

JEDEC STANDARD

Low Power Double Date Rate 4 (LPDDR4)

JESD209-4B

(Revision of JESD209-4A, November 2015)

FEBRUARY 2017

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION



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LOW POWER DOUBLE DATA RATE (LPDDR) 4

From JEDEC Board Ballot JCB-16-51, formulated under the cognizance of the JC-42.6 Subcommittee on Low Power Memories.)

1 Scope

This document defines the LPDDR4 standard, including features, functionalities, AC and DC characteristics, packages, and ball/signal assignments. The purpose of this specification is to define the minimum set of requirements for a JEDEC compliant 16 bit per channel SDRAM device with either one or two channels. LPDDR4 dual channel device density ranges from 4 Gb through 32 Gb and single channel density ranges from 2 Gb through 16 Gb. This document was created using aspects of the following standards: DDR2 (JESD79-2), DDR3 (JESD79-3), DDR4 (JESD79-4), LPDDR (JESD209), LPDDR2 (JESD209-2) and LPDDR3 (JESD209-3).

Each aspect of the standard was considered and approved by committee ballot(s). The accumulation of these ballots was then incorporated to prepare the LPDDR4 standard.

2 Package ballout and Pin definition

2.1 Pad Order

2.1.1 Pad Order for dual channel

| Ch. A Top | Ch. B Top |
|--------------|--------------|
| 1 VDD2 | 101 VDD2 |
| 2 VSS | 102 VSS |
| 3 VDD1 | 103 VDD1 |
| 4 VDD2 | 104 VDD2 |
| 5 VSS | 105 VSS |
| 6 VSSQ | 106 VSSQ |
| 7 DQ8_A | 107 DQ8_B |
| 8 VDDQ | 108 VDDQ |
| 9 DQ9_A | 109 DQ9_B |
| 10 VSSQ | 110 VSSQ |
| 11 DQ10_A | 111 DQ10_B |
| 12 VDDQ | 112 VDDQ |
| 13 DQ11_A | 113 DQ11_B |
| 14 VSSQ | 114 VSSQ |
| 15 DQS1_t_A | 115 DQS1_t_B |
| 16 DQS1_c_A | 116 DQS1_c_B |
| 17 VDDQ | 117 VDDQ |
| 18 DMI1_A | 118 DMI1_B |
| 19 VSSQ | 119 VSSQ |
| 20 DQ12_A | 120 DQ12_B |
| 21 VDDQ | 121 VDDQ |
| 22 DQ13_A | 122 DQ13_B |
| 23 VSSQ | 123 VSSQ |
| 24 DQ14_A | 124 DQ14_B |
| 25 VDDQ | 125 VDDQ |
| 26 DQ15_A | 126 DQ15_B |
| 27 VSSQ | 127 VSSQ |
| 28 ZQ | 128 RESET_n |
| 29 VDDQ | 129 VDDQ |
| 30 VDD2 | 130 VDD2 |
| 31 VDD1 | 131 VDD1 |
| 32 VSS | 132 VSS |
| 33 CA5_A | 133 CA5_B |
| 34 CA4_A | 134 CA4_B |
| 35 VDD2 | 135 VDD2 |
| 36 CA3_A | 136 CA3_B |
| 37 CA2_A | 137 CA2_B |
| 38 VSS | 138 VSS |
| 39 CK_c_A | 139 CK_c_B |
| 40 CK_t_A | 140 CK_t_B |
| Ch. A Bottom | Ch. B Bottom |

NOTE 1 Applications are recommended to follow bit/byte assignments. Bit or Byte swapping at the application level requires review of MR and calibration features assigned to specific data bits/bytes.

NOTE 2 Additional pads are allowed for DRAM mfg-specific pads ("DNU"), or additional power pads as long as the extra pads are grouped with like-named pads.

