# GDQ3BFAM

# DATASHEET

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# 1 FEATURES

- Power supply: $V_{DD}$ = $V_{DDQ}$ = 1.2V (1.14V to 1.26V); $V_{PP}$ = 2.5V (2.375V to 2.75V)
- JEDEC standard package: 96-Ball FBGA (x16)
- Array Configuration: 8 Banks (x16) 2 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 $V_{REF}$ for data inputs
- Data Mask (DM) for write data
- On-Die Termination (ODT): Support Nominal, Park and Dynamic ODT
- Interface: 1.2V Pseudo Open Drain (POD) IO
- Differential clock and data strobe inputs (CK_t ,CK_c; DQS_t, DQS_c)
- Per DRAM Addressability (PDA)
- Data Bus Inversion (DBI)
- Asynchronous reset for power up
- Maximum Power Saving Mode (MPSM)
- Precharge: Auto precharge option for each burst access
- Operating case temperature: -40°C $\leqslant$ $T_{CASE}$ $\leqslant$ 95°C
- Support auto-refresh and self-refresh mode
- Average Refresh Period:

  -7.8μs at -40°C $\leqslant$ $T_{CASE}$ $\leqslant$ 85°C

  -3.9μs at 85°C < $T_{CASE}$ $\leqslant$ 95°C
- Fine granularity refresh 2x, 4x mode for smaller $t_{RFC}$
- Programmable data strobe preambles
- Command Address (CA) Parity is supported
- Write Cyclic Redundancy Code (CRC) is supported
- Connectivity test mode (TEN) is supported
- Gear Down Mode
- Output driver calibration through ZQ pin ($R_{ZQ}$: 240ohm ± 1%)
- JEDEC JESD-79-4D compliant
- RoHS compliant

Note:

1. 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.



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## 1.1 Speed Bins

| Speed | DDR4-1600 | DDR4-1866 | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|
| | 11-11-11 | 13-13-13 | 15-15-15 | 17-17-17 | 19-19-19 | 22-22-22 | |
| $t_{CK\ (min)}$ | 1.25 | 1.071 | 0.937 | 0.833 | 0.75 | 0.625 | ns |
| CAS Latency | 11 | 13 | 15 | 17 | 19 | 22 | nCK |
| $t_{RCD\ (min)}$ | 13.75 | 13.92 | 14.06 | 14.16 | 14.25 | 13.75 | ns |
| $t_{RP\ (min)}$ | 13.75 | 13.92 | 14.06 | 14.16 | 14.25 | 13.75 | ns |
| $t_{RAS\ (min)}$ | 35 | 34 | 33 | 32 | 32 | 32 | ns |
| $t_{RC\ (min)}$ | 48.75 | 47.92 | 47.06 | 46.16 | 46.25 | 45.75 | ns |

## 1.2 Address Table

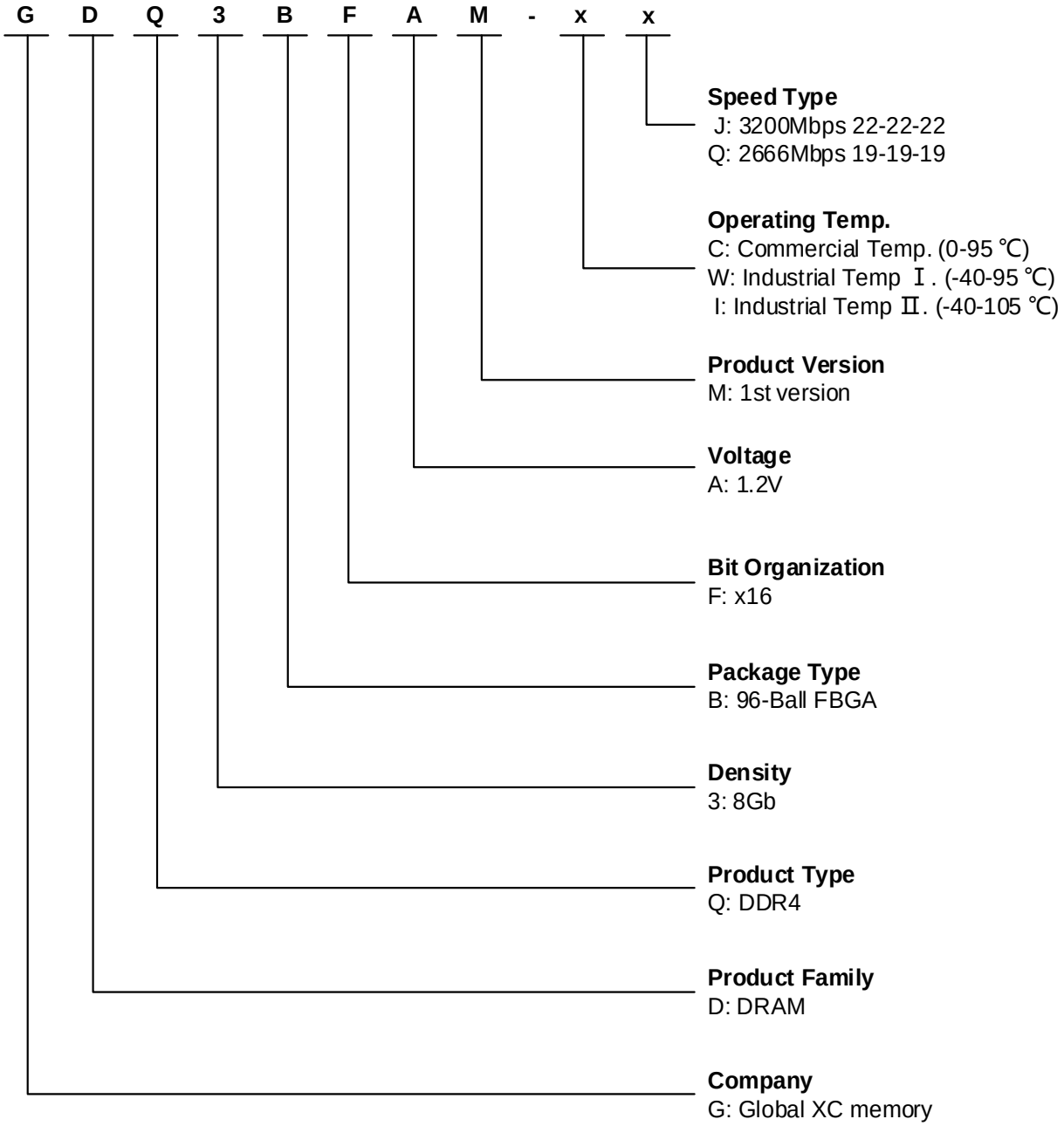
| Parameter | 512Mb x16 |
|---|---|
| Number of Bank Groups | 2 |
| Number of Banks per Bank Group | 4 |
| Bank Group Address | BG0 |
| Bank Address per Bank Group | BA0 ~ BA1 |
| Row Address | A0 ~ A15 |
| Column Address | A0 ~ A9 |
| Page Size | 2KB |



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# 2 ORDERING INFORMATION

## 2.1 Part Number Decoding






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## 2.2 Valid Part Numbers

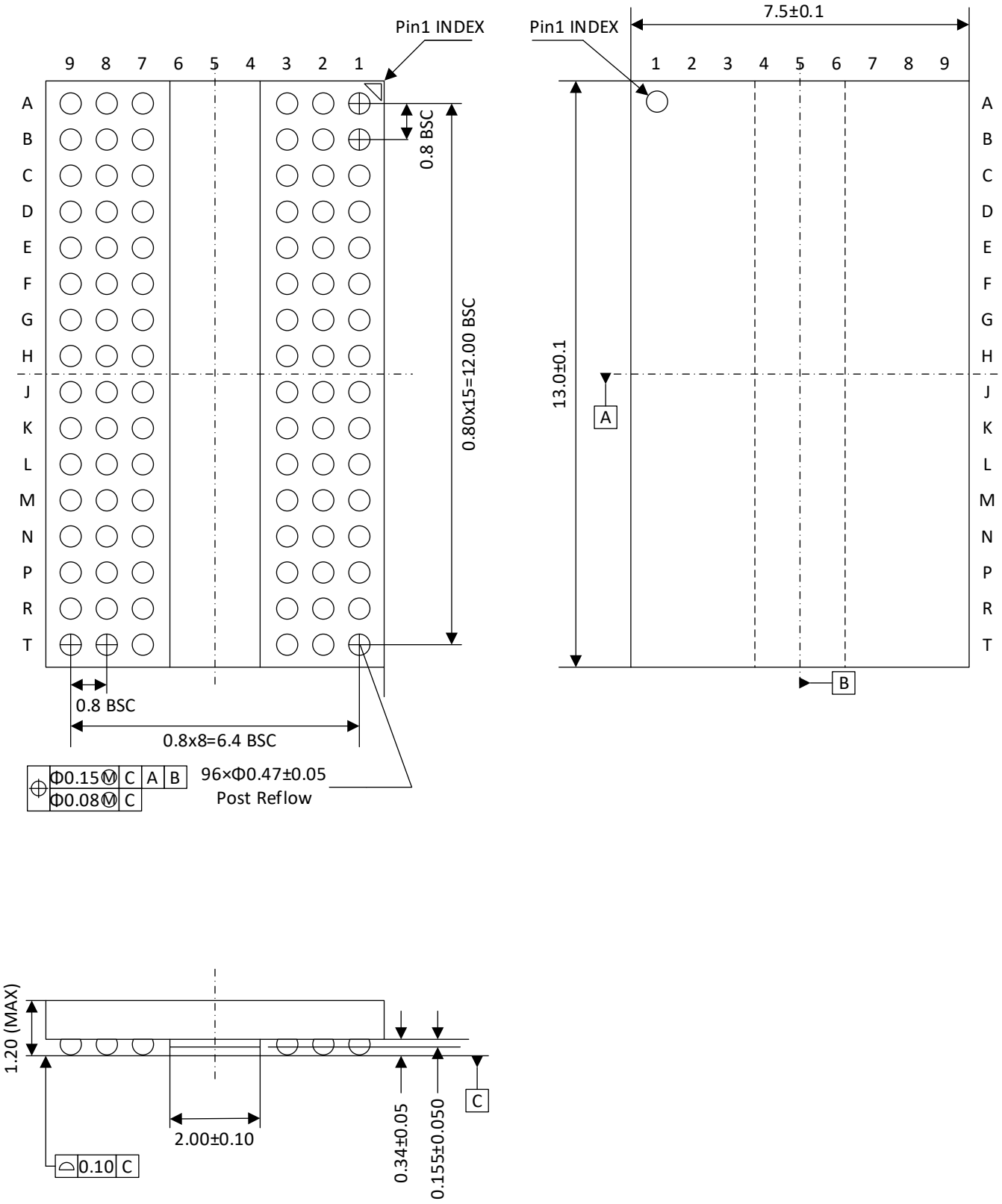
| Part Number | Organization | Data Rate | CL-$t_{RCD}$-$t_{RP}$ |
|---|---|---|---|
| GDQ3BFAM-CQ | 512Mb x16 | 2666Mbps | 19-19-19 |
| GDQ3BFAM-CJ | 512Mb x16 | 3200Mbps | 22-22-22 |
| GDQ3BFAM-WQ | 512Mb x16 | 2666Mbps | 19-19-19 |
| GDQ3BFAM-WJ | 512Mb x16 | 3200Mbps | 22-22-22 |
| GDQ3BFAM-IQ | 512Mb x16 | 2666Mbps | 19-19-19 |
| GDQ3BFAM-IJ | 512Mb x16 | 3200Mbps | 22-22-22 |



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# 3 PACKAGE INFORMATION

## 3.1 Package 96-Ball FBGA (x16)

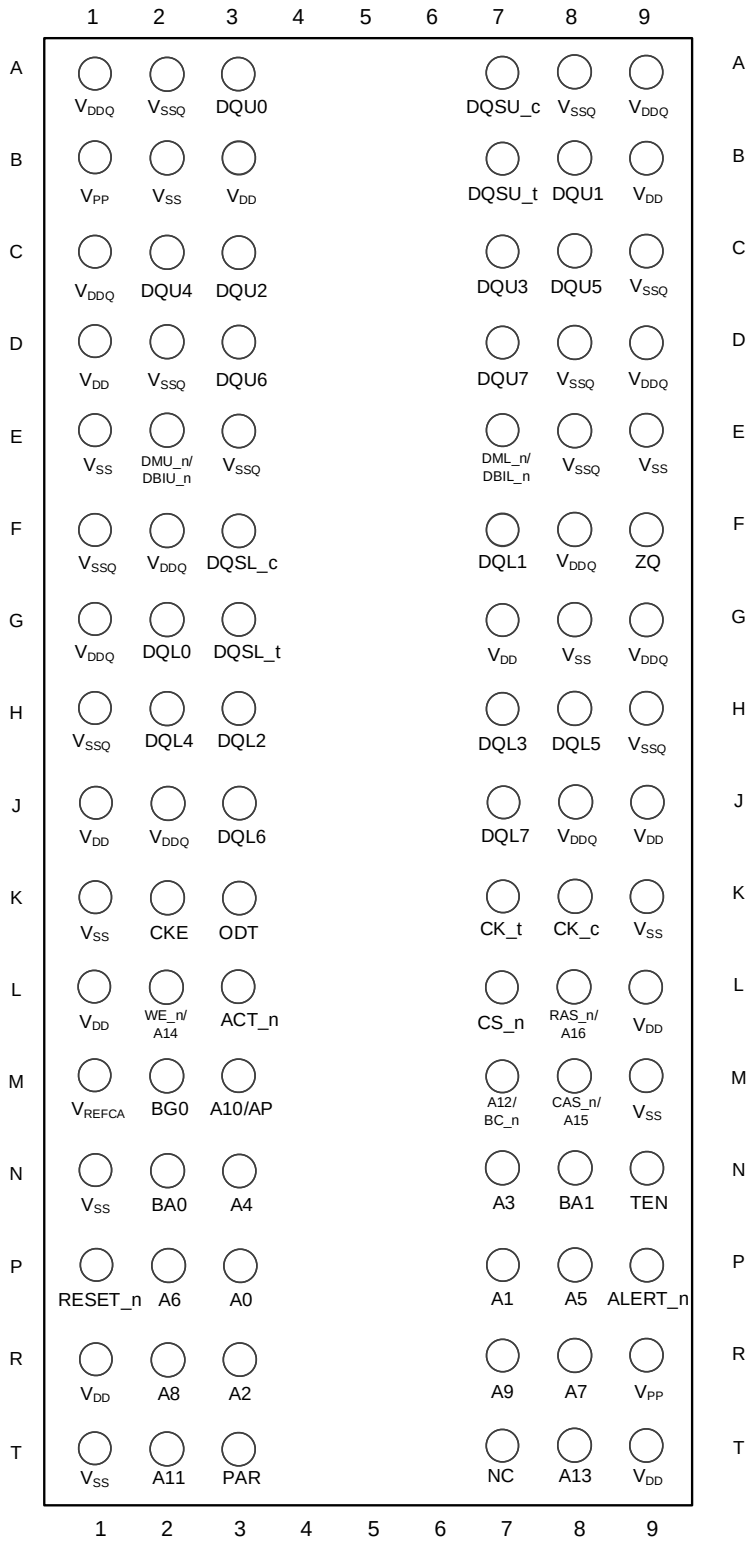





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# 4 BALL ASSIGNMENTS

## 4.1 96-Ball FBGA (x16) Ball Assignments






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## 4.2 Ball 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, however, timing parameters such as tXS are still calculated from the first rising clock edge where CKE HIGH satisfies tIS. After $V_{REFCA}$ and Internal DQ $V_{REF}$ 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 $R_{TT_NOM}$ termination resistance internal to the DDR4 SDRAM. When enabled, ODT is only applied to each DQ, DQS_t, DQS_c, DM_n/DBI_n/TDQS_t and 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 $R_{TT_NOM}$. |
| 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. These balls have multi function. For example, for activation with ACT_n LOW, those are Addressing like A16, A15 and A14 but for non-ACTIVATION command with ACT_n HIGH, those are command pins for READ, WRITE and other command defined in command truth table in JESD79-4D. |
| DM_n, DBI_n DMU_n/ DBIU_n DML_n/ DBIL_n | I/O | **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. 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. |
| BG[1:0] | Input | **Bank Group Inputs:** BG[1:0] define the bank group to which an ACTIVE, READ, WRITE or PRECHARGE command is being applied. BG0 also determines which mode register is to be accessed during an MRS cycle. x4/x8 have BG0 and BG1, but x16 has only BG0. |



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| Symbol | Type | Function |
|---|---|---|
| BA[1:0] | Input | **Bank Address Inputs:** BA[1:0] define the bank to which an ACTIVE, READ, WRITE or PRECHARGE command is being applied. Bank address also determines which mode register is to be accessed during an MRS cycle. |
| A[17:0] | Input | **Address Inputs:** Provide the row address for ACTIVATE commands and the column address for READ/WRITE commands to select one location out of the memory array in the respective bank. (A10/AP, A12/BC_n, RAS_n/A16, CAS_n/A15 and WE_n/A14 have additional functions, see other rows.) The address inputs also provide the op-code during MODE REGISTER SET commands. |
| A10/AP | Input | **Auto-precharge:** A10 is sampled during READ/WRITE commands to determine whether Auto-precharge should be performed to the accessed bank after the READ/WRITE operation. (HIGH: Auto-precharge; LOW: No Auto-precharge). 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” in JESD79-4D. |
| RESET_n | Input | **Active LOW Asynchronous Reset:** Reset is active when RESET_n is LOW, and inactive when RESET_n is HIGH. RESET_n must be HIGH during normal operation. RESET_n is a CMOS rail to rail signal with DC HIGH and LOW at 80% and 20% of $V_{DD}$. |
| DQ<br>DQL,<br>DQU | I/O | **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 DQ3 ~ DQ0 may indicate the internal $V_{REF}$ level during test via mode register setting MR4 A4 = HIGH. During this mode, $R_{TT}$ value should be set to High-Z. This measurement is for verification purposes and is NOT an external voltage supply pin. |
| DQS_t,<br>DQS_c,<br>DQSU_t,<br>DQSU_c,<br>DQSL_t,<br>DQSL_c | I/O | **Data Strobe:** Output with READ data, input with WRITE data. Edge-aligned with READ data, centered-aligned with WRITE data. For x16, DQSL corresponds to the data on DQL0-DQL7; DQSU corresponds to the data on DQU0-DQU7. The data strobe DQS_t, DQSL_t and DQSU_t are paired with differential signals DQS_c, DQSL_c, and DQSU_c, respectively, to provide differential pair signaling to the system during reads and writes. DDR4 SDRAM supports differential data strobe only and does not support single-ended. |
| TDQS_t,<br>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 $R_{TT}$ termination resistance function on TDQS_t/TDQS_c that is applied to DQS_t/DQS_c. When the TDQS function is disabled via mode register A11 = 0 in MR1, DM/DBI/TDQS pin will provide the Data Mask (DM) function or Data Bus Inversion (DBI) 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, BG[1:0], BA[1:0], A[17:0]. Command and address inputs shall have parity check performed when commands are latched via the rising edge of CK_t and when CS_n is LOW. |



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| Symbol | Type | Function |
|---|---|---|
| ALERT_n | I/O | **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 $V_{DD}$ on board. |
| TEN | Input | **Connectivity Test Mode Enable:** TEN is active when HIGH and inactive when LOW. TEN must be LOW during normal operation. It is 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 $V_{DD}$. Using this signal or not is dependent on system. This pin may be DRAM internally pulled low through a weak pull-down resistor to $V_{SS}$. |
| NC | - | **No Connect:** No internal electrical connection is present. |
| $V_{DDQ}$ | Supply | **DQ Power Supply:** 1.2V ± 0.06V |
| $V_{SSQ}$ | Supply | **DQ Ground** |
| $V_{DD}$ | Supply | **Power Supply:** 1.2V ± 0.06V |
| $V_{SS}$ | Supply | **Ground** |
| $V_{PP}$ | Supply | **DRAM Activating Power Supply:** 2.5V (2.375V min, 2.75V max) |
| $V_{REFCA}$ | Supply | **Reference Voltage for CA** |
| ZQ | Supply | **Reference Pin for ZQ Calibration** |

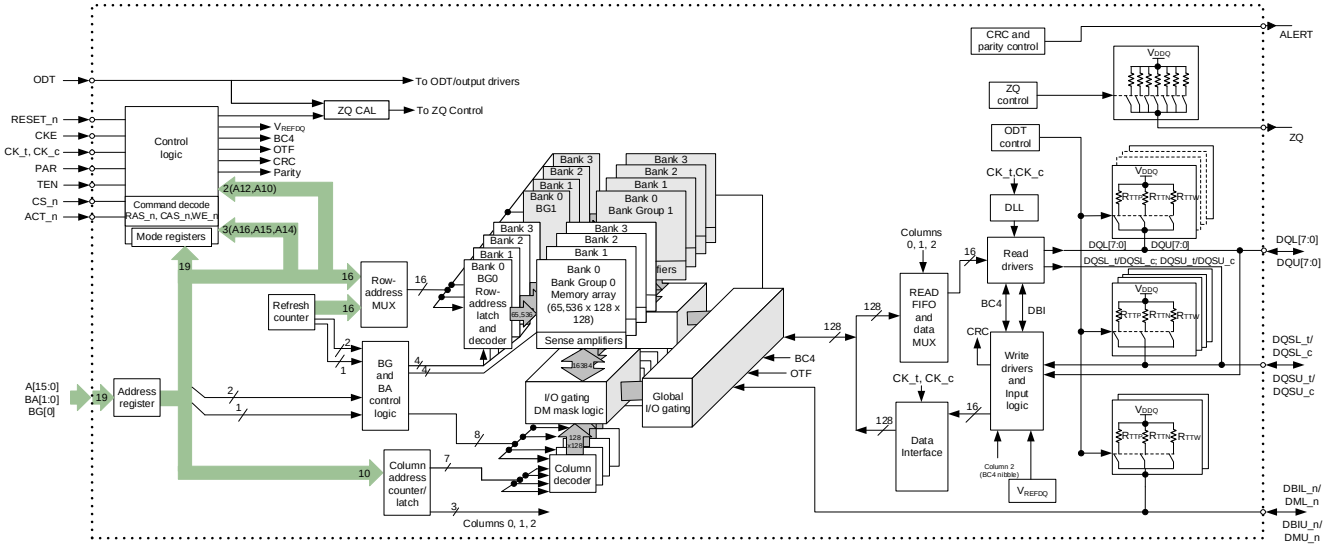


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# 5 Functional Block Diagram

DDR4 SDRAM is a high-speed, CMOS dynamic random-access memory. It is internally configured as a 8-bank (4 banks per Bank Group) DRAM.

**Figure 5-1. 512 Meg x 16 Functional Block Diagram**






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# 6 ABSOLUTE MAXIMUM RATINGS

## 6.1 Absolute Maximum DC Ratings

**Table 6-1. Absolute Maximum DC Ratings**

| Symbol | Parameter | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| $V_{DD}$ | Voltage on $V_{DD}$ pin relative to $V_{SS}$ | -0.3 | 1.5 | V | 1,3 |
| $V_{DDQ}$ | Voltage on $V_{DDQ}$ pin relative to $V_{SS}$ | -0.3 | 1.5 | V | 1,3 |
| $V_{PP}$ | Voltage on $V_{PP}$ pin relative to $V_{SS}$ | -0.3 | 3.0 | V | 4 |
| $V_{IN}$, $V_{OUT}$ | Voltage on any pin except $V_{REFCA}$ relative to $V_{SS}$ | -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. $V_{DD}$ and $V_{DDQ}$ must be within 300mV of each other at all times; and $V_{REFCA}$ must not be greater than 0.6 * $V_{DDQ}$, When $V_{DD}$ and $V_{DDQ}$ are less than 500mV; $V_{REF}$ may be equal to or less than 300mV.
4. $V_{PP}$ must be equal to or greater than $V_{DD}$/$V_{DDQ}$ at all times.
5. Overshoot area above 1.5V is specified in Section 7.3.5 and Section 7.3.6.

## 6.2 Recommended Supply Operating Conditions

**Table 6-2. Recommended Supply Operating Conditions**

| Symbol | Parameter | Ratings | | | Unit | Note |
|---|---|---|---|---|---|---|
| | | Min | Typ. | Max | | |
| $V_{DD}$ | Supply voltage | 1.14 | 1.2 | 1.26 | V | 1,2,3 |
| $V_{DDQ}$ | Supply voltage for output | 1.14 | 1.2 | 1.26 | V | 1,2,3 |
| $V_{PP}$ | Wordline supply voltage | 2.375 | 2.5 | 2.75 | V | 3 |

Note:

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



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## 6.3 DRAM Component Operating Temperature Range

**Table 6-3. Operating Temperature Range**

| Symbol | Parameter | Rating | Unit | Note |
|---|---|---|---|---|
| $T_{OPER}$ | Normal temperature range | 0 ~ 85 | °C | 1,2 |
| | Wide temperature | -40 ~ 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 - 95°C under all operating conditions for the commercial offering; The wide temperature offerings allow the case temperature to go below 0°C to -40°C.
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 3.9µs. It is also possible to specify a component with 1X refresh ($t_{REFI}$ to 7.8µs) 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).



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# 7 AC AND DC INPUT MEASUREMENT LEVELS

## 7.1 AC and DC Logic Input Levels for Single-ended Signals

**Table 7-1. Single-ended AC and DC Input Levels for Command and Address**

| Symbol | Parameter | 1600/1866/2133/2400 | | 2666/2933/3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | | |
| $V_{IH(DC75)}$ | DC input logic HIGH | $V_{REFCA}$ + 0.075 | $V_{DD}$ | - | - | V | - |
| $V_{IL(DC75)}$ | DC input logic LOW | $V_{SS}$ | $V_{REFCA}$ - 0.075 | - | - | V | - |
| $V_{IH(DC65)}$ | DC input logic HIGH | - | - | $V_{REFCA}$ + 0.065 | $V_{DD}$ | V | - |
| $V_{IL(DC65)}$ | DC input logic LOW | - | - | $V_{SS}$ | $V_{REFCA}$ - 0.065 | V | - |
| $V_{IH(AC100)}$ | AC input logic HIGH | $V_{REF}$ + 0.1 | Note 2 | - | - | V | 1 |
| $V_{IL(AC100)}$ | AC input logic LOW | Note 2 | $V_{REF}$ - 0.1 | - | - | V | 1 |
| $V_{IH(AC90)}$ | AC input logic HIGH | - | - | $V_{REF}$ + 0.09 | Note 2 | V | 1 |
| $V_{IL(AC90)}$ | AC input logic LOW | - | - | Note 2 | $V_{REF}$ - 0.09 | V | 1 |
| $V_{REFCA(DC)}$ | Reference voltage for ADD, CMD inputs | 0.49 * $V_{DD}$ | 0.51 * $V_{DD}$ | 0.49 * $V_{DD}$ | 0.51 * $V_{DD}$ | V | 2,3 |

Note:

1. See “Overshoot/Undershoot Specifications” in Section 7.3.4.
2. The AC peak noise on $V_{REFCA}$ may not allow $V_{REFCA}$ to deviate from $V_{REFCA(DC)}$ by more than ± 1%$V_{DD}$ (for reference: approx. ± 12mV)
3. For reference: approx. $V_{DD}/2$ ± 12mV



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## 7.2 AC and DC Input Measurement Levels: $V_{REF}$ Tolerances

The DC-tolerance limits and AC-noise limits for the reference voltages $V_{REFCA}$ are illustrated in the Figure 7-1 below. It shows a valid reference voltage $V_{REF(t)}$ as a function of time. ($V_{REF}$ stands for $V_{REFCA}$).

$V_{REF(DC)}$ is the linear average of $V_{REF(t)}$ over a very long period of time (for example, 1 second). This average has to meet the min/max requirements in Figure 7-1. Furthermore $V_{REF(t)}$ may temporarily deviate from $V_{REF(DC)}$ by no more than ± 1% $V_{DD}$ for the AC-noise limit.

