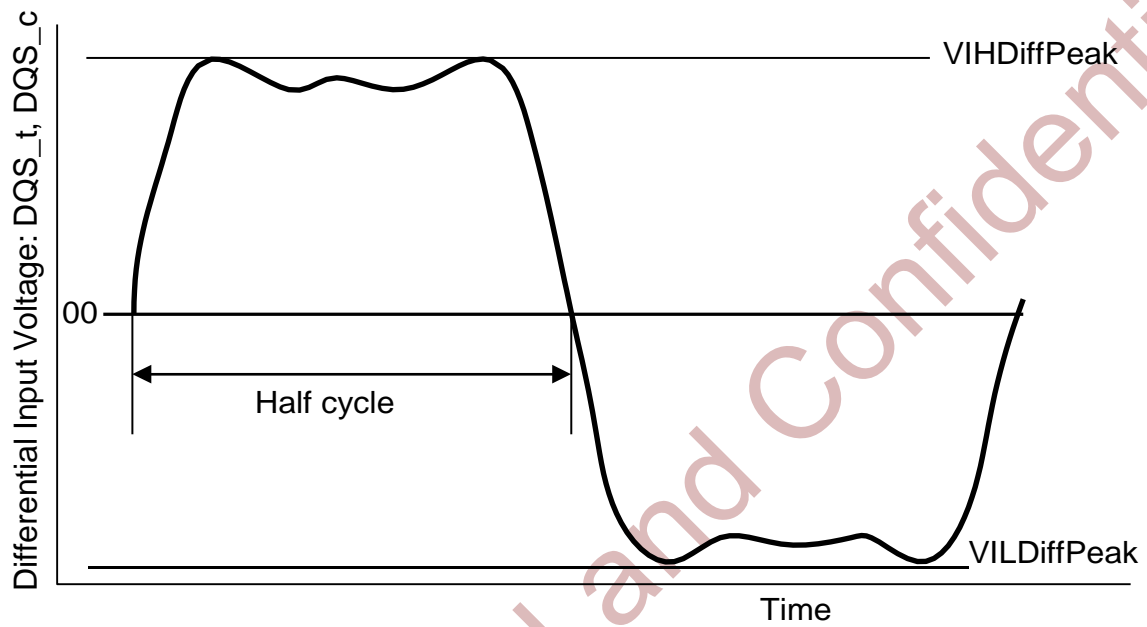


Figure 4-11 DQS Differential Input Signal AC-swing Level

4.7.2 Differential Swing Requirements for DQS (DQS_t - DQS_c)

Table 4-11 Differential Input Swing Requirements for DQS

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|-------------|-----------------------|-----------|--------|------|------|
| | | Min | Max | | |
| VIHDiffPeak | VIH.DIFF.Peak Voltage | 150 | Note 2 | mV | 1 |
| VILDiffPeak | VIL.DIFF.Peak Voltage | Note 2 | -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 of Overshoot, Undershoot Specification for single-ended signals.”

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4.7.3 Peak Voltage Calculation Method

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

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

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

$$f(t) = VDQS_t - VDQS_c$$

The $\text{Max}(f(t))$ or $\text{Min}(f(t))$ 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.

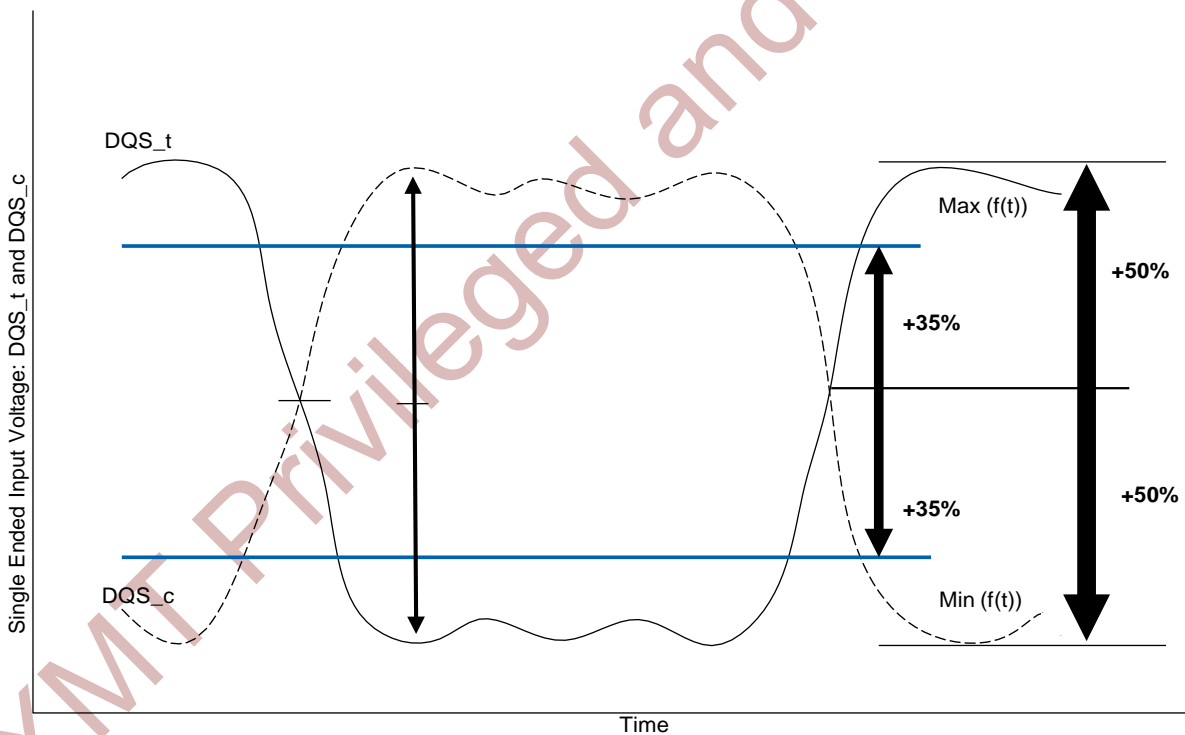


Figure 4-12 Definition of Differential DQS Peak Voltage and Range of Exempt Nonmonotonic Signaling

4.7.4 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 4-12](#). 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 nonmonotonic 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 4-12](#). 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 4-13](#)) and a ring-back's horizontal tangent derived from its positive slope to zero slope transition (point B in [Figure 4-13](#)) 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 4-13](#)) and a ring-back's horizontal tangent derived from its negative slope to zero slope transition (point D in [Figure 4-13](#)) is not a valid horizontal tangent.

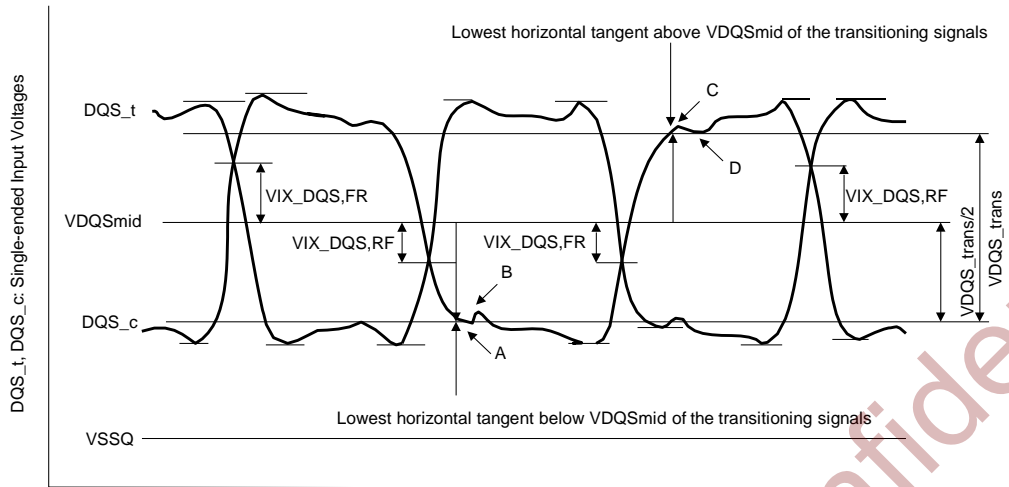


Figure 4-13 Vix Definition (DQS)

Table 4-12 Cross Point Voltage for DQS Differential Input Signals

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|------------------|---|-----------|-----------------|------|-------|
| | | Min | Max | | |
| Vix_DQS_ratio | DQS Differential input crosspoint voltage ratio | - | 25 | % | 1,2 |
| VDQSmid_to_Vcent | VDQSmid offset relative to Vcent_DQ(midpoint) | - | min(VIHdiff,50) | mV | 3,4,5 |

Note:

- Vix_DQS_Ratio is DQS Vix crossing (Vix_DQS_FR or Vix_DQS_RF) divided by VDDQSmid. VDDQSmid 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.
- VDQSmid will be similar to the VREFDQ internal setting value obtained during Vref Training if the DQS and DQs drivers and paths are matched.
- The maximum limit shall not exceed the smaller of VIHdiff minimum limit or 50mV.
- 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.
- The parameter VDQSmid is defined for simulation and ATE testing purposes, it is not expected to be tested in a system.

4.7.5 Differential Input Slew Rate Definition

Input slew rate for differential signals (DQS_t, DQS_c) are defined and measured as shown in Figure 4-14 and Table 4-13.

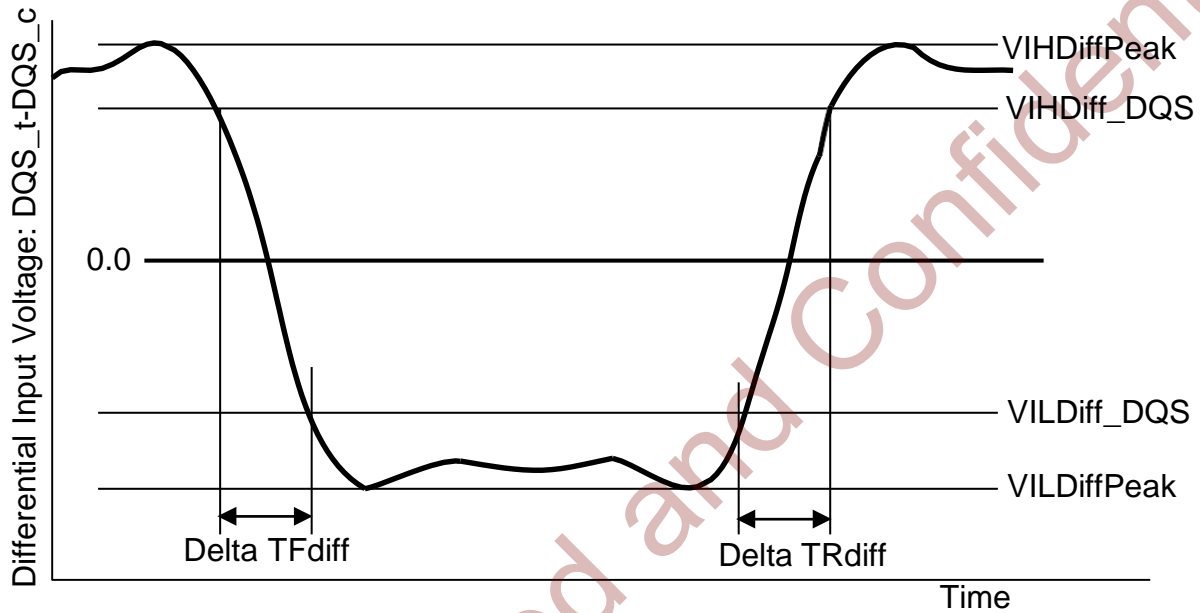


Figure 4-14 Differential Input Slew Rate Definition for DQS_t, DQS_c

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 4-13 Differential Input Slew Rate Definition for DQS_t, DQS_c

| Description | From | To | Defined by |
|---|-------------|-------------|---|
| Differential input slew rate for rising edge(DQS _t - DQS _c) | VILdiff_DQS | VIHdiff_DQS | $ VILDiff_DQS - VIHDiff_DQS / \Delta TRdiff$ |
| Differential input slew rate for falling edge(DQS _t - DQS _c) | VIHdiff_DQS | VILdiff_DQS | $ VILDiff_DQS - VIHDiff_DQS / \Delta TRdiff$ |

Table 4-14 Differential Input Level for DQS_t, DQS_c

| Symbol | Parameter | DDR4-2666 | | Unit |
|-------------|---------------------|-----------|------|------|
| | | Min | Max | |
| VIHdiff_DQS | DC input logic high | 130 | - | mV |
| VILdiff_DQS | DC input logic low | - | -130 | mV |

Table 4-15 Differential Input Slew Rate for DQS_t, DQS_c

| Symbol | Parameter | DDR4-2666 | | Unit |
|---------|------------------------------|-----------|-----|------|
| | | Min | Max | |
| SRIdiff | Differential Input Slew Rate | 2.5 | 18 | V/ns |

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5. AC & DC Output Measurement Levels

This chapter introduces the AC&DC output levels and slew rate for both single-ended and differential signals.

- Output Driver DC Electrical Characteristics on [Page 47](#)
- Single-ended AC & DC Output Levels on [Page 52](#)
- Differential AC & DC Output Levels on [Page 52](#)
- Single-ended Output Slew Rate on [Page 53](#)
- Differential Output Slew Rate on [Page 54](#)
- Single-ended AC and DC Output Levels of Connectivity Test Mode on [Page 57](#)
- Test Load for Connectivity Test Mode Timing on [Page 58](#)

5.1 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 Figure 5-1 below. Output driver impedance RON is defined as the individual pull-up and pull-down resistors (RONPu and RONPd).

$$R_{ONPu} = \frac{V_{DDQ} - V_{out}}{|I_{out}|} \text{ under the condition that } R_{ONPd} \text{ is off}$$

$$R_{ONPd} = \frac{V_{out}}{|I_{out}|} \text{ under the condition that } R_{ONPu} \text{ is off}$$

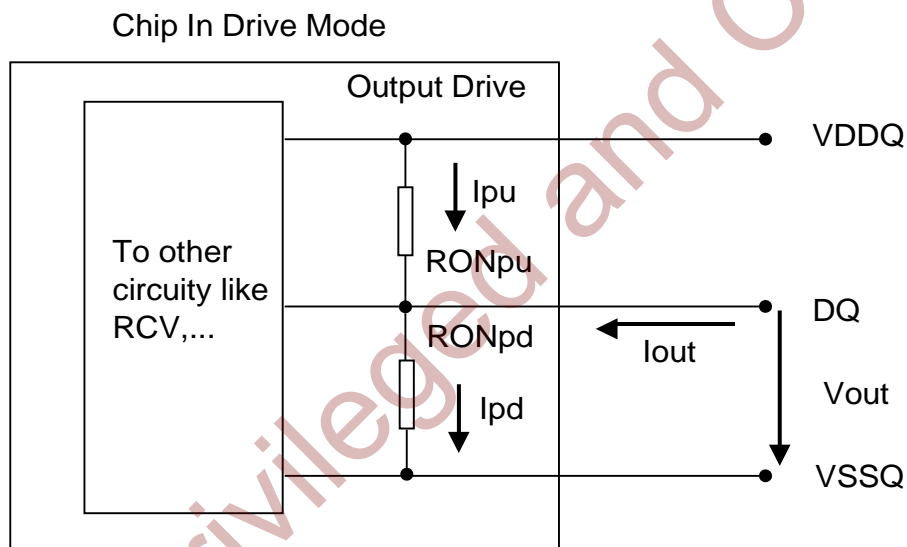


Figure 5-1 Output Driver

Table 5-1 Output Driver DC Electrical Characteristics, Assuming RZQ = 240ohm; Entire Operating Temperature Range; after Proper ZQ Calibration

| RONNOM | Resistor | Vout | Min | Nom | Max | Unit | Note |
|--|----------|---------------------|------|-----|------|-------|---------|
| 34Ω | RON34Pd | $VOL_{dc}=0.5*VDDQ$ | 0.73 | 1.0 | 1.1 | RZQ/7 | 1,2 |
| | | $VOM_{dc}=0.8*VDDQ$ | 0.83 | 1.0 | 1.1 | RZQ/7 | 1,2 |
| | | $VOH_{dc}=1.1*VDDQ$ | 0.83 | 1.0 | 1.25 | RZQ/7 | 1,2 |
| | RON34Pu | $VOL_{dc}=0.5*VDDQ$ | 0.9 | 1.0 | 1.1 | RZQ/7 | 1,2 |
| | | $VOM_{dc}=0.8*VDDQ$ | 0.9 | 1.0 | 1.1 | RZQ/7 | 1,2 |
| | | $VOH_{dc}=1.1*VDDQ$ | 0.8 | 1.0 | 1.25 | RZQ/7 | 1,2 |
| 48Ω | RON48Pd | $VOL_{dc}=0.5*VDDQ$ | 0.73 | 1.0 | 1.1 | RZQ/5 | 1,2 |
| | | $VOM_{dc}=0.8*VDDQ$ | 0.83 | 1.0 | 1.1 | RZQ/5 | 1,2 |
| | | $VOH_{dc}=1.1*VDDQ$ | 0.83 | 1.0 | 1.25 | RZQ/5 | 1,2 |
| | RON48Pu | $VOL_{dc}=0.5*VDDQ$ | 0.9 | 1.0 | 1.25 | RZQ/5 | 1,2 |
| | | $VOM_{dc}=0.8*VDDQ$ | 0.9 | 1.0 | 1.1 | RZQ/5 | 1,2 |
| | | $VOH_{dc}=1.1*VDDQ$ | 0.8 | 1.0 | 1.1 | RZQ/5 | 1,2 |
| Mismatch between pull-up and pull-down, MMPuPd | | $VOM_{dc}=0.8*VDDQ$ | -10 | | 17 | % | 1,2,3,4 |
| Mismatch DQ-DQ within byte variation pull-up, MMPudd | | $VOM_{dc}=0.8*VDDQ$ | | | 10 | % | 1,2,4 |
| Mismatch DQ-DQ within byte variation pull-up, MMPddd | | $VOM_{dc}=0.8*VDDQ$ | | | 10 | % | 1,2,4 |