2.1 Pad Order (cont'd)

2.1.2 Pad Order for single channel

| TOP | |
|--------|---------|
| 1 | VDD2 |
| 2 | VSS |
| 3 | VDD1 |
| 4 | VDD2 |
| 5 | VSS |
| 6 | VSSQ |
| 7 | DQ8 |
| 8 | VDDQ |
| 9 | DQ9 |
| 10 | VSSQ |
| 11 | DQ10 |
| 12 | VDDQ |
| 13 | DQ11 |
| 14 | VSSQ |
| 15 | DQS1_t |
| 16 | DQS1_c |
| 17 | VDDQ |
| 18 | DMI1 |
| 19 | VSSQ |
| 20 | DQ12 |
| 21 | VDDQ |
| 22 | DQ13 |
| 23 | VSSQ |
| 24 | DQ14 |
| 25 | VDDQ |
| 26 | DQ15 |
| 27 | VSSQ |
| 28 | ZQ |
| 29 | VDDQ |
| 30 | VDD2 |
| 31 | RESET_n |
| 32 | VDD1 |
| 33 | VSS |
| 34 | CA5 |
| 35 | CA4 |
| 36 | VDD2 |
| 37 | CA3 |
| 38 | CA2 |
| 39 | VSS |
| 40 | CK_c |
| 41 | CK_t |
| 42 | VDD2 |
| 43 | CKE |
| 44 | CS |
| 45 | VSS |
| 46 | CA1 |
| 47 | CA0 |
| 48 | VDD2 |
| 49 | ODT(ca) |
| 50 | VSS |
| 51 | VDD1 |
| 52 | VSSQ |
| 53 | DQ7 |
| 54 | VDDQ |
| 55 | DQ6 |
| 56 | VSSQ |
| 57 | DQ5 |
| 58 | VDDQ |
| 59 | DQ4 |
| 60 | VSSQ |
| 61 | DMI0 |
| 62 | VDDQ |
| 63 | DQS0_c |
| 64 | DQS0_t |
| 65 | VSSQ |
| 66 | DQ3 |
| 67 | VDDQ |
| 68 | DQ2 |
| 69 | VSSQ |
| 70 | DQ1 |
| 71 | VDDQ |
| 72 | DQ0 |
| 73 | VSSQ |
| 74 | VSS |
| 75 | VDD2 |
| 76 | VDD1 |
| 77 | VSS |
| 78 | VDD2 |
| Bottom | |

NOTE 1 Applications are recommended to follow bit/byte assignments. Bit or Byte swapping at the application level requires review of MR and calibration features assigned to specific data bits/bytes.

NOTE 2 Additional pads are allowed for DRAM mfg-specific pads ("DNU"), or additional power pads as long as the extra pads are grouped with like-named pads.

NOTE 3 A RESET_n pad is added. The RESET_n pad location is vendor specific. See vendor device datasheets for details about RESET_n pad location.

2.2 Package Ballout

2.2.1 272 ball 15 mm x 15 mm 0.4 mm pitch, Quad-Channel POP FBGA (top view) Using Variation VFFCDB for MO-273