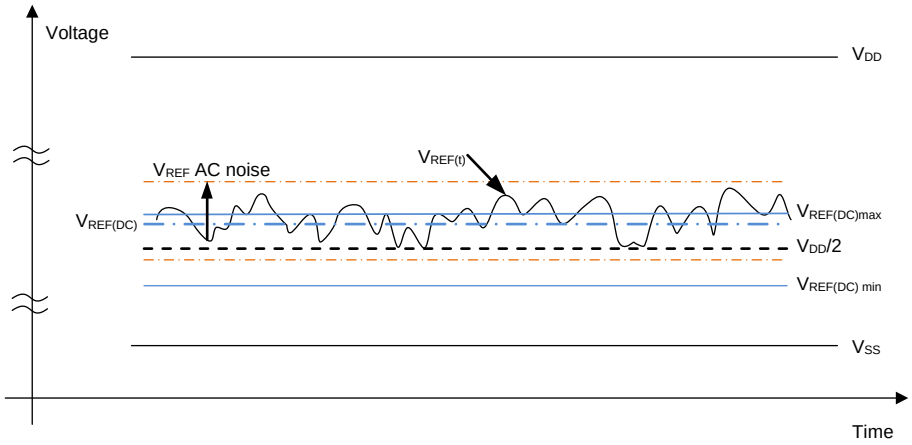



**Figure 7-1. Illustration of $V_{REF(DC)}$ Tolerance and $V_{REF}$ AC-noise Limits**

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

"$V_{REF}$" should be understood as $V_{REF(DC)}$.

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

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



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## 7.3 AC and DC Logic Input Levels for Differential Signals

### 7.3.1 AC and DC Logic Input Levels for Differential Signals

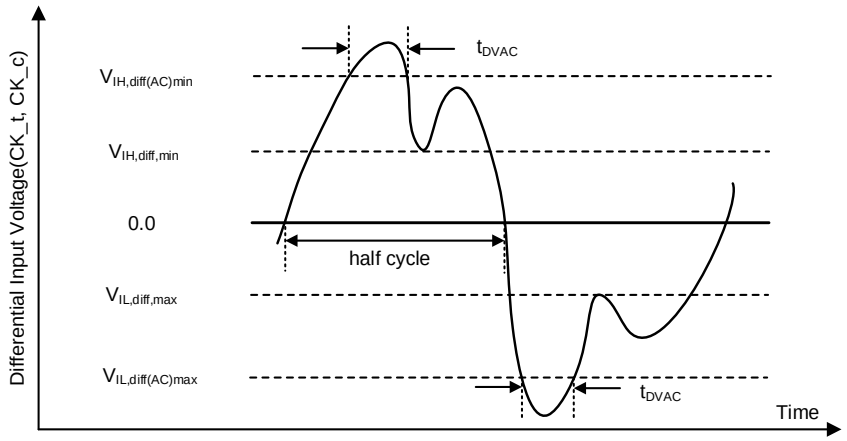



**Figure 7-2. Definition of Differential AC-Swing and "Time above AC-Level" $t_{DVAC}$**

Note:

1. Differential signal rising edge from $V_{IL,diff,max}$ to $V_{IH,diff(AC)min}$ must be monotonic slope.
2. Differential signal falling edge from $V_{IH,diff,min}$ to $V_{IL,diff(AC)max}$ must be monotonic slope.

### 7.3.2 Differential Swing Requirements for Clock (CK_t - CK_c)

**Table 7-2. Differential Input Levels Requirements for CK_t - CK_c**

| Symbol | Parameter | 1600/1866/2133 | | 2400/2666 | | 2933 | | 3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| $V_{IH,diff}$ | Differential input high | +0.150 | Note 3 | +0.135 | Note 3 | 125 | Note 3 | +0.110 | Note 3 | V | 1 |
| $V_{IL,diff}$ | Differential input low | Note 3 | -0.150 | Note 3 | -0.135 | Note 3 | -125 | Note 3 | -0.110 | V | 1 |
| $V_{IH,diff(AC)}$ | Differential input high (AC) | 2 * ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | 2 * ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | 2 * ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | 2 * ($V_{IH(AC)}$ - $V_{REF}$) | Note 3 | V | 2 |
| $V_{IL,diff(AC)}$ | Differential input low (AC) | Note 3 | 2 * ($V_{IL(AC)}$ - $V_{REF}$) | Note 3 | 2 * ($V_{IL(AC)}$ - $V_{REF}$) | Note 3 | 2 * ($V_{IL(AC)}$ - $V_{REF}$) | Note 3 | 2 * ($V_{IL(AC)}$ - $V_{REF}$) | V | 2 |

Note:

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



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**Table 7-3. Allowed Time before Ringback ($t_{DVAC}$) for CK_t - CK_c**

| Slew Rate [V/ns] | $t_{DVAC}$ [ps] @ $\|V_{IHL,diff(AC)}\|$ = 200mV | | $t_{DVAC}$ [ps] @ $\|V_{IHL,diff(AC)}\|$ = 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 | - |

### 7.3.3 Single-ended requirements for differential signals

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

CK_t and CK_c have to approximately reach $V_{SEHmin}/V_{SELmax}$ (approximately equal to the AC-levels ($V_{IH(AC)}/V_{IL(AC)}$) 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 $V_{IH(AC100)}/V_{IL(AC100)}$ is used for ADD/CMD signals, then these AC-levels apply also for the single-ended signals CK_t and CK_c.

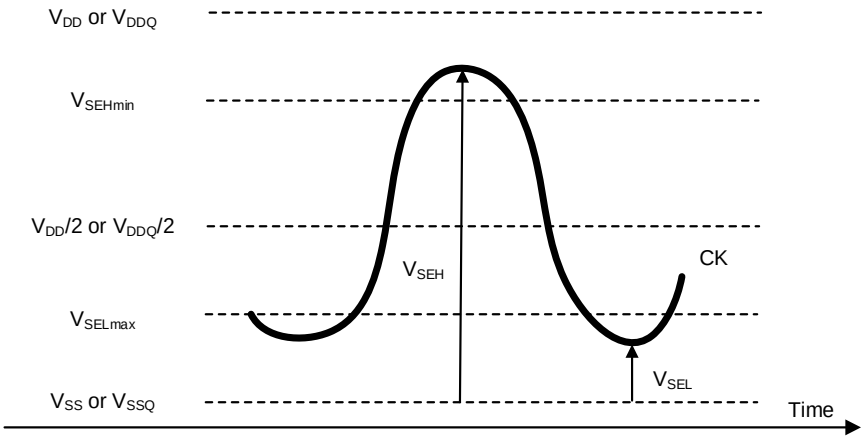



**Figure 7-3. Single-ended Requirement for differential signals**

Note that, while ADD/CMD signal requirements are with respect to $V_{REFCA}$, the single-ended components of differential signals have a requirement with respect to $V_{DD}/2$, 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 $V_{SELmax}$, $V_{SEHmin}$ has no bearing on timing, but adds a restriction on the common mode characteristics of these signals.



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**Table 7-4. Single-ended Levels for CK_t, CK_c**

| Symbol | Parameter | 1600/1866/2133 | | 2400/2666 | | 2933/3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | | |
| $V_{SEH}$ | Single-ended high-level for CK_t, CK_c | $V_{DD}$/2 + 0.100 | Note 3 | $V_{DD}$/2 + 0.095 | Note 3 | $V_{DD}$/2 + 0.085 | Note 3 | V | 1,2 |
| $V_{SEL}$ | Single-ended low-level for CK_t, CK_c | Note 3 | $V_{DD}$/2 - 0.100 | Note 3 | $V_{DD}$/2 - 0.095 | Note 3 | $V_{DD}$/2 - 0.085 | V | 1,2 |

Note:

1. For CK_t - CK_c use $V_{IH(AC)}$ /$V_{IL(AC)}$ of ADD/CMD and $V_{REFCA}$.
2. $V_{IH(AC)}$/$V_{IL(AC)}$ for ADD/CMD is based on $V_{REFCA}$.
3. These values are not defined, however the single-ended signals CK_t, CK_c needs to be within the respective limits ($V_{IH(DC)max}$, $V_{IL(DC)min}$) for single-ended signals as well as the limitations for overshoot and undershoot.

### 7.3.4 Address, Command, and Control Overshoot/Undershoot Specifications

**Table 7-5. AC Overshoot/Undershoot Specification for Address, Command, and Control Pins**

| Parameter | Symbol | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximum peak amplitude above $V_{AOS}$ | $V_{AOSP}$ | 0.06 | | | | | | | V | - |
| Upper boundary of overshoot area $A_{AOS1}$ | $V_{AOS}$ | $V_{DD}$ + 0.24 | | | | | | | V | 1 |
| Maximum peak amplitude allowed for undershoot area | $V_{AUS}$ | 0.30 | | | | | | | V | - |
| Maximum overshoot area per 1 $t_{CK}$ above $V_{AOS}$ | $A_{AOS2}$ | 0.0083 | 0.0071 | 0.0062 | 0.0055 | 0.0055 | 0.0055 | 0.0055 | V-ns | - |
| Maximum overshoot area per 1 $t_{CK}$ between $V_{DD}$ and $V_{AOS}$ | $A_{AOS1}$ | 0.2550 | 0.2185 | 0.1914 | 0.1699 | 0.1699 | 0.1699 | 0.1699 | V-ns | - |
| Maximum undershoot area per 1 $t_{CK}$ below $V_{SS}$ | $A_{AUS}$ | 0.2644 | 0.2265 | 0.1984 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | V-ns | - |
| (A0-A13, BG0-BG1, BA0-BA1, ACT_n, RAS_n/A16, CAS_n/A15, WE_n/A14, CS_n, CKE, ODT) | | | | | | | | | | |

Note:

1. The value of $V_{AOS}$ matches $V_{DD}$ absolute max as defined in Table 6-1 if $V_{DD}$ equals $V_{DD}$ max as defined inTable 6-2. If $V_{DD}$ is above the recommended operating conditions, $V_{AOS}$ remains at $V_{DD}$ absolute max as defined in Table 6-1.



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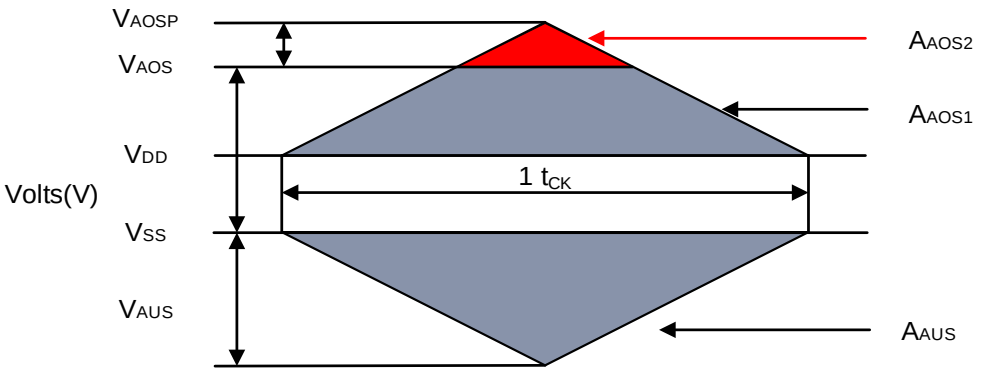



**Figure 7-4. Address, Command, and Control Overshoot and Undershoot Definition**

### 7.3.5 Clock Overshoot/Undershoot Specifications

**Table 7-6. AC Overshoot/Undershoot Specification for Clock**

| Parameter | Symbol | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximum peak amplitude above $V_{COS}$ | $V_{COSP}$ | 0.06 | | | | | | | V | - |
| Upper boundary of overshoot area $A_{COS1}$ | $V_{COS}$ | $V_{DD}$ + 0.24 | | | | | | | V | 1 |
| Maximum peak amplitude allowed for undershoot | $V_{CUS}$ | 0.30 | | | | | | | V | - |
| Maximum overshoot area per 1 UI above $V_{COS}$ | $A_{COS2}$ | 0.0038 | 0.0032 | 0.0028 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | V-ns | - |
| Maximum overshoot area per 1 UI between $V_{DD}$ and $V_{COS}$ | $A_{COS1}$ | 0.1125 | 0.0964 | 0.0844 | 0.0750 | 0.0750 | 0.0750 | 0.0750 | V-ns | - |
| Maximum undershoot area per 1 UI below $V_{SS}$ | $A_{CUS}$ | 0.1144 | 0.098 | 0.0858 | 0.0762 | 0.0762 | 0.0762 | 0.0762 | V-ns | - |
| (CK_t, CK_c) | | | | | | | | | | |

Note:

1. The value of $V_{COS}$ matches $V_{DD}$ absolute max as defined in Table 6-1 if $V_{DD}$ equals $V_{DD}$ max as defined in Table 6-2. If $V_{DD}$ is above the recommended operating conditions, $V_{COS}$ remains at $V_{DD}$ absolute max as defined in Table 6-1.

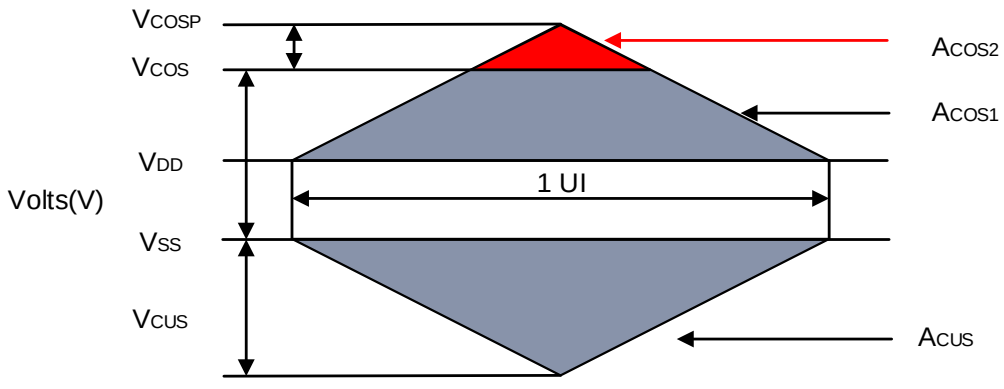



**Figure 7-5. Clock Overshoot and Undershoot Definition**



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### 7.3.6 Data, Strobe and Mask Overshoot/Undershoot Specifications

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

| Parameter | Symbol | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximum peak amplitude above $V_{DOS}$ | $V_{DOSP}$ | 0.16 | | | | | | | V | - |
| Upper boundary of overshoot area $A_{DOS1}$ | $V_{DOS}$ | $V_{DD}$ + 0.24 | | | | | | | V | 1 |
| Lower boundary of undershoot area $A_{DUS1}$ | $V_{DUS}$ | 0.3 | | | | | | | V | 2 |
| Maximum peak amplitude below $V_{DUS}$ | $V_{DUSP}$ | 0.1 | | | | | | | V | - |
| Maximum overshoot area per UI Above $V_{DOS}$ | $A_{DOS2}$ | 0.0150 | 0.0129 | 0.0113 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | V-ns | - |
| Maximum overshoot area per 1 UI Between $V_{DDQ}$ and $V_{DOS}$ | $A_{DOS1}$ | 0.1050 | 0.0900 | 0.0788 | 0.0700 | 0.0700 | 0.0700 | 0.0700 | V-ns | - |
| Maximum undershoot area per 1 UI Between $V_{SSQ}$ and $V_{DUS}$ | $A_{DUS1}$ | 0.1050 | 0.0900 | 0.0788 | 0.0700 | 0.0700 | 0.0700 | 0.0700 | V-ns | - |
| Maximum undershoot area per 1 UI below $V_{DUS}$ | $A_{DUS2}$ | 0.0150 | 0.0129 | 0.0113 | 0.0100 | 0.0100 | 0.0100 | 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 ($V_{IN}$, $V_{OUT}$) max as defined in Table 6-1 if $V_{DDQ}$ equals $V_{DDQ}$ max as defined Table 6-2. If $V_{DDQ}$ is above the recommended operating conditions, $V_{DOS}$ remains at ($V_{IN}$, $V_{OUT}$) max as defined in Table 6-1.
2. The value of $V_{DUS}$ matches ($V_{IN}$, $V_{OUT}$) min as defined in Table 6-1.

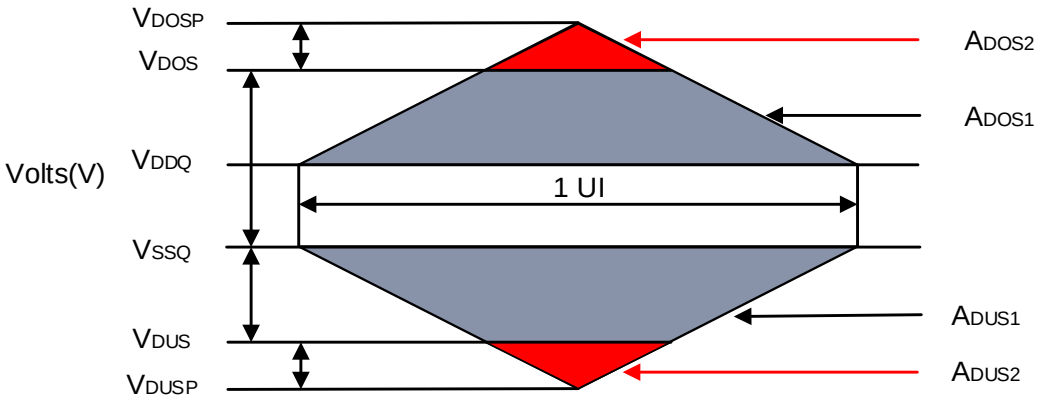



**Figure 7-6. Data, Strobe and Mask Overshoot and Undershoot Definition**



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## 7.4 Slew Rate Definitions

### 7.4.1 Slew Rate Definitions for Differential Input Signals

Input slew rate for differential signals (CK_t, CK_c) are defined and measured as shown in Table 7-8 and Figure 7-7.

**Table 7-8. CK Differential Input Slew Rate Definition**

| Description | From | To | Defined by |
|---|---|---|---|
| Differential input slew rate for rising edge (CK_t - CK_c) | $V_{IL,diff,max}$ | $V_{IH,diff,min}$ | $[V_{IH,diff,min} - V_{IL,diff,max}]$/Delta $TR_{diff}$ |
| Differential input slew rate for falling edge (CK_t - CK_c) | $V_{IH,diff,min}$ | $V_{IL,diff,max}$ | $[V_{IH,diff,min} - V_{IL,diff,max}]$/Delta $TF_{diff}$ |

Note:

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

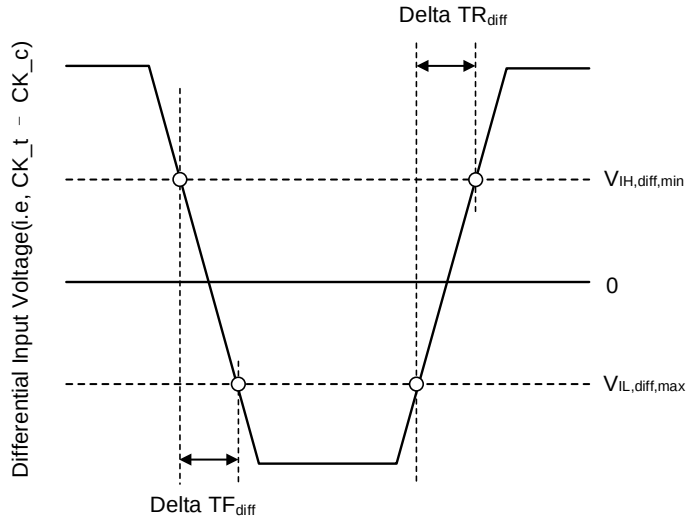



**Figure 7-7. Differential Input Slew Rate Definition for CK_t, CK_c**

### 7.4.2 Slew Rate Definitions for Single-ended Input Signals (CMD/ADD)

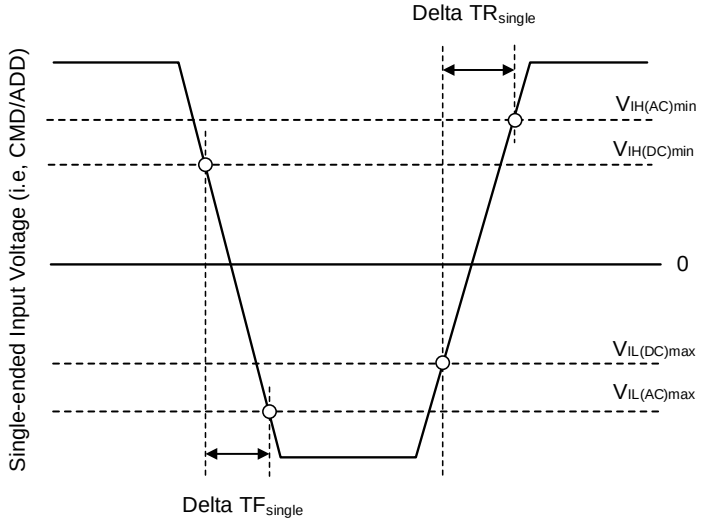



**Figure 7-8. Single-ended Input Slew Rate Definition for CMD and ADD**



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Note:

1. Single-ended input slew rate for rising edge = {$V_{IH(AC)min}$ - $V_{IL(DC)max}$}/Delta $TR_{single}$.
2. Single-ended input slew rate for falling edge = {$V_{IH(DC)min}$ - $V_{IL(AC)max}$}/Delta $TF_{single}$.
3. Single-ended signal rising edge from $V_{IL(DC)max}$ to $V_{IH(DC)min}$ must be monotonic slope.
4. Single-ended signal falling edge from $V_{IH(DC)min}$ to $V_{IL(DC)max}$ must be monotonic slope.

## 7.5 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 shown below. 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 $V_{DD}$ and $V_{SS}$.

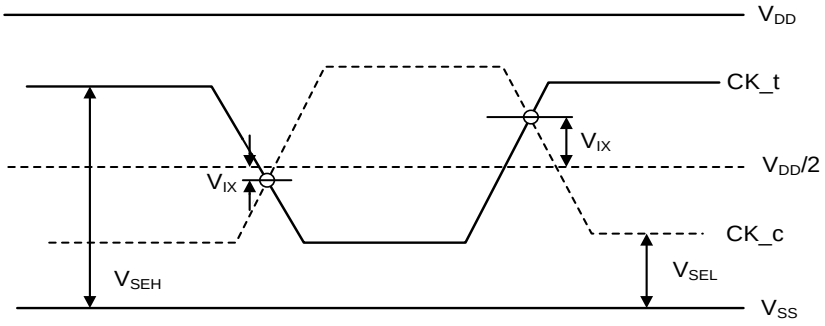



**Figure 7-9. $V_{IX}$ Definition (CK)**

**Table 7-9. Cross Point Voltage for CK Differential Input Signals at DDR4-1666 through DDR4-2400**

| Symbol | Parameter | Input Level | DDR4 – 1666/1866/2133/2400 | |
|---|---|---|---|---|
| | | | Min | Max |
| $V_{IX(CK)}$ | Differential Input Cross Point Voltage relative to $V_{DD}/2$ for CK_t, CK_c | $V_{SEH} > V_{DD}/2 + 145mV$ | - | 120mV |
| | | $V_{DD}/2 + 100mV \leqslant V_{SEH} \leqslant V_{DD}/2 + 145mV$ | - | $(V_{SEH} - V_{DD}/2) - 25mV$ |
| | | $V_{DD}/2 - 145mV \leqslant V_{SEL} \leqslant V_{DD}/2 – 100mV$ | $-(V_{DD}/2 - V_{SEL}) + 25mV$ | - |
| | | $V_{SEL} < V_{DD}/2 - 145mV$ | -120mV | - |

**Table 7-10. Cross Point Voltage for CK Differential Input Signals at DDR4-2666/2933/3200**

| Symbol | Parameter | Input Level | DDR4 – 2666/2933/3200 | |
|---|---|---|---|---|
| | | | Min | Max |
| $V_{IX(CK)}$ | Differential Input Cross Point Voltage relative to $V_{DD}/2$ for CK_t, CK_c | $V_{SEH} > V_{DD}/2 + 145$ mV | - | 110mV |
| | | $V_{DD}/2 + 100mV \leqslant V_{SEH} \leqslant V_{DD}/2 + 145$ mV | - | $(V_{SEH} - V_{DD}/2) - 30mV$ |
| | | $V_{DD}/2 - 145mV \leqslant V_{SEL} \leqslant V_{DD}/2 - 90mV$ | $-(V_{DD}/2 - V_{SEL}) + 30mV$ | - |
| | | $V_{SEL} < V_{DD}/2 - 145mV$ | -110mV | - |



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## 7.6 CMOS Rail to Rail Input Levels for RESET_n

**Table 7-11. CMOS Rail to Rail Input Levels for RESET_n**

| Parameter | Symbol | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| AC Input High Voltage | $V_{IH(AC)_RESET}$ | 0.8 * $V_{DD}$ | $V_{DD}$ | V | 6 |
| DC Input High Voltage | $V_{IH(DC)_RESET}$ | 0.7 * $V_{DD}$ | $V_{DD}$ | V | 2 |
| AC Input Low Voltage | $V_{IL(AC)_RESET}$ | $V_{SS}$ | 0.2 * $V_{DD}$ | V | 7 |
| DC Input Low Voltage | $V_{IL(DC)_RESET}$ | $V_{SS}$ | 0.3 * $V_{DD}$ | V | 1 |
| Rising Time | $T_{R_RESET}$ | - | 1.0 | µs | 4 |
| RESET Pulse Width | $T_{PW_RESET}$ | 1.0 | - | µs | 3, 5 |

Note:

1. After RESET_n is registered LOW, RESET_n level shall be maintained below $V_{IL(DC)_RESET}$ during $T_{PW_RESET}$, otherwise, the DRAM may not be reset.
2. Once RESET_n is registered HIGH, RESET_n level must be maintained above $V_{IH(DC)_RESET}$, otherwise, the DRAM 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 Absolute Maximum DC Ratings.
7. Undershoot might occur. It should be limited by Absolute Maximum DC Ratings.