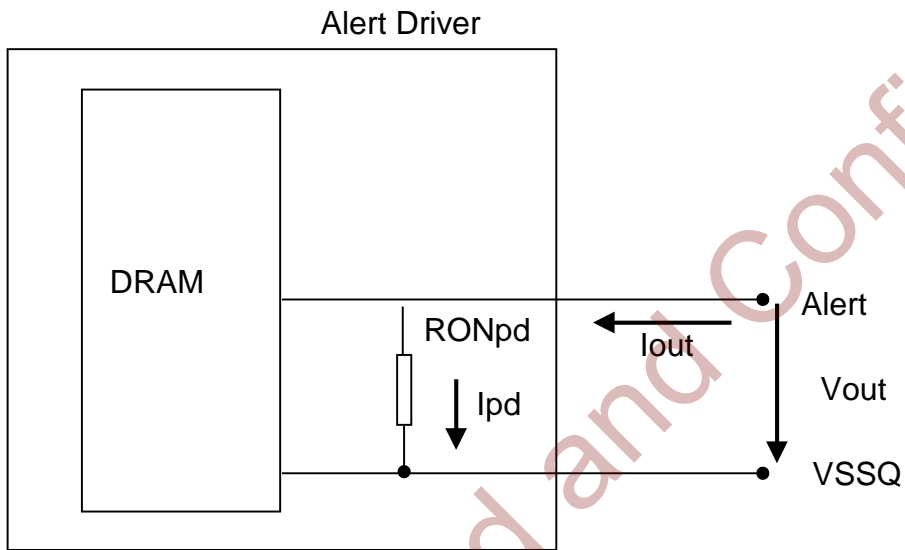
Note:

- 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.
- 4 $MMPuPdd = [(RONPu - RONPd / RONNOM)] * 100$
- 5 RON variance range ratio to RON Nominal value in a given component, including DQS_t and DQS_c.
- 6 $MMPudd = [(RONPuMax - RONPuMin / RONNOM)] * 100$
- 7 $MMPddd = [(RONPdMax - RONPdMin / RONNOM)] * 100$
- 8 This parameter of x16 device is specified for Upper byte and Lower byte.

5.1.1 Alert_n Output Drive Characteristic

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

$$R_{ONpd} = \frac{V_{out}}{|I_{out}|} \text{ under the condition that } R_{ONpu} \text{ is off}$$



| Resistor | Vout | Min | Max | Unit | Note |
|------------|------------------------|-----|-----|------|------|
| R_{ONpd} | $V_{OLdc}=0.1*V_{DDQ}$ | 0.3 | 1.2 | 34Ω | 1 |
| | $V_{OMdc}=0.8*V_{DDQ}$ | 0.3 | 1.2 | 34Ω | 1 |
| | $V_{OHdc}=1.1*V_{DDQ}$ | 0.4 | 1.4 | 34Ω | 1 |

Note:

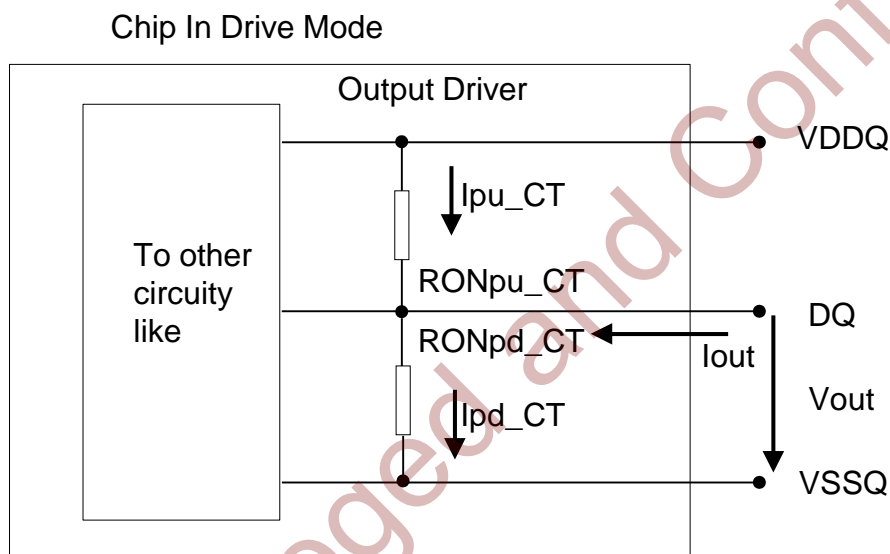
VDDQ voltage is at VDDQ DC. VDDQ DC definition is TBD.

5.1.2 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:

$$RON\ Pu_CT = (VDDQ - VOUT) / |I_{out}|$$

$$RON\ Pd_CT = VOUT / |I_{out}|$$



| RON_{NOM_CT} | Resistor | Vout | Max | Units |
|-----------------|----------|-------------------------|-----|-------|
| 34Ω | RONPd_CT | $VOB_{dc} = 0.2 * VDDQ$ | 1.9 | 34Ω |
| | | $VOL_{dc} = 0.5 * VDDQ$ | 2.0 | 34Ω |
| | | $VOM_{dc} = 0.8 * VDDQ$ | 2.2 | 34Ω |
| | | $VOH_{dc} = 1.1 * VDDQ$ | 2.5 | 34Ω |
| | RONPu_CT | $VOB_{dc} = 0.2 * VDDQ$ | 2.5 | 34Ω |
| | | $VOL_{dc} = 0.5 * VDDQ$ | 2.2 | 34Ω |
| | | $VOM_{dc} = 0.8 * VDDQ$ | 2.0 | 34Ω |
| | | $VOH_{dc} = 1.1 * VDDQ$ | 1.9 | 34Ω |

Note:

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

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5.2 Single-ended AC&DC Output Levels

Table 5-2 Single-ended AC & DC Output Levels

| Symbol | Parameter | DDR4-2666 | Unit |
|---------|---|---------------------|------|
| VOH(DC) | DC output high measurement level (for IV curve linearity) | 1.1 x VDDQ | V |
| VOM(DC) | DC output mid measurement level (for IV curve linearity) | 0.8 x VDDQ | V |
| VOL(DC) | DC output low measurement level (for IV curve linearity) | 0.5 x VDDQ | V |
| VOH(AC) | AC output high measurement level (for output SR) | (0.7 + 0.15) x VDDQ | V |
| VOL(AC) | AC output low measurement level (for output SR) | (0.7 - 0.15) x VDDQ | V |

Note:

The swing of $\pm 0.15 \times VDDQ$ is based on approximately 50% of the static single-ended output peak-to-peak swing with a driver impedance of $RZQ/7\Omega$ and an effective test load of 50Ω to $VTT=VDDQ$.

5.3 Differential AC & DC Output Levels

Table 5-3 Differential AC & DC Output Levels

| Symbol | Parameter | DDR4-2666 | Unit |
|-------------|---|--------------|------|
| VOHdiff(AC) | AC differential output high measurement level (for output SR) | + 0.3 x VDDQ | V |
| VOLdiff(AC) | AC differential output low measurement level (for output SR) | - 0.3 x VDDQ | V |

Note:

The swing of $\pm 0.3 \times VDDQ$ is based on approximately 50% of the static differential output peak-to-peak swing with a driver impedance of $RZQ/7\Omega$ and an effective test load of 50Ω to $VTT = VDDQ$ at each of the differential outputs.

5.4 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 VOL(AC) and VOH(AC) for single ended signals as shown in Table 5-4 and Figure 5-2.

Table 5-4 Single-ended Output Slew Rate Definition

| Description | Measured | | Defined by |
|--|----------|---------|---------------------------------|
| | From | To | |
| Single ended output slew rate for rising edge | VOL(AC) | VOH(AC) | $[VOH(AC)-VOL(AC)]/\Delta TRse$ |
| Single ended output slew rate for falling edge | VOH(AC) | VOL(AC) | $[VOH(AC)-VOL(AC)]/\Delta TFse$ |

Note:

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

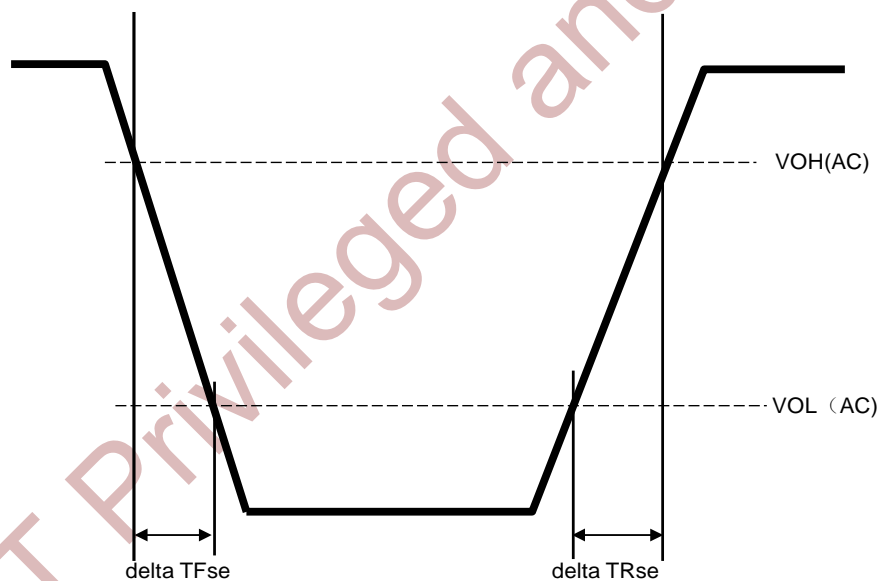


Figure 5-2 Single-ended Output Slew Rate Definition

Table 5-5 Single-ended Output Slew Rate

| Parameter | Symbol | DDR4-2666 | | Unit |
|-------------------------------|--------|-----------|-----|------|
| | | Min | Max | |
| Single ended output slew rate | SRQse | 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:

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).

5.5 Differential Output Slew Rate

With the reference load for timing measurements, output slew rate for falling and rising edges is defined and measured between $V_{OLdiff}(AC)$ and $V_{OHdiff}(AC)$ for differential signals as shown in Table 5-6 and Figure 5-3.

Table 5-6 Differential Output Slew Rate Definition

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

Note:

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

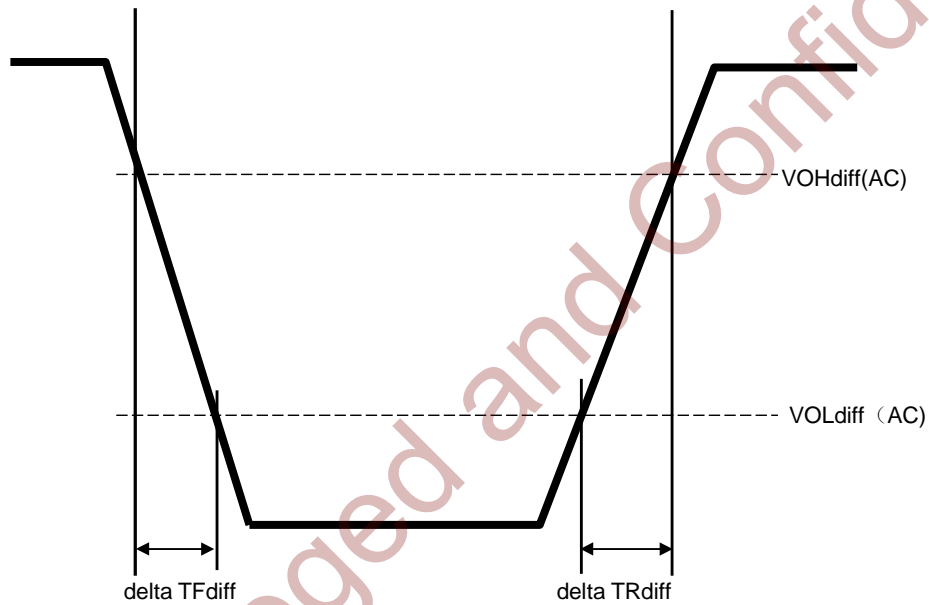


Figure 5-3 Differential Output Slew Rate Definition

Table 5-7 Differential Output Slew Rate

| Parameter | Symbol | DDR4-2666 | | Unit |
|-------------------------------|---------|-----------|-----|------|
| | | Min | Max | |
| Differential output slew rate | SRQdiff | 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;

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5.6 Single-ended AC and DC Output Levels of Connectivity Test Mode

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

Table 5-8 Single-ended AC & DC Output Levels of Connectivity Test Mode

| Symbol | Parameter | DDR4-2666 | Unit | Note |
|--------------|--|---------------------------|------|------|
| $V_{OH(DC)}$ | DC output high measurement level (for IV curve linearity) | $1.1 \times VDDQ$ | V | |
| $V_{OM(DC)}$ | DC output mid measurement level (for IV curve linearity) | $0.8 \times VDDQ$ | V | |
| $V_{OL(DC)}$ | DC output low measurement level (for IV curve linearity) | $0.5 \times VDDQ$ | V | |
| $V_{OB(DC)}$ | DC output below measurement level (for IV curve linearity) | $0.2 \times VDDQ$ | V | |
| $V_{OH(AC)}$ | AC output high measurement level (for output SR) | $VTT + (0.1 \times VDDQ)$ | V | 1 |
| $V_{OL(AC)}$ | AC output below measurement level (for output SR) | $VTT - (0.1 \times VDDQ)$ | V | 1 |

Note:

The effective test load is 50Ω terminated by $VTT = 0.5 \times VDDQ$.

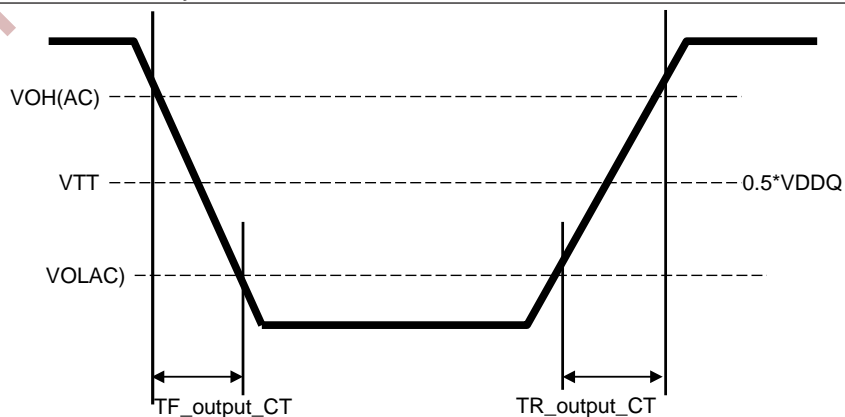


Figure 5-4 Output Slew Rate Definition of Connectivity Test Mode

Table 5-9 Single-ended Output Slew Rate of Connectivity Test Mode

| Parameter | Symbol | DDR4-2666 | | Unit |
|----------------------------|--------------|-----------|-----|------|
| | | Min | Max | |
| Output signal Falling time | TF_output_CT | - | 10 | ns/V |
| Output signal Rising time | TR_output_CT | - | 10 | ns/V |

5.7 Test Load for Connectivity Test Mode Timing

The reference load for ODT timings is defined in Figure 5-5.