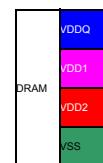
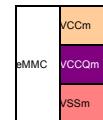
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|----|----------|----------|-------|-------|-------|-------|---------|--------|--------|--------|--------|--------|----------|----------|--------|--------|-------|-------|-------|-------|-------|-------|----------|----------|--------|--------|-------|-------|-------|---------|-------|-------|-------|-------|----------|----------|
| A | DNU | VSS | VDD1 | CA4_a | VDDQ | ZQ1_a | VDDO | DQ15_a | VDD2 | DQ13_a | VDD2 | DMI1_a | VDDQ | DQS1_c_a | VDDQ | DQ10_a | VSS | DQ8_a | DQ0_c | VDD1 | DQ2_c | VDDQ | DQS0_c_c | VDDQ | DQ4_c | VDD2 | DQ5_c | VDD2 | DQ7_c | VDDO | CA0_c | VDDQ | CS1_c | VDD1 | VSS | DNU |
| B | VSS | VDD2 | CA3_a | VSS | CA5_a | VSS | ZQ0_a | VSS | DQ14_a | VSS | DQ12_a | VSS | DQS1_L_a | VSS | DQ11_a | VSS | DQ9_a | VDD2 | VSS | DQ1_c | VSS | DQ3_c | VSS | DQS0_L_c | VSS | DMI0_d | VSS | DQ6_c | VSS | ODTca_c | VSS | CA1_c | VSS | CS0_c | VDD2 | VSS |
| C | CA2_a | CK_c_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CKE0_c | CKE1_c |
| D | VDD2 | CK_t_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CK_L_c | VDD2 |
| E | CKE0_a | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | CK_c_c |
| F | CKE1_a | CS0_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CA2_c | CA3_c |
| G | VDD2 | CS1_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CA4_c | VDD2 |
| H | CA1_a | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | CA5_c |
| J | CA0_a | ODTca_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ZQ0_c | ZQ1_c |
| K | VDDQ | DQ7_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ15_c | VDDQ |
| L | DQ6_a | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | DQ14_c |
| M | DQ5_a | DQ4_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ12_c | DQ13_c |
| N | VDDQ | DMI0_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DMI1_c | VDDQ |
| P | DQS0_c_a | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | DQS1_c_c |
| R | DQ3_a | DQS0_t_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQS1_t_c | DQ11_c |
| T | VDDQ | DQ2_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ10_c | VDDQ |
| U | DQ1_a | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | DQ9_c |
| V | VDD1 | DQ0_a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ8_c | VDD1 |
| W | DQ0_b | VDD2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VDD2 | DQ8_d |
| Y | DQ1_b | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | DQ9_d |
| AA | VDDQ | DQ2_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ10_d | VDDQ |
| AB | DQ3_b | DQS0_t_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQS1_t_d | DQ11_d |
| AC | DQS0_c_b | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | DQS1_c_d |
| AD | VDDQ | DMI0_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DMI1_d | VDDQ |
| AE | DQ5_b | DQ4_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ12_d | DQ13_d |
| AF | DQ6_b | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | DQ14_d |
| AG | VDDQ | DQ7_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | DQ15_d | VDDQ |
| AH | CA0_b | ODTca_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | NC | NC |
| AJ | CA1_b | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | CA5_d |
| AK | VDD2 | CS1_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CA4_d | VDD2 |
| AL | CKE1_b | CS0_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CA2_d | CA3_d |
| AM | CKE0_b | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | CK_c_d |
| AN | VDD2 | CK_t_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CK_t_d | VDD2 |
| AP | CA2_b | CK_c_b | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | CKE0_d | CKE1_d |
| AR | VSS | VDD2 | CA3_b | VSS | CA5_b | VSS | RESET_n | VSS | DQ14_b | VSS | DMI1_b | VSS | DQS1_L_b | VSS | DQ11_b | VSS | DQ9_b | VDD2 | VSS | DQ1_d | VSS | DQ3_d | VSS | DQS0_L_d | VSS | DQ4_d | VSS | DQ6_d | VSS | ODTca_d | VSS | CA1_d | VSS | CS0_d | VDD2 | VSS |
| AT | DNU | VSS | VDD1 | CA4_b | VDDQ | NC | VDDQ | DQ15_b | VDD2 | DQ13_b | VDD2 | DQ12_b | VDDQ | DQS1_c_b | VDDQ | DQ10_b | VSS | DQ8_b | DQ0_d | VDD1 | DQ2_d | VDDQ | DQS0_c_c | VDDQ | DMI0_d | VDD2 | DQ5_d | VDD2 | DQ7_d | VDDQ | CA0_d | VDDQ | CS1_d | VDD1 | VSS | DNU |