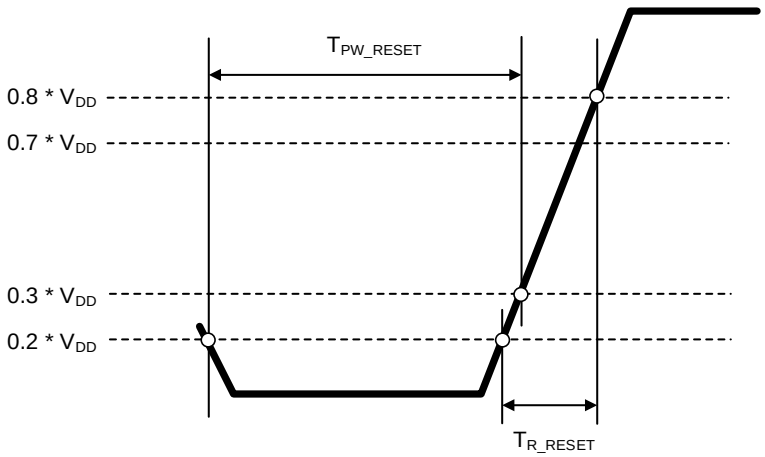



**Figure 7-10. RESET_n Input Slew Rate Definition**



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## 7.7 AC and DC Logic Input Levels for DQS Signals

### 7.7.1 Differential Signal Definition

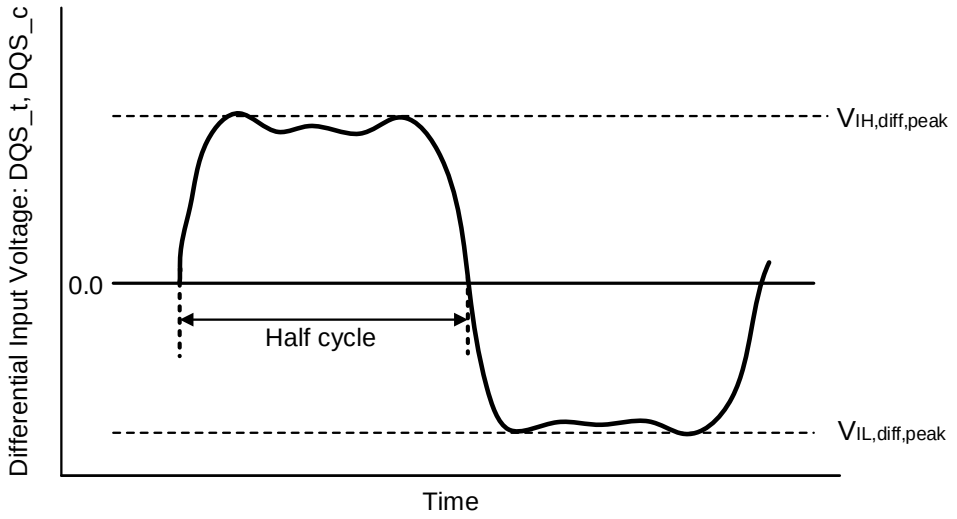



**Figure 7-11 Definition of differential DQS Signal AC-swing Level**

### 7.7.2 Differential Swing Requirements for DQS (DQS_t - DQS_c)

**Table 7-12. Differential Input Swing Requirements for DQS**

| Symbol | Parameter | 1600/1866/2133 | | 2400 | | 2666 | | 2933 | | 3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | | |
| $V_{IH,diff,peak}$ | $V_{IH,diff,peak}$ Voltage | 186 | Note 2 | 160 | Note 2 | 150 | Note 2 | 145 | Note 2 | 140 | Note 2 | mV | 1 |
| $V_{IL,diff,peak}$ | $V_{IL,diff,peak}$ Voltage | Note 2 | -186 | Note 2 | -160 | Note 2 | -150 | Note 2 | -145 | Note 2 | -140 | 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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### 7.7.3 Peak Voltage Calculation Method

The peak voltage of Differential DQS signals are calculated using following equations:

$V_{IH,diff,peak}$ Voltage = Max(f(t))

$V_{IL,diff,peak}$ Voltage = Min(f(t))

f(t) = $V_{DQS_t}$ - $V_{DQS_c}$

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

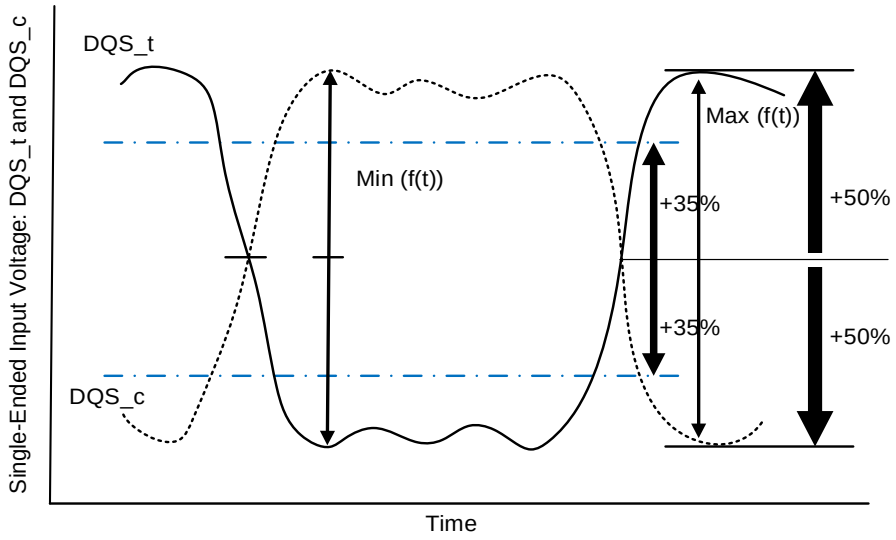



**Figure 7-12. Definition of Differential DQS Peak Voltage and Range of Exempt Non-monotonic Signaling**

### 7.7.4 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 7-13. The differential input cross point voltage $V_{IX_DQS}$ ($V_{IX_DQS,FR}$ and $V_{IX_DQS,RF}$) is measured from the actual cross point of DQS_t, DQS_c relative to the $V_{DQS,mid}$ of the DQS_t and DQS_c signals.

$V_{DQS,mid}$ is the midpoint of the minimum levels achieved by the transitioning DQS_t and DQS_c signals, and noted by $V_{DQS_trans}$. $V_{DQS_trans}$ is the difference between the lowest horizontal tangent above $V_{DQS,mid}$ of the transitioning DQS signals and the highest horizontal tangent below $V_{DQS,mid}$ of the transitioning DQS signals.

A non-monotonic transitioning signal's ledge is exempt or not used in determination of a horizontal tangent provided the said ledge occurs within ± 35% of the midpoint of either $V_{IH,diff,peak}$ Voltage (DQS_t rising) or $V_{IL,diff,peak}$ Voltage (DQS_c rising), refer to Figure 7-13.

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 7-13) and a ring-back's horizontal tangent derived from its positive slope to zero slope transition (point B in Figure 7-13) 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 7-13) and a ring-back's horizontal tangent derived from its negative slope to zero slope transition (point D in Figure 7-13) is not a valid horizontal tangent.



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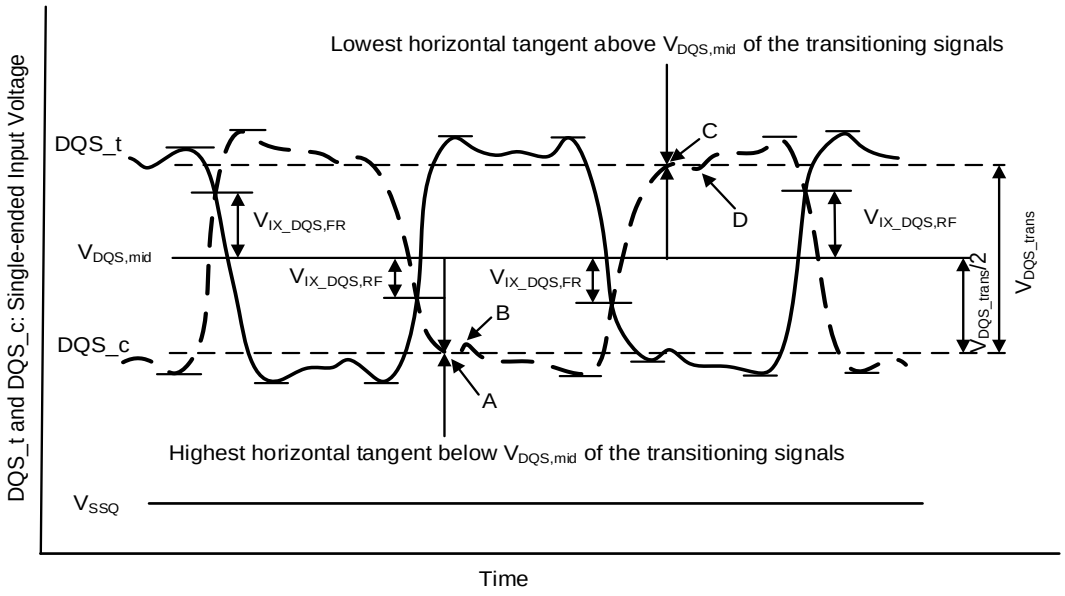



**Figure 7-13. $V_{IX}$ Definition (DQS)**

**Table 7-13. Cross Point Voltage for DQS Differential Input Signals**

| Symbol | Parameter | 1600/1866/2133/2400/2666/2933/3200 | | Unit | Note |
|---|---|---|---|---|---|
| | | Min | Max | | |
| $V_{IX_DQS,ratio}$ | DQS_t and DQS_c crossing relative to the midpoint of the DQS_t and DQS_c signal swings | - | 25 | % | 1,2 |
| $V_{DQS,mid_to_Vcent}$ | $V_{DQS,mid}$ offset relative to $V_{cent_DQ(midpoint)}$ | - | Note 3 | mV | 3,4,5 |

Note:

1. $V_{IX_DQS,ratio}$ is DQS $V_{IX}$ crossing ($V_{IX_DQS,FR}$ or $V_{IX_DQS,RF}$) divided by $V_{DQS_trans}$. $V_{DQS_trans}$ is the difference between the lowest horizontal tangent above $V_{DQS,mid}$ of the transitioning DQS signals and the highest horizontal tangent below $V_{DQS,mid}$ of the transitioning DQS signals.
2. $V_{DQS,mid}$ will be similar to the $V_{REFDQ}$ internal setting value obtained during $V_{REF}$ Training if the DQS and DQs drivers and paths are matched.
3. The maximum limit shall not exceed the smaller of $V_{IH,diff,DQS}$ minimum limit or 50mV.
4. $V_{IX}$ measurements are only applicable for transitioning DQS_t and DQS_c signals when toggling data, preamble and high-z states are not applicable conditions.
5. The parameter $V_{DQS,mid}$ is defined for simulation and ATE testing purposes, it is not expected to be tested in a system.



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### 7.7.5 Differential Input Slew Rate Definition

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

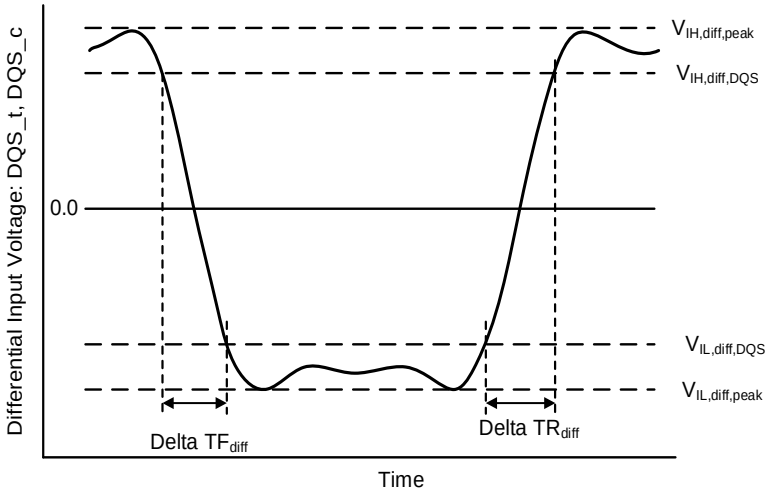



**Figure 7-14. Differential Input Slew Rate Definition for DQS_t, DQS_c**

Note:

1. Differential signal rising edge from $V_{IL,diff,DQS}$ to $V_{IH,diff,DQS}$ must be monotonic slope.
2. Differential signal falling edge from $V_{IH,diff,DQS}$ to $V_{IL,diff,DQS}$ must be monotonic slope.

**Table 7-14. Differential Input Slew Rate Definition for DQS_t, DQS_c**

| Description | From | To | Defined by |
|---|---|---|---|
| Differential input slew rate for rising edge (DQS_t - DQS_c) | $V_{IL,diff,DQS}$ | $V_{IH,diff,DQS}$ | $\lvert V_{IL,diff,DQS} - V_{IH,diff,DQS}\rvert$/Delta $TR_{diff}$ |
| Differential input slew rate for falling edge (DQS_t - DQS_c) | $V_{IH,diff,DQS}$ | $V_{IL,diff,DQS}$ | $\lvert V_{IL,diff,DQS} - V_{IH,diff,DQS}\rvert$/Delta $TF_{diff}$ |

**Table 7-15. Differential Input Level for DQS_t, DQS_c**

| Symbol | Parameter | 1600/1866/2133 | | 2400/2666 | | 2933 | | 3200 | | Unit |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | |
| $V_{IH,diff,DQS}$ | DC input logic high | 136 | - | 130 | - | 115 | - | 110 | - | mV |
| $V_{IL,diff,DQS}$ | DC input logic low | - | -136 | - | -130 | - | -115 | - | -110 | mV |

**Table 7-16. Differential Input Slew Rate for DQS_t, DQS_c**

| Symbol | Parameter | 1600/1866/2133/2400 | | 2666/2933/3200 | | Unit |
|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | |
| $SR_{Idiff}$ | Differential input slew rate | 3 | 18 | 2.5 | 18 | V/ns |



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# 8 AC AND DC OUTPUT MEASUREMENT LEVELS

## 8.1 Output Driver DC Electronic Characteristics

The DDR4 driver supports two different $R_{ON}$ values. These $R_{ON}$ values are referred as strong (low $R_{ON}$) and weak mode (high $R_{ON}$). A functional representation of the output buffer is shown in Figure 8-1 below. Output driver impedance $R_{ON}$ is defined as the individual pull-up and pull-down resistors ($R_{ONPu}$ and $R_{ONPd}$).

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

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

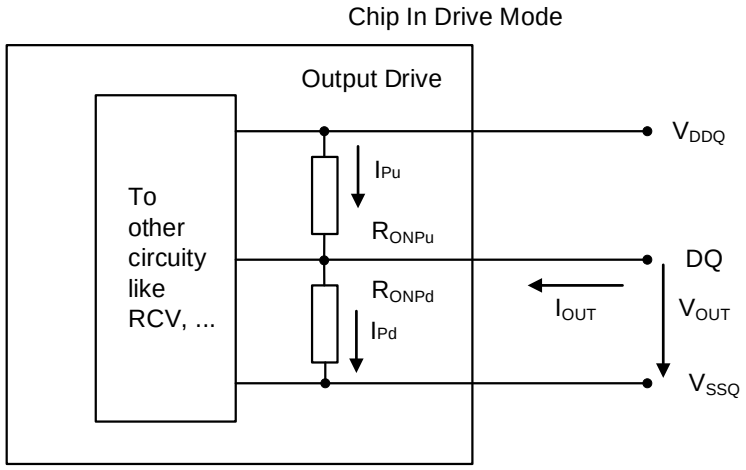



**Figure 8-1. Output Driver**



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**Table 8-1. Output Driver DC Electronical Characteristics, Assuming $R_{ZQ}$ = 240Ω; Entire Operating Temperature Range; after Proper ZQ Calibration**

| $R_{ONnom}$ | Resistor | $V_{OUT}$ | Min | Nom | Max | Unit | Note |
|---|---|---|---|---|---|---|---|
| 34Ω | $R_{ON34Pd}$ | $V_{OL(DC)}$ = 0.5 * $V_{DDQ}$ | 0.73 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1,2 |
| | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 0.83 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1,2 |
| | | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 0.83 | 1.00 | 1.25 | $R_{ZQ}$/7 | 1,2 |
| | $R_{ON34Pu}$ | $V_{OL(DC)}$ = 0.5 * $V_{DDQ}$ | 0.90 | 1.00 | 1.25 | $R_{ZQ}$/7 | 1,2 |
| | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 0.90 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1,2 |
| | | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 0.80 | 1.00 | 1.10 | $R_{ZQ}$/7 | 1,2 |
| 48Ω | $R_{ON48Pd}$ | $V_{OL(DC)}$ = 0.5 * $V_{DDQ}$ | 0.73 | 1.00 | 1.10 | $R_{ZQ}$/5 | 1,2 |
| | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 0.83 | 1.00 | 1.10 | $R_{ZQ}$/5 | 1,2 |
| | | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 0.83 | 1.00 | 1.25 | $R_{ZQ}$/5 | 1,2 |
| | $R_{ON48Pu}$ | $V_{OL(DC)}$ = 0.5 * $V_{DDQ}$ | 0.90 | 1.00 | 1.25 | $R_{ZQ}$/5 | 1,2 |
| | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 0.90 | 1.00 | 1.10 | $R_{ZQ}$/5 | 1,2 |
| | | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 0.80 | 1.00 | 1.10 | $R_{ZQ}$/5 | 1,2 |
| Mismatch between pull-up and pull-down, $MM_{PuPd}$ | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | -10 | - | 17 | % | 1,2,3,4 |
| Mismatch DQ-DQ within byte variation pull-up, $MM_{Pudd}$ | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | - | - | 10 | % | 1,2,4 |
| Mismatch DQ-DQ within byte variation pull-down, $MM_{Pddd}$ | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | - | - | 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.
2. Pull-up and pull-down output driver impedances are recommended to be calibrated at 0.8 * $V_{DDQ}$. Other calibration schemes may be used to achieve the linearity spec shown above, e.g. calibration at 0.5 * $V_{DDQ}$ and 1.1 * $V_{DDQ}$.
3. Measurement definition for mismatch between pull-up and pull-down, $MM_{PuPd}$: Measure $R_{ONPu}$ and $R_{ONPd}$ both at 0.8 * $V_{DD}$ separately; $R_{ONnom}$ is the nominal $R_{ON}$ value.
   $MM_{PuPd} = [(R_{ONPu} - R_{ONPd})/R_{ONnom}] * 100$
4. $R_{ON}$ variance range ratio to $R_{ON}$ nominal value in a given component, including DQS_t and DQS_c.
   $MM_{Pudd} = [(R_{ONPu,max} - R_{ONPu,min})/R_{ONnom}] * 100$
   $MM_{Pddd} = [(R_{ONPd,max} - R_{ONPd,min})/R_{ONnom}] * 100$
5. This parameter of x16 device is specified for upper byte and lower byte.



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### 8.1.1 Alert_n Output Driver Characteristic

A functional representation of the output buffer is shown in Figure 8-2. Output driver impedance $R_{ON}$ is defined as follows:

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

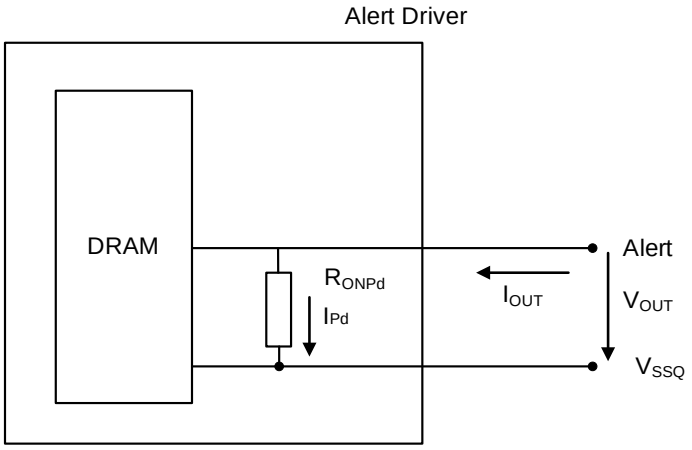



**Figure 8-2. Functional Representation of the Output Buffer**

**Table 8-2. Output Driver Impedance**

| Resister | $V_{OUT}$ | Min | Max | Unit | Note |
|---|---|---|---|---|---|
| $R_{ONPd}$ | $V_{OL(DC)}$ = 0.1 * $V_{DDQ}$ | 0.3 | 1.2 | 34Ω | 1 |
| | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 0.4 | 1.2 | 34Ω | 1 |
| | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 0.4 | 1.4 | 34Ω | 1 |

Note:

1. $V_{DDQ}$ voltage is at $V_{DDQ(DC)}$. $V_{DDQ(DC)}$ definition is TBD.



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### 8.1.2 Output Driver Characteristic of Connectivity Test (CT) Mode

Following output driver impedance $R_{ON}$ will be applied Test Output Pin during Connectivity Test (CT) Mode. The individual pull-up and pull-down resistors ($R_{ONPu_CT}$ and $R_{ONPd_CT}$) are defined as follows:

$R_{ONPu_CT} = \frac{V_{DDQ} - V_{OUT}}{|I_{OUT}|}$ when $R_{ONPd_CT}$ is off.

$R_{ONPd_CT} = \frac{V_{OUT}}{|I_{OUT}|}$ when $R_{ONPu_CT}$ is off.

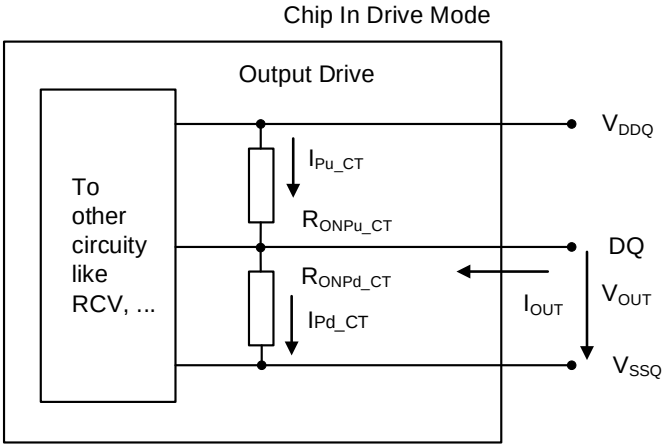



**Figure 8-3. Output Driver**

**Table 8-3. $R_{ONPu_CT}$ and $R_{ONPd_CT}$**

| $R_{ONnom_CT}$ | Resister | $V_{OUT}$ | Max | Unit |
|---|---|---|---|---|
| 34Ω | $R_{ONPd_CT}$ | $V_{OB(DC)}$ = 0.2 * $V_{DDQ}$ | 1.9 | 34Ω |
| | | $V_{OL(DC)}$ = 0.5 * $V_{DDQ}$ | 2.0 | 34Ω |
| | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 2.2 | 34Ω |
| | | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 2.5 | 34Ω |
| | $R_{ONPu_CT}$ | $V_{OB(DC)}$ = 0.2 * $V_{DDQ}$ | 2.5 | 34Ω |
| | | $V_{OL(DC)}$ = 0.5 * $V_{DDQ}$ | 2.2 | 34Ω |
| | | $V_{OM(DC)}$ = 0.8 * $V_{DDQ}$ | 2.0 | 34Ω |
| | | $V_{OH(DC)}$ = 1.1 * $V_{DDQ}$ | 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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## 8.2 Single-ended AC and DC Output Levels

**Table 8-4. Single-ended AC and DC Output Levels**

| Symbol | Parameter | DDR4-1600 to DDR4-3200 | Unit |
|---|---|---|---|
| $V_{OH(DC)}$ | DC output high measurement level (for IV curve linearity) | 1.1 * $V_{DDQ}$ | V |
| $V_{OM(DC)}$ | DC output mid measurement level (for IV curve linearity) | 0.8 * $V_{DDQ}$ | V |
| $V_{OL(DC)}$ | DC output low measurement level (for IV curve linearity) | 0.5 * $V_{DDQ}$ | V |
| $V_{OH(AC)}$ | AC output high measurement level (for output SR) | (0.7 + 0.15) * $V_{DDQ}$ | V |
| $V_{OL(AC)}$ | AC output low measurement level (for output SR) | (0.7 - 0.15) * $V_{DDQ}$ | V |

Note:

The swing of ± 0.15 * $V_{DDQ}$ is based on approximately 50% of the static single-ended output peak-to-peak swing with a driver impedance of $R_{ZQ}/7$ and an effective test load of 50Ω to $V_{TT} = V_{DDQ}$.

## 8.3 Differential AC&DC Output Levels

**Table 8-5. Differential AC&DC Output Levels**

| Symbol | Parameter | DDR4-1600 to DDR4-3200 | Unit |
|---|---|---|---|
| $V_{OH,diff(AC)}$ | AC differential output high measurement level (for output SR) | +0.3 * $V_{DDQ}$ | V |
| $V_{OL,diff(AC)}$ | AC differential output low measurement level (for output SR) | -0.3 * $V_{DDQ}$ | V |

Note:

The swing of ± 0.3 * $V_{DDQ}$ is based on approximately 50% of the static single-ended output peak-to-peak swing with a driver impedance of $R_{ZQ}/7$ and an effective test load of 50Ω to $V_{TT} = V_{DDQ}$ at each of the differential outputs.



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## 8.4 Single-ended Output Slew Rate

With the reference load for timing measurements, output slew rate for falling and rising edges is defined and measured between $V_{OL(AC)}$ and $V_{OH(AC)}$ for single-ended signals as shown in Table 8-6 and Figure 8-3.

**Table 8-6. Single-ended Output Slew Rate Definition**

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

Note:

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

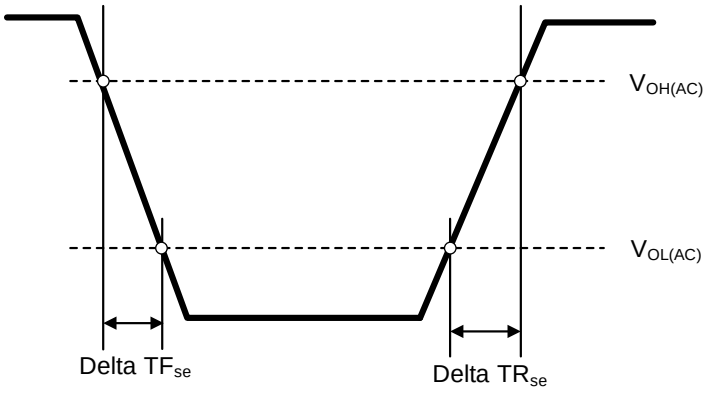



**Figure 8-3**. **Single-ended Output Slew Rate Definition**

**Table 8-7. Single-ended Output Slew Rate**

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | | 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 Singnals; For $R_{ON} = R_{ZQ}/7$ setting.

Note:

In two cases, a maximum slew rate of 12V/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 9V/ns applies.



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## 8.5 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 8-8 and Figure 8-4.

**Table 8-8. Differential Output Slew Rate Definition**

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

Note:

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

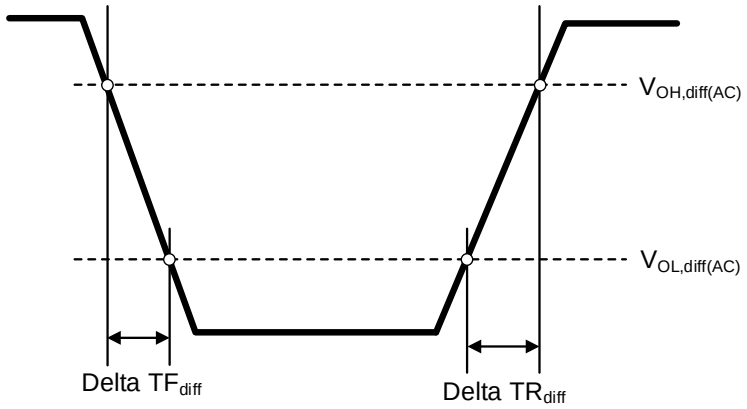



**Figure 8-4. Differential Output Slew Rate Definition**

**Table 8-9. Differential Output Slew Rate**

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | | Unit |
|---|---|---|---|---|
| | | Min | Max | |
| Differential output slew rate | $SRQ_{diff}$ | 8 | 18 | V/ns |

Description:

SR: Slew Rate; Q: Query Output (like in DQ, which stands for Data-in, Query-Output);

Diff: Differential Singnals; For $R_{ON} = R_{ZQ}/7$ setting.



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

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

**Table 8-10. Single-ended AC&DC Output Level of Connectivity Test Mode**

| Symbol | Parameter | DDR4-1600 to DDR4-3200 | Unit | Note |
|---|---|---|---|---|
| $V_{OH(DC)}$ | DC output high measurement level (for IV curve linearity) | 1.1 * $V_{DDQ}$ | V | - |
| $V_{OM(DC)}$ | DC output mid measurement level (for IV curve linearity) | 0.8 * $V_{DDQ}$ | V | - |
| $V_{OL(DC)}$ | DC output low measurement level (for IV curve linearity) | 0.5 * $V_{DDQ}$ | V | - |
| $V_{OB(DC)}$ | DC output below measurement level (for IV curve linearity) | 0.2 * $V_{DDQ}$ | V | - |
| $V_{OH(AC)}$ | AC output high measurement level (for output SR) | $V_{TT}$ + (0.1 * $V_{DDQ}$) | V | 1 |
| $V_{OL(AC)}$ | AC output below measurement level (for output SR) | $V_{TT}$ - (0.1 * $V_{DDQ}$) | V | 1 |

Note:

1. The effective test load is 50Ω terminated by $V_{TT}$ = 0.5 * $V_{DDQ}$.

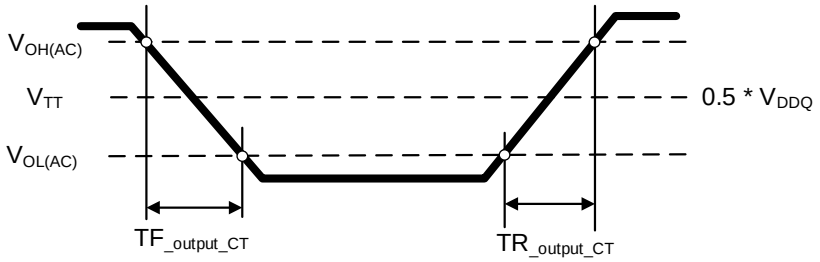



**Figure 8-5. Output Slew Rate Definition of Connectivity Test Mode**

**Table 8-11. Single-ended Output Slew Rate of Connectivity Test Mode**

| Parameter | Symbol | DDR4-1600 to DDR4-3200 | | Unit |
|---|---|---|---|---|
| | | Min | Max | |
| Output signal Falling time | $TF_{output_CT}$ | - | 10 | ns/V |
| Output signal Rising time | $TR_{output_CT}$ | - | 10 | ns/V |

## 8.7 Reference Load for Connectivity Test Mode Timing

The reference load for ODT timings is defined in Figure 8-6.