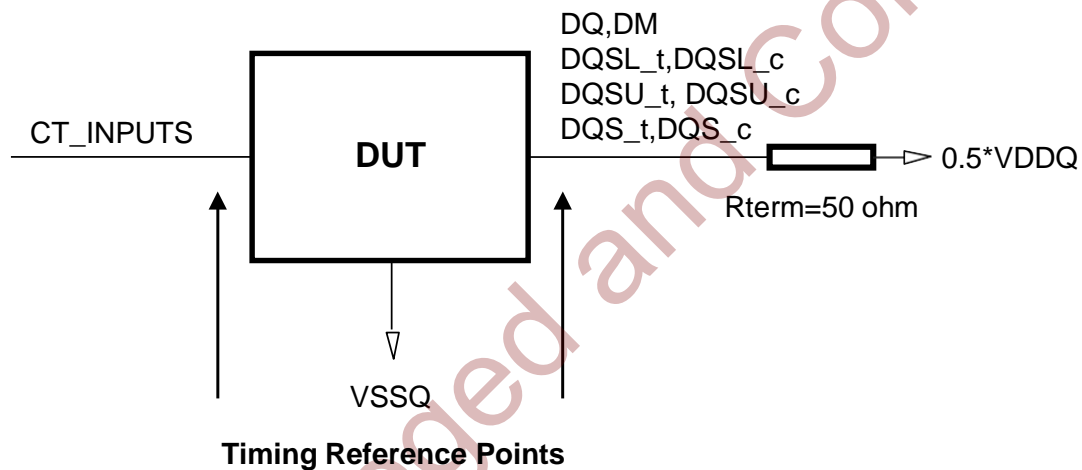


Figure 5-5 Connectivity Test Mode Timing Reference Load

6. Speed Bin

6.1 DDR4-2666 Speed Bins and Operations

Table 6-1 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 (13.75) ^{5,11} | 18 | 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 (13.75) ^{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 | 1,2,3,4,9,10 |
| | CL = 10 | CL = 12 | tCK(AVG) | 1.5 1.6 | ns | 1,2,3,9,10 |
| CWL = 9,11 | CL = 10 | CL = 12 | tCK(AVG) | Reserved | ns | 4 |
| | CL = 11 | CL = 13 | tCK(AVG) | 1.25 <1.5 (Optional) ^{5,11} | ns | 1,2,3,4,9 |
| | 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 (Optional) ^{5,11} | ns | 1,2,3,4,9 |
| | 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 (Optional) ^{5,11} | ns | 1,2,3,4,9 |
| | CL = 16 | CL = 19 | tCK(AVG) | Reserved | 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 (Optional) ^{5,11} | ns | 1,2,3,4,9 |
| | CL = 18 | CL = 21 | tCK(AVG) | 0.833 <0.937 | ns | 1,2,3,9 |
| 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 |

| Speed Bin | | DDR4-2666 | | Unit | Note |
|-------------------------------------|--------|--|-----|------|------|
| CL-nRCD-nRP | | 19-19-19 | | | |
| Parameter | Symbol | Min | Max | | |
| Supported CL Settings with Read DBI | | 12,(13),14,(15),17,(18),19, (20),21,22,23 | | nCK | 12 |
| Supported CWL Settings | | 9,10,11,12,14,16,18 | | nCK | |

Speed Bin Table Note

Absolute Specifications

- VDDQ = VDD = 1.20V ± 0.06 V
 - VPP = 2.5V (2.375V min, 2.75V max)
 - The values defined with above-mentioned table are DLL ON case.
 - DDR4-1600, 1866, 2133 and 2400 Speed Bin Tables are valid only when Gear Down 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 [JEDEC-79C 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 1.071 ns or 0.937 ns or 0.833 ns). 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 corresponding 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 corresponding 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 corresponding 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 corresponding 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.

6.2 tREFI and tRFC Parameters

Table 6-2 tREFI and tRFC Parameters

| Refresh Mode | Parameter | | 8Gb | Unit |
|--------------|-----------|-----------------------|---------------|------|
| | | tREFI(base) | 7.8 | us |
| 1x mode | tREFI1 | 0 °C ≤ TCASE ≤ 85 °C | tREFI(base) | us |
| | | 85 °C < TCASE ≤ 95 °C | tREFI(base)/2 | us |
| | | tRFC1(min) | 350 | ns |
| 2x mode | tREFI2 | 0 °C ≤ TCASE ≤ 85 °C | tREFI(base)/2 | us |
| | | 85 °C < TCASE ≤ 95 °C | tREFI(base)/4 | us |
| | | tRFC2(min) | 260 | ns |
| 4x mode | tREFI4 | 0 °C ≤ TCASE ≤ 85 °C | tREFI(base)/4 | us |
| | | 85 °C < TCASE ≤ 95 °C | tREFI(base)/8 | us |
| | | tRFC4(min) | 160 | ns |

7. IDD and IDDQ Specification Parameters and Test Conditions

In this chapter, IDD, IPP and IDDQ measurement conditions such as test load and patterns are defined.

- [IDD, IPP and IDDQ Measurement Conditions on Page 63](#)
- [IDD Specifications on Page 92](#)

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7.1 IDD, IPP and IDDQ Measurement Conditions

Figure 7-1 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 7-2. 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 $V_{IN} \leq V_{ILAC}(\max)$.
- “1” and “High” is defined as $V_{IN} \geq V_{IHAC}(\min)$.
- “MID-LEVEL” is defined as inputs are $V_{REF} = V_{DD} / 2$.
- Basic IDD, IPP and IDDQ Measurement Conditions are described in Table 7-2.
- Detailed IDD, IPP and IDDQ Measurement-Loop Patterns are described Table 7-3.
- IDD Measurements are done after properly initializing the DDR4 SDRAM. This includes but is not limited to setting

$R_{ON} = R_{ZQ}/7$ (34 Ohm in MR1);

$R_{TT_NOM} = R_{ZQ}/6$ (40 Ohm in MR1);

RTT_WR = RZQ/2 (120 Ohm in MR2);

RTT_PARK = Disable;

Qoff = 0 (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}
- 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.

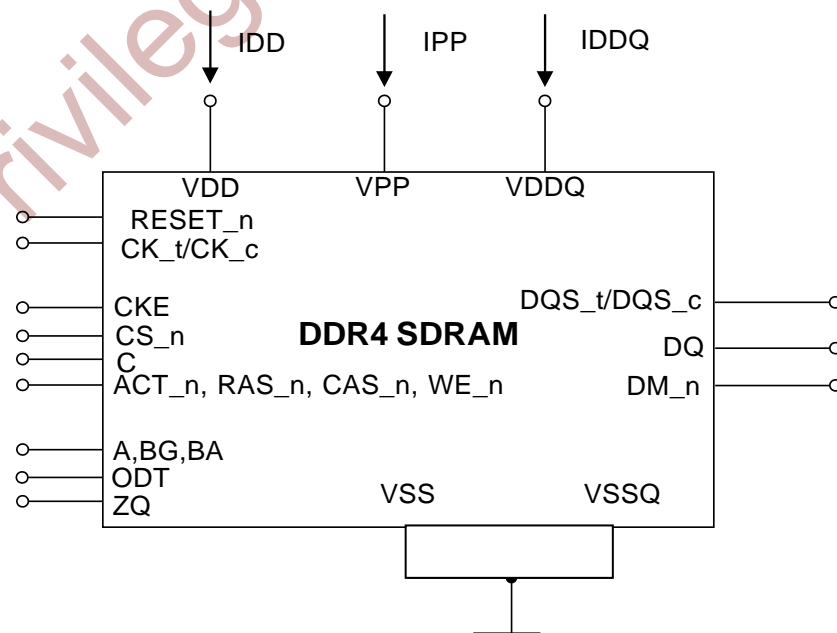


Figure 7-1 Measurement Setup and Test Load for IDD, IPP and IDDQ Measurements

Note:

DIMM level Output test load condition may be different from above

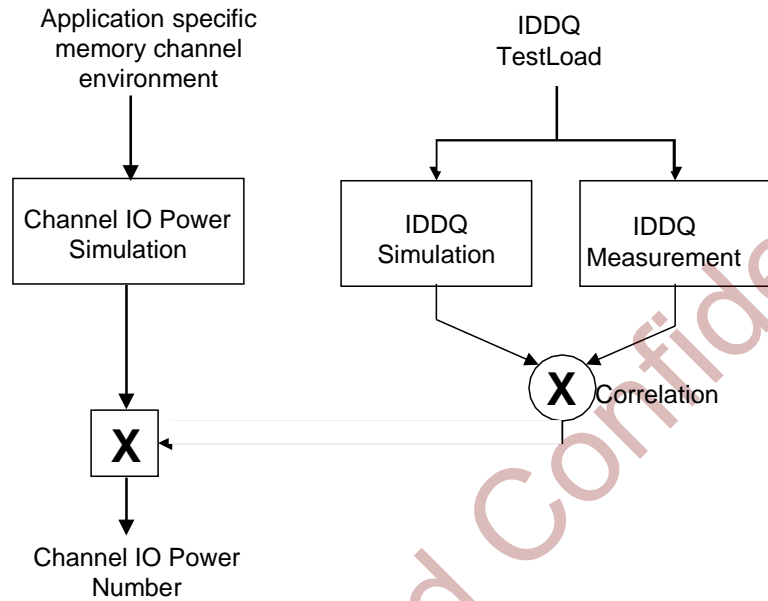


Figure 7-2 Correlation from Simulated Channel IO Power to Actual Channel IO Power Supported by IDDQ Measurement.

Table 7-1 Timings used for IDD, IPP and IDDQ Measurement-Loop Patterns

| Symbol | DDR4-1600 | | | DDR4-1866 | | | DDR4-2133 | | | DDR4-2400 | | | | Unit | |
|--------|-----------|----------|----------|-----------|----------|----------|-----------|----------|----------|-----------|----------|----------|----------|------|-----|
| | 10-10-10 | 11-11-11 | 12-12-12 | 12-12-12 | 13-13-13 | 14-14-14 | 14-14-14 | 15-15-15 | 16-16-16 | 15-15-15 | 16-16-16 | 17-17-17 | 18-18-18 | | |
| tCK | 1.25 | | | 1.071 | | | 0.937 | | | 0.833 | | | | ns | |
| CL | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 | 16 | 15 | 16 | 17 | 18 | nCK | |
| CWL | 9 | 11 | 11 | 10 | 12 | 12 | 11 | 14 | 14 | 12 | 16 | 16 | 16 | nCK | |
| nRCD | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 | 16 | 15 | 16 | 17 | 18 | nCK | |
| nRC | 38 | 39 | 40 | 44 | 45 | 46 | 50 | 51 | 52 | 54 | 55 | 56 | 57 | nCK | |
| nRAS | 28 | | | 32 | | | 36 | | | 39 | | | | nCK | |
| nRP | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 | 16 | 15 | 16 | 17 | 18 | nCK | |
| nFAW | x4 | 16 | | | 16 | | | 16 | | | 16 | | | | nCK |
| | x8 | 20 | | | 22 | | | 23 | | | 26 | | | | nCK |
| | x16 | 28 | | | 28 | | | 32 | | | 36 | | | | nCK |
| nRRDS | x4 | 4 | | | 4 | | | 4 | | | 4 | | | | nCK |
| | x8 | 4 | | | 4 | | | 4 | | | 4 | | | | nCK |
| | x16 | 5 | | | 6 | | | 6 | | | 7 | | | | nCK |
| nRRDL | x4 | 5 | | | 5 | | | 6 | | | 6 | | | | nCK |
| | x8 | 5 | | | 5 | | | 6 | | | 6 | | | | nCK |
| | x16 | 6 | | | 6 | | | 7 | | | 8 | | | | nCK |
| tCCD_S | 4 | | | 4 | | | 4 | | | 4 | | | | nCK | |
| tCCD_L | 5 | | | 5 | | | 6 | | | 6 | | | | nCK | |
| tWTR_S | 2 | | | 3 | | | 3 | | | 3 | | | | nCK | |
| tWTR_L | 6 | | | 7 | | | 8 | | | 9 | | | | nCK | |

| Symbol | DDR4-1600 | | | DDR4-1866 | | | DDR4-2133 | | | DDR4-2400 | | | | Unit |
|-----------|-----------|----------|----------|-----------|----------|----------|-----------|----------|----------|-----------|----------|----------|----------|------|
| | 10-10-10 | 11-11-11 | 12-12-12 | 12-12-12 | 13-13-13 | 14-14-14 | 14-14-14 | 15-15-15 | 16-16-16 | 15-15-15 | 16-16-16 | 17-17-17 | 18-18-18 | |
| nRFC 2Gb | 128 | | | 150 | | | 171 | | | 193 | | | | nCK |
| nRFC 4Gb | 208 | | | 243 | | | 278 | | | 313 | | | | nCK |
| nRFC 8Gb | 280 | | | 327 | | | 374 | | | 421 | | | | nCK |
| nRFC 16Gb | 440 | | | 514 | | | 587 | | | 661 | | | | nCK |

| Symbol | DDR4-2666 | | | | DDR4-2933 | | | | DDR4-3200 | | | Unit |
|-----------|-----------|----------|----------|----------|-----------|----------|----------|----------|-----------|----------|----------|------|
| | 17-17-17 | 18-18-18 | 19-19-19 | 20-20-20 | 19-19-19 | 20-20-20 | 21-21-21 | 22-22-22 | 20-20-20 | 22-22-22 | 24-24-24 | |
| tCK | 0.75 | | | | 0.682 | | | | 0.625 | | | ns |
| CL | 17 | 18 | 19 | 20 | 19 | 20 | 21 | 22 | 20 | 22 | 24 | nCK |
| CWL | 16 | 16 | 18 | 18 | 18 | 18 | 20 | 20 | 18 | 20 | 20 | nCK |
| nRCD | 17 | 18 | 19 | 20 | 19 | 20 | 21 | 22 | 20 | 22 | 24 | nCK |
| nRC | 60 | 61 | 62 | 63 | 66 | 67 | 68 | 69 | 72 | 74 | 76 | nCK |
| nRAS | 43 | | | | 47 | | | | 52 | | | nCK |
| nRP | 17 | 18 | 19 | 20 | 19 | 20 | 21 | 22 | 20 | 22 | 24 | nCK |
| nFAW | x4 | 16 | | | 16 | | | | 16 | | | nCK |
| | x8 | 28 | | | 31 | | | | 34 | | | nCK |
| | x16 | 40 | | | 44 | | | | 48 | | | nCK |
| nRRDS | x4 | 4 | | | 4 | | | | 4 | | | nCK |
| | x8 | 4 | | | 4 | | | | 4 | | | nCK |
| | x16 | 8 | | | 8 | | | | 9 | | | nCK |
| nRRDL | x4 | 7 | | | 8 | | | | 8 | | | nCK |
| | x8 | 7 | | | 8 | | | | 8 | | | nCK |
| | x16 | 9 | | | 10 | | | | 11 | | | nCK |
| tCCD_S | 4 | | | 4 | | | | 4 | | | nCK | |
| tCCD_L | 7 | | | 8 | | | | 8 | | | nCK | |
| tWTR_S | 4 | | | 4 | | | | 4 | | | nCK | |
| tWTR_L | 10 | | | 11 | | | | 12 | | | nCK | |
| nRFC 2Gb | 214 | | | 235 | | | | 256 | | | nCK | |
| nRFC 4Gb | 347 | | | 382 | | | | 416 | | | nCK | |
| nRFC 8Gb | 467 | | | 514 | | | | 560 | | | nCK | |
| nRFC 16Gb | 734 | | | 807 | | | | 880 | | | nCK | |

Table 7-2 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, nRCD, CL 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 7-3; 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 7-3); Output Buffer and RTT: Enabled in Mode Registers ² ; ODT Signal: stable at 0; Pattern Details: see Table 7-3. |
| 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 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 7-4 DM_n: stable at 1; Bank Activity: Cycling with one bank active at a time: 0,0,1,1,2,2,... (see Table 7-4) ; Output Buffer and RTT: Enabled in Mode Registers ² ; ODT Signal: stable at 0; Pattern Details: see Table 7-4 |
| 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 |

| Symbol | Description |
|-----------------------|---|
| IDD2N | Precharge Standby Current (AL=0) CKE: High; External clock: On; tCK, CL BL: 8 ¹ ; AL: 0; CS_n: stable at 1; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-5 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 7-5 |
| 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 BL: 8 ¹ ; AL: 0; CS_n: stable at 1; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-6 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 7-6 Pattern Details: Table 7-6 |
| 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 |

| Symbol | Description |
|-----------|---|
| 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 BL: 8¹; 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 Registers²; 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 BL: 8¹; 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 Registers²; ODT Signal: stable at 0 |
| IDD3N | Active Standby Current CKE: High; External clock: On; tCK, CL BL: 8¹ AL: 0; CS_n: stable at 1; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-5 Data IO: VDDQ; DM_n: stable at 1; Bank Activity: all banks open; Output Buffer and RTT: Enabled in Mode Registers²; ODT Signal: stable at 0; Pattern Details: see Table 7-5 |
| IDD3NA | Active Standby Current (AL=CL-1) AL = CL-1, Other conditions: see IDD3N |

| Symbol | Description |
|-----------------------|--|
| IPP3N | Active Standby IPP Current Same condition with IDD3N |
| IDD3P | Active Power-Down Current CKE: Low; External clock: On; tCK, CL 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 BL: 8 ² ; AL: 0; CS_n: High between RD; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-7 Data IO: seamless Read data burst with different data between one burst and the next one according to Table 7-7 DM_n: stable at 1; Bank Activity: all banks open, RD commands cycling through banks: 0,0,1,1,2,2,... (see Table 7-7) Output Buffer and RTT: Enabled in Mode Registers ² ; ODT Signal: stable at 0; Pattern Details: see Table 7-7 |
| 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 |

| Symbol | Description |
|-----------|---|
| IDD4W | Operating Burst Write Current CKE: High; External clock: On; tCK, CL BL: 8 ¹ ; AL: 0; CS_n: High between WR; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-8; Data IO: seamless Write data burst with different data between one burst and the next one according to Table 7-8 DM_n: stable at 1; Bank Activity: all banks open, WR commands cycling through banks: 0,0,1,1,2,2,... (Table 7-8); Output Buffer and RTT: Enabled in Mode Registers ² ; ODT Signal: stable at High; Pattern Details: see Table 7-8 |
| 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 BL: 8 ¹ ; AL: 0; CS_n: High between REF; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-10 Data IO: VDDQ; DM_n: stable at 1; Bank Activity: REF command every nRFC (see Table 7-10); Output Buffer and RTT: Enabled in Mode Registers ² ; ODT Signal: stable at 0; Pattern Details: see Table 7-10 |
| IPP5B | Burst Refresh Write IPP Current (1X REF) Same condition with IDD5B |

| Symbol | Description |
|--------|---|
| 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 |
| IDD6N | Self Refresh Current: Normal Temperature Range TCASE: 0 - 85°C; Low Power Array Self Refresh (LP ASR) : Normal ⁴ ; CKE: Low; External clock: Off; CK_t and CK_c#: Low; CL 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) TCASE: 0 - 95°C; Low Power Array Self Refresh (LP ASR) : Extended ⁴ ; CKE: Low; External clock: Off; CK_t and CK_c: Low; CL 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 |
| IPP6E | Self Refresh IPP Current: Extended Temperature Range Same condition with IDD6E |

| Symbol | Description |
|--------|--|
| IDD6R | Self-Refresh Current: Reduced Temperature Range T_{CASE}: 0 - TBD (~35-45)°C; Low Power Array Self Refresh (LP ASR) : Reduced⁴; CKE: Low; External clock: Off; CK_t and CK_c#: Low; CL BL: 8¹; 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 Registers²; 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 Array Self Refresh (LP ASR) : Auto⁴; Partial Array Self-Refresh (PASR): Full Array; CKE: Low; External clock: Off; CK_t and CK_c#: Low; CL BL: 8¹; 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 Registers²; ODT Signal: MID-LEVEL |
| IPP6A | Auto Self-Refresh IPP Current Same condition with IDD6A |

| Symbol | Description |
|--------|--|
| IDD7 | <p>Operating Bank Interleave Read Current CKE: High; External clock: On; tCK, nRC, nRAS, nRCD, nRRD, nFAW, CL BL: 8¹; AL: CL-1; CS_n: High between ACT and RDA; Command, Address, Bank Group Address, Bank Address Inputs: partially toggling according to Table 7-11; Data IO: Read data bursts with different data between one burst and the next one according to Table 7-11 DM_n: stable at 1; Bank Activity: two times interleaved cycling through banks (0, 1, ...7) with different addressing, see Table 7-11 Output Buffer and RTT: Enabled in Mode Registers²; ODT Signal: stable at 0; Pattern Details: see Table 7-11</p> |
| IPP7 | <p>Operating Bank Interleave Read IPP Current Same condition with IDD7</p> |
| IDD8 | <p>Maximum Power Down Current TBD</p> |
| IPP8 | <p>Maximum Power Down IPP Current Same condition with IDD8</p> |

7.1.1 IDD0, IDD0A and IPP0 Measurement-Loop Pattern

 Table 7-3 IDD0, IDD0A and IPP0 Measurement-Loop Pattern¹

| 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 | | | |
|-------------|-------------|----------|--|--|--|-------|-------------|-------------|------------|-----|---------------------|----------------------|----------------|----------|-------------|----------|--------|--------|--------|-------------------|---|---|--|
| logging | Static High | 0 | 0 | ACT | 0 | 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 | 0 | 0 | | |
| | | | 3,4 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ² | 3 | 0 | 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 | 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 | | | | | | | | | | | | | | | | | | |
| | | | 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 | | | | | | | | | | | | | | | | | | | | |

For x4 and x8 only

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.

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7.1.2 IDD1, IDD1A and IPP1 Measurement-Loop Pattern

 Table 7-4 IDD1, IDD1A and IPP1 Measurement-Loop Pattern¹

| 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 | | | |
|-----------|-------------|-------------------|--|--|------|-------|---------------|---------------|--------------|-----|---------------------|----------------------|----------------|--------------|-------------|----------|--------|--------|--------|-------------------|---|---|--|
| Toggleing | Static High | 0 | 0 | ACT | 0 | 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 | 0 | 0 | 0 | |
| | | | 3,4 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ^b | 3 | 0 | 0 | 0 | 0 | 7 | F | 0 | 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 | 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 | 0 | 0 | 0 | 0 |
| | | ... | repeat pattern nRC + 1...4 until 1*nRC + nRAS - 1, truncate if necessary | | | | | | | | | | | | | | | | | | | | |
| | | 1*nRC + 0 | ACT | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 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 | 0 | 0 | 0 | 0 | |
| | | 1*nRC + 3, 4 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 3 ^b | 3 | 0 | 0 | 0 | 0 | 7 | F | 0 | 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 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 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 | 0 | 0 | 0 | 0 | 0 | 0 | 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 | | | | | | | | | | | | | | | | | | | |

| 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 | |
|-----------|-----|----------|--------------|--|------|-------|---------------|---------------|--------------|-----|---------------------|----------------------|---------|--------------|-------------|----------|--------|--------|--------|-------------------|--|
| | | 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 | | | | | | | | | | | | | | | | | |
| | | 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 | | | | | | | | | | | | | | | | | |

For x4 and x8 only

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.

7.1.3 IDD2N, IDD2NA, IDD2NL, IDD2NG, IDD2ND, IDD2N_par, IPP2, IDD3N, IDD3NA and IDD3P Measurement-Loop Pattern

 Table 7-5 IDD2N, IDD2NA, IDD2NL, IDD2NG, IDD2ND, IDD2N_par, IPP2, IDD3N, IDD3NA and IDD3P Measurement-Loop Pattern¹

| 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 | 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 | 0 | |
| | | | 2 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ² | 3 | 0 | 0 | 0 | 0 | 7 | F | 0 | 0 |
| | | | 3 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ² | 3 | 0 | 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.

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7.1.4 IDD2NT and IDDQ2NT Measurement-Loop Pattern

 Table 7-6 IDD2NT and IDDQ2NT Measurement-Loop Pattern¹

| 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 | 0 | |
| | | | 2 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 3 ² | 3 | 0 | 0 | 0 | 7 | F | 0 | |
| | | | 3 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 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 | | | | | | | | | | | | | | | | | | |
| | | 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 | | | | | | | | | | | | | | | | | | | | |

For x4 and x8 only

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

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7.1.5 IDD4R, IDDR4RA, IDD4RB and IDDQ4R Measurement-Loop Pattern¹

 Table 7-7 IDD4R, IDDR4RA, IDD4RB and IDDQ4R Measurement-Loop Pattern¹

| 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] ² | 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 | 1 | 0 | 0 | 3 ² | 3 | 0 | 0 | 0 | 7 | F | 0 | - | |
| | | 1 | 4 | RD | 0 | 1 | 1 | 0 | 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 | 0 | 0 | - |
| | | | 6, 7 | D_#,D_# | 1 | 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 | | | | | | | | | | | | | | | | | | |
| | | 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

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7.1.6 IDD4W, IDD4WA, IDD4WB and IDD4W_par Measurement-Loop Pattern

 Table 7-8 IDD4W, IDD4WA, IDD4WB and IDD4W_par Measurement-Loop Pattern¹

| 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 | 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 | 0 | | |
| | | | 2, 3 | D_#,D_# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ² | 3 | 0 | 0 | 0 | 7 | F | 0 | | |
| | | 1 | 4 | WR | 0 | 1 | 1 | 0 | 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 | 0 | 0 | |
| | | | 6, 7 | D_#,D_# | 1 | 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 | | | | | | | | | | | | | | | | | | |
| | | 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 | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | For x4 and x8 only | | |

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.

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7.1.7 IDD4WC Measurement-Loop Pattern

 Table 7-9 IDD4WC Measurement-Loop Pattern¹

| 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] ² | 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 | 0 | D0=00, D1=FF D2=FF, D3=00 D4=FF, D5=00 D6=00, D7=FF D8=LRLC | |
| | | | 1,2 | D,D | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| | | | 3,4 | D#,D# | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 3 ² | 3 | 0 | 0 | 0 | 7 | F | 0 | - |
| | | | 5 | WR | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 7 | F | 0 | 0 | D0=FF, D1=00 D2=00, D3=FF D4=00, D5=FF D6=FF, D7=00 D8=LRLC |
| | | | 6,7 | D,D | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| | | | 8,9 | D#,D# | 1 | 1 | 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 | | | | | | | | | | | | | | | | | | |
| | | 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 | | | | | | | | | | | | | | | | | | | | |

For x4 and x8 only

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

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7.1.8 IDD5B Measurement-Loop Pattern

 Table 7-10 IDD5B Measurement-Loop Pattern¹

| 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 | 0 | - | |
| | | 1 | 1 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| | | 2 | 1 | D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| | | 3 | 1 | D#,D# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ² | 3 | 0 | 0 | 0 | 0 | 7 | F | 0 | - |
| | | 4 | 1 | D#,D# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3 ² | 3 | 0 | 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 | | | | | | | | | | | | | | | | | | | |
| | | 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 | | | | | | | | | | | | | | | | | | | | |

For x4 and x8 only

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.

7.1.9 IDD7 Measurement-Loop Pattern

 Table 7-11 IDD7 Measurement-Loop Pattern¹

| 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 | | | |
|---------------|-------------|----------|--------------|--|--|-------|------------|------------|--------------|-----|---------------------|----------------------|---------|----------------|-------------|----------|--------|--------|--------|-------------------|---|--|--|
| Toggleing | 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 | 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 | 0 | 0 | | |
| | | | 3 | D# | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 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 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | | | nRRD+1 | RDA | 0 | 1 | 1 | 0 | 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 | | | | | | | | | | | | | | | | | | | |

| 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 | | |
|-----------------------------------|-----|----------|-----------------|--|-----------------|------------------|------------------------|------------------------|-----------------------|-----|---------------------|----------------------|---------|---------------------|-------------|----------|--------|--------|--------|-------------------|--------------------|--|
| | | 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] = 1 instead | | | | | | | | | | | | | | | | | For x4 and x8 only | |
| | | 11 | 2nFAW + nRRD | repeat Sub-Loop 1, use BG[1:0] ² = 3, BA[1:0] = 2 instead | | | | | | | | | | | | | | | | | | |
| | | 12 | 2nFAW + 2*nRRD | repeat Sub-Loop 0, use BG[1:0] ² = 2, BA[1:0] = 3 instead | | | | | | | | | | | | | | | | | | |
| | | 13 | 2nFAW + 3*nRRD | repeat Sub-Loop 1, use BG[1:0] ² = 3, BA[1:0] = 0 instead | | | | | | | | | | | | | | | | | | |
| | | 14 | 2nFAW + 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.

7.2 IDD Specifications

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

Table 7-12 IDD and IDDQ Specifications

| Symbol | Width | 2666 | Unit |
|---------|-------|------|------|
| IDD0 | x8 | TBD | mA |
| IDD0A | x8 | TBD | mA |
| IDD1 | x8 | TBD | mA |
| IDD1A | x8 | TBD | mA |
| IDD2N | x8 | TBD | mA |
| IDD2NA | x8 | TBD | mA |
| IDD2NT | x8 | TBD | mA |
| IDD2P | x8 | TBD | mA |
| IDD2Q | x8 | TBD | mA |
| IDD3P | x8 | TBD | mA |
| IDD3N | x8 | TBD | mA |
| IDD4R | x8 | TBD | mA |
| IDD4W | x8 | TBD | mA |
| IDD5B | x8 | TBD | mA |
| IDD6A | x8 | TBD | mA |
| IDD6E | x8 | TBD | mA |
| IDD6N | x8 | TBD | mA |
| IDD6R | x8 | TBD | mA |
| IDD7 | x8 | TBD | mA |
| IDD8 | x8 | TBD | mA |
| IDDQ2NT | x8 | TBD | mA |

Note:

- 1 Maximum limits are specified
- 2 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.

Table 7-13 IPP Specifications

| Symbol | Width | 2666 | Unit |
|--------|-------|------|------|
| IPP0 | x8 | TBD | mA |
| IPP1 | x8 | TBD | mA |
| IPP2N | x8 | TBD | mA |
| IPP3N | x8 | TBD | mA |
| IPP5B | x8 | TBD | mA |
| IPP6N | x8 | TBD | mA |
| IPP7 | x8 | TBD | mA |

Note:

- 1 Maximum limits are specified
- 2 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.

Table 7-14 IDD6 Specification

| Symbol | Temperature Range | 2666 | Unit | Note |
|--------|-------------------|------|------|---------|
| | | x8 | | |
| IDD6R | 0 ~ 45 °C | TBD | mA | 4,6,9 |
| IDD6N | 0 ~ 85 °C | TBD | mA | 3,4 |
| IDD6E | 0 ~ 95 °C | TBD | mA | 4,5,6 |
| IDD6A | 0 ~ 95 °C | TBD | mA | 4,6,7,8 |

Note:

- 1 Some IDD currents are higher for x16 organization due to larger page-size architecture.
- 2 Max. values for IDD currents considering worst case conditions of process, temperature and voltage.
- 3 Applicable for MR2 settings A6=0 and A7=0.
- 4 Supplier data sheets include a max value for IDD6.
- 5 Applicable for MR2 settings A6=0 and A7=1. IDD6E is only specified for devices which support the Extended Temperature Range feature.
- 6 Refer to the supplier data sheet for the value specification method (e.g. max, typical) for IDD6E and IDD6A
- 7 Applicable for MR2 settings A6=1 and A7=0. IDD6A is only specified for devices which support the Auto Self Refresh feature.
- 8 The number of discrete temperature ranges supported and the associated Ta - Tz values are supplier/design specific. Temperature ranges are specified for all supported values of TOPER. Refer to supplier data sheet for more information.
- 9 Applicable for MR2 settings MR2 [A7:A6 = 01]: Reduced Temperature range. IDD6R is verified by design and characterization, and may not be subject to production test

8. Input/Output Capacitance

Table 8-1 Silicon Pad I/O Capacitance

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|--------------------|---|-----------|------|------|----------|
| | | Min | Max | | |
| C_{IO} | Input/output capacitance | 0.55 | 1.15 | pF | 1,2,3 |
| C_{DIO} | Input/output capacitance delta | -0.1 | 0.1 | pF | 1,2,3,11 |
| C_{DDQS} | Input/output capacitance delta DQS_t and DQS_c | - | 0.05 | pF | 1,2,3,5 |
| C_{CK} | Input capacitance, CK_t and CK_c | 0.2 | 0.7 | pF | 1,3 |
| C_{DCK} | Input capacitance delta CK_t and CK_c | - | 0.05 | pF | 1,3,4 |
| C_I | Input capacitance (CTRL, ADD, CMD pins only) | 0.2 | 0.7 | pF | 1,3,6 |
| C_{DI_CTRL} | Input capacitance delta (All CTRL pins only) | -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 | pF | 1,2,9,10 |
| C_{ALERT} | Input/output capacitance of ALERT | 0.5 | 1.5 | pF | 1,3 |
| C_{ZQ} | Input/output capacitance of ZQ | - | 2.3 | pF | 1,3,12 |
| C_{TEN} | Input capacitance of TEN | 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 deembedding 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 $C_{IO}(DQS_T)-C_{IO}(DQS_C)$
- 6 C_I 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 C_{DI_CTRL} applies to ODT, CS_n and CKE
- 8 $C_{DI_CTRL} = C_I(CTRL)-0.5*(C_I(CLK_T)+C_I(CLK_C))$
- 9 $C_{DI_ADD_CMD}$ applies to, A0-A17, BA0-BA1, BG0-BG1, RAS_n/A16, CAS_n/A15, WE_n/A14, ACT_n and PAR.
- 10 $C_{DI_ADD_CMD} = C_I(ADD_CMD)-0.5*(C_I(CLK_T)+C_I(CLK_C))$
- 11 $C_{DIO} = C_{IO}(DQ,DM)-0.5*(C_{IO}(DQS_T)+C_{IO}(DQS_C))$
- 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 CTEN might not be valid and system shall verify TEN signal with Vendor specific information.