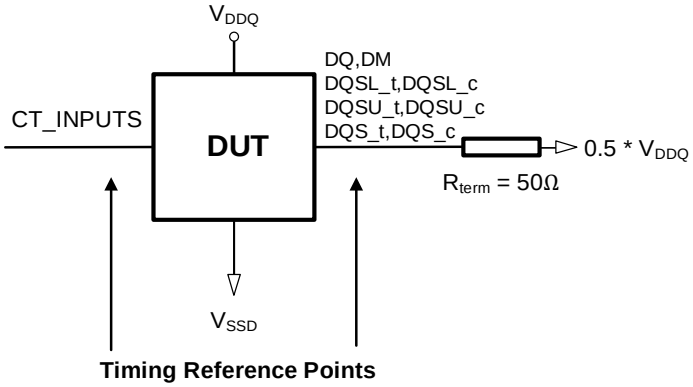



**Figure 8-6. Connectivity Test Mode Timing Reference Load**



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# 9 SPEED BIN

## 9.1 DDR4-2400 Speed Bins and Operations

**Table 9-1. DDR4-2400 Speed Bins and Operations**

| Speed Bin | | | | DDR4-2400 | | Unit | Note |
|---|---|---|---|---|---|---|---|
| CL-nRCD-nRP | | | | 17-17-17 | | | |
| Parameter | | | Symbol | Min | Max | | |
| Internal READ command to first data | | | $t_{AA}$ | 14.16 (13.75)(9) | 18.00 | ns | 9 |
| Internal READ command to first data with Read DBI enabled | | | $t_{AA_DBI}$ | $t_{AA\ (min)}$ + 3nCK | $t_{AA\ (max)}$ + 3nCK | ns | 9 |
| ACT to internal READ or WRITE delay time | | | $t_{RCD}$ | 14.16 (13.75)(9) | - | ns | 9 |
| PRE command period | | | $t_{RP}$ | 14.16 (13.75)(9) | - | ns | 9 |
| ACT to PRE command period | | | $t_{RAS}$ | 32 | 9 * $t_{REFI}$ | ns | 9 |
| ACT to ACT or REF command period | | | $t_{RC}$ | 46.16 (45.75)(9) | - | ns | 9 |
| | Normal | READ DBI | | | | | |
| CWL = 9 | CL = 9 | CL = 11 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4,5,8 |
| | CL = 10 | CL = 12 | $t_{CK\ (avg)}$ | 1.5 | 1.6 | ns | 1,2,3,4,5,8 |
| CWL = 9,11 | CL = 10 | CL = 12 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 11 | CL = 13 | $t_{CK\ (avg)}$ | 1.25 | <1.5 | ns | 1,2,3,4,5 |
| | CL = 12 | CL = 14 | $t_{CK\ (avg)}$ | 1.25 | <1.5 | ns | 1,2,3,5 |
| CWL = 10,12 | CL = 12 | CL = 14 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 13 | CL = 15 | $t_{CK\ (avg)}$ | 1.071 | <1.25 | ns | 1,2,3,4,5 |
| | CL = 14 | CL = 16 | $t_{CK\ (avg)}$ | 1.071 | <1.25 | ns | 1,2,3,5 |
| CWL = 11,14 | CL = 14 | CL = 17 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 15 | CL = 18 | $t_{CK\ (avg)}$ | 0.937 | <1.071 | ns | 1,2,3,4,5 |
| | CL = 16 | CL = 19 | $t_{CK\ (avg)}$ | 0.937 | <1.071 | ns | 1,2,3,5 |
| CWL = 12,16 | CL = 15 | CL = 18 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4 |
| | CL = 16 | CL = 19 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4 |
| | CL = 17 | CL = 20 | $t_{CK\ (avg)}$ | 0.833 | <0.937 | ns | 1,2,3,4 |
| | CL = 18 | CL = 21 | $t_{CK\ (avg)}$ | 0.833 | <0.937 | ns | 1,2,3 |
| Supported CL Settings | | | | 10,(11),12,(13),14,(15),16,17,18 | | nCK | 10 |
| Supported CL Settings with READ DBI | | | | 12,(13),14,(15),16,(18),19,20,21 | | nCK | 10 |
| Supported CWL Settings | | | | 9, 10, 11, 12, 14, 16 | | nCK | - |



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## 9.2 DDR4-2666 Speed Bins and Operations

**Table 9-2. 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 | | | $t_{AA}$ | 14.25 (13.75)(9) | 18.00 | ns | 9 |
| Internal READ command to first data with Read DBI enabled | | | $t_{AA_DBI}$ | $t_{AA\ (min)}$ + 3nCK | $t_{AA\ (max)}$ + 3nCK | ns | 9 |
| ACT to internal READ or WRITE delay time | | | $t_{RCD}$ | 14.25 (13.75)(9) | - | ns | 9 |
| PRE command period | | | $t_{RP}$ | 14.25 (13.75)(9) | - | ns | 9 |
| ACT to PRE command period | | | $t_{RAS}$ | 32 | 9 * $t_{REFI}$ | ns | 9 |
| ACT to ACT or REF command period | | | $t_{RC}$ | 46.25 (13.75)(9) | - | ns | 9 |
| | Normal | READ DBI | | | | | |
| CWL = 9 | CL = 9 | CL = 11 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4,6,8 |
| | CL = 10 | CL = 12 | $t_{CK\ (avg)}$ | 1.5 | 1.6 | ns | 1,2,3,6,8 |
| CWL = 9,11 | CL = 10 | CL = 12 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 11 | CL = 13 | $t_{CK\ (avg)}$ | 1.25 | <1.5 | ns | 1,2,3,4,6 |
| | CL = 12 | CL = 14 | $t_{CK\ (avg)}$ | 1.25 | <1.5 | ns | 1,2,3,6 |
| CWL = 10,12 | CL = 12 | CL = 14 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 13 | CL = 15 | $t_{CK\ (avg)}$ | 1.071 | <1.25 | ns | 1,2,3,4,6 |
| | CL = 14 | CL = 16 | $t_{CK\ (avg)}$ | 1.071 | <1.25 | ns | 1,2,3,6 |
| CWL = 11,14 | CL = 14 | CL = 17 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 15 | CL = 18 | $t_{CK\ (avg)}$ | 0.937 | <1.071 | ns | 1,2,3,4,6 |
| | CL = 16 | CL = 19 | $t_{CK\ (avg)}$ | 0.937 | <1.071 | ns | 1,2,3,6 |
| CWL = 12,16 | CL = 15 | CL = 18 | $t_{CK\ (avg)}$ | Reserved | | ns | 4 |
| | CL = 16 | CL = 19 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4,6 |
| | CL = 17 | CL = 20 | $t_{CK\ (avg)}$ | 0.833 | <0.937 | ns | 1,2,3,4,6 |
| | CL = 18 | CL = 21 | $t_{CK\ (avg)}$ | 0.833 | <0.937 | ns | 1,2,3,6 |
| CWL = 14,18 | CL = 17 | CL = 20 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4 |
| | CL = 18 | CL = 21 | $t_{CK\ (avg)}$ | Reserved | | ns | 1,2,3,4 |
| | CL = 19 | CL = 22 | $t_{CK\ (avg)}$ | 0.75 | <0.833 | ns | 1,2,3,4 |
| | CL = 20 | CL = 23 | $t_{CK\ (avg)}$ | 0.75 | <0.833 | ns | 1,2,3 |
| Supported CL Settings | | | | 10,(11),12,(13),14,(15),16,(17),18,19,20 | | nCK | 10 |
| Supported CL Settings with READ DBI | | | | 12,(13),14,(15),16,(18),19,(20),21,22,23 | | nCK | 10 |
| Supported CWL Settings | | | | 9,10,11,12,14,16,18 | | nCK | - |



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## 9.3 DDR4-3200 Speed Bins and Operations

**Table 9-3. DDR4-3200 Speed Bins and Operations**

| Speed Bin | | | DDR4-3200 | | Unit | Note |
|---|---|---|---|---|---|---|
| CL-nRCD-nRP | | | 22-22-22 | | | |
| Parameter | | Symbol | Min | Max | | |
| Internal READ command to first data | | $t_{AA}$ | 13.75 | 18.00 | ns | 9 |
| Internal READ command to first data with READ DBI enabled | | $t_{AA_DBI}$ | $t_{AA\ (min)}$ + 4nCK | $t_{AA\ (max)}$ + 4nCK | ns | 9 |
| ACT to internal Read or Write delay time | | $t_{RCD}$ | 13.75 | - | ns | 9 |
| PRE command period | | $t_{RP}$ | 13.75 | - | ns | 9 |
| ACT to PRE command period | | $t_{RAS}$ | 32 | 9 * tREFI | ns | 9 |
| ACT to ACT or REF command period | | $t_{RC}$ | 45.75 | - | ns | 9 |
| | Normal | Read DBI | | | | |
| CWL = 9 | CL = 9 | CL = 11 | $t_{CK\ (avg)}$ | Reserved | ns | 1,2,3,4,7,8 |
| | CL = 10 | CL = 12 | $t_{CK\ (avg)}$ | 1.5 1.6 | ns | 1,2,3,7,8 |
| CWL = 9,11 | CL = 10 | CL = 12 | $t_{CK\ (avg)}$ | Reserved | ns | 4 |
| | CL = 11 | CL = 13 | $t_{CK\ (avg)}$ | 1.25 <1.5 | ns | 1,2,3,4,7 |
| | CL = 12 | CL = 14 | $t_{CK\ (avg)}$ | 1.25 <1.5 | ns | 1,2,3,7 |
| CWL = 10,12 | CL = 12 | CL = 14 | $t_{CK\ (avg)}$ | Reserved | ns | 4 |
| | CL = 13 | CL = 15 | $t_{CK\ (avg)}$ | 1.071 <1.25 | ns | 1,2,3,4,7 |
| | CL = 14 | CL = 16 | $t_{CK\ (avg)}$ | 1.071 <1.25 | ns | 1,2,3,7 |
| CWL = 11,14 | CL = 14 | CL = 17 | $t_{CK\ (avg)}$ | Reserved | ns | 4 |
| | CL = 15 | CL = 18 | $t_{CK\ (avg)}$ | 0.937 <1.071 | ns | 1,2,3,4,7 |
| | CL = 16 | CL = 19 | $t_{CK\ (avg)}$ | 0.937 <1.071 | ns | 1,2,3,7 |
| CWL = 12,16 | CL = 15 | CL = 18 | $t_{CK\ (avg)}$ | Reserved | ns | 4 |
| | CL = 16 | CL = 19 | $t_{CK\ (avg)}$ | Reserved | ns | 1,2,3,4,7 |
| | CL = 17 | CL = 20 | $t_{CK\ (avg)}$ | 0.833 <0.937 | ns | 1,2,3,4,7 |
| | CL = 18 | CL = 21 | $t_{CK\ (avg)}$ | 0.833 <0.937 | ns | 1,2,3,7 |
| CWL = 14,18 | CL = 17 | CL = 20 | $t_{CK\ (avg)}$ | Reserved | ns | 1,2,3,4 |
| | CL = 18 | CL = 21 | $t_{CK\ (avg)}$ | Reserved | ns | 1,2,3,4 |
| | CL = 19 | CL = 22 | $t_{CK\ (avg)}$ | 0.75 <0.833 | ns | 1,2,3,4 |
| | CL = 20 | CL = 23 | $t_{CK\ (avg)}$ | 0.75 <0.833 | ns | 1,2,3 |
| CWL = 16,20 | CL = 20 | CL = 24 | $t_{CK\ (avg)}$ | Reserved | ns | 1,2,3,4,7 |
| | CL = 21 | CL = 25 | $t_{CK\ (avg)}$ | 0.682 <0.75 | ns | 1,2,3,4,7 |
| | CL = 22 | CL = 26 | $t_{CK\ (avg)}$ | 0.682 <0.75 | ns | 1,2,3,7 |
| | CL = 24 | CL = 28 | $t_{CK\ (avg)}$ | 0.682 <0.75 | ns | 1,2,3,7 |
| CWL = 16,20 | CL = 20 | CL = 24 | $t_{CK\ (avg)}$ | Reserved | ns | 1,2,3,4 |
| | CL = 22 | CL = 26 | $t_{CK\ (avg)}$ | 0.625 <0.682 | ns | 1,2,3,4 |
| | CL = 24 | CL = 28 | $t_{CK\ (avg)}$ | 0.625 <0.682 | ns | 1,2,3 |
| Supported CL Settings | | | 10,11,12,13,14,15,16,17,18,19,20,22,24 | | nCK | - |



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| Speed Bin | | DDR4-3200 | | Unit | Note |
|---|---|---|---|---|---|
| CL-nRCD-nRP | | 22-22-22 | | | |
| Parameter | Symbol | Min | Max | | |
| Supported CL Settings with READ DBI | | 12,13,14,15,16,18,19,20,21,22,23,24,26,28 | | nCK | - |
| Supported CWL Settings | | 9,10,11,12,14,16,18,20 | | nCK | - |

## Speed Bin Table Note

### Absolute Specifications

- $V_{DDQ}$ = $V_{DD}$ = 1.20V ± 0.06V
- $V_{PP}$ = 2.5V (2.375V min, 2.75V max)
- The values defined with above-mentioned table are DLL ON case.
- DDR4-2400, 2666, 2933 and 3200 Speed Bin Tables are valid only when gear down mode is disabled.

1. The CL setting and CWL setting result in $t_{CK\ (avg)min}$ and $t_{CK\ (avg)max}$ requirements. When selecting $t_{CK\ (avg)}$, both need to be fulfilled: Requirements from CL setting as well as requirements from CWL setting.
2. $t_{CK\ (avg)min}$ 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 $t_{AA}$ following rounding algorithm defined in JEDEC-79D Section 13.5.
3. $t_{CK\ (avg)max}$ limits: Calculate $t_{CK\ (avg)}$ = $t_{AA\ (max)}$/CL SELECTED and round the resulting $t_{CK\ (avg)}$ down to the next valid speed bin (i.e. 1.5ns or 1.25ns or 1.071ns or 0.937ns or 0.833ns). This result is $t_{CK\ (avg)max}$ corresponding to CL SELECTED.
4. 'Reserved' settings are not allowed. User must program a different value.
5. 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.
6. 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.
7. Any DDR4-3200 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. DDR4-1600 AC timing apply if DRAM operates at lower than 1600MT/s data rate.
9. Parameters apply from $t_{CK\ (avg)min}$ to $t_{CK\ (avg)max}$ at all standard JEDEC clock period values as stated in the Speed Bin Tables.
10. CL number in parentheses, it means that these numbers are optional.
11. DDR4 SDRAM supports CL = 9 as long as a system meets $t_{AA\ (min)}$, $t_{RCD\ (min)}$, $t_{RP\ (min)}$, and $t_{RC\ (min)}$.
12. 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.

## 9.4 $t_{REFI}$ and $t_{RFC}$ Parameters

In the Fixed 1x Refresh rate mode, only REF1x commands are permitted. In the Fixed 2x Refresh rate mode, only REF2x commands are permitted. In the Fixed 4x Refresh rate mode, only REF4x commands are permitted. When the on-the-fly 1x/2x Refresh rate mode is enabled, both REF1x and REF2x commands are permitted. When the on-the-fly 1x/4x Refresh rate mode is enabled, both REF1x and REF4x commands are permitted.



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**Table 9-1. $t_{REFI}$ and $t_{RFC}$ Parameters**

| Refresh Mode | Parameter | | 8Gb | Unit |
|---|---|---|---|---|
| | $t_{REFI(base)}$ | | 7.8 | μs |
| 1x mode | $t_{REFI1}$ | -40°C ≤ $T_{CASE}$ ≤ 85°C | $t_{REFI(base)}$ | μs |
| | | 85°C < $T_{CASE}$ ≤ 95°C | $t_{REFI(base)}$/2 | μs |
| | $t_{RFC1}$ | | 350 | ns |
| 2x mode | $t_{REFI2}$ | -40°C ≤ $T_{CASE}$ ≤ 85°C | $t_{REFI(base)}$/2 | μs |
| | | 85°C < $T_{CASE}$ ≤ 95°C | $t_{REFI(base)}$/4 | μs |
| | $t_{RFC2}$ | | 260 | ns |
| 4x mode | $t_{REFI4}$ | -40°C ≤ $T_{CASE}$ ≤ 85°C | $t_{REFI(base)}$/4 | μs |
| | | 85°C < $T_{CASE}$ ≤ 95°C | $t_{REFI(base)}$/8 | μs |
| | $t_{RFC4}$ | | 160 | ns |



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# 10 $I_{DD}$ AND $I_{DDQ}$ SPECIFICATION PARAMETERS AND TEST CONDITIONS

## 10.1 $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurement Conditions

In this chapter, $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ measurement conditions such as test load and patterns are defined. Figure 10-1 shows the setup and test load for $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ measurements.

- $I_{DD}$ currents (such as $I_{DD0}$, $I_{DD0A}$, $I_{DD1}$, $I_{DD1A}$, $I_{DD2N}$, $I_{DD2NA}$, $I_{DD2NL}$, $I_{DD2NT}$, $I_{DD2P}$, $I_{DD2Q}$, $I_{DD3N}$, $I_{DD3NA}$, $I_{DD3P}$, $I_{DD4R}$, $I_{DD4RA}$, $I_{DD4W}$, $I_{DD4WA}$, $I_{DD5B}$, $I_{DD5F2}$, $I_{DD5F4}$, $I_{DD6N}$, $I_{DD6E}$, $I_{DD6R}$, $I_{DD6A}$, $I_{DD7}$ and $I_{DD8}$) are measured as time-averaged currents with all $V_{DD}$ balls of the DDR4 SDRAM under test tied together. Any $I_{PP}$ or $I_{DDQ}$ current is not included in $I_{DD}$ currents.
- $I_{PP}$ currents have the same definition as $I_{DD}$ except that the current on the $V_{PP}$ supply is measured.
- $I_{DDQ}$ currents (such as $I_{DDQ2NT}$ and $I_{DDQ4R}$) are measured as time-averaged currents with all $V_{DDQ}$ balls of the DDR4 SDRAM under test tied together. Any $I_{DD}$ current is not included in $I_{DDQ}$ currents.

Attention: $I_{DDQ}$ values cannot be directly used to calculate I/O power of the DDR4 SDRAM. They can be used to support correlation of simulated I/O power to actual I/O power as outlined in Figure 10-2. In DRAM module application, $I_{DDQ}$ cannot be measured separately since $V_{DD}$ and $V_{DDQ}$ are using one merged-power layer in Module PCB.

For $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ measurements, the following definitions apply:

- "0" and "LOW" is defined as $V_{IN} \leqslant V_{IL(AC)max}$.
- "1" and "HIGH" is defined as $V_{IN} \geqslant V_{IH(AC)min}$.
- "MID-LEVEL" is defined as inputs are $V_{REF} = V_{DD}/2$.
- Timings used for IDD, IPP and IDDQ Measurement-Loop Patterns are provided in Table 10-1.
- Basic $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurement Conditions are described inTable 10-2.
- Detailed $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurement-Loop Patterns are described in Table 10-3 to 10-11.
- $I_{DD}$ Measurements are done after properly initializing the DDR4 SDRAM. This includes but is not limited to setting:

  $R_{ON} = R_{ZQ}/7$ (34Ω in MR1);

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

  $R_{TT_WR} = R_{ZQ}/2$ (120Ω in MR2);

  $R_{TT_PARK}$ = Disable;

  $Q_{off}$ = 0B (Output Buffer enabled) in MR1;

  $T_{DQS_t}$ 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 $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurement-Loop Patterns need to be executed at least one time before actual $I_{DD}$ or $I_{DDQ}$ measurement can be taken.
- Define D = {CS_n, ACT_n, RAS_n, CAS_n, WE_n}: = {HIGH, LOW, LOW, LOW, LOW} ; apply BG/BA changes when directed.
- Define D# = {CS_n, ACT_n, RAS_n, CAS_n, WE_n}: = {HIGH, HIGH, HIGH, HIGH, HIGH}; apply invert of BG/BA changes when directed above.



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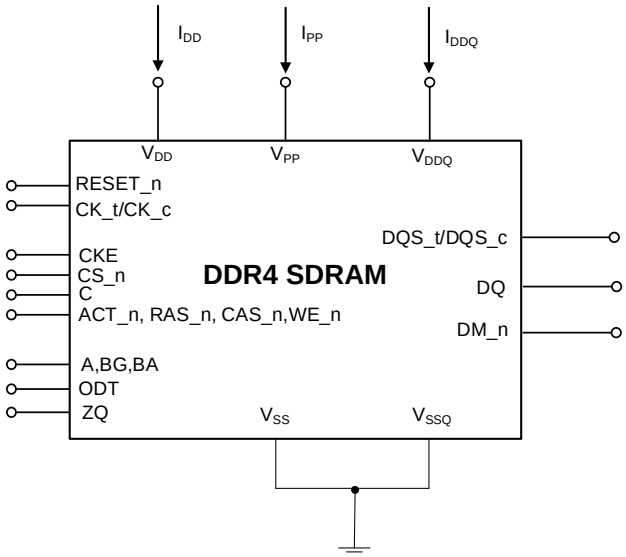



**Figure 10-1. Measurement Setup and Test Load for $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurements**

Note:
DIMM level Output test load condition may be different from above

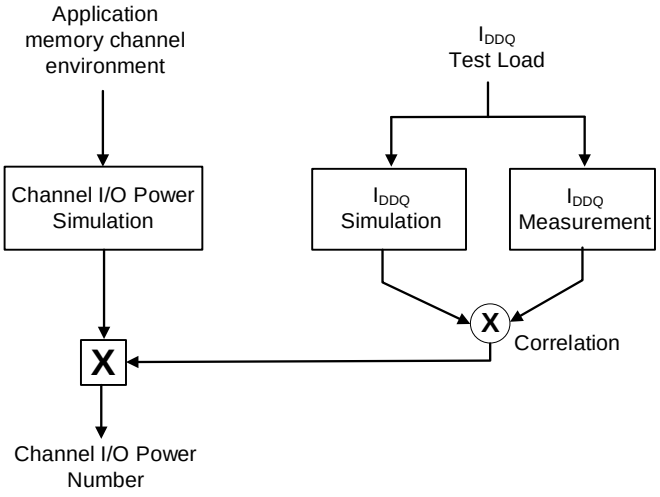



**Figure 10-2. Correlation from Simulated Channel I/O Power to Actual Channel I/O Power Supported by $I_{DDQ}$ Measurement**

**Table 10-1. Timings used for $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurement-Loop Patterns**

| Symbol | | DDR4-1600 | DDR4-1866 | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|---|---|
| | | 11-11-11 | 13-13-13 | 15-15-15 | 17-17-17 | 19-19-19 | 21-21-21 | 22-22-22 | |
| $t_{CK}$ | | 1.25 | 1.071 | 0.937 | 0.833 | 0.75 | 0.682 | 0.625 | ns |
| CL | | 11 | 13 | 15 | 17 | 19 | 21 | 22 | nCK |
| CWL | | 11 | 12 | 14 | 16 | 18 | 20 | 20 | nCK |
| nRCD | | 11 | 13 | 15 | 17 | 19 | 21 | 22 | nCK |
| nRC | | 39 | 45 | 51 | 56 | 62 | 68 | 74 | nCK |
| nRAS | | 28 | 32 | 36 | 39 | 43 | 47 | 52 | nCK |
| nRP | | 11 | 13 | 15 | 17 | 19 | 21 | 22 | nCK |
| nFAW | x8 | 20 | 22 | 23 | 26 | 28 | 31 | 34 | nCK |
| | x16 | 28 | 28 | 32 | 36 | 40 | 44 | 48 | nCK |



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| Symbol | | DDR4-1600 | DDR4-1866 | DDR4-2133 | DDR4-2400 | DDR4-2666 | DDR4-2933 | DDR4-3200 | Unit |
|---|---|---|---|---|---|---|---|---|---|
| | | 11-11-11 | 13-13-13 | 15-15-15 | 17-17-17 | 19-19-19 | 21-21-21 | 22-22-22 | |
| nRRDS | x8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | nCK |
| | x16 | 5 | 6 | 6 | 7 | 8 | 8 | 9 | nCK |
| nRRDL | x8 | 5 | 5 | 6 | 6 | 7 | 8 | 8 | nCK |
| | x16 | 6 | 6 | 7 | 8 | 9 | 10 | 11 | nCK |
| $t_{CCD_S}$ | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | nCK |
| $t_{CCD_L}$ | | 5 | 5 | 6 | 6 | 7 | 8 | 8 | nCK |
| $t_{WTR_S}$ | | 2 | 3 | 3 | 3 | 4 | 4 | 4 | nCK |
| $t_{WTR_L}$ | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | nCK |
| nRFC 2Gb | | 128 | 150 | 171 | 193 | 214 | 235 | 256 | nCK |
| nRFC 4Gb | | 208 | 243 | 278 | 313 | 347 | 382 | 416 | nCK |
| nRFC 8Gb | | 280 | 327 | 374 | 421 | 467 | 514 | 560 | nCK |



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**Table 10-2. Basic $I_{DD}$, $I_{PP}$ and $I_{DDQ}$ Measurement Conditions**

| Symbol | Description |
|---|---|
| $I_{DD0}$ | **Operating One Bank Active-Precharge Current (AL = 0)**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**$t_{CK}$, nRC, nRAS, nRCD, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n:** HIGH between ACT and PRE;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-3.<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** Cycling with one bank active at a time: 0, 0, 1, 1, 2, 2, ... (see Table 10-3);<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers[2];<br>**ODT Signal:** Stable at 0;<br>**Pattern Details:** See Table 10-3. |
| $I_{DD0A}$ | **Operating One Bank Active-Precharge Current (AL = CL - 1)**<br>**AL = CL - 1, Other conditions:** See $I_{DD0}$. |
| $I_{PP0}$ | **Operating One Bank Active-Precharge $I_{PP}$ Current (AL = 0)**<br>Same condition with $I_{DD0}$. |
| $I_{DD1}$ | **Operating One Bank Active-Read-Precharge Current (AL = 0)**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**$t_{CK}$, nRC, nRAS, nRCD, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n**: HIGH between ACT, RD and PRE;<br>**Command, Address, Bank Group Address, Bank Address Inputs, Data IO:** Partially toggling according to Table 10-4.<br>**DM_n:** stable at 1;<br>**Bank Activity:** Cycling with one bank active at a time: 0, 0, 1, 1, 2, 2, ... (see Table 10-4);<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers[2];<br>**ODT Signal:** Stable at 0;<br>**Pattern Details:** See Table 10-4. |
| $I_{DD1A}$ | **Operating One Bank Active-Read-Precharge Current (AL = CL - 1)**<br>**AL = CL - 1, Other conditions**: See $I_{DD1}$. |
| $I_{PP1}$ | **Operating One Bank Active-Read-Precharge $I_{PP}$ Current**<br>Same condition with $I_{DD1}$. |
| $I_{DD2N}$ | **Precharge Standby Current (AL = 0)**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**$t_{CK}$, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n**: stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-5.<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks closed;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers[2];<br>**ODT Signal:** Stable at 0;<br>**Pattern Details:** See Table 10-5. |
| $I_{DD2NA}$ | **Precharge Standby Current (AL = CL - 1)**<br>**AL = CL - 1, Other conditions:** See $I_{DD2N}$. |
| $I_{PP2N}$ | **Precharge Standby $I_{PP}$ Current**<br>Same condition with $I_{DD2N}$. |
| $I_{DD2NT}$ | **Precharge Standby ODT Current**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**$t_{CK}$, CL:** See Table 10-1; |