Table 8-2 DRAM Package Electrical Specifications (x8)

| Symbol | Parameter | DDR4-2666 | | Unit | Note |
|------------------------|-------------------------------|-----------|------|------|---------------|
| | | Min | Max | | |
| Z _{IO} | Input/output Zpkg | 45 | 85 | Ω | 1,2,4,5,10,11 |
| T _{dIO} | Input/output Pkg Delay | 14 | 42 | ps | 1,3,4,5,10,11 |
| L _{io} | Input/Output Lpkg | - | 3.3 | nH | 11,12 |
| C _{io} | Input/Output Cpkg | - | 0.78 | pF | 11,13 |
| Z _{IO DQS} | DQS_t and DQS_c Zpkg | 45 | 85 | Ω | 1,2,5,7,10 |
| T _{dIO DQS} | DQS_t and DQS_c Pkg Delay | 14 | 42 | ps | 1,3,5,7,10 |
| L _{io DQS} | DQS Lpkg | - | 3.3 | nH | 11,12 |
| C _{io DQS} | DQS Cpkg | - | 0.78 | pF | 11,13 |
| DZ _{DIO DQS} | Delta Zpkg DQS_t, DQS_c | - | 10 | Ω | 1,2,5,7,10 |
| D _{TdDIO DQS} | Delta Delay DQS_t, DQS_c | - | 5 | ps | 1,3,5,7,10 |
| Z _{I CTRL} | Input- CTRL pins Zpkg | 50 | 90 | Ω | 1,2,5,9,10,11 |
| T _{dI CTRL} | Input- CTRL pins Pkg Delay | 14 | 42 | ps | 1,3,5,9,10,11 |
| L _{i CTRL} | Input CTRL Lpkg | - | 3.4 | nH | 11,12 |
| C _{i CTRL} | Input CTRL Cpkg | - | 0.7 | pF | 11,13 |
| Z _{IADD CMD} | Input- CMD ADD pins Zpkg | 50 | 90 | Ω | 1,2,5,8,10,11 |
| T _{dIADD_CMD} | Input- CMD ADD pins Pkg Delay | 14 | 45 | ps | 1,3,5,8,10,11 |
| L _{iADD_CMD} | Input CMD ADD Lpkg | - | 3.6 | nH | 11,12 |
| C _{iADD_CMD} | Input CMD ADD Cpkg | - | 0.74 | pF | 11,13 |
| Z _{CK} | CK_t and CK_c Zpkg | 50 | 90 | Ω | 1,2,5,10,11 |
| T _{dCK} | CK_t and CK_c Pkg Delay | 14 | 42 | ps | 1,3,5,10,11 |
| L _{i CLK} | Input CK Lpkg | - | 3.4 | nH | 11,12 |
| C _{i CLK} | Input CK Cpkg | - | 0.7 | pF | 11,13 |
| DZ _{DCK} | Delta Zpkg CK_t and CK_c | - | 10 | Ω | 1,2,5,6,10 |
| D _{TdCK} | Delta Delay CK_t and CK_c | - | 5 | ps | 1,3,5,6,10 |
| Z _{OZQ} | ZQ Zpkg | - | 100 | Ω | 1,2,5,10,11 |
| T _{dO ZQ} | ZQ Delay | 20 | 90 | ps | 1,3,5,10,11 |
| Z _{OALERT} | ALERT Zpkg | 40 | 100 | Ω | 1,2,5,10,11 |
| T _{dOALERT} | ALERT Delay | 20 | 55 | ps | 1,3,5,10,11 |

Note:

1 This parameter is not subject to production test. It is verified by design and characterization. The package parasitic (L & C) are validated using package only samples. The capacitance is measured with VDD, VDDQ, VSS, VSSQ shorted with all other signal pins floating. The inductance is measured with VDD, VDDQ, VSS and VSSQ shorted and all other signal pins shorted at the die side(not pin). Measurement procedure tbd

2 Package only impedance (Zpkg) is calculated based on the Lpkg and Cpkg total for a given pin where:

$$Z_{\text{pkg}} \text{ (total per pin)} = \sqrt{L_{\text{pkg}}/C_{\text{pkg}}}$$

3 Package only delay(Tpkg) is calculated based on Lpkg and Cpkg total for a given pin where:

$$T_{\text{dpkg}} \text{ (total per pin)} = \sqrt{L_{\text{pkg}}/C_{\text{pkg}}}$$

4 Z & Td IO applies to DQ, DM, DQS_C, DQS_T, TDQS_T and TDQS_C

5 This parameter applies to monolithic devices only; stacked/dual-die devices are not covered here

6 Absolute value of ZCK_t-ZCK_c for impedance(Z) or absolute value of TdCK_t-TdCK_c for delay(Td).

7 Absolute value of ZIO(DQS_t)-ZIO(DQS_c) for impedance(Z) or absolute value of TdIO(DQS_t)-TdIO(DQS_c) for delay(Td)

8 ZI & Td ADD CMD applies to A0-A17, BA0-BA1, BG0-BG1, RAS_n CAS_n, WE_n.

9 ZI & Td CTRL applies to ODT, CS_n and CKE.

10 This table applies to monolithic X4 and X8 devices.

11 Package implementations shall meet spec if the Zpkg and Pkg Delay fall within the ranges shown, and the maximum Lpkg and Cpkg do not exceed the maximum values shown.

12 It is assumed that Lpkg can be approximated as $L_{\text{pkg}} = Z_o * T_d$.

13 It is assumed that Cpkg can be approximated as $C_{\text{pkg}} = T_d / Z_o$.

9. Electrical Characteristics & AC Timing

This chapter introduces the following five topics to build a completely safe operation environment for DDR4 SDRAM:

- Reference Load for AC Timing and Output Slew Rate on [Page 102](#)
- tREFI on [Page 103](#)
- Clock Specification on [Page 103](#)
- Timing Parameters by Speed Grade on [Page 105](#)
- Rounding Algorithms on [Page 127](#)
- DQ Input Receiver Compliance Mask for Voltage and Timing on [Page 128](#)
- Command, Control, and Address Setup, Hold and Derating on [Page 134](#)

9.1 Reference Load for AC Timing and Output Slew Rate

Figure 9-1 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 = $1.0 \cdot VDDQ$,
- The minimum DC Low level of Output signal = $\{ 34 / (34 + 50) \} \cdot VDDQ = 0.4 \cdot VDDQ$
- The nominal reference level of an Output signal can be approximated by the following:
- The center of maximum DC High and minimum DC Low = $\{ (1 + 0.4) / 2 \} \cdot VDDQ = 0.7 \cdot VDDQ$

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.

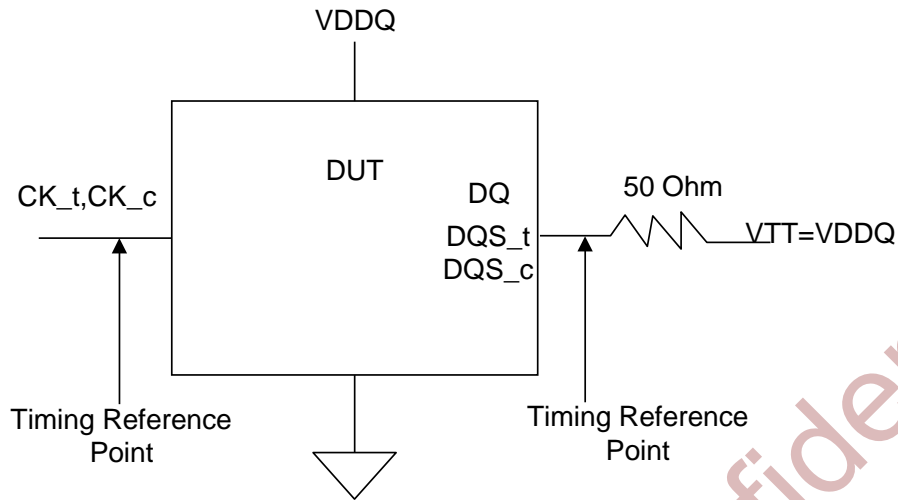


Figure 9-1 Reference Load for AC Timing and Output Slew Rate

9.2 tREFI

Average periodic Refresh interval (t_{REFI}) of DDR4 SDRAM is defined as shown in Table 9-1 below.

 Table 9-1 t_{REFI} by Device Density

| Parameter | Symbol | | 8Gb | Unit |
|-----------------------------------|------------|---|-----|---------------|
| Average periodic refresh interval | t_{REFI} | $0^{\circ}\text{C} \leq \text{TCASE} \leq 85^{\circ}\text{C}$ | 7.8 | μs |
| | | $85^{\circ}\text{C} < \text{TCASE} \leq 95^{\circ}\text{C}$ | 3.9 | μs |

9.3 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.

9.3.1 Definition for $t_{CK}(\text{abs})$

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

9.3.2 Definition for $t_{CK}(\text{avg})$

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.

$$tCK(avg) = \left[\frac{N}{\sum_{j=1}^N tCK(abs)_j} \right] / N \quad N=200$$

9.3.3 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.

$$tCH(avg) = \left[\frac{N}{\sum_{j=1}^N tCH_j} \right] \{N \times tCK(avg)\} \quad N=200$$

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

$$tCH(avg) = \left[\frac{N}{\sum_{j=1}^N tCH_j} \right] \{N \times tCK(avg)\} \quad N=200$$

9.3.4 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.

9.4 Timing Parameters by Speed Grade

9.4.1 Timing Parameters by Speed Bin for DDR4-1600 to 2400

Table 9-2 Timing Parameters by Speed Bin for DDR4-1600 to 2400

| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|--|-----------------|--|------|-----------|-------|-----------|--------|-----------|--------|-----------|--------|
| Parameter | Symbol | 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 | ns | |
| Average Clock Period | tCK (avg) | 1.25 | <1.5 | 1.071 | <1.25 | 0.937 | <1.071 | 0.833 | <0.937 | 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 | tCK (avg) | |
| Average low pulse width | tCL (avg) | 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 | - | tCK (avg) | 23 |
| Absolute clock LOW pulse width | tCL (abs) | 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 | ps | 23, 25 |
| Clock Period Jitter- deterministic | JIT (per)_dj | -31 | 31 | -27 | 27 | -23 | 23 | -21 | 21 | ps | 26 |
| Clock Period Jitter during DLL locking period | tJIT (per, lck) | -50 | 50 | -43 | 43 | -38 | 38 | -33 | 33 | ps | |
| Cycle to Cycle Period Jitter | tJIT (cc) | - | 125 | - | 107 | - | 94 | - | 83 | ps | |
| Cycle to Cycle Period Jitter during DLL locking period | tJIT (cc, lck) | - | 100 | - | 86 | - | 75 | - | 67 | ps | |
| Cumulative error across 2 cycles | tERR (2per) | -92 | 92 | -79 | 79 | -69 | 69 | -61 | 61 | ps | |
| Cumulative error across 3 cycles | tERR (3per) | -109 | 109 | -94 | 94 | -82 | 82 | -73 | 73 | ps | |
| Cumulative error across 4 cycles | tERR (4per) | -121 | 121 | -104 | 104 | -91 | 91 | -81 | 81 | ps | |
| Cumulative error across 5 cycles | tERR (5per) | -131 | 131 | -112 | 112 | -98 | 98 | -87 | 87 | ps | |
| Cumulative error across 6 cycles | tERR (6per) | -139 | 139 | -119 | 119 | -104 | 104 | -92 | 92 | ps | |
| Cumulative error across 7 cycles | tERR (7per) | -145 | 145 | -124 | 124 | -109 | 109 | -97 | 97 | ps | |
| Cumulative error across 8 cycles | tERR (8per) | -151 | 151 | -129 | 129 | -113 | 113 | -101 | 101 | ps | |
| Cumulative error across 9 cycles | tERR (9per) | -156 | 156 | -134 | 134 | -117 | 117 | -104 | 104 | ps | |
| Cumulative error across 10 cycles | tERR (10per) | -160 | 160 | -137 | 137 | -120 | 120 | -107 | 107 | ps | |
| Cumulative error across 11 cycles | tERR (11per) | -164 | 164 | -141 | 141 | -123 | 123 | -110 | 110 | ps | |
| Cumulative error across 12 cycles | tERR (12per) | -168 | 168 | -144 | 144 | -126 | 126 | -112 | 112 | ps | |
| Cumulative error across 13 cycles | tERR (13per) | -172 | 172 | -147 | 147 | -129 | 129 | -114 | 114 | ps | |



| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|--|---------------|--|-----|---------------------|-----|---------------------|-----|-------------------|-----|------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Cumulative error across 14 cycles | tERR (14per) | -175 | 175 | -150 | 150 | -131 | 131 | -116 | 116 | ps | |
| Cumulative error across 15 cycles | tERR (15per) | -178 | 178 | -152 | 152 | -133 | 133 | -118 | 118 | ps | |
| Cumulative error across 16 cycles | tERR (16per) | -180 | 189 | -155 | 155 | -135 | 135 | -120 | 120 | ps | |
| Cumulative error across 17 cycles | tERR (17per) | -183 | 183 | -157 | 157 | -137 | 137 | -122 | 122 | ps | |
| Cumulative error across 18 cycles | tERR (18per) | -185 | 185 | -159 | 159 | -139 | 139 | -124 | 124 | ps | |
| Cumulative error across n = 13, 14 . . . 49, 50 cycles | tERR (nper) | $tERR(nper)_{min} = ((1 + 0.68 \ln(n)) * tJIT(per)_{total min})$ $tERR(nper)_{max} = ((1 + 0.68 \ln(n)) * tJIT(per)_{total max})$ | | | | | | | | ps | |
| Command and Address setup time to CK_t,CK_c referenced to Vih(ac) / Vil(ac) levels | tIS (base) | 115 | - | 100 | - | 80 | - | 62 | - | ps | |
| Command and Address setup time to CK_t,CK_c referenced to Vref levels | tIS (Vref) | 215 | - | 200 | - | 180 | - | 162 | - | ps | |
| Command and Address hold time to CK_t,CK_c referenced to Vih(dc) / Vil(dc) levels | tIH (base) | 140 | - | 125 | - | 105 | - | 87 | - | ps | |
| Command and Address hold time to CK_t,CK_c referenced to Vref levels | tIH (Vref) | 215 | - | 200 | - | 180 | - | 162 | - | ps | |
| Control and Address Input pulse width for each input | tIPW | 600 | - | 525 | - | 460 | - | 410 | - | ps | |
| Command and Address Timing | | | | | | | | | | | |
| CAS_n to CAS_n command delay for same bank group | tCCD_L | Max (5nCK, 6.250ns) | - | Max (5nCK, 5.355ns) | - | Max (5nCK, 5.355ns) | - | Max (5nCK, 5ns) | - | nCK | 34 |
| CAS_n to CAS_n command delay for different bank group | tCCD_S | 4 | - | 4 | - | 4 | - | 4 | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 2KB page size | tRRD_S (2K) | Max (4nCK, 6ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 5.3ns) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 1KB page size | tRRD_S (1K) | Max (4nCK, 5ns) | - | Max (4nCK, 4.2ns) | - | Max (4nCK, 3.7ns) | - | Max (4nCK, 3.3ns) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 1/2KB page size | tRRD_S (1/2K) | Max (4nCK, 5.0ns) | - | Max (4nCK, 4.2ns) | - | Max (4nCK, 3.7ns) | - | Max (4nCK, 3.3ns) | - | 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) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to same bank group for 1KB page size | tRRD_L (1K) | Max (4nCK, 6.0ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 4.9ns) | - | nCK | 34 |

| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|---|---------------|-----------------------------|-----|-----------------------------|-----|-----------------------------|-----|------------------------------|-----|------|-----------|
| Parameter | Symbol | 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, 6.0ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 5.3.0ns) | - | 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) | - | ns | 34 |
| Four activate window for 1KB page size | tFAW_1K | Max (20nCK, 25ns) | - | Max (20nCK, 23ns) | - | 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) | - | ns | 34 |
| Delay from start of internal Write transaction to internal read command for same bank group | tWTR_S | Max (2nCK, 2.5ns) | - | Max (2nCK, 2.5ns) | - | Max (2nCK, 2.5ns) | - | Max (2nCK, 2.5ns) | - | ns | 1,2,34 |
| 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) | - | ns | 1,34 |
| Internal READ Command to PRE-CHARGE Command delay | tRTP | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | ns | 34 |
| WRITE recovery time | tWR | 15 | - | 15 | - | 15 | - | 15 | - | ns | 1 |
| Write recovery time when CRC and DM are enabled | tWR_CRC_DM | tWR + max (4nCK, 3.75ns) | - | tWR + max (5CK, 3.75ns) | - | tWR + max (5nCK, 3.75ns) | - | tWR + max (5nCK, 3.75ns) | - | ns | 1, 28 |
| delay from start of internal write trans- action to internal read command for different bank group with both CRC and DM enabled | tWTR_S_CRC_DM | tWTR_S + max (4nCK, 3.75ns) | - | tWTR_S + max (5nCK, 3.75ns) | - | tWTR_S + max (5nCK, 3.75ns) | - | tWTR_S + max (5nCK, 3.75ns) | - | ns | 2, 29, 34 |
| delay from start of internal write trans- action to internal read command for same bank group with both CRC and DM enabled | tWTR_L_CRC_DM | tWTR_L + max (4nCK, 3.75ns) | - | tWTR_L + max (5nCK, 3.75ns) | - | tWTR_L + max (5nCK, 3.75ns) | - | tWTR_L + max (5nCK, 3.75ns) | - | ns | 3, 30, 34 |
| DLL locking time | tDLLK | 597 | - | 597 | - | 768 | - | 768 | - | nCK | |
| Mode Register Set command cycle time | tMRD | 8 | - | 8 | - | 8 | - | 8 | - | nCK | |
| Mode Register Set command update delay | tMOD | max (24nCK, 15ns) | - | max (24nCK, 15ns) | - | max (24nCK, 15ns) | - | max (24nCK, 15ns) | - | nCK | 50 |
| Multi-Purpose Register Recovery Time | tMPRR | 1 | - | 1 | - | 1 | - | 1 | - | nCK | 33 |
| Multi Purpose Register Write Recov- ery Time | tWR_MPR | tMOD (min) + AL + PL | - | tMOD (min) + AL + PL | - | tMOD (min) + AL + PL | - | tMOD(min) + AL + PL | - | ns | |



| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note | |
|--|------------|--|---------|-------------------------|---------|-------------------------|---------|-------------------------|---------|-------------|----------------|--|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | | |
| Auto precharge write recovery + pre-charge 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 | - | 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 | - | UI | 46,47 | |
| CS_n to Command Address Latency | | | | | | | | | | | | |
| CS_n to Command Address Latency | tCAL | max (3nCK, 3.748 ns) | - | max (3nCK, 3.748 ns) | - | max (3nCK, 3.748 ns) | - | max (3nCK, 3.748 ns) | - | nCK | | |
| Mode Register Set command cycle time in CAL mode | tMRD_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 | - | nCK | | |
| DRAM Data Timing | | | | | | | | | | | | |
| DQS_t,DQS_c to DQ skew, per group, per acces | tDQSQ | - | 0.16 | - | 0.16 | - | 0.16 | - | 0.17 | tCK (avg)/2 | 13,18,39,49 | |
| DQ output hold time from DQS_t,DQS_c | tQH | 0.76 | - | 0.76 | - | 0.76 | - | 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 | - | 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 | - | UI | 17,18,39,49 | |
| DQ low impedance time from CK_t,CK_c | tLZ (DQ) | -450 | 225 | -390 | 195 | -360 | 180 | -330 | 175 | ps | 39 | |
| DQ high impedance time from CK_t,CK_c | tHZ (DQ) | - | 225 | - | 195 | - | 180 | - | 175 | ps | 39 | |
| Data Strobe Timing | | | | | | | | | | | | |
| DQS_t, DQS_c differential READ Preamble(1 clock preamble) | tRPRE | 0.9 | Note 44 | 0.9 | Note 44 | 0.9 | Note 44 | 0.9 | Note 44 | nCK | 39, 40 | |
| DQS_t, DQS_c differential READ Preamble(2 clock preamble) | tRPRE2 | NA | NA | NA | NA | NA | NA | 1.8 | Note 44 | tCK | 39, 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 | tCK | 39 | |
| DQS_t,DQS_c differential output high time | tQSH | 0.4 | - | 0.4 | - | 0.4 | - | 0.4 | - | tCK | 21,39 | |
| DQS_t,DQS_c differential output low time | tQSL | 0.4 | - | 0.4 | - | 0.4 | - | 0.4 | - | tCK | 20,39 | |
| DQS_t, DQS_c differential WRITE Preamble(1 clock preamble) | tWPRE | 0.9 | - | 0.9 | - | 0.9 | - | 0.9 | - | tCK | 42 | |



| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|---|------------------|---------------------------|------|-----------|------|-----------|------|-----------|------|------|----------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| DQS_t, DQS_c differential WRITE Preamble(2 clock preamble) | tWPRE2 | NA | NA | NA | NA | NA | NA | 1.8 | - | tCK | 43 |
| DQS_t, DQS_c differential WRITE Postamble | tWPST | 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 | ps | 39 |
| DQS_t and DQS_c high-impedance time (Referenced from RL+BL/2) | tHZ (DQS) | - | 225 | - | 195 | - | 180 | - | 175 | ps | 39 |
| 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 | 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 | 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 | tCK | 42 |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (2 clock preamble) | tDQSS2 | NA | NA | NA | NA | NA | NA | TBD | TBD | 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 | - | 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 | - | tCK | |
| DQS_t, DQS_c rising edge output vari-ance window per DRAM | tDQSCKI (DLL On) | - | 370 | - | 330 | - | 310 | - | 290 | ps | 37,38,39 |
| DQS_t, DQS_c rising edge output timing locatino from rising CK_t, CK_c with DLL On mode | tDQSCK (DLL On) | -225 | 225 | -195 | 195 | -180 | 180 | -175 | 175 | ps | 37,38,39 |
| MPSM Timing | | | | | | | | | | | |
| Command path disable delay upon MPSM entry | tMPED | tMOD (min) + tCPDED (min) | | | | | | | | tCK | |
| Valid clock requirement after MPSM entry | tCKMPE | tMOD (min) + tCPDED (min) | | | | | | | | tCK | |
| Valid clock requirement before MPSM exit | tCKMPX | tCKSRX (min) | | | | | | | | tCK | |
| Exit MPSM to commands not requir- ing a locked DLL | tXMP | tXS (min) | | | | | | | | tCK | |
| Exit MPSM to commands requiring a locked DLL | tXMPDLL | tXMP (min) + tXSDLL (min) | | | | | | | | tCK | |
| CS setup time to CKE | tMPX_S | tISmin + tIHmin | | | | | | | | ns | |
| Calibration Timing | | | | | | | | | | | |
| Power-up and RESET calibration time | tZQinit | 1024 | - | 1024 | - | 1024 | - | 1024 | - | nCK | |



| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|--|-----------------|----------------------------------|---------|----------------------------------|---------|----------------------------------|---------|-------------------------------|---------|------|-------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Normal operation Full calibration time | tZQoper | 512 | - | 512 | - | 512 | - | 512 | - | nCK | |
| Normal operation Short calibration time | tZQCS | 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) | - | nCK | |
| Exit Self Refresh to commands not requiring a locked DLL | tXS | 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 | - | 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 | - | nCK | |
| Exit Self Refresh to commands re-quiring a locked DLL | tXSDLL | tDLLK (min) | - | tDLLK (min) | - | tDLLK (min) | - | tDLLK (min) | - | nCK | |
| Minimum CKE low width for Self re- fresh entry to exit timing | tCKESR | tCKE (min) + 1nCK | - | tCKE (min) + 1nCK | - | tCKE (min) + 1nCK | - | tCKE (min) + 1nCK | - | nCK | |
| Minimum CKE low width for Self re- fresh entry to exit timing with CA Par- ity enabled | tCKESR_ PAR | 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, 10 ns) | - | max (5nCK, 10 ns) | - | max (5nCK, 10 ns) | - | max(5nCK, 10ns) | - | nCK | |
| 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 | - | 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) | - | 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) | - | nCK | |
| CKE minimum pulse width | tCKE | max (3nCK, 5ns) | - | max (3nCK, 5ns) | - | max (3nCK, 5ns) | - | max(3nCK, 5ns) | - | nCK | 31,32 |
| Command pass disable delay | tCPDED | 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 | | 6 |



| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|---|--------------|-------------------------|-----|-------------------------|-----|-------------------------|-----|-------------------------|-----|-----------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Timing of ACT command to Power Down entry | tACTPDEN | 1 | - | 1 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of PRE or PREA command to Power Down entry | tPRPDEN | 1 | - | 1 | - | 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 | - | 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)) | - | 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 | - | nCK | 5 |
| Timing of WR command to Power Down entry (BC4MRS) | tWRP-BC4DEN | 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 | - | nCK | 5 |
| Timing of REF command to Power Down entry | tREFPDEN | 1 | - | 1 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of MRS command to Power Down entry | tMRSPDEN | tMOD (min) | - | tMOD (min) | - | tMOD (min) | - | tMOD (min) | - | nCK | |
| 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) | - | nCK | |
| Mode Register Set command update delay in PDA mode | tMOD_PDA | tMOD | | tMOD | | tMOD | | tMOD | | nCK | |
| ODT Timing | | | | | | | | | | | |
| Asynchronous RTT turn-on delay (Power-Down with DLL frozen) | tAONAS | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | ns | |
| Asynchronous RTT turn-off delay (Power-Down with DLL frozen) | tAOFAS | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | ns | |
| RTT dynamic change skew | tADC | 0.3 | 0.7 | 0.3 | 0.7 | 0.3 | 0.7 | 0.3 | 0.7 | tCK(avg) | |
| Write Leveling Timing | | | | | | | | | | | |
| First DQS_t/DQS_n rising edge after write leveling mode is programmed | tWLMRD | 40 | - | 40 | - | 40 | - | 40 | - | nCK | 12 |
| DQS_t/DQS_n delay after write leveling mode is programmed | tWLDQSEN | 25 | - | 25 | - | 25 | - | 25 | - | nCK | 12 |
| Write leveling setup time from rising CK_t, CK_c crossing to rising DQS_t/ DQS_n crossing | tWLS | 0.13 | - | 0.13 | - | 0.13 | - | 0.13 | - | tCK(avg) | |

| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|---|----------------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Write leveling hold time from rising DQS_t/DQS_n crossing to rising CK_t, CK_crossing | tWLH | 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 | ns | |
| Write leveling output error | tWLOE | | | | | | | 0 | 2 | ns | |
| CA Parity Timing | | | | | | | | | | | |
| Commands not guaranteed to be executed during this time | tPAR_UNKNOWN | - | PL | - | PL | - | PL | - | PL | nCK | |
| Delay from errant command to ALERT_n assertion | tPAR_ALERT_ON | - | PL + 6ns | - | PL + 6ns | - | PL + 6ns | - | PL + 6ns | nCK | |
| Pulse width of ALERT_n signal when asserted | tPAR_ALERT_PW | 48 | 96 | 56 | 112 | 64 | 128 | 72 | 144 | 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 | nCK | |
| Parity Latency | PL | 4 | | 4 | | 4 | | 5 | | nCK | |
| CRC Error Reporting | | | | | | | | | | | |
| CRC error to ALERT_n latency | tCRC_ALERT | 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 | nCK | |
| tREFI | | | | | | | | | | | |
| tRFC1 (min) | 8Gb | 350 | - | 350 | - | 350 | - | 350 | - | ns | 34 |
| tRFC2 (min) | 8Gb | 260 | - | 260 | - | 260 | - | 260 | - | ns | 34 |
| tRFC4 (min) | 8Gb | 160 | - | 160 | - | 160 | - | 160 | - | ns | 34 |

9.4.2 Timing Parameters by Speed Bin for DDR4-2666 to 3200

Table 9-3 Timing Parameters by Speed Bin for DDR4-2666 to 3200

| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|--|----------------|--|--------|-----------|--------|-----------|--------|----------|-------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Clock Timing | | | | | | | | | |
| Minimum Clock Cycle Time (DLL off mode) | tCK (DLL_OFF) | 8 | 20 | 8 | 20 | 8 | 20 | ns | |
| Average Clock Period | tCK(avg) | 0.75 | <0.833 | 0.682 | <0.750 | 0.625 | <0.682 | ns | 35,36 |
| Average high pulse width | tCH(avg) | 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 | 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 | - | tCK(avg) | 23 |
| Absolute clock LOW pulse width | tCL(abs) | 0.45 | - | 0.45 | - | 0.45 | - | tCK(avg) | 24 |
| Clock Period Jitter- total | JIT(per)_tot | -38 | 38 | -34 | 34 | -32 | 32 | ps | 25 |
| Clock Period Jitter-deterministic | JIT(per)_dj | -19 | 19 | -17 | 17 | -16 | 16 | ps | 26 |
| Clock Period Jitter during DLL locking period | tJIT(per, lck) | -30 | 30 | -27 | 27 | -25 | 25 | ps | |
| Cycle to Cycle Period Jitter | tJIT(cc) | - | 75 | - | 68 | - | 62 | ps | |
| Cycle to Cycle Period Jitter during DLL locking period | tJIT(cc, lck) | - | 60 | - | 55 | - | 50 | ps | |
| Cumulative error across 2 cycles | tERR(2per) | -55 | 55 | -50 | 50 | -46 | 46 | ps | |
| Cumulative error across 3 cycles | tERR(3per) | -66 | 66 | -60 | 60 | -55 | 55 | ps | |
| Cumulative error across 4 cycles | tERR(4per) | -73 | 73 | -66 | 66 | -61 | 61 | ps | |
| Cumulative error across 5 cycles | tERR(5per) | -78 | 78 | -71 | 71 | -65 | 65 | ps | |
| Cumulative error across 6 cycles | tERR(6per) | -83 | 83 | -75 | 75 | -69 | 69 | ps | |
| Cumulative error across 7 cycles | tERR(7per) | -87 | 87 | -79 | 79 | -73 | 73 | ps | |
| Cumulative error across 8 cycles | tERR(8per) | -91 | 91 | -83 | 83 | -76 | 76 | ps | |

| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|-------------|--|-----|-----------|-----|-----------|-----|------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Cumulative error across 9 cycles | tERR(9per) | -94 | 94 | -85 | 85 | -78 | 78 | ps | |
| Cumulative error across 10 cycles | tERR(10per) | -96 | 96 | -88 | 88 | -80 | 80 | ps | |
| Cumulative error across 11 cycles | tERR(11per) | -99 | 99 | -90 | 90 | -83 | 83 | ps | |
| Cumulative error across 12 cycles | tERR(12per) | -101 | 101 | -92 | 92 | -84 | 84 | ps | |
| Cumulative error across 13 cycles | tERR(13per) | -103 | 103 | -93 | 93 | -86 | 86 | ps | |
| Cumulative error across 14 cycles | tERR(14per) | -104 | 104 | -95 | 95 | -87 | 87 | ps | |
| Cumulative error across 15 cycles | tERR(15per) | -106 | 106 | -97 | 97 | -89 | 89 | ps | |
| Cumulative error across 16 cycles | tERR(16per) | -108 | 108 | -98 | 98 | -90 | 90 | ps | |
| Cumulative error across 17 cycles | tERR(17per) | -110 | 110 | -100 | 100 | -92 | 92 | ps | |
| Cumulative error across 18 cycles | tERR(18per) | -112 | 112 | -101 | 101 | -93 | 93 | ps | |
| Cumulative error across n = 13, 14 . . . 49, 50 cycles | tERR(nper) | $tERR(nper)_{min} = ((1 + 0.68\ln(n)) * tJIT(per)_{total\ min})$ $tERR(nper)_{max} = ((1 + 0.68\ln(n)) * tJIT(per)_{total\ max})$ | | | | | | ps | |
| Command and Address setup time to CK_t, CK_c referenced to Vih(ac) / Vil(ac) levels | tIS(base) | 55 | - | 48 | - | 40 | - | ps | |
| Command and Address setup time to CK_t, CK_c referenced to Vref levels | tIS(Vref) | 145 | - | 138 | - | 130 | - | ps | |
| Command and Address hold time to CK_t, CK_c referenced to Vih(dc) / Vil(dc) levels | tIH(base) | 80 | - | 73 | - | 65 | - | ps | |
| Command and Address hold time to CK_t, CK_c referenced to Vref levels | tIH(Vref) | 145 | - | 138 | - | 130 | - | ps | |
| Control and Address Input pulse width for each input | tIPW | 385 | - | 365 | - | 340 | - | ps | |
| Command and Address Timing | | | | | | | | | |



| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|--------------|------------------------|-----|--------------------------|-----|----------------------|-----|------|--------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| CAS_n to CAS_n command delay for same bank group | tCCD_L | Min = Max(5nCK, 5ns) | | | | | | nCK | 34 |
| CAS_n to CAS_n command delay for different bank group | tCCD_S | 4 | - | 4 | - | 4 | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 2KB page size | tRRD_S(2K) | Min = Max(4nCK, 5.3ns) | | | | | | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 1KB page size | tRRD_S(1K) | Min=Max(4nCK, 3.0ns) | | Min=Max(4nCK, 2.7ns) | | Min=Max(4nCK, 2.5ns) | | nCK | 34 |
| ACTIVATE to ACTIVATE Command de-lay to different bank group for 1/2KB page size | tRRD_S(1/2K) | Min=Max(4nCK, 3.0ns) | | Min=Max(4nCK, 2.7ns) | | Min=Max(4nCK, 2.5ns) | | nCK | 34 |
| ACTIVATE to ACTIVATE Command de-lay to same bank group for 2KB page size | tRRD_L(2K) | Min=Max(4nCK, 6.4ns) | | Min=Max(4nCK, 6.4ns) | | Min=Max(4nCK, 6.4ns) | | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to same bank group for 1KB page size | tRRD_L(1K) | Min=Max(4nCK, 4.9ns) | | Min=Max(4nCK, 4.9ns) | | Min=Max(4nCK, 4.9ns) | | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 1/ 2KB page size | tRRD_L(1/2K) | Min=Max(4nCK, 4.9ns) | | Min=Max(4nCK, 4.9ns) | | Min=Max(4nCK, 4.9ns) | | nCK | 34 |
| Four activate window for 2KB page size | tFAW_2K | Min=Max(28nCK, 30ns) | | Min=Max(28nCK, 30ns) | | Min=Max(28nCK, 30ns) | | ns | 34 |
| Four activate window for 1KB page size | tFAW_1K | Min=Max(20nCK, 21ns) | | Min=Max(20nCK, 21ns) | | Min=Max(20nCK, 21ns) | | ns | 34 |
| Four activate window for 1/2KB page size | tFAW_1/2K | Min=Max(16nCK, 12ns) | | Min=Max(16nCK, 10.875ns) | | Min=Max(16nCK, 10ns) | | ns | 34 |
| Delay from start of internal Write transaction to internal Read command for different bank group. | tWTR_S | Min=Max(2nCK, 2.5ns) | | Min=Max(2nCK, 2.5ns) | | Min=Max(2nCK, 2.5ns) | | ns | 1,2,34 |



| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|---------------|---|-----|----------------------|-----|----------------------|-----|------|---------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Delay from start of internal write transaction to internal read command for same bank group | tWTR_L | Min=Max(4nCK, 7.5ns) | | Min=Max(4nCK, 7.5ns) | | Min=Max(4nCK, 7.5ns) | | ns | 1 34 |
| Internal READ Command to PRE- CHARGE Command delay | tRTP | Min=Max(4nCK, 7.5ns) | | Min=Max(4nCK, 7.5ns) | | Min=Max(4nCK, 7.5ns) | | ns | 34 |
| WRITE recovery time | tWR | 15 | - | 15 | - | 15 | - | ns | 1 |
| Write recovery time when CRC and DM are enabled | tWR_CRC_DM | Min=tWR + Max (5nCK, 3.75ns) | | | | | | ns | 1 28 |
| delay from start of internal write trans- action to internal read command for different bank group with both CRC and DM enabled | tWTR_S_CRC_DM | Min=tWTR_S + Max(5nCK, 3.75ns) | | | | | | ns | 2 29 34 |
| delay from start of internal write trans- action to internal read command for same bank group with both CRC and DM enabled | tWTR_L_CRC_DM | Min=tWTR_L + Max(5nCK, 3.75ns) | | | | | | ns | 3 30 34 |
| DLL locking time | tDLLK | 1024 | - | 1024 | - | 1024 | - | nCK | |
| Mode Register Set command cycle time | tMRD | 8 | - | 8 | - | 8 | - | nCK | |
| Mode Register Set command update delay | tMOD | Min=Max(24nCK, 15ns) | | | | | | nCK | 50 |
| Multi-Purpose Register Recovery Time | tMPRR | 1 | - | 1 | - | 1 | - | nCK | 33 |
| Multi Purpose Register Write Recov- ery Time | tWR_MPR | Min=tMOD (min) + AL + PL | | | | | | nCK | |
| Auto precharge write recovery + pre- charge 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 | - | UI | 45, 47 |
| DQ0 or DQL0 driven to 0 hold time from last DQS falling edge | tPDA_H | 0.5 | - | 0.5 | - | 0.5 | - | UI | 46, 47 |
| CS_n to Command Address Latency | | | | | | | | | |
| CS_n to Command Address Latency | tCAL | max(3nCK, 3.748 ns) | - | max(3nCK, 3.748 ns) | - | max(3nCK, 3.748 ns) | - | nCK | |



| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|-----------|-------------|---------|-------------|---------|-------------|---------|------------|--------------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Mode Register Set command cycle time in CAL mode | tMRD_tCAL | tMOD + tCAL | - | tMOD + tCAL | - | tMOD + tCAL | - | nCK | |
| Mode Register Set update delay in CAL mode | tMOD_tCAL | tMOD + tCAL | - | tMOD + tCAL | - | tMOD + tCAL | - | nCK | |
| DRAM Data Timing | | | | | | | | | |
| DQS_t, DQS_c to DQ skew, per group, per acces | tDQSQ | - | 0.18 | - | 0.19 | - | TBD | tCK(avg)/2 | 13, 18,39,49 |
| DQ output hold time from DQS_t, DQS_c | tQH | 0.74 | - | 0.72 | - | TBD | - | tCK(avg)/2 | 17,18,39,49 |
| Data Valid Window per device per UI : (tQH - tDQSQ) of each UI on a given DRAM | tDVWd | 0.64 | - | TBD | - | 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 | 0.72 | - | TBD | - | 0.72 | - | UI | 17,18,39,49 |
| DQ low impedance time from CK_t, CK_c | tLZ(DQ) | -310 | 170 | -280 | 165 | -250 | 160 | ps | 39 |
| DQ high impedance time from CK_t, CK_c | tHZ(DQ) | - | 170 | - | 165 | - | 160 | ps | 39 |
| Data Strobe Timing | | | | | | | | | |
| DQS_t, DQS_c differential READ Preamble(1 clock preamble) | tRPRE | 0.9 | Note 44 | 0.9 | Note 44 | 0.9 | Note 44 | tCK | 39,40 |
| DQS_t, DQS_c differential READ Preamble(2 clock preamble) | tRPRE2 | 1.8 | Note 44 | 1.8 | Note 44 | 1.8 | Note 44 | tCK | 39, 41 |
| DQS_t, DQS_c differential READ Postamble | tRPST | 0.33 | Note 45 | 0.33 | Note 45 | 0.33 | Note 45 | tCK | 39 |
| DQS_t, DQS_c differential output high time | tQSH | 0.4 | - | 0.4 | - | 0.4 | - | tCK | 21,39 |
| DQS_t, DQS_c differential output low time | tQSL | 0.4 | - | 0.4 | - | 0.4 | - | tCK | 20,39 |
| DQS_t, DQS_c differential WRITE Preamble(1 clock preamble) | tWPRES | 0.9 | - | 0.9 | - | 0.9 | - | tCK | 42 |
| DQS_t, DQS_c differential WRITE Preamble(2 clock preamble) | tWPRES2 | 1.8 | - | 1.8 | - | 1.8 | - | tCK | 43 |



| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|------------------|-------------------------|------|-------------------------|------|-------------------------|------|------|-----------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| DQS_t, DQS_c differential WRITE Postamble | tWPST | 0.33 | - | 0.33 | - | 0.33 | - | tCK | |
| DQS_t and DQS_c low-impedance time (Referenced from RL-1) | tLZ(DQS) | -310 | 170 | -280 | 165 | -250 | 160 | ps | 39 |
| DQS_t and DQS_c high-impedance time (Referenced from RL+BL/2) | tHZ(DQS) | - | 170 | - | 165 | - | 160 | ps | 39 |
| DQS_t, DQS_c differential input low pulse width | tDQSL | 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 | 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 | tCK | 42 |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (2 clock preamble) | tDQSS2 | TBD | TBD | TBD | TBD | TBD | TBD | tCK | 43 |
| DQS_t, DQS_c falling edge setup time to CK_t, CK_c rising edge | tDSS | 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 | - | tCK | |
| DQS_t, DQS_c rising edge output variance window per DRAM | tDQSCKI (DLL On) | | 270 | | 265 | | 260 | ps | 37, 38,39 |
| DQS_t, DQS_c rising edge output timing locatino from rising CK_t, CK_c with DLL On mode | tDQSCK | -170 | 170 | -165 | 165 | -160 | 160 | 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) | - | tCK | |
| Valid clock requirement after MPSM entry | tCKMPE | tMOD(min) + tCPDED(min) | - | tMOD(min) + tCPDED(min) | - | tMOD(min) + tCPDED(min) | - | tCK | |
| Valid clock requirement before MPSM exit | tCKMPX | tCKSRX(min) | - | tCKSRX(min) | - | tCKSRX(min) | - | tCK | |
| Exit MPSM to commands not requiring a locked DLL | tXMP | tXS(min) | - | tXS(min) | - | tXS(min) | - | tCK | |
| Exit MPSM to commands requiring a locked DLL | tXMPDLL | tXMP(min) + tXSDLL(min) | - | tXMP(min) + tXSDLL(min) | - | tXMP(min) + tXSDLL(min) | - | tCK | |
| CS setup time to CKE | tMPX_S | tISmin + tIHmin | - | tISmin + tIHmin | - | tISmin + tIHmin | - | ns | |

| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|--|----------------|---------------------------------|-----|-----------------------|-----|-----------------------|-----|------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Calibration Timing | | | | | | | | | |
| Power-up and RESET calibration time | tZQinit | 1024 | - | 1024 | - | 1024 | - | nCK | |
| Normal operation Full calibration time | tZQoper | 512 | - | 512 | - | 512 | - | nCK | |
| Normal operation Short calibration time | tZQCS | 128 | - | 128 | - | 128 | - | nCK | |
| Reset/Self Refresh Timing | | | | | | | | | |
| Exit Reset from CKE HIGH to a valid command | tXPR | Min= max (5nCK,tRFC(min)+ 10ns) | | | | | | nCK | |
| Exit Self Refresh to commands not requiring a locked DLL | tXS | Min=tRFC(min) + 10ns | | | | | | nCK | |
| SRX to commands not requiring a locked DLL in Self Refresh ABORT | tXS_ABORT(min) | Min=tRFC4(min) + 10ns | | | | | | nCK | |
| Exit Self Refresh to ZQCL,ZQCS and MRS (CL,CWL,WR,RTP and Gear Down) | tXS_FAST(min) | Min=tRFC4(min) + 10ns | | | | | | nCK | |
| Exit Self Refresh to commands re- quiring a locked DLL | tXSDLL | tDLLK(min) | - | tDLLK(min) | - | tDLLK(min) | - | nCK | |
| Minimum CKE low width for Self re- fresh entry to exit timing | tCKESR | tCKE(min) + 1nCK | - | tCKE(min) + 1nCK | - | tCKE(min) + 1nCK | - | nCK | |
| Minimum CKE low width for Self re- fresh entry to exit timing with CA Par- ity enabled | tCKESR_PAR | 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,10 ns) | - | Max (5nCK,10 ns) | - | Max (5nCK,10 ns) | - | nCK | |
| 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 | - | nCK | |



| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note | |
|---|-------------|------------------------------|---------|-----------------|---------|-----------------|---------|------|-------|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | | |
| 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) | - | nCK | | |
| Power Down Timing | | | | | | | | | | |
| Exit Power Down with DLL on to any valid command;Exit Precharge Pow- er Down with DLL frozen to com- mands not requiring a locked DLL | tXP | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | nCK | | |
| CKE minimum pulse width | tCKE | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | | 31 32 | |
| Command pass disable delay | tCPDED | 4 | - | 4 | - | 4 | - | nCK | | |
| Power Down Entry to Exit Timing | tPD | tCKE(min) | 9*tREFI | tCKE(min) | 9*tREFI | tCKE(min) | 9*tREFI | | 6 | |
| Timing of ACT command to Power Down entry | tACTPDEN | 2 | - | 2 | - | 2 | - | nCK | 7 | |
| Timing of PRE or PREA command to Power Down entry | tPRPDEN | 2 | - | 2 | - | 2 | - | nCK | 7 | |
| Timing of RD/RDA command to Pow- er Down entry | tRDPDEN | Min=RL + 4 + 1 | | | | | | | nCK | |
| Timing of WR command to Power Down entry (BL8OTF, BL8MRS, BC4OTF) | tWRPDEN | Min=WL + 4 + (tWR/tCK(avg)) | | | | | | | nCK | 4 |
| Timing of WRA command to Power Down entry(BL8OTF, BL8MRS, BC4OTF) | tWRAPDEN | Min=WL + 4 + WR + 1 | | | | | | | nCK | 5 |
| Timing of WR command to Power Down entry (BC4MRS) | tWRPBC4DEN | Min=WL + 2 + (tWR/tCK(avg)) | | | | | | | nCK | 4 |
| Timing of WRA command to Power Down entry (BC4MRS) | tWRAPBC4DEN | Min=WL + 2 + WR + 1 | | | | | | | nCK | 5 |
| Timing of REF command to Power Down entry | tREFPDEN | 2 | - | 2 | - | 2 | - | nCK | 7 | |
| Timing of MRS command to Power Down entry | tMRSPDEN | tMOD(min) | - | tMOD (min) | - | tMOD (min) | - | | | |

| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|---------------|-------------------|----------|-------------------|----------|-------------------|----------|----------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Mode Register Set command cycle time in PDA mode | tMRD_PDA | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | nCK | |
| Mode Register Set command update delay in PDA mode | tMOD_PDA | tMOD | | tMOD | | tMOD | | nCK | |
| Asynchronous RTT turn-on delay (Power-Down with DLL frozen) | tAONAS | 1 | 9 | 1 | 9 | 1 | 9 | ns | |
| Asynchronous RTT turn-off delay (Power-Down with DLL frozen) | tAOFAS | 1 | 9 | 1 | 9 | 1 | 9 | ns | |
| RTT dynamic change skew | tADC | 0.28 | 0.72 | 0.26 | 0.74 | 0.26 | 0.74 | tCK(avg) | |
| First DQS_t/DQS_n rising edge after write leveling mode is programmed | tWLMRD | 40 | - | 40 | - | 40 | - | nCK | 12 |
| DQS_t/DQS_n delay after write leveling mode is programmed | tWLDQSEN | 25 | - | 25 | - | 25 | - | nCK | 12 |
| Write leveling setup time from rising CK_t, CK_c crossing to rising DQS_t/ DQS_n crossing | tWLS | 0.13 | - | 0.13 | - | 0.13 | - | tCK(avg) | |
| Write leveling hold time from rising DQS_t/DQS_n crossing to rising CK_t, CK_c crossing | tWLH | 0.13 | - | 0.13 | - | 0.13 | - | tCK(avg) | |
| Write leveling output delay | tWLO | 0 | 0.95 | 0 | 0.95 | 0 | 0.95 | ns | |
| Write leveling output error | tWLOE | - | 2 | - | 2 | - | 2 | ns | |
| CA Parity Timing | | | | | | | | | |
| Commands not guaranteed to be executed during this time | tPAR_UNKNOWN | - | PL | - | PL | - | PL | nCK | |
| Delay from errant command to ALERT_n assertion | tPAR_ALERT_ON | - | PL + 6ns | - | PL + 6ns | - | PL + 6ns | nCK | |
| Pulse width of ALERT_n signal when asserted | tPAR_ALERT_PW | 80 | 160 | 88 | 176 | 96 | 192 | nCK | |



| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|----------------|-------------|-----|-------------|-----|-------------|-----|------|------|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Time from when Alert is asserted till controller must start providing DES commands in Persistent CA parity mode | tPAR_ALERT_RSP | - | 71 | - | 78 | - | 85 | nCK | |
| Parity Latency | PL | 5 | | 6 | | 6 | | nCK | |
| CRC error to ALERT_n latency | tCRC_ALERT | 3 | 13 | 3 | 13 | 3 | 13 | ns | |
| CRC ALERT_n pulse width | CRC_ALERT_PW | 6 | 10 | 6 | 10 | 6 | 10 | nCK | |
| Gear Down Timing | | | | | | | | | |
| Exit RESET from CKE HIGH to a valid MRS geardown (T2/Reset) | tXPR_GEAR | tXPR | - | tXPR | - | tXPR | - | | |
| CKE High Assert to Gear Down Enable time(T2/CKE) | tXS_GEAR | tXS | - | tXS | - | tXS | - | | |
| MRS command to Sync pulse time(T3) | tSYNC_GEAR | tMOD + 4nCK | - | tMOD + 4nCK | - | tMOD + 4nCK | - | | 27 |
| Sync pulse to First valid command(T4) | tCMD_GEAR | tMOD | - | tMOD | - | tMOD | - | | 27 |
| Geardown setup time | tGEAR_setup | 2 | - | | | 2 | - | nCK | |
| Geardown hold time | tGEAR_hold | 2 | - | | | 2 | - | nCK | |
| tREFI | | | | | | | | | |
| tRFC1 (min) | 8Gb | 350 | - | 350 | - | 350 | - | ns | 34 |
| tRFC2 (min) | 8Gb | 260 | - | 260 | - | 260 | - | ns | 34 |
| tRFC4 (min) | 8Gb | 160 | - | 160 | - | 160 | - | 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 Read Auto Precharge) 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 Section 9.5
- 5 WR in clock cycles as programmed in MR0.
- 6 tREFI depends on T_{OPER}.
- 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 $t_{nPARAM}[nCK]=RU\{t_{nPARAM}[ns]/t_{CK}(avg)[ns]\}$, 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 $t_{jit(per)}_{total}$ 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”.
- 35 This parameter must keep consistency with “Speed Bin”.
- 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 $RONNOM = 34\Omega$
- 40 1tCK toggle mode with setting MR4:A11 to 0
- 41 2tCK toggle mode with setting MR4:A11 to 1, which is valid for DDR4-2400/2666/3200 speed grade.
- 42 1tCK mode with setting MR4:A12 to 0
- 43 2tCK mode with setting MR4:A12 to 1, which is valid for DDR4-2400/2666/3200 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 “Clock to Data Strobe Relationship” of DDR4 Operation Guide. Boundary of DQS Low-Z occur one cycle earlier in 2tCK toggle mode which is illustrated in “Read Preamble”.
- 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 "Clock to Data Strobe Relationship" of DDR4 Operation Guide.
- 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 $V_{TT} = VDDQ$
- 50 For MR7 commands, the minimum delay to a subsequent non-MRS command is 5nCK.

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9.5 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: $nCK = \text{ceiling} [(\text{parameter_in_ns} / \text{application_tCK_in_ns}) - 0.025]$
- 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: $nCK = \text{truncate} [\{ (\text{parameter_in_ps} \times 1000) / (\text{application_tCK_in_ps}) + 974 \} / 1000]$
- Either algorithm yields identical results. In case of conflict between results, the preferred algorithm is the integer math algorithm.
- This algorithm applies to all timing parameters documented in a Serial Presence Detect (SPD) when converting from ns to nCK. Other timing parameters may use a simpler algorithm: $nCK = \text{ceiling} (\text{parameter_in_ns} \div \text{application_tCK_in_ns})$.

9.6 The DQ Input Receiver Compliance Mask for Voltage and Timing

The DQ input receiver compliance mask for voltage and timing is shown in Figure 9-2 below. The receiver mask (Rx Mask) defines area the input signal must not encroach in order for the DRAM input receiver 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.