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|---|---|
| | **BL:** 8(1);<br>**AL:** 0;<br>**CS_n**: Stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-6.<br>**Data I/O:** $V_{SSQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks closed;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** Toggling according to Table 10-6;<br>**Pattern Details:** See Table 10-6. |
| $I_{DDQ2NT}$ | **Precharge Standby ODT $I_{DDQ}$ Current**<br>Same definition like for $I_{DD2NT}$, however measuring $I_{DDQ}$ current instead of $I_{DD}$ current. |
| $I_{DD2NL}$ | **Precharge Standby Current with CAL enabled**<br>Same definition like for $I_{DD2N}$, CAL enabled(3). |
| $I_{DD2NG}$ | **Precharge Standby Current with Gear Down mode enabled**<br>Same definition like for $I_{DD2N}$, Gear Down mode enabled(3),(5). |
| $I_{DD2ND}$ | **Precharge Standby Current with DLL disabled**<br>Same definition like for $I_{DD2N}$, DLL disabled(3) . |
| $I_{DD2N_par}$ | **Precharge Standby Current with CA parity enabled**<br>Same definition like for $I_{DD2N}$, CA parity enabled(3) . |
| $I_{DD2P}$ | **Precharge Power-Down Current**<br>**CKE:** LOW;<br>**External clock:** On;<br>**$t_{CK}$, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n**: Stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Stable at 0;<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks closed;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** Stable at 0. |
| $I_{PP2P}$ | **Precharge Power-Down $I_{PP}$ Current**<br>Same condition with $I_{DD2P}$. |
| $I_{DD2Q}$ | **Precharge Quiet Standby Current**<br>**CKE**: HIGH;<br>**External clock:** On;<br>**tCK, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n**: Stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Stable at 0;<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks closed;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** Stable at 0. |
| $I_{DD3N}$ | **Active Standby Current (AL = 0)**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**tCK, CL:** see Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n:** Stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-5.<br>**Data IO**: $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks open;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers2;<br>**ODT Signal:** Stable at 0;<br>**Pattern Details:** See Table 10-5. |



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| $I_{DD3NA}$ | **Active Standby Current (AL = CL - 1)**<br>**AL = CL - 1, Other conditions:** See $I_{DD3N}$ |
| $I_{PP3N}$ | **Active Standby $I_{PP}$ Current**<br>Same condition with $I_{DD3N}$. |
| $I_{DD3P}$ | **Active Power-Down Current**<br>**CKE:** LOW;<br>**External clock:** On;<br>**tCK, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n:** Stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Stable at 0;<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks open;<br>**Output Buffer and $R_{TT}$**: Enabled in Mode Registers2;<br>**ODT Signal:** Stable at 0. |
| $I_{PP3P}$ | **Active Power-Down $I_{PP}$ Current**<br>Same condition with $I_{DD3P}$. |
| $I_{DD4R}$ | **Operating Burst Read Current**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**tCK, CL:** See Table 10-1;<br>**BL:** 8(2);<br>**AL:** 0;<br>**CS_n**: HIGH between RD;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-7.<br>**Data I/O**: Seamless read data burst with different data between one burst and the next one according to Table 10-7.<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks open, RD commands cycling through banks: 0, 0, 1, 1, 2, 2, ... (see Table 10-7)<br>**Output Buffer and $R_{TT}$**: Enabled in Mode Registers(2);<br>**ODT Signal:** Stable at 0;<br>**Pattern Details:** See Table 10-7. |
| $I_{DD4RA}$ | **Operating Burst Read Current (AL = CL - 1)**<br>**AL = CL - 1, Other conditions:** See $I_{DD4R}$. |
| $I_{DD4RB}$ | **Operating Burst Read Current with Read DBI**<br>**Read DBI enabled(3), Other conditions:** See $I_{DD4R}$. |
| $I_{PP4R}$ | **Operating Burst Read $I_{PP}$ Current**<br>Same condition with $I_{DD4R}$. |
| $I_{DDQ4R}$ | **Operating Burst Read $I_{DDQ}$ Current**<br>Same definition like for $I_{DD4R}$, however measuring $I_{DDQ}$ current instead of $I_{DD}$ current. |
| $I_{DDQ4RB}$ | **Operating Burst Read $I_{DDQ}$ Current with READ DBI**<br>Same definition like for $I_{DD4RB}$, however measuring $I_{DDQ}$ current instead of $I_{DD}$ current. |
| $I_{DD4W}$ | **Operating Burst Write Current**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**$t_{CK}$, CL:** See Table 10-1;<br>**BL:** 81;<br>**AL:** 0;<br>**CS_n:** HIGH between WR;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-8;<br>**Data I/O**: Seamless write data burst with different data between one burst and the next one according to Table 10-8<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks open, WR commands cycling through banks: 0, 0, 1, 1, 2, 2, ... (Table 10-8);<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers2;<br>**ODT Signal:** Stable at HIGH;<br>**Pattern Details:** See Table 10-8. |



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| Symbol | Description |
|---|---|
| $I_{DD4WA}$ | **Operating Burst Write Current (AL = CL - 1)**<br>**AL = CL - 1, Other conditions:** See $I_{DD4W}$. |
| $I_{DD4WB}$ | **Operating Burst Write Current with Write DBI**<br>**Write DBI enabled3, Other conditions:** See $I_{DD4W}$. |
| $I_{DD4WC}$ | **Operating Burst Write Current with Write CRC**<br>**Write CRC enabled3, Other conditions:** See $I_{DD4W}$. |
| $I_{DD4W_par}$ | **Operating Burst Write Current with CA Parity**<br>**CA Parity enabled3, Other conditions:** See $I_{DD4W}$. |
| $I_{PP4W}$ | **Operating Burst Write $I_{PP}$ Current**<br>Same condition with $I_{DD4W}$. |
| $I_{DD5B}$ | **Burst Refresh Current (1X REF)**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**$t_{CK}$, CL nRFC:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n:** HIGH between REF;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-10.<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** REF command every nRFC (see Table 10-10);<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** Stable at 0;<br>**Pattern Details**: See Table 10-10. |
| $I_{PP5B}$ | **Burst Refresh Write $I_{PP}$ Current (1X REF)**<br>Same condition with $I_{DD5B}$. |
| $I_{DD5F2}$ | **Burst Refresh Current (2X REF)**<br>**$t_{RFC}$ = $t_{RFC_}$ * 2, Other conditions:** See $I_{DD5B}$. |
| $I_{PP5F2}$ | **Burst Refresh Write $I_{PP}$ Current (2X REF)**<br>Same condition with $I_{DD5F2}$. |
| $I_{DD5F4}$ | **Burst Refresh Current (4X REF)**<br>**$t_{RFC}$ = $t_{RFC_}$ * 4, Other conditions:** See $I_{DD5B}$. |
| $I_{PP5F4}$ | **Burst Refresh Write $I_{PP}$ Current (4X REF)**<br>Same condition with $I_{DD5F4}$. |
| $I_{DD6N}$ | **Self Refresh Current: Normal Temperature Range**<br>**$T_{CASE}$ for CT devices:** 0 - 85°C, **$T_{CASE}$ for IT devices:** -40 - 85°C;<br>**Low Power Auto Self Refresh (LP ASR)**: Normal(4);<br>**CKE:** LOW;<br>**External clock:** Off; CK_t and CK_c: LOW;<br>**CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n, Command, Address, Bank Group Address, Bank Address, Data I/O:** HIGH;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** SELF REFRESH operation;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** MID-LEVEL. |
| $I_{PP6N}$ | **Self Refresh $I_{PP}$ Current: Normal Temperature Range**<br>Same condition with $I_{DD6N}$. |
| $I_{DD6E}$ | **Self Refresh Current: Extended Temperature Range)**<br>**$T_{CASE}$ for CT devices:** 0 - 95°C, **$T_{CASE}$ for IT devices:** -40 - 95°C;<br>**Low Power Auto Self Refresh (LP ASR)**: Extended(4);<br>**CKE:** LOW;<br>**External clock:** Off; CK_t and CK_c: LOW;<br>**CL:** See Table 10-1;<br>**BL:** 8(1)<br>**AL:** 0;<br>**CS_n, Command, Address, Bank Group Address, Bank Address, Data I/O:** HIGH;<br>**DM_n**: Stable at 1;<br>**Bank Activity:** Extended Temperature SELF REFRESH operation;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** MID-LEVEL. |



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| Symbol | Description |
|---|---|
| $I_{PP6E}$ | **Self Refresh $I_{PP}$ Current: Extended Temperature Range**<br>Same condition with $I_{DD6E}$. |
| $I_{DD6R}$ | **Self Refresh Current: Reduced Temperature Range**<br>**$T_{CASE}$ for CT devices:** 0 - 45°C, **$T_{CASE}$ for IT devices:** -40 - 45°C;<br>**Low Power Auto Self Refresh (LP ASR)**: Reduced(4);<br>**CKE:** LOW;<br>**External clock:** Off; CK_t and CK_c: LOW;<br>**CL:** See Table 10-1;<br>**BL:** 8(1)<br>**AL:** 0;<br>**CS_n, Command, Address, Bank Group Address, Bank Address, Data I/O:** HIGH;<br>**DM_n**: Stable at 1;<br>**Bank Activity:** Extended Temperature SELF REFRESH operation;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** MID-LEVEL. |
| $I_{PP6R}$ | **Self Refresh $I_{PP}$ Current: Reduced Temperature Range**<br>Same condition with $I_{DD6R}$. |
| $I_{DD6A}$ | **Auto Self Refresh Current**<br>**$T_{CASE}$ for CT devices:** 0 - 95°C, **$T_{CASE}$ for IT devices:** -40 - 95°C;<br>**Low Power Auto Self Refresh (LP ASR)**: Auto(4);<br>**CKE:** LOW;<br>**External clock:** Off; CK_t and CK_c: LOW;<br>**CL:** See Table 10-1;<br>**BL:** 8(1)<br>**AL:** 0;<br>**CS_n, Command, Address, Bank Group Address, Bank Address, Data I/O:** HIGH;<br>**DM_n**: Stable at 1;<br>**Bank Activity:** Auto SELF REFRESH operation;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** MID-LEVEL. |
| $I_{PP6A}$ | **Auto Self Refresh $I_{PP}$ Current**<br>Same condition with $I_{DD6A}$. |
| $I_{DD7}$ | **Operating Bank Interleave Read Current**<br>**CKE:** HIGH;<br>**External clock:** On;<br>**tCK, nRC, nRAS, nRCD, nRRD, nFAW, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** CL-1;<br>**CS_n**: HIGH between ACT and RDA;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Partially toggling according to Table 10-11;<br>**Data I/O:** Read data bursts with different data between one burst and the next one according to Table 10-11;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** Two times interleaved cycling through banks (0, 1, ...7) with different addressing, see Table 10-11;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2);<br>**ODT Signal:** Stable at 0;<br>**Pattern Details:** See Table 10-11. |
| $I_{PP7}$ | **Operating Bank Interleave Read $I_{PP}$ Current**<br>Same condition with $I_{DD7}$. |
| $I_{DD8}$ | **Maximum Power Down Current**<br>**Place DRAM in MPSM then CKE:** HIGH;<br>**External Clock:** On;<br>**tCK, CL:** See Table 10-1;<br>**BL:** 8(1);<br>**AL:** 0;<br>**CS_n:** stable at 1;<br>**Command, Address, Bank Group Address, Bank Address Inputs:** Stable at 0;<br>**Data I/O:** $V_{DDQ}$;<br>**DM_n:** Stable at 1;<br>**Bank Activity:** All banks closed;<br>**Output Buffer and $R_{TT}$:** Enabled in Mode Registers(2); |



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| | **ODT Signal:** Stable at 0. |
| $I_{PP8}$ | **Maximum Power Down $I_{PP}$ Current**<br>Same condition with $I_{DD8}$. |

Note:

1. Burst length: BL8 fixed by MRS: set MR0[A1:0 = 00].
2. Output buffer enable:
   Set MR1 [A12 = 0]: Qoff = Output buffer enabled
   Set MR1 [A2:1 = 00]: Output Driver Impedance Control = $R_{ZQ}/7$
   $R_{TT_NOM}$ enable:
   Set MR1 [A10:8 = 011]: $R_{TT_NOM} = R_{ZQ}/6$
   $R_{TT_WR}$ enable:
   Set MR2 [A10:9 = 01]: $R_{TT_WR} = R_{ZQ}/2$
   $R_{TT_PARK}$ diabale:
   Set MR5 [A8:6 = 000]
3. CAL enabled: Set MR4 [A8:6 = 001]: 1600MT/s
   010]: 1866MT/s, 2133MT/s
   011]: 2400MT/s
   Gear Down mode enabled: Set MR3 [A3 = 1]: 1/4 Rate
   DLL disabled: Set: MR1 [A0 = 0]
   CA parity enabled: Set MR5 [A2:0 = 001]: 1600MT/s,1866MT/s, 2133MT/s
   010]: 2400MT/s
   Read DBI enabled: Set MR5 [A12 = 1]
   Write DBI enabled: Set: MR5 [A11 = 1]
4. Low Power Auto Self Refresh (LP ASR): Set MR2 [A7:6 = 00]: Normal
   01]: Reduced Temperature range
   10]: Extended Temperature range
   11]: Auto Self Refresh
5. $I_{DD2NG}$ should be measured after sync pulse (NOP) input.



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### 10.1.1 $I_{DD0}$, $I_{DD0A}$ and $I_{PP0}$ Measurement-Loop Pattern

**Table 10-3. $I_{DD0}$, $I_{DD0A}$ and $I_{PP0}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are $V_{DDQ}$.
2. BG1 is a “Don’t Care” for x16 device.
3. C[2:0] are used only for 3DS device.
4. DQ signals are $V_{DDQ}$.



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### 10.1.2 $I_{DD1}$, $I_{DD1A}$ and $I_{PP1}$ Measurement-Loop Pattern

**Table 10-4. $I_{DD1}$, $I_{DD1A}$ and $I_{PP1}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are used according to RD Commands, otherwise $V_{DDQ}$.
2. BG1 is a “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 $V_{DDQ}$.



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### 10.1.3 $I_{DD2N}$, $I_{DD2NA}$, $I_{DD2NL}$, $I_{DD2NG}$, $I_{DD2ND}$, $I_{DD2N_par}$, $I_{PP2}$, $I_{DD3N}$, $I_{DD3NA}$ and $I_{DD3P}$ Measurement-Loop Pattern

**Table 10-5. $I_{DD2N}$, $I_{DD2NA}$, $I_{DD2NL}$, $I_{DD2NG}$, $I_{DD2ND}$, $I_{DD2N_par}$, $I_{PP2}$, $I_{DD3N}$, $I_{DD3NA}$ and $I_{DD3P}$ Measurement-Loop Pattern(1)**

| CK_t/CK_c | CKE | Sub-Loop | Cycle Number | Command | CS_n | ACT_n | RAS_n/A16 | CAS_n/A15 | WE_n/A14 | ODT | C[2:0](3) | BG[1:0](2) | BA[1:0] | A12/BC_n | A[17,13,11] | A[10]/AP | A[9:7] | A[6:3] | A[2:0] | Data(4) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Toggling | Static High | 0 | 0 | D, D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 1 | D, D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 2 | D#, D# | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3(2) | 3 | 0 | 0 | 0 | 7 | F | 0 | 0 |
| | | | 3 | D#, D# | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 3(2) | 3 | 0 | 0 | 0 | 7 | F | 0 | 0 |
| | | 1 | 4-7 | Repeat Sub-Loop 0, use BG[1:0](2) = 1, BA[1:0] = 1 instead | | | | | | | | | | | | | | | |
| | | 2 | 8-11 | Repeat Sub-Loop 0, use BG[1:0](2) = 0, BA[1:0] = 2 nstead | | | | | | | | | | | | | | | |
| | | 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 $V_{DDQ}$.
2. BG1 is a “Don’t Care” for x16 device.
3. C[2:0] are used only for 3DS device.
4. DQ signals are $V_{DDQ}$.



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### 10.1.4 $I_{DD2NT}$ and $I_{DDQ2NT}$ Measurement-Loop Pattern

**Table 10-6. $I_{DD2NT}$ and $I_{DDQ2NT}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are $V_{DDQ}$.
2. BG1 is a “Don’t Care” for x16 device.
3. C[2:0] are used only for 3DS device.
4. DQ signals are $V_{DDQ}$.



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### 10.1.5 $I_{DD4R}$, $I_{DDR4RA}$, $I_{DD4RB}$ and $I_{DDQ4R}$ Measurement-Loop Pattern[1]

**Table 10-7. $I_{DD4R}$, $I_{DDR4RA}$, $I_{DDR4RB}$ and $I_{DDQ4R}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are used according to RD Commands, otherwise $V_{DDQ}$.
2. BG1 is a “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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### 10.1.6 $I_{DD4W}$, $I_{DDR4WA}$, $I_{DD4WB}$ and $I_{DD4W_par}$ Measurement-Loop Pattern

**Table 10-8. $I_{DD4W}$, $I_{DDR4WA}$, $I_{DDR4WB}$ and $I_{DD4W_par}$ Measurement-Loop Pattern[1]**

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

Note:

1. DQS_t, DQS_c are used according to WR Commands, otherwise $V_{DDQ}$.
2. BG1 is a “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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### 10.1.7 $I_{DD4WC}$ Measurement-Loop Pattern

**Table 10-9. $I_{DD4WC}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are $V_{DDQ}$.
2. BG1 is a “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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### 10.1.8 $I_{DD5B}$ Measurement-Loop Pattern

**Table 10-10. $I_{DD5B}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are $V_{DDQ}$.
2. BG1 is a “Don’t Care” for x16 device.
3. C[2:0] are used only for 3DS device.
4. DQ signals are $V_{DDQ}$.



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### 10.1.9 $I_{DD7}$ Measurement-Loop Pattern

**Table 10-11. $I_{DD7}$ Measurement-Loop Pattern(1)**

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

Note:

1. DQS_t, DQS_c are $V_{DDQ}$.
2. BG1 is a “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 $V_{DDQ}$.



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## 10.2 $I_{DD}$ Specifications

$I_{DD}$ and $I_{PP}$ values are for full operation range of voltage and temperature unless otherwise noted.

**Table 10-12. $I_{DD}$ and $I_{DDQ}$ Specifications**

| Symbol | Width | 2400 | 2666 | 3200 | Unit |
|---|---|---|---|---|---|
| $I_{DD0}$ | x16 | 91 | 93 | 101 | mA |
| $I_{DD1}$ | x16 | 116 | 119 | 126 | mA |
| $I_{DD2N}$ | x16 | 71 | 73 | 79 | mA |
| $I_{DD2NT}$ | x16 | 80 | 83 | 90 | mA |
| $I_{DD2P}$ | x16 | 52 | 53 | 55 | mA |
| $I_{DD2Q}$ | x16 | 68 | 70 | 74 | mA |
| $I_{DD3N}$ | x16 | 96 | 98 | 103 | mA |
| $I_{DD3P}$ | x16 | 69 | 69 | 71 | mA |
| $I_{DD4R}$ | x16 | 244 | 263 | 294 | mA |
| $I_{DD4W}$ | x16 | 228 | 247 | 278 | mA |
| $I_{DD5R}$ | x16 | 86 | 89 | 94 | mA |
| $I_{DD6N}$ | x16 | 82 | 82 | 82 | mA |
| $I_{DD6E}$ | x16 | 100 | 100 | 100 | mA |
| $I_{DD6R}$ | x16 | 79 | 79 | 79 | mA |
| $I_{DD6A}$ | x16 | 100 | 100 | 100 | mA |
| $I_{DD7}$ | x16 | 297 | 302 | 311 | mA |



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**Table 10-13. $I_{PP}$ Specifications**

| Symbol | Width | 2400 | 2666 | 3200 | Unit |
|---|---|---|---|---|---|
| $I_{PP0}$ | x16 | 6 | 6 | 6 | mA |
| $I_{PP3N}$ | x16 | 5 | 5 | 5 | mA |
| $I_{PP5R}$ | x16 | 5 | 5 | 5 | mA |
| $I_{PP7}$ | x16 | 25 | 25 | 25 | mA |

**Table 10-14. $I_{DD6}$ Specification**

| Symbol | Temperature Range | Width | 2400 | 2666 | 3200 | Unit | Note |
|---|---|---|---|---|---|---|---|
| $I_{DD6N}$ | 0 ~ 85℃ | x16 | 82 | 82 | 82 | mA | 3,4 |
| $I_{DD6E}$ | 0 ~ 95℃ | x16 | 100 | 100 | 100 | mA | 4,5,6 |
| $I_{DD6R}$ | 0 ~ 45℃ | x16 | 79 | 79 | 79 | mA | 4,6,9 |
| $I_{DD6A}$ | 0 ~ 95℃ | x16 | 100 | 100 | 100 | mA | 4,6,7,8 |

Note:

1. Some $I_{DD}$ currents are higher for x16 organization due to larger page size architecture.
2. Max values for $I_{DD}$ currents considering worst case cond itions of process, temperature and voltage.
3. Applicable for MR2 settings A6 = 0 and A7 = 0.
4. Datasheet include a max value for $I_{DD6}$.
5. Applicable for MR2 settings A6 = 0 and A7 = 1. $I_{DD6E}$ is only specified for devices which support the Extended Temperature Range feature.
6. Refer to datasheet for the value specification method (e.g. max, typical) for $I_{DD6E}$ and $I_{DD6A}$.
7. Applicable for MR2 settings A6 = 1 and A7 = 0. $I_{DD6A}$ 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 $T_{OPER}$. Refer to supplier data shee t for more information.
9. Applicable for MR2 settings MR2 [A7:A6 = 01]: Reduced Temperature range. $I_{DD6R}$ is verified by design and characterization, and may not be subject to production test.



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# 11 INPUT/OUTPUT CAPACITANCE

**Table 11-1. Silicon Pad I/O Capacitance**

| Symbol | Parameter | 1600/1866/2133 | | 2400/2666 | | 3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | | |
| $C_{IO}$ | Input/output capacitance | 0.55 | 1.4 | 0.55 | 1.15 | 0.55 | 1.00 | pF | 1,2,3 |
| $C_{DIO}$ | Input/output capacitance delta | -0.1 | 0.1 | -0.1 | 0.1 | -0.1 | 0.1 | pF | 1,2,3,11 |
| $C_{DDQS}$ | Input/output capacitance delta DQS_t and DQS_c | - | 0.05 | - | 0.05 | - | 0.05 | pF | 1,2,3,5 |
| $C_{CK}$ | Input capacitance, CK_t and CK_c | 0.2 | 0.8 | 0.2 | 0.7 | 0.2 | 0.7 | pF | 1,3 |
| $C_{DCK}$ | Input capacitance delta CK_t and CK_c | - | 0.05 | - | 0.05 | - | 0.05 | pF | 1,3,4 |
| $C_I$ | Input capacitance (CTRL, ADD, CMD pins only) | 0.2 | 0.8 | 0.2 | 0.7 | 0.2 | 0.55 | pF | 1,3,6 |
| $C_{DI_CTRL}$ | Input capacitance delta (All CTRL pins only) | -0.1 | 0.1 | -0.1 | 0.1 | -0.1 | 0.1 | pF | 1,3,7,8 |
| $C_{DI_ADD_CMD}$ | Input capacitance delta (All ADD/ CMD pins only) | -0.1 | 0.1 | -0.1 | 0.1 | -0.1 | 0.1 | pF | 1,2,9,10 |
| $C_{ALERT}$ | Input/output capacitance of ALERT | 0.5 | 1.5 | 0.5 | 1.5 | 0.5 | 1.5 | pF | 1,3 |
| $C_{ZQ}$ | Input/output capacitance of ZQ | - | 2.3 | - | 2.3 | - | 2.3 | pF | 1,3,12 |
| $C_{TEN}$ | Input capacitance of TEN | 0.2 | 2.3 | 0.2 | 2.3 | 0.2 | 2.3 | pF | 1,3,13 |

Note:

1. This parameter is not subject to production test. It is verified by design and characterization. The silicon only capacitance is validated by deembedding the package L & C parasitic. The capacitance is measured with $V_{DD}$, $V_{DDQ}$, $V_{SS}$, $V_{SSQ}$ applied with all other signal pins floating.
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 of CK_t - CK_c.
5. Absolute value of $C_{IO}$(DQS_t) - $C_{IO}$(DQS_c).
6. CI applies to ODT, CS_n, CKE, A0 - A17, BA0 - BA1, BG0 - BG1, RAS_n/A16, CAS_n/A15, WE_n/A14, ACT_n and PAR.
7. $C_{DI_CTRL}$ 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: 5pF.
13. TEN pin may be DRAM internally pulled low through a weak pull-down resistor to $V_{SS}$. In this case $C_{TEN}$ might not be valid and system shall verify TEN signal with Vendor specific information.



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**Table 11-2. DRAM Package Electrical Specifications (x16)**

| Parameter | | Symbol | 1600/1866/2133/ 2400/2666 | | 2933 | | 3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | Max | Min | Max | Min | Max | | |
| Input/ output | Zpkg | $Z_{IO}$ | 45 | 85 | 45 | 85 | 45 | 85 | ohm | 1, 2, 4 |
| | Package delay | $Td_{IO}$ | 14 | 45 | 14 | 45 | 14 | 45 | ps | 1, 3, 4 |
| | Lpkg | $L_{IO}$ | — | 3.4 | — | 3.4 | — | 3.4 | nH | 11 |
| | Cpkg | $C_{IO}$ | — | 0.82 | — | 0.82 | — | 0.82 | pF | 11 |
| LDQS_t/ LDQS_c/ UDQS_t/ UDQS_c | Zpkg | $Z_{IO\ DQS}$ | 45 | 85 | 45 | 85 | 45 | 85 | ohm | 1, 2 |
| | Package delay | $Td_{IO\ DQS}$ | 14 | 45 | 14 | 45 | 14 | 45 | ps | 1, 3 |
| | Lpkg | $L_{IO\ DQS}$ | — | 3.4 | — | 3.4 | — | 3.4 | nH | 11 |
| | Cpkg | $C_{IO\ DQS}$ | — | 0.82 | — | 0.82 | — | 0.82 | pF | 11 |
| LDQS_t/ LDQS_c, UDQS_t/ UDQS_c, | Delta Zpkg | $DZ_{IO\ DQS}$ | — | 10.5 | — | 10.5 | — | 10.5 | ohm | 1, 2, 6 |
| | Delta delay | $DTd_{IO\ DQS}$ | — | 5 | — | 5 | — | 5 | ps | 1, 3, 6 |
| Input CTRL pins | Zpkg | $Z_{I\ CTRL}$ | 50 | 90 | 50 | 90 | 50 | 90 | ohm | 1, 2, 8 |
| | Package delay | $Td_{I\ CTRL}$ | 14 | 42 | 14 | 42 | 14 | 42 | ps | 1, 3, 8 |
| | Lpkg | $L_{I\ CTRL}$ | — | 3.4 | — | 3.4 | — | 3.4 | nH | 11 |
| | Cpkg | $C_{I\ CTRL}$ | — | 0.7 | — | 0.7 | — | 0.7 | pF | 11 |
| Input CMD ADD pins | Zpkg | $Z_{I\ ADD\ CMD}$ | 50 | 90 | 50 | 90 | 50 | 90 | ohm | 1, 2, 7 |
| | Package delay | $Td_{I\ ADD\ CMD}$ | 14 | 52 | 14 | 52 | 14 | 52 | ps | 1, 3, 7 |
| | Lpkg | $L_{I\ ADD\ CMD}$ | — | 3.9 | — | 3.9 | — | 3.9 | nH | 11 |
| | Cpkg | $C_{I\ ADD\ CMD}$ | — | 0.86 | — | 0.86 | — | 0.86 | pF | 11 |
| CK_t, CK_c | Zpkg | $Z_{CK}$ | 50 | 90 | 50 | 90 | 50 | 90 | ohm | 1, 2 |
| | Package delay | $Td_{CK}$ | 14 | 42 | 14 | 42 | 14 | 42 | ps | 1, 3 |
| | Delta Zpkg | $DZ_{DCK}$ | — | 10.5 | — | 10.5 | — | 10.5 | ohm | 1, 2, 5 |
| | Delta delay | $DTd_{DCK}$ | — | 5 | — | 5 | — | 5 | ps | 1, 3, 5 |
| Input CLK | Lpkg | $L_{I\ CLK}$ | — | 3.4 | — | 3.4 | — | 3.4 | nH | 11 |
| | Cpkg | $C_{I\ CLK}$ | — | 0.7 | — | 0.7 | — | 0.7 | pF | 11 |
| ZQ Zpkg | | $Z_{O\ ZQ}$ | — | 100 | — | 100 | — | 100 | ohm | 1, 2 |
| ZQ delay | | $Td_{O\ ZQ}$ | 20 | 90 | 20 | 90 | 20 | 90 | ps | 1, 3 |
| ALERT Zpkg | | $Z_{O\ ALERT}$ | 40 | 100 | 40 | 100 | 40 | 100 | ohm | 1, 2 |
| ALERT delay | | $Td_{O\ ALERT}$ | 20 | 55 | 20 | 55 | 20 | 55 | ps | 1, 3 |

Note:

1. The package parasitic (L and C) are validated using package only samples. The capaci- tance is measured with $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ shorted with all other signal pins float- ing. The inductance is measured with $V_{DD}$, $V_{DDQ}$, $V_{SS}$, and $V_{SSQ}$ shorted and all other sig- nal pins shorted at the die, not pin, side.



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2. Package-only impedance (Zpkg) is calculated based on the Lpkg and Cpkg total for a given pin where: Zpkg (total per pin) = SQRT (Lpkg/Cpkg).
3. Package-only delay (Tpkg) is calculated based on Lpkg and Cpkg total for a given pin where: Tdpkg (total per pin) = SQRT (Lpkg × Cpkg).
4. $Z_{IO}$ and $Td_{IO}$ apply to DQ, DM, TDQS_t and TDQS_c.
5. Absolute value of ZCK_t, ZCK_c for impedance (Z) or absolute value of TdCK_t, TdCK_c for delay (Td).
6. 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).
7. $Z_{I\ ADD\ CMD}$ and $Td_{I\ ADD\ CMD}$ apply to A[17:0], BA[1:0], BG[1:0], RAS_n CAS_n, and WE_n.
8. $Z_{I\ CTRL}$ and $Td_{I\ CTRL}$ apply to ODT, CS_n, and CKE.
9. Package implementations will meet specification if the Zpkg and package delay fall within the ranges shown, and the maximum Lpkg and Cpkg do not exceed the maxi- mum values shown.
10. It is assumed that Lpkg can be approximated as Lpkg = $Z_O$ × Td.
11. It is assumed that Cpkg can be approximated as Cpkg = Td/$Z_O$.



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# 12 ELECTRICAL CHARACTERISTICS AND AC TIMING

## 12.1 Reference Load for AC Timing and Output Slew Rate

Figure 12-1 represents the effective reference load of 50Ω used in defining the relevant AC timing parameters of the device as well as output slew rate measurements.

$R_{ON}$ nominal of DQ, DQS_t and DQS_c drivers uses 34Ω to specify the relevant AC timing parameter values of the device.

- The maximum DC high level of output signal = 1.0 * $V_{DDQ}$
- The minimum DC low level of output signal = {34/(34 + 50)} * $V_{DDQ}$ = 0.4 * $V_{DDQ}$
- 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} * $V_{DDQ}$ = 0.7 * $V_{DDQ}$

The actual reference level of output signal might vary with driver $R_{ON}$ 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.

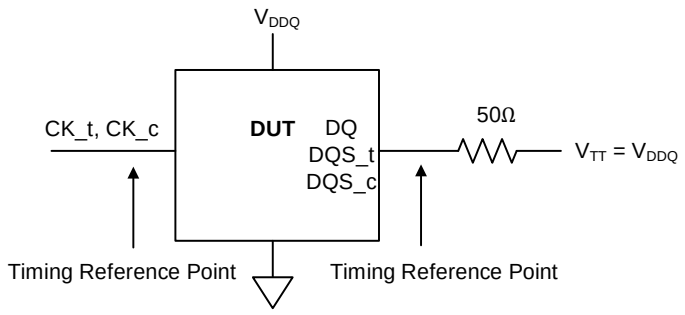



**Figure 12-1. Reference Load for AC Timing and Output Slew Rate**

## 12.2 $t_{REFI}$

Average periodic Refresh interval ($t_{REFI}$) of DDR4 SDRAM is defined as shown in Table 12-1 below.

**Table 12-1. $t_{REFI}$ by Device Density**

| Parameter | Symbol | | 8Gb | Unit |
|---|---|---|---|---|
| Average periodic refresh interval | $t_{REFI}$ | -40°C ≤ $T_{CASE}$ ≤ 85°C | 7.8 | µs |
| | | 85°C < $T_{CASE}$ ≤ 95°C | 3.9 | µs |

## 12.3 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.

### 12.3.1 Definition for $t_{CK\ (ABS)}$

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



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### 12.3.2 Definition for $t_{CK\ (avg)}$

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

$$t_{CK\ (avg)} = (\sum_{j=1}^{N} t_{CK\ (abs)j})/N \quad N = 200$$

### 12.3.3 Definition for $t_{CH\ (avg)}$ and $t_{CL\ (avg)}$

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

$$t_{CH\ (avg)} = (\sum_{j=1}^{N} t_{CHj})/(N * t_{CK\ (avg)}) \quad N = 200$$

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

$$t_{CL\ (avg)} = (\sum_{j=1}^{N} t_{CLj})/(N * t_{CK\ (avg)}) \quad N = 200$$

### 12.3.4 Definition for $t_{ERR\ (nper)}$

$t_{ERR}$ is defined as the cumulative error across n consecutive cycles of n * $t_{CK\ (avg)}$. $t_{ERR}$ is not subject to production test.



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## 12.4 Timing Parameters by Speed Grade

### 12.4.1 Timing Parameters by Speed Bin for DDR4-1600 to 2400

**Table 12-2. 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) | $t_{CK(DLL_OFF)}$ | 8 | 20 | 8 | 20 | 8 | 20 | 8 | 20 | ns | - |
| Average Clock Period | $t_{CK\ (avg)}$ | 1.25 | <1.5 | 1.071 | <1.25 | 0.937 | <1.071 | 0.833 | <0.937 | ns | 35,36 |
| Average high pulse width | $t_{CH\ (avg)}$ | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | $t_{CK\ (avg)}$ | - |
| Average low pulse width | $t_{CL\ (avg)}$ | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | $t_{CK\ (avg)}$ | - |
| Absolute Clock Period | $t_{CK\ (abs)}$ | Min: $t_{CK\ (avg)min} + t_{JIT\ (per)min_tot}$ | | | | | | | | $t_{CK\ (avg)}$ | - |
| | | Max: $t_{CK\ (avg)max} + t_{JIT\ (per)max_tot}$ | | | | | | | | | |
| Absolute clock HIGH pulse width | $t_{CH\ (abs)}$ | 0.45 | - | 0.45 | - | 0.45 | - | 0.45 | - | $t_{CK\ (avg)}$ | 23 |
| Absolute clock LOW pulse width | $t_{CL\ (abs)}$ | 0.45 | - | 0.45 | - | 0.45 | - | 0.45 | - | $t_{CK\ (avg)}$ | 24 |
| Clock Period Jitter- total | $t_{JIT\ (per)_tot}$ | -63 | 63 | -54 | 54 | -47 | 47 | -42 | 42 | ps | 25 |
| Clock Period Jitter- deterministic | $t_{JIT\ (per)_dj}$ | -31 | 31 | -27 | 27 | -23 | 23 | -21 | 21 | ps | 26 |
| Clock Period Jitter during DLL locking period | $t_{JIT\ (per,\ lck)}$ | -50 | 50 | -43 | 43 | -38 | 38 | -33 | 33 | ps | - |
| Cycle to Cycle Period Jitter | $t_{JIT\ (cc)}$ | - | 125 | - | 107 | - | 94 | - | 83 | ps | - |
| Cycle to Cycle Period Jitter during DLL locking period | $t_{JIT\ (cc,\ lck)}$ | - | 100 | - | 86 | - | 75 | - | 67 | ps | - |
| Cumulative error across 2 cycles | $t_{ERR\ (2per)}$ | -92 | 92 | -79 | 79 | -69 | 69 | -61 | 61 | ps | - |
| Cumulative error across 3 cycles | $t_{ERR\ (3per)}$ | -109 | 109 | -94 | 94 | -82 | 82 | -73 | 73 | ps | - |
| Cumulative error across 4 cycles | $t_{ERR\ (4per)}$ | -121 | 121 | -104 | 104 | -91 | 91 | -81 | 81 | ps | - |
| Cumulative error across 5 cycles | $t_{ERR\ (5per)}$ | -131 | 131 | -112 | 112 | -98 | 98 | -87 | 87 | ps | - |
| Cumulative error across 6 cycles | $t_{ERR\ (6per)}$ | -139 | 139 | -119 | 119 | -104 | 104 | -92 | 92 | ps | - |
| Cumulative error across 7 cycles | $t_{ERR\ (7per)}$ | -145 | 145 | -124 | 124 | -109 | 109 | -97 | 97 | ps | - |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Cumulative error across 8 cycles | $t_{ERR\ (8per)}$ | -151 | 151 | -129 | 129 | -113 | 113 | -101 | 101 | ps | - |
| Cumulative error across 9 cycles | $t_{ERR\ (9per)}$ | -156 | 156 | -134 | 134 | -117 | 117 | -104 | 104 | ps | - |
| Cumulative error across 10 cycles | $t_{ERR\ (10per)}$ | -160 | 160 | -137 | 137 | -120 | 120 | -107 | 107 | ps | - |
| Cumulative error across 11 cycles | $t_{ERR\ (11per)}$ | -164 | 164 | -141 | 141 | -123 | 123 | -110 | 110 | ps | - |
| Cumulative error across 12 cycles | $t_{ERR\ (12per)}$ | -168 | 168 | -144 | 144 | -126 | 126 | -112 | 112 | ps | - |
| Cumulative error across 13 cycles | $t_{ERR\ (13per)}$ | -172 | 172 | -147 | 147 | -129 | 129 | -114 | 114 | ps | - |
| Cumulative error across 14 cycles | $t_{ERR\ (14per)}$ | -175 | 175 | -150 | 150 | -131 | 131 | -116 | 116 | ps | - |
| Cumulative error across 15 cycles | $t_{ERR\ (15per)}$ | -178 | 178 | -152 | 152 | -133 | 133 | -118 | 118 | ps | - |
| Cumulative error across 16 cycles | $t_{ERR\ (16per)}$ | -180 | 189 | -155 | 155 | -135 | 135 | -120 | 120 | ps | - |
| Cumulative error across 17 cycles | $t_{ERR\ (17per)}$ | -183 | 183 | -157 | 157 | -137 | 137 | -122 | 122 | ps | - |
| Cumulative error across 18 cycles | $t_{ERR\ (18per)}$ | -185 | 185 | -159 | 159 | -139 | 139 | -124 | 124 | ps | - |
| Cumulative error across n = 13, 14 . . . 49, 50 cycles | $t_{ERR\ (nper)}$ | $t_{ERR\ (nper)min} = ((1 + 0.68ln(n)) * t_{JIT\ (per)_total\ min})$<br>$t_{ERR\ (nper)max} = ((1 + 0.68ln(n)) * t_{JIT\ (per)_total\ max})$ | | | | | | | | ps | - |
| Command and Address setup time to CK_t, CK_c referenced to $V_{IH(AC)}/V_{IL(AC)}$ levels | $t_{IS\ (base)}$ | 115 | - | 100 | - | 80 | - | 62 | - | ps | - |
| Command and Address setup time to CK_t, CK_c referenced to $V_{REF}$ levels | $t_{IS\ (VREF)}$ | 215 | - | 200 | - | 180 | - | 162 | - | ps | - |
| Command and Address hold time to CK_t, CK_c referenced to $V_{IH(DC)}/V_{IL(DC)}$ levels | $t_{IH\ (base)}$ | 140 | - | 125 | - | 105 | - | 87 | - | ps | - |
| Command and Address hold time to CK_t, CK_c referenced to $V_{REF}$ levels | $t_{IH\ (VREF)}$ | 215 | - | 200 | - | 180 | - | 162 | - | ps | - |
| Control and Address Input pulse width for each input | $t_{IPW}$ | 600 | - | 525 | - | 460 | - | 410 | - | ps | - |
| **Command and Address Timing** | | | | | | | | | | | |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| CAS_n to CAS_n command delay for same bank group | $t_{CCD_L}$ | 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 | $t_{CCD_S}$ | 4 | - | 4 | - | 4 | - | 4 | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 2KB page size | $t_{RRD_S\ (2K)}$ | 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 | $t_{RRD_S\ (1K)}$ | 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 | $t_{RRD_S\ (1/2K)}$ | 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 | $t_{RRD_L\ (2K)}$ | 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 | $t_{RRD_L\ (1K)}$ | Max (4nCK, 6.0ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 4.9ns) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to same bank group for 1/2KB page size | $t_{RRD_L\ (1/2K)}$ | Max (4nCK, 6.0ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 5.3ns) | - | Max (4nCK, 4.9ns) | - | nCK | 34 |
| Four activate window for 2KB page size | $t_{FAW\ (2K)}$ | Max (28nCK, 35ns) | - | Max (28nCK, 30ns) | - | Max (28nCK, 30ns) | - | Max (28nCK, 30ns) | - | ns | 34 |
| Four activate window for 1KB page size | $t_{FAW\ (1K)}$ | Max (20nCK, 25ns) | - | Max (20nCK, 23ns) | - | Max (20nCK, 21ns) | - | Max (20nCK, 21ns) | - | ns | 34 |
| Four activate window for 1/2KB page size | $t_{FAW\ (1/2K)}$ | Max (16nCK, 20ns) | - | Max (16nCK, 17ns) | - | Max (16nCK, 15ns) | - | Max (16nCK, 13ns) | - | ns | 34 |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Delay from start of internal WRITE transaction to internal READ command for different bank group | $t_{WTR_S}$ | 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 | $t_{WTR_L}$ | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | ns | 1, 34 |
| Internal READ command to PRECHARGE command delay | $t_{RTP}$ | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | ns | - |
| WRITE recovery time | $t_{WR}$ | 15 | - | 15 | - | 15 | - | 15 | - | ns | 1 |
| Write recovery time when CRC and DM are enabled | $t_{WR_CRC_DM}$ | $t_{WR}$ + Max (4nCK, 3.75ns) | - | $t_{WR}$ + Max (5nCK, 3.75ns) | - | $t_{WR}$ + Max (5nCK, 3.75ns) | - | $t_{WR}$ + Max (5nCK, 3.75ns) | - | ns | 1, 28 |
| Delay from start of internal WRITE transaction to internal READ command for different bank group with both CRC and DM enabled | $t_{WTR_S_CRC_DM}$ | $t_{WTR_S}$ + Max (4nCK, 3.75ns) | - | $t_{WTR_S}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_S}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_S}$ + Max (5nCK, 3.75ns) | - | ns | 2,,29, 34 |
| Delay from start of internal WRITE transaction to internal READ command for same bank group with both CRC and DM enabled | $t_{WTR_L_CRC_DM}$ | $t_{WTR_L}$ + Max (4nCK, 3.75ns) | - | $t_{WTR_L}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_L}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_L}$ + Max (5nCK, 3.75ns) | - | ns | 3, 30, 34 |
| DDL locking time | $t_{DLLK}$ | 597 | - | 597 | - | 768 | - | 768 | - | nCK | - |
| MODE REGISTER SET command cycle time | $t_{MRD}$ | 8 | - | 8 | - | 8 | - | 8 | - | nCK | - |
| MODE REGISTER SET command update delay | $t_{MOD}$ | Max (24nCK, 15ns) | - | Max (24nCK, 15ns) | - | Max (24nCK, 15ns) | - | Max (24nCK, 15ns) | - | nCK | 50 |
| Mult-Purpose Register Recovery Time | $t_{MPRR}$ | 1 | - | 1 | - | 1 | - | 1 | - | nCK | 33 |
| Mult-Purpose Register Write Recovery Time | $t_{WR_MPR}$ | $t_{MOD\ (min)}$ +AL + PL | - | $t_{MOD\ (min)}$ +AL + PL | - | $t_{MOD\ (min)}$ +AL + PL | - | $t_{MOD\ (min)}$ +AL + PL | - | ns | - |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Auto precharge write recovery + precharge time | $t_{DAL\ (min)}$ | Programmed WR + roundup ($t_{RP}/t_{CK\ (avg)}$) | | | | | | | | nCK | - |
| DQ0 or DQL0 driven to 0 set-up time to first DQS rising edge | $t_{PDA_S}$ | 0.5 | - | 0.5 | - | 0.5 | - | 0.5 | - | UI | 45, 47 |
| DQ0 or DQL0 driven to 0 hold time from last DQS falling edge | $t_{PDA_H}$ | 0.5 | - | 0.5 | - | 0.5 | - | 0.5 | - | UI | 46, 47 |
| **CS_n to Command Address Latency** | | | | | | | | | | | |
| CS_n to Command Address Latency | $t_{CAL}$ | Max (3nCK, 3.748ns) | - | Max (3nCK, 3.748ns) | - | Max (3nCK, 3.748ns) | - | Max (3nCK, 3.748ns) | - | nCK | - |
| MODE REGISTER SET command cycle time in CAL mode | $t_{MRD_CAL}$ | $t_{MOD} + t_{CAL}$ | - | $t_{MOD} + t_{CAL}$ | - | $t_{MOD} + t_{CAL}$ | - | $t_{MOD} + t_{CAL}$ | - | nCK | - |
| MODE REGISTER SET update delay in CAL mode | $t_{MOD_CAL}$ | $t_{MOD} + t_{CAL}$ | - | $t_{MOD} + t_{CAL}$ | - | $t_{MOD} + t_{CAL}$ | - | $t_{MOD} + t_{CAL}$ | - | nCK | - |
| **DRAM Data Timing** | | | | | | | | | | | |
| DQS_t, DQS_c to DQ skew, per group, per access | $t_{DQSQ}$ | - | 0.16 | - | 0.16 | - | 0.16 | - | 0.17 | $t_{CK\ (avg)}/2$ | 13,18,39,49 |
| DQ output hold time per group, pre access from DQS_t, DQS_c | $t_{QH}$ | 0.76 | - | 0.76 | - | 0.76 | - | 0.74 | - | $t_{CK\ (avg)}/2$ | 13,17,18,39, 49 |
| Data Valid Window per device per UI: ($t_{QH}$ - $t_{DQSQ}$) of each UI on a given DRAM | $t_{DVWd}$ | 0.63 | - | 0.63 | - | 0.64 | - | 0.64 | - | UI | 17,18,39,49 |
| Data Valid Window per pin per UI: ($t_{QH}$ - $t_{DQSQ}$) each UI on a pin of a given DRAM | $t_{DVWp}$ | 0.66 | - | 0.66 | - | 0.69 | - | 0.72 | - | UI | 17,18,39,49 |
| DQ low impedance time from CK_t, CK_c | $t_{LZ\ (DQ)}$ | -450 | 225 | -390 | 195 | -360 | 180 | -330 | 175 | ps | 39 |
| DQ high impedance time from CK_t, CK_c | $t_{HZ\ (DQ)}$ | - | 225 | - | 195 | - | 180 | - | 175 | ps | 39 |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| **Data Strobe Timing** | | | | | | | | | | | |
| DQS_t, DQS_c differential READ Preamble (1 clock preamble) | $t_{RPRE}$ | 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) | $t_{RPRE2}$ | N/A | N/A | NA | N/A | N/A | N/A | 1.8 | Note 44 | $t_{CK}$ | 39,41 |
| DQS_t, DQS_c differential READ Postamble | $t_{RPST}$ | 0.33 | Note 45 | 0.33 | Note 45 | 0.33 | Note 45 | 0.33 | Note 45 | $t_{CK}$ | 39 |
| DQS_t, DQS_c differential output high time | $t_{QSH}$ | 0.4 | - | 0.4 | - | 0.4 | - | 0.4 | - | $t_{CK}$ | 21,39 |
| DQS_t, DQS_c differential output low time | $t_{QSL}$ | 0.4 | - | 0.4 | - | 0.4 | - | 0.4 | - | $t_{CK}$ | 20,39 |
| DQS_t, DQS_c differential WRITE Preamble (1 clock preamble) | $t_{WPRE}$ | 0.9 | - | 0.9 | - | 0.9 | - | 0.9 | - | $t_{CK}$ | 42 |
| DQS_t, DQS_c differential WRITE Preamble (2 clock preamble) | $t_{WPRE2}$ | NA | NA | NA | NA | NA | NA | 1.8 | - | $t_{CK}$ | 43 |
| DQS_t, DQS_c differential WRITE Postamble | $t_{WPST}$ | 0.33 | - | 0.33 | - | 0.33 | - | 0.33 | - | $t_{CK}$ | - |
| DQS_t and DQS_c low-impedance time (Referenced from RL - 1) | $t_{LZ\ (DQS)}$ | -450 | 225 | -390 | 195 | -360 | 180 | -330 | 175 | ps | 39 |
| DQS_t and DQS_c high-impedance time (Referenced from RL + BL/2) | $t_{HZ\ (DQS)}$ | - | 225 | - | 195 | - | 180 | - | 175 | ps | 39 |
| DQS_t, DQS_c differential input low pulse width | $t_{DQSL}$ | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | $t_{CK}$ | - |
| DQS_t, DQS_c differential input high pulse width | $t_{DQSH}$ | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | $t_{CK}$ | - |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (1 clock preamble) | $t_{DQSS}$ | -0.27 | 0.27 | -0.27 | 0.27 | -0.27 | 0.27 | -0.27 | 0.27 | $t_{CK}$ | 42 |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (2 clock preamble) | $t_{DQSS2}$ | N/A | N/A | N/A | N/A | N/A | N/A | -0.5 | 0.5 | - | 43 |



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| 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 falling edge setup time to CK_t, CK_c rising edge | $t_{DSS}$ | 0.18 | - | 0.18 | - | 0.18 | - | 0.18 | - | $t_{CK}$ | - |
| DQS_t, DQS_c falling edge hold time from CK_t, CK_c rising edge | $t_{DSH}$ | 0.18 | - | 0.18 | - | 0.18 | - | 0.18 | - | $t_{CK}$ | - |
| DQS_t, DQS_c rising edge output variance window per DRAM | $t_{DQSCKI\ (DLL\ On)}$ | - | 370 | - | 330 | - | 310 | - | 290 | ps | 37,38,39 |
| DQS_t, DQS_c rising edge output timing location from rising CK_t, CK_c with DDL on mode | $t_{DQSCK\ (DLL\ On)}$ | -225 | 225 | -195 | 195 | -180 | 180 | -175 | 175 | ps | 37,38,39 |
| **MPSM Timing** | | | | | | | | | | | |
| Command path disable delay upon MPSM entry | $t_{MPED}$ | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | tCK | - |
| Valid clock requirement after MPSM entry | $t_{CKMPE}$ | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)} + t_{CPDED\ (min)}$ | - | tCK | - |
| Valid clock requirement before MPSM exit | $t_{CKMPX}$ | $t_{CKSRX\ (min)}$ | - | $t_{CKSRX\ (min)}$ | - | $t_{CKSRX\ (min)}$ | - | $t_{CKSRX\ (min)}$ | - | tCK | - |
| Exit MPSM to commands not requiring a locked DLL | $t_{XMP}$ | $t_{XS\ (min)}$ | - | $t_{XS\ (min)}$ | - | $t_{XS\ (min)}$ | - | $t_{XS\ (min)}$ | - | tCK | - |
| Exit MPSM to commands requiring a locked DLL | $t_{XMPDLL}$ | $t_{XMP\ (min)} + t_{XSDLL\ (min)}$ | - | $t_{XMP\ (min)} + t_{XSDLL\ (min)}$ | - | $t_{XMP\ (min)} + t_{XSDLL\ (min)}$ | - | $t_{XMP\ (min)} + t_{XSDLL\ (min)}$ | - | tCK | - |
| CS setup time to CKE | $t_{MPX_S}$ | $t_{IS\ (min)} + t_{IH\ (min)}$ | - | $t_{IS\ (min)} + t_{IH\ (min)}$ | - | $t_{IS\ (min)} + t_{IH\ (min)}$ | - | $t_{IS\ (min)} + t_{IH\ (min)}$ | - | ns | - |
| **Calibration Timing** | | | | | | | | | | | |
| Power-up and RESET calibration time | $t_{ZQinit}$ | 1024 | - | 1024 | - | 1024 | - | 1024 | - | nCK | - |
| Normal operation Full calibration time | $t_{ZQoper}$ | 512 | - | 512 | - | 512 | - | 512 | - | nCK | - |
| Normal operation short calibration time | $t_{ZQCS}$ | 128 | - | 128 | - | 128 | - | 128 | - | nCK | - |



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| Speed | | DDR4-1600 | | DDR4-1866 | | DDR4-2133 | | DDR4-2400 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| **Reset/Self Refresh Timing** | | | | | | | | | | | |
| Exit reset from CKE HIGH to a valid command | $t_{XPR}$ | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | nCK | - |
| Exit self refresh to commands not requiring a locked DLL | $t_{XS}$ | $t_{RFC\ (min)}$ + 10ns | - | $t_{RFC\ (min)}$ + 10ns | - | $t_{RFC\ (min)}$ + 10ns | - | $t_{RFC\ (min)}$ + 10ns | - | nCK | - |
| SRX to Commands not requiring a locked DLL in self refresh abort | $t_{XS_ABORT\ (min)}$ | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | nCK | - |
| Exit self refresh to ZQCL, ZQCS and MRS (CL, CWL, WR, RTP and Gear Down) | $t_{XS_FAST\ (min)}$ | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | nCK | - |
| Exit self refresh to commands requiring a locked DLL | $t_{XSDLL}$ | $t_{DLLK\ (min)}$ | - | $t_{DLLK\ (min)}$ | - | $t_{DLLK\ (min)}$ | - | $t_{DLLK\ (min)}$ | - | nCK | - |
| Minimum CKE low width for self refresh entry to exit timing | $t_{CKESR}$ | $t_{CKE\ (min)}$ + 1nCK | - | $t_{CKE\ (min)}$ + 1nCK | - | $t_{CKE\ (min)}$ + 1nCK | - | $t_{CKE\ (min)}$ + 1nCK | - | nCK | - |
| Minimum CKE low width for self refresh entry to exit timing with CA Parity enabled | $t_{CKESR_PAR}$ | $t_{CKE\ (min)}$ + 1nCK + PL | - | $t_{CKE\ (min)}$ + 1nCK + PL | - | $t_{CKE\ (min)}$ + 1nCK + PL | - | $t_{CKE\ (min)}$ + 1nCK + PL | - | nCK | - |
| Valid Clock Requirement after self refresh Entry (SRE) or Power-Down Entry (PDE) | $t_{CKSRE}$ | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | nCK | - |
| Valid Clock Requirement after self refresh Entry (SRE) or Power-Down when CA Parity is enabled | $t_{cksre_PAR}$ | 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 | $t_{CKSRX}$ | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | nCK | - |
| **Power Down Timing** | | | | | | | | | | | |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Exit power-down with DLL on to any valid command, Exit Precharge Power Down with DLL frozen to commands not requiring a locked DLL | $t_{XP}$ | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | nCK | - |
| CKE minimum pulse width | $t_{CKE}$ | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | nCK | 31,32 |
| Command pass disable delay | $t_{CPDED}$ | 4 | - | 4 | - | 4 | - | 4 | - | nCK | - |
| Power Down Entry to Exit Timing | $t_{PD}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | nCK | 6 |
| Timing of ACT command to Power Down entry | $t_{ACTPDEN}$ | 1 | - | 1 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of PRE or PREA command to Power Down entry | $t_{PRPDEN}$ | 1 | - | 1 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of RD/RDA command to Power Down entry | $t_{RDPDEN}$ | RL + 4 + 1 | - | RL + 4 + 1 | - | RL + 4 + 1 | - | RL + 4 + 1 | - | nCK | - |
| Timing of WR command to Power Down entry (BL8OTF, BL8MRS, BC4OTF) | $t_{WRPDEN}$ | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | nCK | 4 |
| Timing of WRA command to Power Down entry (BL8OTF, BL8MRS, BC4OTF) | $t_{WRAPDEN}$ | 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) | $t_{WRP-BC4DEN}$ | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | nCK | 4 |
| Timing of WRA command to Power Down entry (BC4MRS) | $t_{WRAP-BC4DEN}$ | 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 | $t_{REFPDEN}$ | 1 | - | 1 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of MRS command to Power Down entry | $t_{MRSPDEN}$ | $t_{MOD\ (min)}$ | - | $t_{MOD\ (min)}$ | - | $t_{MOD\ (min)}$ | - | $t_{MOD\ (min)}$ | - | nCK | - |
| **PDA Timing** | | | | | | | | | | | |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| MODE REGISTER SET command cycle time in PDA mode | $t_{MRD_PDA}$ | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | nCK | - |
| MODE REGISTER SET command update delay in PDA mode | $t_{MOD_PDA}$ | $t_{MOD}$ | | $t_{MOD}$ | | $t_{MOD}$ | | $t_{MOD}$ | | nCK | - |
| **ODT Timing** | | | | | | | | | | | |
| Asynchronous $R_{TT}$ turn-on delay (Power-Down with DLL frozen) | $t_{AONAS}$ | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | ns | - |
| Asynchronous $R_{TT}$ turn-off delay (Power-Down with DLL frozen) | $t_{AOFAS}$ | 1 | 9 | 1 | 9 | 1 | 9 | 1 | 9 | ns | - |
| $R_{TT}$ dynamic change skew | $t_{ADC}$ | 0.3 | 0.7 | 0.3 | 0.7 | 0.3 | 0.7 | 0.3 | 0.7 | $t_{CK\ (avg)}$ | - |
| **Write Leveling Timing** | | | | | | | | | | | |
| First DQS_t/DQS_c rising edge after write leveling mode is programmed | $t_{WLMRD}$ | 40 | - | 40 | - | 40 | - | 40 | - | nCK | 12 |
| DQS_t/DQS_c delay after write leveling mode is programmed | $t_{WLDQSEN}$ | 25 | - | 25 | - | 25 | - | 25 | - | nCK | 12 |
| Write leveling setup time from rising CK_t, CK_c crossing to rising DQS_t/DQS_c crossing | $t_{WLS}$ | 0.13 | - | 0.13 | - | 0.13 | - | 0.13 | - | $t_{CK\ (avg)}$ | - |
| Write leveling hold time from rising DQS_t/DQS_c crossing to rising CK_t, CK_c crossing | $t_{WLH}$ | 0.13 | - | 0.13 | - | 0.13 | - | 0.13 | - | $t_{CK\ (avg)}$ | - |
| Write leveling output delay | $t_{WLO}$ | 0 | 9.5 | 0 | 9.5 | 0 | 9.5 | 0 | 9.5 | ns | - |
| Write leveling output error | $t_{WLOE}$ | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | ns | - |
| **CA Parity Timing** | | | | | | | | | | | |