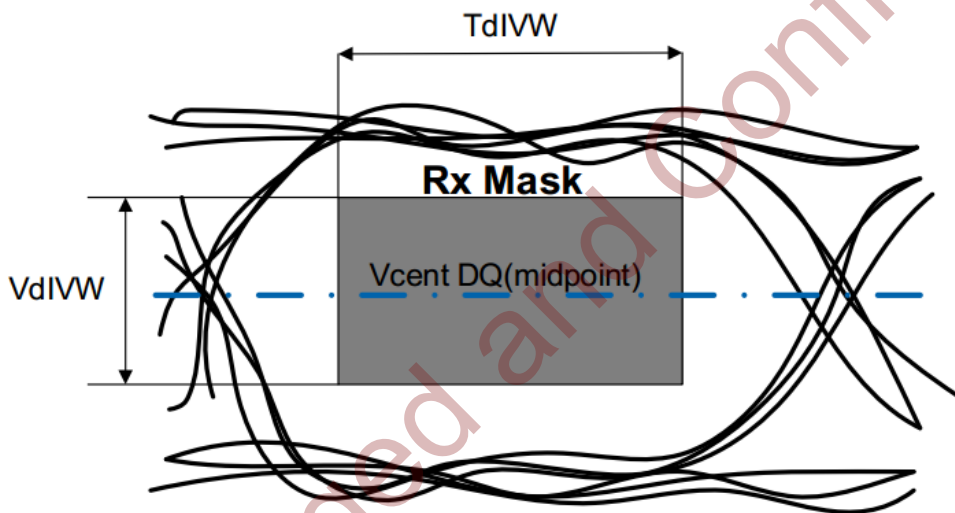


Figure 9-2 DQ Receiver(Rx) Compliance Mask

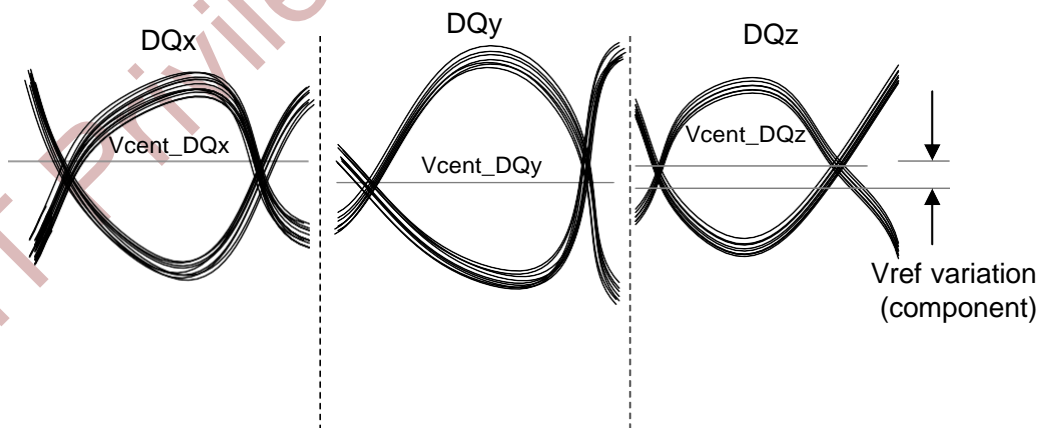


Figure 9-3 Across Pin Vref DQ Voltage Variation

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(pin avg) 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 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 9-3. This clarifies that any DRAM component level variation must be accounted for within the DRAM Rx mask. The component level Vref will be set by the system to account for RON and ODT settings.

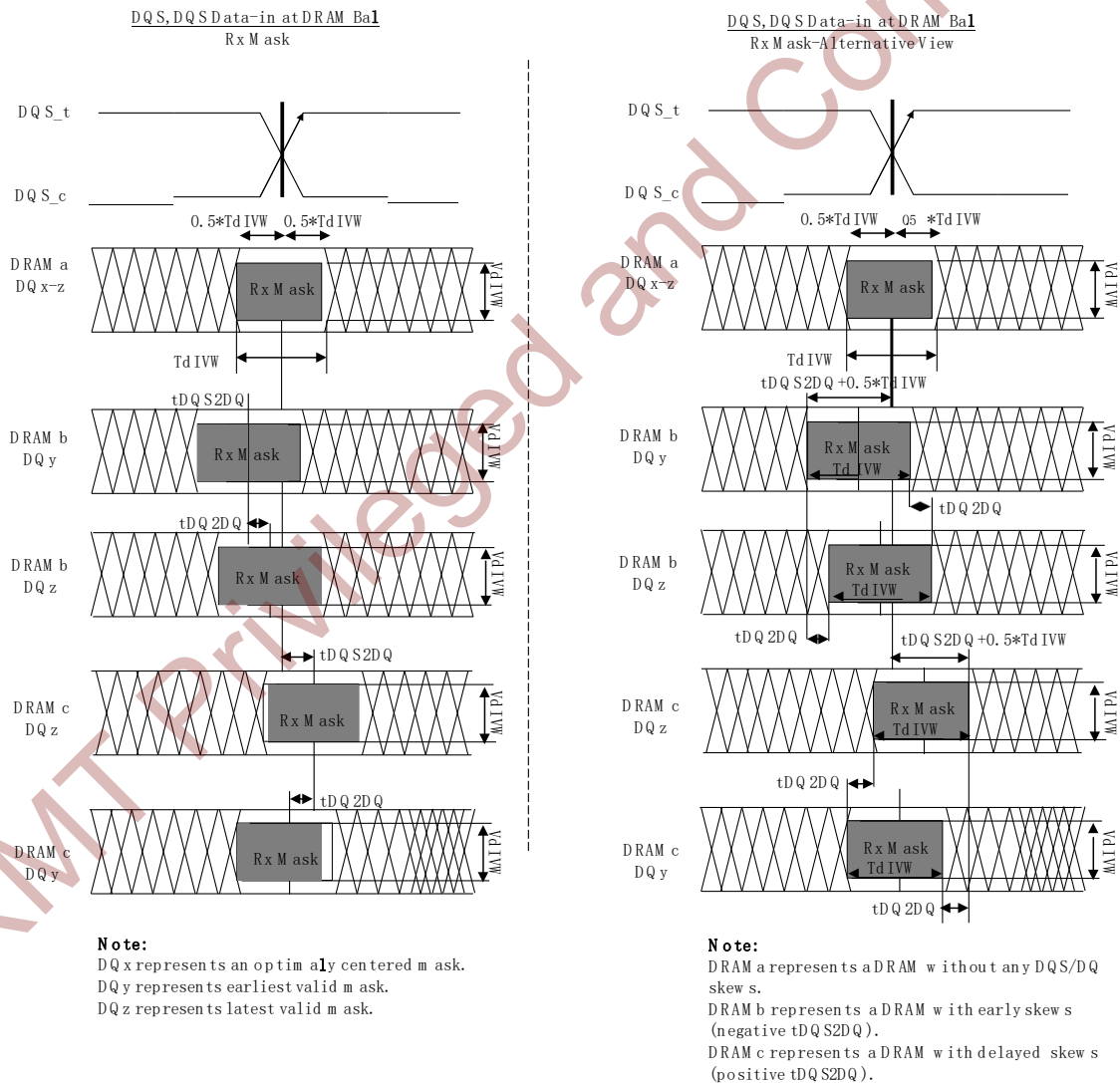


Figure 9-4 DQS to DQ and DQ to DQ Timings at DRAM Balls

Note:

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

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All of the timing terms in Figure 9-4 are measured at the V_{dIVW} voltage levels centered around $V_{cent_DQ}(\text{midpoint})$ 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 9-5 below: A low to high transition t_{r1} is measured from $.5*V_{dIVW}(\text{max})$ below $V_{cent_DQ}(\text{midpoint})$ to the last transition through $0.5*V_{dIVW}(\text{max})$ above $V_{cent_DQ}(\text{midpoint})$ while t_{r2} is measured from the last transition through $0.5*V_{dIVW}(\text{max})$ above $V_{cent_DQ}(\text{midpoint})$ to the first transition through the $0.5*V_{IHL_AC}(\text{min})$ above $V_{cent_DQ}(\text{midpoint})$.

Rising edge slew rate equations:

- $srr1 = V_{dIVW}(\text{max}) / t_{r1}$
- $srr2 = (V_{IHL_AC}(\text{min}) - V_{dIVW}(\text{max})) / (2*t_{r2})$

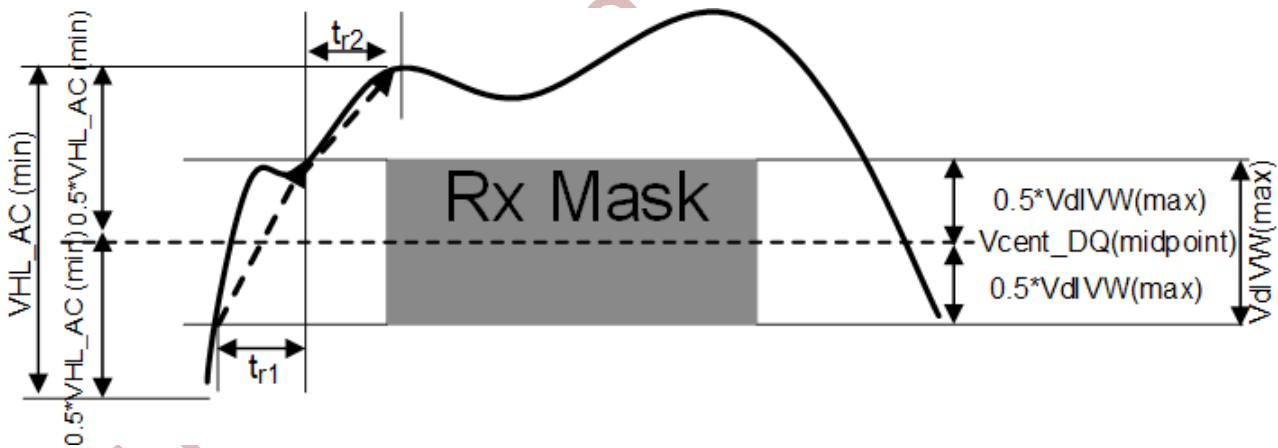


Figure 9-5 Slew Rate Conditions for Rising Transition

The falling edge slew rates are defined by srf1 and srf2. The slew rate measurement points for a falling edge are shown in Figure 9-6 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:

- $srf1 = VdiVW(max) / tf1$
- $srf2 = (VIHL_AC(min) - VdiVW(max)) / (2 * tf2)$

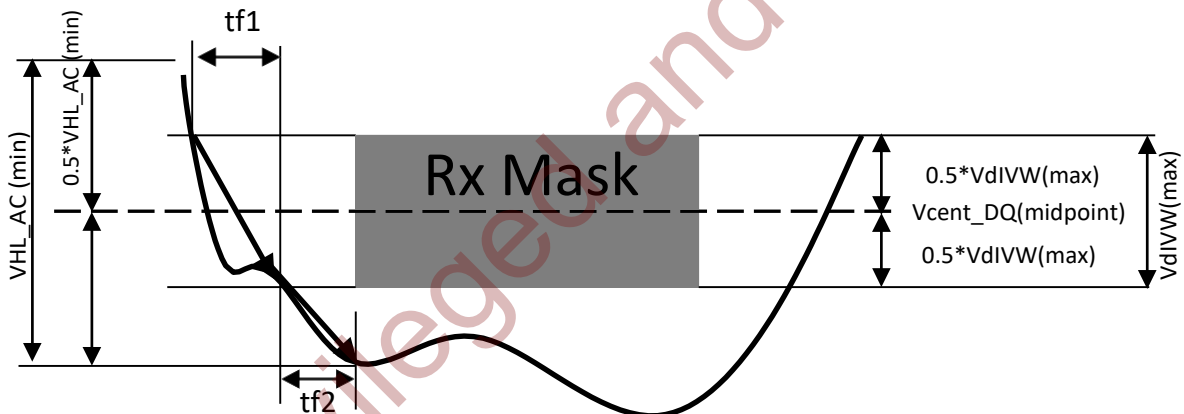


Figure 9-6 Slew Rate Conditions for Falling Transition

Table 9-4 DRAM DQs In Receive Mode; * UI=tck(avg)min/2

| 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 | Input Slew Rate over VdIVW if tCK >= 0.937ns | 1.0 | 9 | 1.0 | 9 | 1 | 9 | V/ns | 8,10 |
| srf1 | 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*srr1 | 9 | 0.2*srr1 | 9 | V/ns | 9,10 |

Note:

- 1 Data Rx mask voltage and timing total input valid window where V_{dIVW} is centered around V_{cent_DQ} (midpoint) after V_{refDQ} 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 V_{ref} range 1.
- 3 Overshoot and Undershoot Specifications see “AC Overshoot Specification for Data, Strobe and Mask”
- 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 T_{diPW} .
- 5 DQ minimum input pulse width defined at the V_{cent_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 V_{dIVW} Mask centered at V_{cent_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 V_{dIVW} 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 $T_{diVW}(min)$, $V_{diVW}(max)$, and minimum slew rate limits, then either $T_{diVW}(min)$ or minimum slew rates would have to be increased to the point where the minimum input pulse width would no longer be violated.

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

The total t_{IS} (setup time) and t_{IH} (hold time) required is calculated to account for slew rate variation by adding the data sheet t_{IS} (base) values, the $V_{IL}(AC)/V_{IH}(AC)$ points, and t_{IH} (base) values, the $V_{IL}(DC)/V_{IH}(DC)$ points; to the Δt_{IS} and Δt_{IH} derating values, respectively. The base values are derived with single-end signals at 1V/ns and differential clock at 2V/ns. Example: t_{IS} (total setup time) = t_{IS} (base) + Δt_{IS} . For a valid transition, the input signal has to remain above/below $V_{IH}(AC)/V_{IL}(AC)$ for the time defined by t_{VAC} .

Although the total setup time for slow slew rates might be negative (for example, a valid input signal will not have reached $V_{IH}(AC)/V_{IL}(AC)$ 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 rising signal is defined as the slew rate between the last crossing of VIH(DC)min and the first crossing of VIL(AC)min that does not ring back above VIL(DC)max.

Table 9-5 Command, Address, Control Setup and Hold Values

| DDR4- | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | 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 | 48 | 40 | ps | VIH/L(ac) |
| tIH(base,DC 65) | - | - | - | - | 80 | 73 | 65 | ps | VIH/L(dc) |
| tIS/tIH@ VREF | 215 | 200 | 180 | 162 | 145 | 138 | 130 | 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 9-6 Command, Address, Control Input Voltage Values

| DDR4- | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Reference |
|----------------|------|------|------|------|------|------|------|------|-----------|
| VIH. CA(AC)min | 100 | 100 | 100 | 100 | 90 | 90 | 90 | mV | VIH/L(ac) |
| VIH. CA(DC)min | 75 | 75 | 75 | 75 | 65 | 65 | 65 | mV | VIH/L(dc) |
| VIL. CA(DC)max | -75 | -75 | -75 | -75 | -65 | -65 | -65 | mV | VIH/L(ac) |
| VIL. CA(AC)max | -100 | -100 | -100 | -100 | -90 | -90 | -90 | mV | VIH/L(dc) |

Note:

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

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Table 9-7 Derating Values DDR4-1600/1866/2133/2400 tIS/tIH-ac/dc Based

| | | $\Delta tIS, \Delta tIH$ derating in [ps] AC/DC Based ¹ | | | | | | | | | | | | | | | |
|---|------|--|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | CK _t , CK _c Differential Slew Rate | | | | | | | | | | | | | | | |
| | | 10.0 V/ns | | 8.0 V/ns | | 6.0 V/ns | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.5 V/ns | | 1.0 V/ns | |
| | | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH |
| 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 9-8 Derating Values DDR4-2666 tIS/tIH-ac/dc Based

| | | $\Delta tIS, \Delta tIH$ derating in [ps] AC/DC based ¹ | | | | | | | | | | | | | | | |
|-----------------------------------|-----|--|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | CK_t, CK_c Differential Slew Rate | | | | | | | | | | | | | | | |
| | | 10.0 V/ns | | 8.0 V/ns | | 6.0 V/ns | | 4.0 V/ns | | 3.0 V/ns | | 2.0 V/ns | | 1.5 V/ns | | 1.0 V/ns | |
| | | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH | ΔtIS | ΔtIH |
| ADDR,CNTL Input Slew Rate V/ns | 7 | 68 | 47 | 69 | 47 | 70 | 48 | 72 | 50 | 73 | 52 | 77 | 56 | 85 | 63 | 100 | 78 |
| | 6 | 66 | 45 | 67 | 46 | 68 | 47 | 69 | 49 | 71 | 50 | 75 | 54 | 83 | 62 | 98 | 77 |
| | 5 | 63 | 43 | 64 | 44 | 65 | 45 | 66 | 46 | 68 | 48 | 72 | 52 | 80 | 60 | 95 | 75 |
| | 4 | 59 | 40 | 59 | 40 | 60 | 41 | 62 | 43 | 64 | 45 | 68 | 49 | 75 | 56 | 90 | 71 |
| | 3 | 51 | 34 | 52 | 35 | 53 | 36 | 54 | 38 | 56 | 40 | 60 | 43 | 68 | 51 | 83 | 66 |
| | 2 | 36 | 24 | 37 | 24 | 38 | 25 | 39 | 27 | 41 | 29 | 45 | 33 | 53 | 40 | 68 | 55 |
| | 1.5 | 21 | 13 | 22 | 13 | 23 | 14 | 24 | 16 | 26 | 18 | 30 | 22 | 38 | 29 | 53 | 44 |
| | 1 | -9 | -9 | -8 | -8 | -8 | -8 | -6 | -6 | -4 | -4 | 0 | 0 | 8 | 8 | 23 | 23 |
| | 0.9 | -15 | -13 | -15 | -12 | -14 | -11 | -12 | -9 | -10 | -7 | -6 | -4 | 1 | 4 | 16 | 19 |
| | 0.8 | -23 | -17 | -23 | -17 | -22 | -16 | -20 | -14 | -18 | -12 | -14 | -8 | -7 | -1 | 8 | 14 |
| | 0.7 | -34 | -23 | -33 | -22 | -32 | -21 | -30 | -20 | -28 | -18 | -25 | -14 | -17 | -6 | -2 | 9 |
| | 0.6 | -47 | -31 | -47 | -30 | -46 | -29 | -44 | -27 | -42 | -25 | -38 | -22 | -31 | -14 | -16 | 1 |
| | 0.5 | -67 | -42 | -66 | -41 | -65 | -40 | -63 | -38 | -61 | -36 | -58 | -33 | -50 | -25 | -35 | -10 |
| 0.4 | -95 | -58 | -95 | -57 | -94 | -56 | -92 | -54 | -90 | -53 | -86 | -49 | -79 | -41 | -64 | -26 | |

Note:

 1. VIH/L(ac) = \pm tbd mV, VIH/L(dc) = \pm tbd mV; relative to VREFCA.