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|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Commands not guaranteed to be executed during this time | $t_{PAR_UNKNOWN}$ | - | PL | - | PL | - | PL | - | PL | nCK | - |
| Delay from errant command to ALERT_n assertion | $t_{PAR_ALERT_ON}$ | - | PL + 6ns | - | PL + 6ns | - | PL + 6ns | - | PL + 6ns | nCK | - |
| Pulse width of ALERT_n signal when asserted | $t_{PAR_ALERT_PW}$ | 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 | $t_{PAR_ALERT_RSP}$ | - | 43 | - | 50 | - | 57 | - | 64 | nCK | - |
| Parity Latency | PL | 4 | | 4 | | 4 | | 5 | | nCK | - |
| **CRC Error Reporting** | | | | | | | | | | | |
| CRC error to ALERT_n latency | $t_{CRC_ALERT}$ | 3 | 13 | 3 | 13 | 3 | 13 | 3 | 13 | ns | - |
| CRC ALERT_n pulse width | $t_{CRC_ALERT_PW}$ | 6 | 10 | 6 | 10 | 6 | 10 | 6 | 10 | nCK | - |
| **$t_{REFI}$** | | | | | | | | | | | |
| $t_{RFC1\ (min)}$ | 8Gb | 350 | - | 350 | - | 350 | - | 350 | - | ns | 34 |
| $t_{RFC2\ (min)}$ | 8Gb | 260 | - | 260 | - | 260 | - | 260 | - | ns | 34 |
| $t_{RFC4\ (min)}$ | 8Gb | 160 | - | 160 | - | 160 | - | 160 | - | ns | 34 |



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### 12.4.2 Timing Parameters by Speed Bin for DDR4-2666 to 3200

**Table 12-3. 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) | $t_{CK\ (DLL_OFF)}$ | 8 | 20 | 8 | 20 | 8 | 20 | ns | - |
| Average Clock Period | $t_{CK\ (avg)}$ | 0.75 | <0.833 | 0.682 | <0.750 | 0.625 | <0.682 | ns | 35,36 |
| Average high pulse width | $t_{CH\ (avg)}$ | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | $t_{CK\ (avg)}$ | - |
| Average low pulse width | $t_{CL\ (avg)}$ | 0.48 | 0.52 | 0.48 | 0.52 | 0.48 | 0.52 | $t_{CK\ (avg)}$ | - |
| Absolute Clock Period | $t_{CK\ (abs)}$ | Min = $t_{CK\ (avg)min}$ + $t_{JIT(per)min_tot}$ | | | | | | $t_{CK\ (avg)}$ | - |
| | | Max = $t_{CK\ (avg)max}$ + $t_{JIT(per)max_tot}$ | | | | | | | |
| Absolute clock HIGH pulse width | $t_{CH\ (abs)}$ | 0.45 | - | 0.45 | - | 0.45 | - | $t_{CK\ (avg)}$ | 23 |
| Absolute clock LOW pulse width | $t_{CL\ (abs)}$ | 0.45 | - | 0.45 | - | 0.45 | - | $t_{CK\ (avg)}$ | 24 |
| Clock Period Jitter-total | $t_{JIT\ (per)_tot}$ | -38 | 38 | -34 | 34 | -32 | 32 | ps | 25 |
| Clock Period Jitter-deterministic | $t_{JIT\ (per)_dj}$ | -19 | 19 | -17 | 17 | -16 | 16 | ps | 26 |
| Clock Period Jitter during DLL locking period | $t_{JIT\ (per,\ lck)}$ | -30 | 30 | -27 | 27 | -25 | 25 | ps | - |
| Cycle to Cycle Period Jitter | $t_{JIT\ (cc)}$ | - | 75 | - | 68 | - | 62 | ps | 25 |
| Cycle to Cycle Period Jitter during DLL locking period | $t_{JIT\ (cc,\ lck)}$ | - | 60 | - | 55 | - | 50 | ps | - |
| Cumulative error across 2 cycles | $t_{ERR\ (2per)}$ | -55 | 55 | -50 | 50 | -46 | 46 | ps | - |
| Cumulative error across 3 cycles | $t_{ERR\ (3per)}$ | -66 | 66 | -60 | 60 | -55 | 55 | ps | - |
| Cumulative error across 4 cycles | $t_{ERR\ (4per)}$ | -73 | 73 | -66 | 66 | -61 | 61 | ps | - |
| Cumulative error across 5 cycles | $t_{ERR\ (5per)}$ | -78 | 78 | -71 | 71 | -65 | 65 | ps | - |
| Cumulative error across 6 cycles | $t_{ERR\ (6per)}$ | -83 | 83 | -75 | 75 | -69 | 69 | ps | - |
| Cumulative error across 7 cycles | $t_{ERR\ (7per)}$ | -87 | 87 | -79 | 79 | -73 | 73 | ps | - |
| Cumulative error across 8 cycles | $t_{ERR\ (8per)}$ | -91 | 91 | -83 | 83 | -76 | 76 | ps | - |
| Cumulative error across 9 cycles | $t_{ERR\ (9per)}$ | -94 | 94 | -85 | 85 | -78 | 78 | ps | - |



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| Speed | | DDR4-2666 | | DDR4-2933 | | DDR4-3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Cumulative error across 10 cycles | $t_{ERR\ (10per)}$ | -96 | 96 | -88 | 88 | -80 | 80 | ps | - |
| Cumulative error across 11 cycles | $t_{ERR\ (11per)}$ | -99 | 99 | -90 | 90 | -83 | 83 | ps | - |
| Cumulative error across 12 cycles | $t_{ERR\ (12per)}$ | -101 | 101 | -92 | 92 | -84 | 84 | ps | - |
| Cumulative error across 13 cycles | $t_{ERR\ (13per)}$ | -103 | 103 | -93 | 93 | -86 | 86 | ps | - |
| Cumulative error across 14 cycles | $t_{ERR\ (14per)}$ | -104 | 104 | -95 | 95 | -87 | 87 | ps | - |
| Cumulative error across 15 cycles | $t_{ERR\ (15per)}$ | -106 | 106 | -97 | 97 | -89 | 89 | ps | - |
| Cumulative error across 16 cycles | $t_{ERR\ (16per)}$ | -108 | 108 | -98 | 98 | -90 | 90 | ps | - |
| Cumulative error across 17 cycles | $t_{ERR\ (17per)}$ | -110 | 110 | -100 | 100 | -92 | 92 | ps | - |
| Cumulative error across 18 cycles | $t_{ERR\ (18per)}$ | -112 | 112 | -101 | 101 | -93 | 93 | ps | - |
| Cumulative error across n = 13, 14 . . . 49, 50 cycles | $t_{ERR\ (nper)}$ | $t_{ERR\ (nper)min} = ((1 + 0.68ln(n)) * t_{JIT\ (per)_total\ min})$ | | | | | | ps | - |
| | | $t_{ERR\ (nper)max} = ((1 + 0.68ln(n)) * t_{JIT\ (per)_total\ max})$ | | | | | | | |
| Command and Address setup time to CK_t, CK_c referenced to $V_{IH(AC)}/V_{IL(AC)}$ levels | $t_{IS\ (base)}$ | 55 | - | 48 | - | 40 | - | ps | - |
| Command and Address setup time to CK_t, CK_c referenced to $V_{REF}$ levels | $t_{IS\ (V_{REF})}$ | 145 | - | 138 | - | 130 | - | ps | - |
| Command and Address hold time to CK_t, CK_c referenced to $V_{IH(DC)}/V_{IL(DC)}$ levels | $t_{IH\ (base)}$ | 80 | - | 73 | - | 65 | - | ps | - |
| Command and Address hold time to CK_t, CK_c referenced to $V_{REF}$ levels | $t_{IH\ (V_{REF})}$ | 145 | - | 138 | - | 130 | - | ps | - |
| Control and Address Input pulse width for each input | $t_{IPW}$ | 385 | - | 365 | - | 340 | - | ps | - |
| **Command and Address Timing-** | | | | | | | | | |
| CAS_n to CAS_n command delay for same bank group | $t_{CCD_L}$ | Max (5nCK, 5ns) | - | Max (5nCK, 5ns) | - | Max (5nCK, 5ns) | - | nCK | 34 |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| CAS_n to CAS_n command delay for different bank group | $t_{CCD_S}$ | 4 | - | 4 | - | 4 | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 2KB page size | $t_{RRD_S\ (2K)}$ | 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 | $t_{RRD_S\ (1K)}$ | Max (4nCK, 3ns) | - | Max (4nCK, 2.7ns) | - | Max (4nCK, 2.5ns) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to different bank group for 1/2KB page size | $t_{RRD_S\ (1/2K)}$ | Max (4nCK, 3ns) | - | Max (4nCK, 2.7ns) | - | Max (4nCK, 2.5ns) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to same bank group for 2KB page size | $t_{RRD_L\ (2K)}$ | 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 | $t_{RRD_L\ (1K)}$ | Max (4nCK, 4.9ns) | - | Max (4nCK, 4.9ns) | - | Max (4nCK, 4.9ns) | - | nCK | 34 |
| ACTIVATE to ACTIVATE Command delay to same bank group for 1/2KB page size | $t_{RRD_L\ (1/2K)}$ | Max (4nCK, 4.9ns) | - | Max (4nCK, 4.9ns) | - | Max (4nCK, 4.9ns) | - | nCK | 34 |
| Four activate window for 2KB page size | $t_{FAW\ (2K)}$ | Max (28nCK, 30ns) | - | Max (28nCK, 30ns) | - | Max (28nCK, 30ns) | - | ns | 34 |
| Four activate window for 1KB page size | $t_{FAW\ (1K)}$ | Max (20nCK, 21ns) | - | Max (20nCK, 21ns) | - | Max (20nCK, 21ns) | - | ns | 34 |
| Four activate window for 1/2KB page size | $t_{FAW\ (1/2K)}$ | Max (16nCK, 12ns) | - | Max (16nCK, 10.875ns) | - | Max (16nCK, 10ns) | - | ns | 34 |
| Delay from start of internal WRITE transaction to internal READ command for different bank group | $t_{WTR_S}$ | 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 | $t_{WTR_L}$ | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | ns | 1, 34 |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Internal READ Command to PRCHARGE command delay | $t_{RTP}$ | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | Max (4nCK, 7.5ns) | - | ns | - |
| WRITE recovery time | $t_{WR}$ | 15 | - | 15 | - | 15 | - | ns | 1 |
| Write recovery time when CRC and DM are enabled | $t_{WR_CRC_DM}$ | $t_{WR}$ + Max (5nCK, 3.75ns) | - | $t_{WR}$ + Max (5nCK, 3.75ns) | - | $t_{WR}$ + Max (5nCK, 3.75ns) | - | ns | 1, 28 |
| Delay from start of internal WRITE transaction to internal READ command for different bank group with both CRC and DM enabled | $t_{WTR_S_CRC_DM}$ | $t_{WTR_S}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_S}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_S}$ + Max (5nCK, 3.75ns) | - | ns | 2, 29, 34 |
| Delay from start of internal WRITE transaction to internal READ command for same bank group with both CRC and DM enabled | $t_{WTR_L_CRC_DM}$ | $t_{WTR_L}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_L}$ + Max (5nCK, 3.75ns) | - | $t_{WTR_L}$ + Max (5nCK, 3.75ns) | - | ns | 3, 30, 34 |
| DDL locking time | $t_{DLLK}$ | 1024 | - | 1024 | - | 1024 | - | nCK | - |
| MODE REGISTER SET command cycle time | $t_{MRD}$ | 8 | - | 8 | - | 8 | - | nCK | - |
| MODE REGISTER SET command update delay | $t_{MOD}$ | Max (24nCK, 15ns) | - | Max (24nCK, 15ns) | - | Max (24nCK, 15ns) | - | nCK | - |
| Mult-Purpose Register Recovery Time | $t_{MPRR}$ | 1 | - | 1 | - | 1 | - | nCK | 33 |
| Mult-Purpose Register Write Recovery Time | $t_{WR_MPR}$ | $t_{MOD\ (min)}$ + AL + PL | - | $t_{MOD\ (min)}$ + AL + PL | - | $t_{MOD\ (min)}$ + AL + PL | - | nCK | - |
| Auto precharge write recovery + precharge time | $t_{DAL\ (min)}$ | Programmed WR + roundup ($t_{RP}/t_{CK\ (avg)}$) | | | | | | nCK | - |
| DQ0 or DQL0 driven to 0 set-up time to first DQS rising edge | $t_{PDA_S}$ | 0.5 | - | 0.5 | - | 0.5 | - | UI | 45, 47 |
| DQ0 or DQL0 driven to 0 hold time from last DQS falling edge | $t_{PDA_H}$ | 0.5 | - | 0.5 | - | 0.5 | - | UI | 46, 47 |
| **CS_n to Command Address Latency** | | | | | | | | | |
| CS_n to Command Address Latency | $t_{CAL}$ | Max (3nCK, 3.748ns) | - | Max (3nCK, 3.748ns) | - | Max (3nCK, 3.748ns) | - | nCK | - |



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| 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 | $t_{MRD_tCAL}$ | $t_{MOD}$ + $t_{CAL}$ | - | $t_{MOD}$ + $t_{CAL}$ | - | $t_{MOD}$ + $t_{CAL}$ | - | nCK | - |
| MODE REGISTER SET update delay in CAL mode | $t_{MOD_tCAL}$ | $t_{MOD}$ + $t_{CAL}$ | - | $t_{MOD}$ + $t_{CAL}$ | - | $t_{MOD}$ + $t_{CAL}$ | - | nCK | - |
| **DRAM Data Timing** | | | | | | | | | |
| DQS_t, DQS_c to DQ skew, per group, per access | $t_{DQSQ}$ | - | 0.18 | - | 0.19 | - | 0.20 | $t_{CK\ (avg)}$/2 | 13,18,39,49 |
| DQ output hold time per group, per access from QDS_t, DQS_c | $t_{QH}$ | 0.74 | - | 0.72 | - | 0.70 | - | $t_{CK\ (avg)}$/2 | 17,18,39,49 |
| Data Valid Window per device per UI: ($t_{QH}$ - $t_{DQSQ}$) of each UI on a given DRAM | $t_{DVWd}$ | 0.64 | - | 0.64 | - | 0.64 | - | UI | - |
| Data Valid Window per pin per UI: ($t_{QH}$ - $t_{DQSQ}$) each UI on a pin of a given DRAM | $t_{DVWp}$ | 0.72 | - | 0.72 | - | 0.72 | - | UI | - |
| DQ low impedance time from CK_t, CK_c | $t_{LZ\ (DQ)}$ | -310 | 170 | -280 | 165 | -250 | 160 | ps | - |
| DQ high impedance time from CK_t, CK_c | $t_{HZ\ (DQ)}$ | - | 170 | - | 165 | - | 160 | ps | - |
| **Data Strobe Timing** | | | | | | | | | |
| DQS_t, DQS_c differential READ Preamble (1 clock preamble) | $t_{RPRE}$ | 0.9 | Note 44 | 0.9 | Note 44 | 0.9 | Note 44 | $t_{CK}$ | - |
| DQS_t, DQS_c differential READ Preamble (2 clock preamble) | $t_{RPRE2}$ | 1.8 | Note 44 | 1.8 | Note 44 | 1.8 | Note 44 | $t_{CK}$ | - |
| DQS_t, DQS_c differential READ Postamble | $t_{RPST}$ | 0.33 | Note 45 | 0.33 | Note 45 | 0.33 | Note 45 | $t_{CK}$ | - |
| DQS_t, DQS_c differential output high time | $t_{QSH}$ | 0.4 | - | 0.4 | - | 0.4 | - | $t_{CK}$ | 21,39 |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| DQS_t, DQS_c differential output low time | $t_{QSL}$ | 0.4 | - | 0.4 | - | 0.4 | - | $t_{CK}$ | 20,39 |
| DQS_t, DQS_c differential WRITE Preamble (1 clock preamble) | $t_{WPRE}$ | 0.9 | - | 0.9 | - | 0.9 | - | $t_{CK}$ | 42 |
| DQS_t, DQS_c differential WRITE Preamble (2 clock preamble) | $t_{WPRE2}$ | 1.8 | - | 1.8 | - | 1.8 | - | $t_{CK}$ | 43 |
| DQS_t, DQS_c differential WRITE Postamble | $t_{WPST}$ | 0.33 | - | 0.33 | - | 0.33 | - | $t_{CK}$ | - |
| DQS_t and DQS_c low-impedance time (Referenced from RL-1) | $t_{LZ\ (DQS)}$ | -310 | 170 | -280 | 165 | -250 | 160 | ps | 39 |
| DQS_t and DQS_c high-impedance time (Referenced from RL+BL/2) | $t_{HZ\ (DQS)}$ | - | 170 | - | 165 | - | 160 | ps | 39 |
| DQS_t, DQS_c differential input low pulse width | $t_{DQSL}$ | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | $t_{CK}$ | - |
| DQS_t, DQS_c differential input high pulse width | $t_{DQSH}$ | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | $t_{CK}$ | - |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (1 clock preamble) | $t_{DQSS}$ | -0.27 | 0.27 | -0.27 | 0.27 | -0.27 | 0.27 | $t_{CK}$ | 42 |
| DQS_t, DQS_c rising edge to CK_t, CK_c rising edge (2 clock preamble) | $t_{DQSS2}$ | TBD | TBD | TBD | TBD | TBD | TBD | $t_{CK}$ | 43 |
| DQS_t, DQS_c falling edge setup time to CK_t, CK_c rising edge | $t_{DSS}$ | 0.18 | - | 0.18 | - | 0.18 | - | $t_{CK}$ | - |
| DQS_t, DQS_c falling edge hold time from CK_t, CK_c rising edge | $t_{DSH}$ | 0.18 | - | 0.18 | - | 0.18 | - | $t_{CK}$ | - |
| DQS_t, DQS_c rising edge output variance window per DRAM | $t_{DQSCKI\ (DLL\ On)}$ | - | 270 | - | 265 | - | 260 | ps | 37,38,39 |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| DQS_t, DQS_c rising edge output timing location from rising CK_t, CK_c with DDL on mode | tDQSCK(DLL On) | -170 | 170 | -165 | 165 | -160 | 160 | ps | 37,38,39 |
| **MPSM Timing** | | | | | | | | | |
| Command path disable delay upon MPSM entry | $t_{MPED}$ | $t_{MOD\ (min)}$ + $t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)}$ + $t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)}$ + $t_{CPDED\ (min)}$ | - | $t_{CK}$ | - |
| Valid clock requirement after MPSM entry | $t_{CKMPE}$ | $t_{MOD\ (min)}$ + $t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)}$ + $t_{CPDED\ (min)}$ | - | $t_{MOD\ (min)}$ + $t_{CPDED\ (min)}$ | - | $t_{CK}$ | - |
| Valid clock requirement before MPSM exit | $t_{CKMPX}$ | $t_{CKSRX\ (min)}$ | - | $t_{CKSRX\ (min)}$ | - | $t_{CKSRX\ (min)}$ | - | $t_{CK}$ | - |
| Exit MPSM to commands not requiring a locked DLL | $t_{XMP}$ | $t_{XS\ (min)}$ | - | $t_{XS\ (min)}$ | - | $t_{XS\ (min)}$ | - | $t_{CK}$ | - |
| Exit MPSM to commands requiring a locked DLL | $t_{XMPDLL}$ | $t_{XMP\ (min)}$ + $t_{XSDLL\ (min)}$ | - | $t_{XMP\ (min)}$ + $t_{XSDLL\ (min)}$ | - | $t_{XMP\ (min)}$ + $t_{XSDLL\ (min)}$ | - | $t_{CK}$ | - |
| CS setup time to CKE | $t_{MPX_S}$ | $t_{IS\ (min)}$ + $t_{IH\ (min)}$ | - | $t_{IS\ (min)}$ + $t_{IH\ (min)}$ | - | $t_{IS\ (min)}$ + $t_{IH\ (min)}$ | - | ns | - |
| **Calibration Timing** | | | | | | | | | |
| Power-up and RESET calibration time | $t_{ZQinit}$ | 1024 | - | 1024 | - | 1024 | - | nCK | - |
| Normal operation Full calibration time | $t_{ZQoper}$ | 512 | - | 512 | - | 512 | - | nCK | - |
| Normal operation Short calibration time | $t_{ZQCS}$ | 128 | - | 128 | - | 128 | - | nCK | - |
| **Reset/Self Refresh Timing** | | | | | | | | | |
| Exit reset from CKE HIGH to a valid command | $t_{XPR}$ | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | Max (5nCK, $t_{RFC\ (min)}$ + 10ns) | - | nCK | - |
| Exit self refresh to commands not requiring a locked DLL | $t_{XS}$ | $t_{RFC\ (min)}$ + 10ns | - | $t_{RFC\ (min)}$ + 10ns | - | $t_{RFC\ (min)}$ + 10ns | - | nCK | - |
| SRX to commands not requiring a locked DLL in self refresh abort | $t_{XS_ABORT\ (min)}$ | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | nCK | - |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Exit self refresh to ZQCL, ZQCS and MRS (CL, CWL, WR, RTP and Gear Down) | $t_{XS_FAST\ (min)}$ | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | $t_{RFC4\ (min)}$ + 10ns | - | nCK | - |
| Exit self refresh to commands requiring a locked DLL | $t_{XSDLL}$ | $t_{DLLK\ (min)}$ | - | $t_{DLLK\ (min)}$ | - | $t_{DLLK\ (min)}$ | - | nCK | - |
| Minimum CKE low width for self refresh entry to exit timing | $t_{CKESR}$ | $t_{CKE\ (min)}$ + 1nCK | - | $t_{CKE\ (min)}$ + 1nCK | - | $t_{CKE\ (min)}$ + 1nCK | - | nCK | - |
| Minimum CKE low width for self refresh entry to exit timing with CA Parity enabled | $t_{CKESR_PAR}$ | $t_{CKE\ (min)}$ + 1nCK + PL | - | $t_{CKE\ (min)}$ + 1nCK + PL | - | $t_{CKE\ (min)}$ + 1nCK + PL | - | nCK | - |
| Valid Clock Requirement after self refresh Entry (SRE) or Power-Down Entry (PDE) | $t_{CKSRE}$ | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | Max (5nCK, 10ns) | - | nCK | - |
| Valid Clock Requirement after self refresh Entry (SRE) or Power-Down when CA Parity is enabled | $t_{cksre_PAR}$ | 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 | $t_{CKSRX}$ | 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 | $t_{XP}$ | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | Max (4nCK, 6ns) | - | nCK | - |
| CKE minimum pulse width | $t_{CKE}$ | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | Max (3nCK, 5ns) | - | nCK | 31,32 |
| Command pass disable delay | $t_{CPDED}$ | 4 | - | 4 | - | 4 | - | nCK | - |
| Power Down Entry to Exit Timing | $t_{PD}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | $t_{CKE\ (min)}$ | 9 * $t_{REFI}$ | nCK | 6 |
| Timing of ACT command to Power Down entry | $t_{ACTPDEN}$ | 2 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of PRE or PREA command to Power Down entry | $t_{PRPDEN}$ | 2 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of RD/RDA command to Power Down entry | $t_{RDPDEN}$ | RL + 4 + 1 | - | RL + 4 + 1 | - | RL + 4 + 1 | - | nCK | - |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Timing of WR command to Power Down entry (BL8OTF, BL8MRS, BC4OTF) | $t_{WRPDEN}$ | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 4 + ($t_{WR}/t_{CK\ (avg)}$) | - | nCK | 4 |
| Timing of WRA command to Power Down entry (BL8OTF, BL8MRS, BC4OTF) | $t_{WRAPDEN}$ | WL + 4 + WR + 1 | - | WL + 4 + WR + 1 | - | WL + 4 + WR + 1 | - | nCK | 5 |
| Timing of WR command to Power Down entry (BC4MRS) | $t_{WRP-BC4DEN}$ | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | WL + 2 + ($t_{WR}/t_{CK\ (avg)}$) | - | nCK | 4 |
| Timing of WRA command to Power Down entry (BC4MRS) | $t_{WRAP-BC4DEN}$ | WL + 2 + WR + 1 | - | WL + 2 + WR + 1 | - | WL + 2 + WR + 1 | - | nCK | 5 |
| Timing of REF command to Power Down entry | $t_{REFPDEN}$ | 2 | - | 2 | - | 2 | - | nCK | 7 |
| Timing of MRS command to Power Down entry | $t_{MRSPDEN}$ | $t_{MOD\ (min)}$ | - | $t_{MOD\ (min)}$ | - | $t_{MOD\ (min)}$ | - | nCK | - |
| **PDA Timing** | | | | | | | | | |
| MODE REGISTER SET command cycle time in PDA mode | $t_{MRD_PDA}$ | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | Max (16nCK, 10ns) | - | nCK | - |
| MODE REGISTER SET command update delay in PDA mode | $t_{MOD_PDA}$ | $t_{MOD}$ | | $t_{MOD}$ | | $t_{MOD}$ | | nCK | - |
| **ODT Timing** | | | | | | | | | |
| Asynchronous $R_{TT}$ turn-on delay (Power-Down with DLL frozen) | $t_{AONAS}$ | 1 | 9 | 1 | 9 | 1 | 9 | ns | - |
| Asynchronous $R_{TT}$ turn-off delay (Power-Down with DLL frozen) | $t_{AOFAS}$ | 1 | 9 | 1 | 9 | 1 | 9 | ns | - |
| $R_{TT}$ dynamic change skew | $t_{ADC}$ | 0.28 | 0.72 | 0.26 | 0.74 | 0.26 | 0.74 | $t_{CK\ (avg)}$ | - |
| **Write Leveling Timing** | | | | | | | | | |
| First DQS_t/DQS_c rising edge after write leveling mode is programmed | $t_{WLMRD}$ | 40 | - | 40 | - | 40 | - | nCK | 12 |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| DQS_t/DQS_c delay after write leveling mode is programmed | $t_{WLDQSEN}$ | 25 | - | 25 | - | 25 | - | nCK | 12 |
| Write leveling setup time from rising CK_t, CK_c crossing to rising DQS_t/DQS_c crossing | $t_{WLS}$ | 0.13 | - | 0.13 | - | 0.13 | - | tCK(avg) | - |
| Write leveling hold time from rising DQS_t/DQS_c crossing to rising CK_t, CK_c crossing | $t_{WLH}$ | 0.13 | - | 0.13 | - | 0.13 | - | $t_{CK\ (avg)}$ | - |
| Write leveling output delay | $t_{WLO}$ | 0 | 9.5 | 0 | 9.5 | 0 | 9.5 | ns | - |
| Write leveling output error | $t_{WLOE}$ | 0 | 2 | 0 | 2 | 0 | 2 | ns | - |
| **CA Parity Timing** | | | | | | | | | |
| Commands not guaranteed to be executed during this time | $t_{PAR_UNKNOWN}$ | - | PL | - | PL | - | PL | nCK | - |
| Delay from errant command to ALERT_n assertion | $t_{PAR_ALERT_ON}$ | - | PL + 6ns | - | PL + 6ns | - | PL + 6ns | nCK | - |
| Pulse width of ALERT_n signal when asserted | $t_{PAR_ALERT_PW}$ | 80 | 160 | 88 | 176 | 96 | 192 | nCK | - |
| Time from when Alert is asserted till controller must start providing DES commands in Persistent CA parity mode | $t_{PAR_ALERT_RSP}$ | - | 71 | - | 78 | - | 85 | nCK | - |
| Parity Latency | PL | 5 | | 6 | | 6 | | nCK | - |
| CRC error to ALERT_n latency | $t_{CRC_ALERT}$ | 3 | 13 | 3 | 13 | 3 | 13 | ns | - |
| CRC ALERT_n pulse width | $t_{CRC_ALERT_PW}$ | 6 | 10 | 6 | 10 | 6 | 10 | nCK | - |
| **Gear Down Timing** | | | | | | | | | |
| Exit RESET from CKE HIGH to a valid MRS geardown (T2/Reset) | $t_{XPR_GEAR}$ | $t_{XPR}$ | - | $t_{XPR}$ | - | $t_{XPR}$ | - | - | - |
| CKE High Assert to Gear Down Enable time (T2/CKE) | $t_{XS_GEAR}$ | $t_{XS}$ | - | $t_{XS}$ | - | $t_{XS}$ | - | - | - |
| MRS command to Sync pulse time(T3) | $t_{SYNC_GEAR}$ | $t_{MOD}$ + 4nCK | - | $t_{MOD}$ + 4nCK | - | $t_{MOD}$ + 4nCK | - | - | 27 |



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|---|---|---|---|---|---|---|---|---|---|
| Parameter | Symbol | Min | Max | Min | Max | Min | Max | | |
| Sync pulse to First valid command(T4) | $t_{CMD_GEAR}$ | $t_{MOD}$ | - | $t_{MOD}$ | - | $t_{MOD}$ | - | - | 27 |
| Geardown setup time | $t_{GEAR\ setup}$ | 2 | - | 2 | - | 2 | - | nCK | - |
| Geardown hold time | $t_{GEAR\ hold}$ | 2 | - | 2 | - | 2 | - | nCK | - |
| **$t_{REFI}$** | | | | | | | | | |
| $t_{RFC1}$ | 8Gb | 350 | - | 350 | - | 350 | - | ns | 34 |
| $t_{RFC2}$ | 8Gb | 260 | - | 260 | - | 260 | - | ns | 34 |
| $t_{RFC4}$ | 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. $t_{WR}$ is defined in ns, for calculation of $t_{WRPDEN}$ it is necessary to round up $t_{WR}/t_{CK}$ following rouding algorithm defined in Section 12.5.
5. WR in clock cycles as programmed in MR0.
6. $t_{REFI}$ 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 $I_{DD}$ spec will not be applied until finishing those operations.
8. For these parameters, the DDR4 SDRAM device supports $t_{nPARAM\ [nCK]}$ = ROUND UP{$t_{PARAM[ns]}/t_{CK(avg)[ns]}$}, which is in clock cycles assuming all input clock jitter specifications are satisfied.
9. When CRC and DM are both enabled, $t_{WR_CRC_DM}$ is used in place of $t_{WR}$.
10. When CRC and DM are both enabled, $t_{WTR_S_CRC_DM}$ is used in place of $t_{WTR_S}$.
11. When CRC and DM are both enabled, $t_{WTR_L_CRC_DM}$ is used in place of $t_{WTR_L}$.
12. The max value is 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.



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14. The deterministic component of the total timing.
15. DQ to DQ static offset relative to strobe per group.
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).
18. DRAM DBI mode is off.
19. DRAM DBI mode is enabled. Applicable to x8 and x16 DRAM only.
20. $t_{QSL}$ 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. $t_{QSH}$ 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 $t_{REFI}$.
23. $t_{CH(abs)}$ is the absolute instantaneous clock high pulse width, as measured from one rising edge to the following falling edge.
24. $t_{CL(abs)}$ 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, $t_{WR_CRC_DM}$ is used in place of $t_{WR}$.
29. When CRC and DM are both enabled, $t_{WTR_S_CRC_DM}$ is used in place of $t_{WTR_S}$.
30. When CRC and DM are both enabled, $t_{WTR_L_CRC_DM}$ is used in place of $t_{WTR_L}$.
31. After CKE is registered LOW, CKE signal level shall be maintained below $V_{IL(DC)}$ for $t_{CKE}$ specification (low pulse width).
32. After CKE is registered HIGH, CKE signal level shall be maintained above $V_{IH(DC)}$ for $t_{CKE}$ 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 $t_{CK\ (avg)min}$ to $t_{CK\ (avg)max}$ at all standard JEDEC clock period values as stated in the Section 9 SPEED BIN .
35. This parameter must keep consistency with Section 9 SPEED BIN
36. DDR4-1600 AC timing apply if DRAM operates at lower than 1600MT/s data rate. UI = $t_{CK\ (avg)min}/2$.
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 $R_{ONnom}$ = 34Ω.
40. $1t_{CK}$ toggle mode with setting MR4: A11 to 0.



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41. $2t_{CK}$ toggle mode with setting MR4: A11 to 1, which is valid for DDR4-2400/2666/3200 speed grade.
42. $1t_{CK}$ mode with setting MR4: A12 to 0.
43. $2t_{CK}$ 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 $t_{LZ(DQS)min}$ on the left side and $t_{DQSCK(max)}$ on the right side.
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. $V_{REFDQ}$ value must be set to either its midpoint or $V_{cent_DQ(midpoint)}$ in order to capture DQ0 or DQL0 low level for entering PDA mode.
48. The maximum read postamble is bound by $t_{DQSCK\ (min)}$ plus $t_{QSH\ (min)}$ on the left side and $t_{HZ(DQS)max}$ on the right side.
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 * $V_{DDQ}$ as a center level of the static single-ended output peak-to-peak swing with a driver impedance of 34 Ω and an effective test load of 50Ω to $V_{TT} = V_{DDQ}$.
50. For MR7 commands, the minimum delay to a subsequent non-MRS command is 5nCK.



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## 12.5 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 933.33MHz which yields a clock period of 1.0714ns. Similarly, a system with a memory clock frequency of 1066.66MHz yields mathematically a clock period of 0.9375ns. 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 1ps.

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 $t_{CK\ (avg)min}$ are defined to 1ps of accuracy; for example, 0.9375ns is defined as 937ps and 1.0714ns is defined as 1071ps.
- Using real math, parameters like $t_{AA\ (min)}$, $t_{RCD\ (min)}$, etc. which are programmed in systems in numbers of clocks (nCK) but expressed in units of time (in ns) are divided by the clock period (in ns) yielding a unitless ratio, a correction factor of 2.5% is subtracted, then the result is set to the next higher integer number of clocks:
  nCK = ceiling [(parameter_in_ns/application_$t_{CK}$_ in_ns) - 0.025]
- Alternatively, programmers may prefer to use integer math instead of real math by expressing timing in ps, scaling the desired parameter value by 1000, dividing by the application clock period, adding an inverse correction factor of 97.4%, dividing the result by 1000, then truncating down to the next lower integer value:
  nCK = truncate [{(parameter_in_ps * 1000)/(application_$t_{CK}$_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 = ceiling (parameter_in_ns/application_$t_{CK}$_in_ns).

## 12.6 The DQ Input Receiver Compliance Mask for Voltage and Timing

The DQ input receiver compliance mask for voltage and timing is shown in Figure 12-2 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. 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.

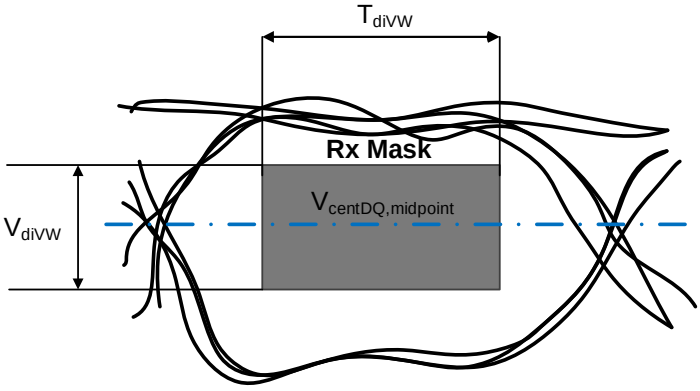



**Figure 12-2. DQ Receiver (Rx) Compliance mask**



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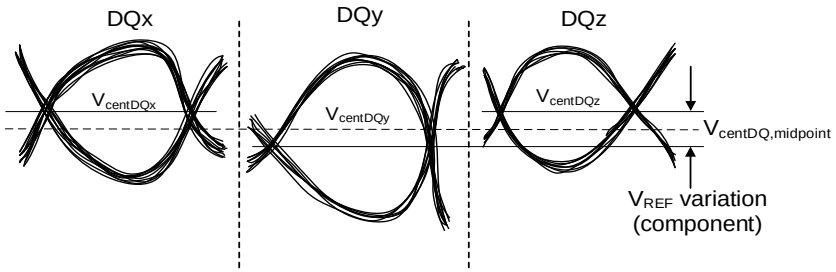



**Figure 12-3. Across Pin $V_{REFDQ}$ Voltage Variation**

The $V_{REFDQ}$ voltage is an internal reference voltage level that shall be set to the properly trained setting, which is generally $V_{centDQ,midpoint}$, in order to have valid Rx Mask values.

$V_{centDQ,midpoint}$ is defined as the midpoint between the largest $V_{REFDQ}$ voltage level and the smallest $V_{REFDQ}$ voltage level across all DQ pins for a given DRAM component. Each DQ pin $V_{REF}$ level is defined by the center, i.e. widest opening, of the cumulative data input eye as depicted in Figure 12-3. This clarifies that any DRAM component level variation must be accounted for within the DRAM Rx mask. The component level $V_{REF}$ will be set by the system to account for $R_{ON}$ and ODT settings.

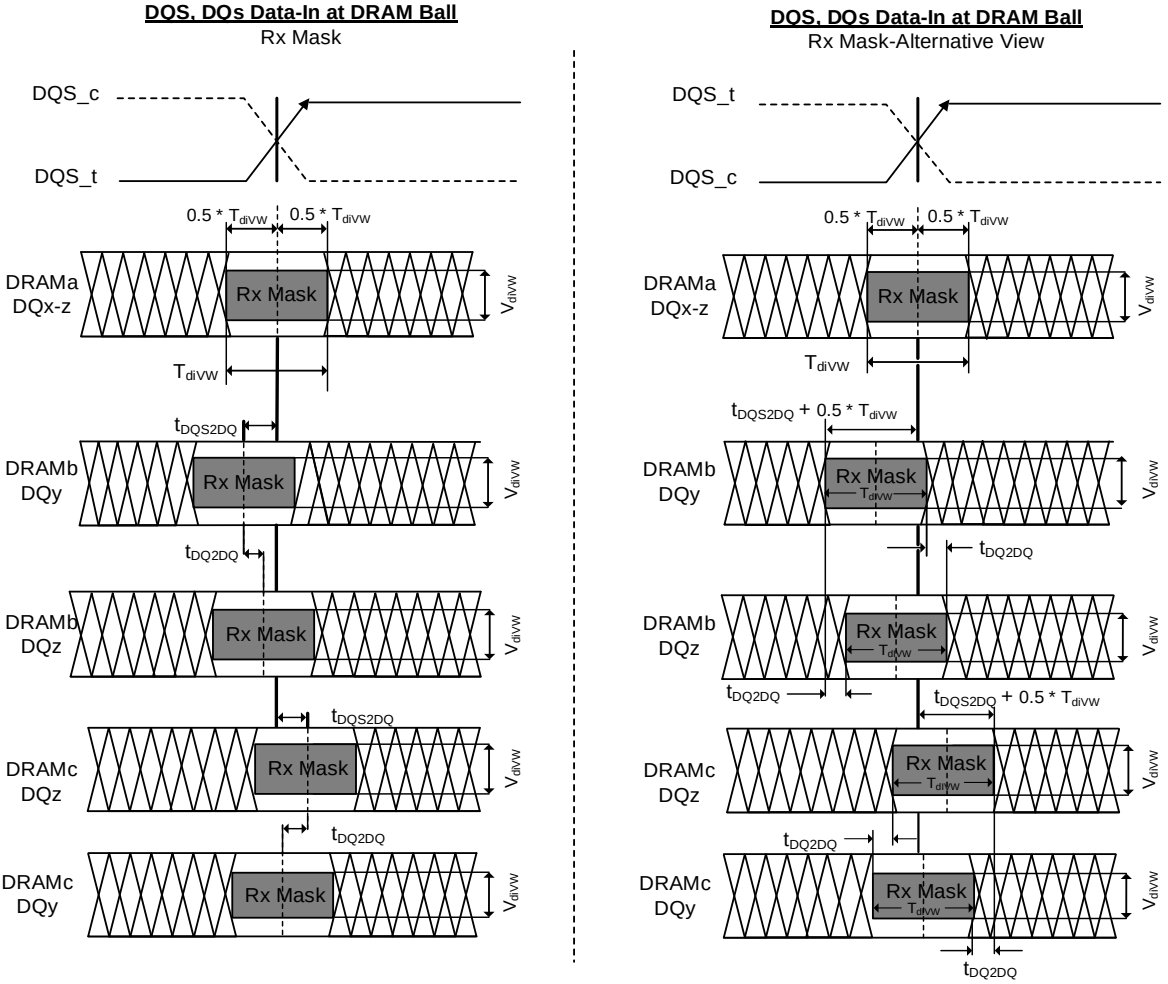



**Figure 12-4. DQS to DQ and DQ to DQ Timings at DRAM Balls**

Note:

- DQx represents an optimally centered mask.
- DQy represents earliest valid mask.
- DQz represents lasted valid mask.

Note:

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



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Note:

1. Figures show skew allowed between DRAM to DRAM and between DQ to DQ for a DRAM. Signals assume data centered aligned at DRAM Latch.
2. $T_{diPW}$ is not shown; composite data-eyes shown would violate $T_{diPW}$.
3. $V_{centDQ,midpoint}$ is not shown but is assumed to be midpoint of $V_{diVW}$.

All of the timing term in Figure 12-4 are measured at the $V_{diVW}$ voltage levels centered around $V_{centDQ,midpoint}$ 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 12-5 below: A LOW to HIGH transition tr1 is measured from 0.5 * $V_{diVW,max}$ below $V_{centDQ,midpoint}$ to the last transition through 0.5 * $V_{diVW,max}$ above $V_{centDQ,midpoint}$ while tr2 is measured from the last transition through 0.5*VdiVW(max) above Vcent_DQ(midpoint) to the first transition through the 0.5 * $V_{IHL(AC)min}$ above $V_{centDQ,midpoint}$.

Rising edge slew rate equations:

- srr1 = $V_{diVW,max}/t_{r1}$
- srr2 = $(V_{IHL(AC)min} - V_{diVW,max})/(2 * t_{r2})$

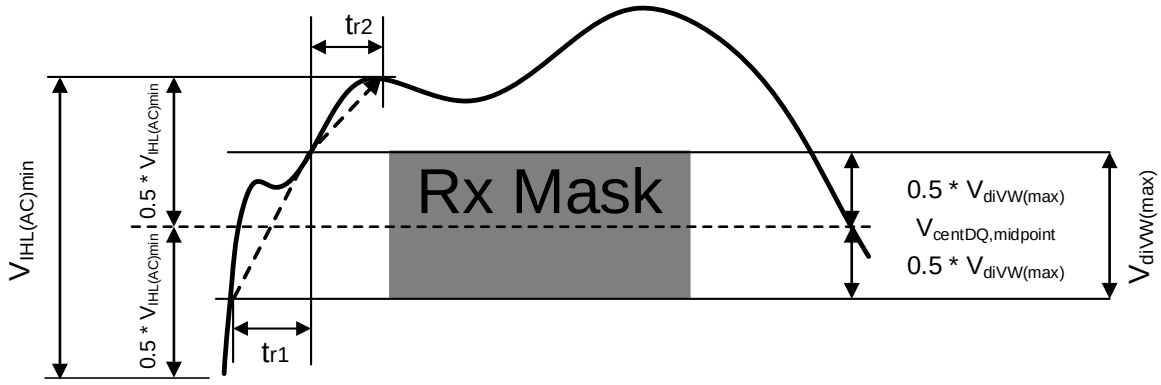



**Figure 12-5. Slew Rate Conditions for Rising Transition**

The falling edge slew rates are defined by srf1 and srf2. The slew rate measurement points for a falling edge are shown in Figure 12-6 below: A HIGH to LOW transition $t_{f1}$ is measured from 0.5 * $V_{diVW,max}$ above $V_{centDQ,midpoint}$ to the last transition through 0.5 * $V_{diVW,max}$ below $V_{centDQ,midpoint}$ while $t_{f2}$ is measured from the last transition through 0.5 * $V_{diVW,max}$ below $V_{centDQ,midpoint}$ to the first transition through the 0.5 * $V_{IHL(AC)min}$ below $V_{centDQ\ (pin\ mid)}$.

Falling edge slew rate equations:

- srf1 = $V_{diVW,max}/t_{f1}$
- srf2 = $(V_{IHL(AC)min} - V_{diVW,max})/(2 * t_{f2})$



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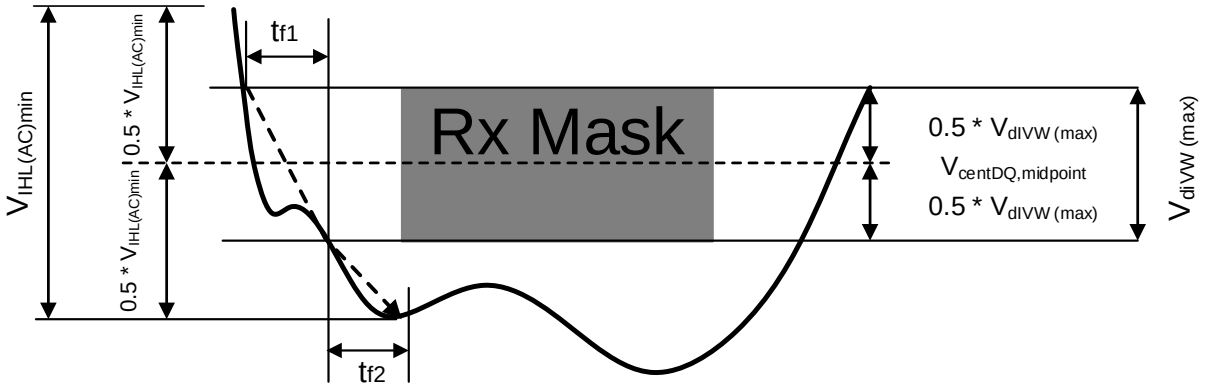



**Figure 12-6. Slew Rate Conditions for Falling Transition**

**Table 12-4. DRAM DQs in Receive Mode; UI = $t_{CK\ (avg)min}$/2**

| Symbol | Parameter | 1600/1866/2133 | | 2400 | | 2666 | | 2933 | | 3200 | | Unit | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | | |
| $V_{diVW}$ | Rx Mask voltage - pk-pk | - | 136 | - | 130 | - | 120 | - | 115 | - | 110 | mV | 1,2,10 |
| $T_{diVW}$ | Rx timing window | - | 0.2 | - | 0.2 | - | 0.22 | - | 0.23 | - | 0.23 | UI | 1,2,10 |
| $V_{IHL(AC)}$ | DQ AC input swing pk-pk | 186 | - | 160 | - | 150 | - | 145 | - | 140 | - | mV | 3,4,10 |
| $T_{diPW}$ | DQ input pulse width | 0.58 | - | 0.58 | - | 0.58 | - | 0.58 | - | 0.58 | - | UI | 5,10 |
| $t_{DQS2DQ}$ | Rx Mask DQS to DQ offset | -0.17 | 0.17 | -0.17 | 0.17 | -0.19 | 0.19 | -0.22 | 0.22 | -0.22 | 0.22 | UI | 6,10 |
| $t_{DQ2DQ}$ | Rx Mask DQ to DQ offset | - | 0.1 | - | 0.1 | - | 0.105 | - | 0.115 | - | 0.125 | UI | 7 |
| srr1 srf1 | Input Slew Rate over $V_{dIVW}$ if $t_{CK}$ ≥ 0.937ns | 1.0 | 9 | 1.0 | 9 | 1.0 | 9 | 1 | 9 | 1.0 | 9 | V/ns | 8,10 |
| srf1 srf2 | Input Slew Rate over $V_{dIVW}$ if 0.937ns > $t_{CK}$ ≥ 0.625ns | - | - | 1.25 | 9 | 1.25 | 9 | 1.25 | 9 | 1.25 | 9 | V/ns | 8,10 |
| srr2 | Rising Input Slew Rate over 1/2 $V_{IHL(AC)}$ | 0.2 * srr1 | 9 | 0.2 * srr1 | 9 | 0.2 * srr1 | 9 | 0.2 * srr1 | 9 | 0.2 * srr1 | 9 | V/ns | 9,10 |
| srf2 | Falling Input Slew Rate over 1/2 $V_{IHL(AC)}$ | 0.2 * srf1 | 9 | 0.2 * srf1 | 9 | 0.2 * srf1 | 9 | 0.2 * srr1 | 9 | 0.2 * srf1 | 9 | V/ns | 9,10 |



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Note:

1. Data Rx mask voltage and timing total input valid window where $V_{dIVW}$ is centered around $V_{centDQ,midpoint}$ 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 = $1^{e-16}$ when the Rx mask is not violated.
2. Defined over the DQ internal $V_{REF}$ range 1.
3. Overshoot and undershoot specifications apply.
4. DQ input pulse signal swing into the receiver must meet or exceed $V_{IHL(AC)min}$. $V_{IHL(AC)min}$ 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 $V_{centDQ,midpoint,}$.
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 $V_{centDQ,midpoint}$. Slowest DQ slew rate to fastest DQ slew rate per transition edge must be within 1.7V/ns of each other.
9. Input slew rate between $V_{diVW}$ mask edge and $V_{IHL(AC)min}$ 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.



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## 12.7 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 $\Delta t_{IS}$ and $\Delta t_{IH}$ 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) + $\Delta t_{IS}$. 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 $V_{IH(AC)}/V_{IL(AC)}$. For slew rates that fall between the values listed in derating tables, the derating values may be obtained by linear interpolation.

Setup ($t_{IS}$) nominal slew rate for a rising signal is defined as the slew rate between the last crossing of $V_{IL(DC)max}$ and the first crossing of $V_{IH(AC)min}$ that does not ring back below $V_{IH(DC)min}$. Setup ($t_{IS}$) nominal slew rate for a falling signal is defined as the slew rate between the last crossing of $V_{IH(DC)min}$ and the first crossing of $V_{IL(AC)max}$ that does not ring back above $V_{IL(DC)max}$.

Hold ($t_{IH}$) nominal slew rate for a rising signal is defined as the slew rate between the last crossing of $V_{IL(DC)max}$ and the first crossing of $V_{IH(AC)min}$ that does not ring back below $V_{IH(DC)min}$.

Hold ($t_{IH}$) nominal slew rate for a falling signal is defined as the slew rate between the last crossing of $V_{IH(DC)min}$ and the first crossing of $V_{IL(AC)min}$ that does not ring back above $V_{IL(DC)max}$.

**Table 12-5. Command, Address, Control Setup and Hold Values**

| DDR4 | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Reference |
|---|---|---|---|---|---|---|---|---|---|
| $t_{IS}$ (base, AC100) | 115 | 100 | 80 | 62 | - | - | - | ps | $V_{IHL(AC)}$ |
| $t_{IH}$ (base, DC75) | 140 | 125 | 105 | 87 | - | - | - | ps | $V_{IHL(DC)}$ |
| $t_{IS}$ (base, AC90) | - | - | - | - | 55 | 48 | 40 | ps | $V_{IHL(AC)}$ |
| $t_{IH}$ (base, DC65) | - | - | - | - | 80 | 73 | 65 | ps | $V_{IHL(DC)}$ |
| $t_{IS}/t_{IH}$ ($V_{REF}$) | 215 | 200 | 180 | 162 | 145 | 138 | 130 | ps | $V_{IHL(DC)}$ |

Note:

1. Base AC/DC referenced for 1V/ns slew rate and 2V/ns clock slew rate.
2. Values listed are referenced only; applicable limits are defined elsewhere.

**Table 12-6. Command, Address, Control Input Voltage Values**

| DDR4 | 1600 | 1866 | 2133 | 2400 | 2666 | 2933 | 3200 | Unit | Reference |
|---|---|---|---|---|---|---|---|---|---|
| $V_{IH(AC)min}$ | 100 | 100 | 100 | 100 | 90 | 90 | 90 | mV | $V_{IHL(AC)}$ |
| $V_{IH(DC)min}$ | 75 | 75 | 75 | 75 | 65 | 65 | 65 | mV | $V_{IHL(DC)}$ |
| $V_{IL(DC)max}$ | -75 | -75 | -75 | -75 | -65 | -65 | -65 | mV | $V_{IHL(AC)}$ |
| $V_{IL(AC)max}$ | -100 | -100 | -100 | -100 | -90 | -90 | -90 | mV | $V_{IHL(DC)}$ |

Note:

1. Command, Address, Control input levels relative to $V_{REFCA}$.
2. Values listed are referenced only; applicable limits are defined elsewhere.



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**Table 12-7. Derating Values DDR4-1600/1866/2133/2400 $t_{IS}/t_{IH}$ - AC/DC Based**

| $\Delta t_{IS}$, $\Delta t_{IH}$ derating in [ps] AC/DC Based[1] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CK_t, CK_c Differential Slew Rate | | | | | | | | | | | | | | |
| | | 10.0V/ns | | 8.0V/ns | | 6.0V/ns | | 4.0V/ns | | 3.0V/ns | | 2.0V/ns | | 1.5V/ns | | 1.0V/ns | |
| | | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ |
| 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. $V_{IHL(AC)}$ = ± 100mV, $V_{IHL(DC)}$ = ± 75mV; relative to $V_{REFCA}$.



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**Table 12-8. Derating Values DDR4-2666/2933/3200 $t_{IS}/t_{IH}$ - AC/DC Based**

| $\Delta t_{IS}$, $\Delta t_{IH}$ derating in [ps] AC/DC Based[1] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CK_t, CK_c Differential Slew Rate | | | | | | | | | | | | | | |
| | | 10.0V/ns | | 8.0V/ns | | 6.0V/ns | | 4.0V/ns | | 3.0V/ns | | 2.0V/ns | | 1.5V/ns | | 1.0V/ns | |
| | | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ | $\Delta t_{IS}$ | $\Delta t_{IH}$ |
| ADDR, CNTL Input Slew Rate V/ns | 7.0 | 68 | 47 | 69 | 47 | 70 | 48 | 72 | 50 | 73 | 52 | 77 | 56 | 85 | 63 | 100 | 78 |
| | 6.0 | 66 | 45 | 67 | 46 | 68 | 47 | 69 | 49 | 71 | 50 | 75 | 54 | 83 | 62 | 98 | 77 |
| | 5.0 | 63 | 43 | 64 | 44 | 65 | 45 | 66 | 46 | 68 | 48 | 72 | 52 | 80 | 60 | 95 | 75 |
| | 4.0 | 59 | 40 | 59 | 40 | 60 | 41 | 62 | 43 | 64 | 45 | 68 | 49 | 75 | 56 | 90 | 71 |
| | 3.0 | 51 | 34 | 52 | 35 | 53 | 36 | 54 | 38 | 56 | 40 | 60 | 43 | 68 | 51 | 83 | 66 |
| | 2.0 | 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 |
| | 1.0 | -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. $V_{IHL(AC)}$ = ± 90mV, $V_{IHL(DC)}$ = ± 65mV; relative to $V_{REFCA}$.



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# 13 REVISION HISTORY

| Version No | Description | Page | Date |
|---|---|---|---|
| 0.9 | Preliminary release | All | 2023/11/6 |
| 1.0 | Update the IDD, IDDQ and IPP Specifications | 62/63 | 2024/5/14 |



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