2.2.2 LPDDR4 34x34 Quad x16 Channel (Fits 14x14 0.4 mm pitch) - Using MO-317A

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
|----|-------|-------|----------|----------|--------|-----------|-------|--------|--------|--------|--------|--------|--------|----------|----------|--------|-------|--------|--------|----------|----------|--------|--------|-------|--------|--------|--------|-----------|-----------|--------|----------|----------|-------|-------|
| A | NC | VDD2 | DQ3_A | VSS | DQ5_A | ODT(ca)_A | CA0_A | CS1_A | CKE1_A | CA2_A | VSS | DQ13_A | VDD2 | VDD1 | DQ10_A | ZQ1_A | ZQ1_D | DQ10_C | VDD1 | VDD2 | DQ13_C | VSS | VSS | CA2_C | CKE1_C | CS1_C | CA0_C | ODT(ca)_C | DQ5_C | VSS | DQ3_C | VDD2 | NC | |
| B | VSS | DQ2_A | VDD0 | DM10_A | VDD0 | DO7_A | VDD2 | CS0_A | CKE0_A | VDD2 | CA4_A | DQ15_A | VDD0 | DM11_A | DQ11_A | VSS | ZQ0_D | VSS | DQ11_C | DM11_C | VDD0 | DQ15_C | CA4_C | VDD2 | CKE0_C | CS0_C | VDD2 | DQ7_C | VDD0 | DM10_C | VDD2 | DQ2_C | VSS | |
| C | DO0_A | VDD0 | VSS | DO4_A | VDD0 | CA1_A | VDD2 | CS3_A | VSS | VDD0 | DO12_A | VSS | DO9_A | RESET_n | RFU | DO9_C | VDD0 | VSS | DQ12_C | DO12_C | VDD0 | VSS | CA3_C | VSS | DQ15_D | CA1_C | VDD0 | DO4_C | VSS | VDD0 | DO0_C | VDD0 | | |
| D | VDD1 | DQ1_A | DQ50_L_A | DQ50_S_A | VSS | DQ6_A | VSS | CK_L_A | CK_C_A | VSS | CA5_A | DQ14_A | VSS | DQ51_L_A | DQ51_T_A | VDD0 | DQ8_A | DQ8_C | VDD0 | DQ51_L_C | DQ51_C_C | VSS | DQ14_C | CA5_C | VSS | CK_C_C | CK_L_C | VSS | DQ6_C | VSS | DQ50_C_C | DQ50_L_C | DQ1_C | VDD1 |
| E | VDD2 | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | VDD2 | |
| F | VDD2 | VDD2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VDD2 | VDD2 | |
| G | VSS | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | VSS | |
| H | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| J | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| K | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| L | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| M | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| N | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| P | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| R | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| T | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| U | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| V | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| W | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| Y | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AA | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AB | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AC | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AD | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AE | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AF | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AG | RFU | RFU | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | RFU | RFU | |
| AH | VSS | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | VSS | |
| AJ | VDD2 | VDD2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VDD2 | VDD2 | |
| AK | VDD2 | VSS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | VSS | VDD2 | |
| AL | VDD1 | DQ1_B | DQ50_L_B | DQ50_S_B | VSS | DQ6_B | VSS | CK_L_B | CK_C_B | VSS | CA5_B | DQ14_B | VSS | DQ51_L_B | DQ51_T_B | VDD0 | DQ8_B | DQ8_D | VDD0 | DQ51_L_D | DQ51_C_D | VSS | DQ14_D | CA5_D | VSS | CK_C_D | CK_L_D | VSS | DQ6_D | VSS | DQ50_C_D | DQ50_L_D | DQ1_D | VDD1 |
| AM | DQ0_B | VDDQ | VSS | VSS | DQ4_B | VDD0 | CA1_B | VDD2 | VSS | CA3_B | VSS | VDD0 | DQ12_B | VSS | VDDQ | DQ9_B | VDD2 | VDD2 | DQ9_D | VDD0 | VDD0 | VSS | DQ12_D | VDDQ | VSS | CA3_D | VSS | DQ15_D | CA1_D | VDDQ | DQ4_D | VSS | VDD0 | DQ0_D |
| AN | VSS | DQ2_B | VDD0 | VDD0 | DM10_B | VDD0 | DO7_B | VDD2 | CS0_B | CKE0_B | VDD2 | CA4_B | DQ15_B | VDD0 | DM11_B | DQ11_B | VSS | RFU | VSS | DO11_D | DM11_D | VDD0 | DQ15_D | CA4_D | VDD2 | CKE0_D | CS0_D | VDD2 | DO7_D | VDD0 | DM10_D | VDD0 | DQ2_D | VSS |
| AP | NC | VDD2 | DQ3_B | VSS | DQ5_B | ODT(ca)_B | CA0_B | CS1_B | CKE1_B | CA2_B | VSS | VSS | DQ13_B | VDD2 | VDD1 | DQ10_B | RFU | RFU | DQ10_D | VDD1 | VDD2 | DQ13_D | VSS | VSS | CA2_D | CKE1_D | CS1_D | CA0_D | ODT(ca)_D | DQ5_D | VSS | DQ3_D | VDD2 | NC |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |

2.2.3 144 ball ePoP MCP One-Channel FBGA (top view) using MO-323A

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|----|----------|----------|--------|--------|-------|-------|-------|-------|--------|--------|--------|-------|-------|-----------|-------|----------|----------|------|------|
| A | DNU | VSSm | VSSm | VCCQm | VSSm | VSSm | DAT5m | VCCQm | DAT0m | CLKm | VCCm | DAT6m | VCCQm | DAT7m | VCCQm | VSSm | RSTM | VSSm | DNU |
| B | VSSm | VSSm | VCCm | VSSm | VDDI | VCCm | DAT1m | DAT4m | VSSm | VCCQm | VSSm | DAT2m | DAT3m | VSSm | DSm | VSSm | CMDm | VCCm | VSSm |
| C | VSSm | VCCm | | | | | | | | | | | | | | VSSm | VSSm | | |
| D | VSF1 | VSF3 | | | | | | | | | | | | | | VSF5 | VSF8 | | |
| E | VSF2 | VSF4 | | | | | | | | | | | | | | VSF6 | VSF9 | | |
| F | RESET_n | VSS | | | | | | | | | | | | | | VSF7 | RFU | | |
| G | ZQ1_A | ZQ0_A | | | | | | | | | | | | | | RFU | RFU | | |
| H | VSS | VSS | | | | | | | | | | | | | | VSS | VSS | | |
| J | VDD1 | VDD1 | | | | | | | | | | | | | | VDD1 | VDD1 | | |
| K | VDD2 | VDD2 | | | | | | | | | | | | | | VDD2 | VDD2 | | |
| L | VSS | VDDQ | | | | | | | | | | | | | | VDDQ | VSS | | |
| M | DQ8_A | DQ9_A | | | | | | | | | | | | | | DQ1_A | DQ0_A | | |
| N | VDD2 | DQ10_A | | | | | | | | | | | | | | DQ2_A | VDD2 | | |
| P | DQ11_A | VSS | | | | | | | | | | | | | | VSS | DQ3_A | | |
| R | DQS1_t_A | DQS1_c_A | | | | | | | | | | | | | | DQS0_c_A | DQS0_t_A | | |
| T | VSS | VDDQ | | | | | | | | | | | | | | VDDQ | VSS | | |
| U | DM1_A | VSS | | | | | | | | | | | | | | VSS | DM0_A | | |
| V | VDD2 | VDDQ | | | | | | | | | | | | | | VDDQ | VDD2 | | |
| W | DQ12_A | DQ13_A | | | | | | | | | | | | | | DQ5_A | DQ4_A | | |
| Y | VSS | VDD2 | DQ14_A | VDD1 | CA5_A | VSS | CA2_A | VDD2 | CK_c_A | VSS | CKE0_A | CS0_A | CA1_A | VDD2 | VSS | DQ7_A | DQ6_A | VDD2 | VSS |
| AA | DNU | VSS | VDDQ | DQ15_A | VDD2 | CA4_A | CA3_A | VSS | CK1_A | CKE1_A | CS1_A | VSS | CA0_A | DDT(ca)_A | VDD1 | VDDQ | VSS | VSS | DNU |



eMCP 144FBGA
19x21

NOTE 1 0.4 mm pitch, 2 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 Body size: 8 mm x 9.5 mm

NOTE 4 ODT(ca)_A balls are wired to ODT(ca)_A pads of Rank 0 DRAM die. ODT(ca) pads for other ranks (if present) are disabled in the package.

NOTE 5 DRAM die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 6 The flash ball-out supports e•MMC 5.x

NOTE 7 Vendor specific function (VSF) - this terminal should not have any external electrical connections, but it may have an internal connection. The terminal may be routed to provide accessibility and may be used for general purpose vendor specific operations.

2.2.4 200 ball x32 Discrete Package, 0.80 mm x 0.65 mm using MO-311

| 0.80 mm Pitch | | | | | | | | | | | | |
|---------------|------|-----------|----------|--------|--------|---|---|--------|--------|----------|---------|------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| A | DNU | DNU | VSS | VDD2 | ZQ0 | | | ZQ1 | VDD2 | VSS | DNU | DNU |
| B | DNU | DQ0_A | VDDQ | DQ7_A | VDDQ | | | VDDQ | DQ15_A | VDDQ | DQ8_A | DNU |
| C | VSS | DQ1_A | DMI0_A | DQ6_A | VSS | | | VSS | DQ14_A | DMI1_A | DQ9_A | VSS |
| D | VDDQ | VSS | DQS0_t_A | VSS | VDDQ | | | VDDQ | VSS | DQS1_t_A | VSS | VDDQ |
| E | VSS | DQ2_A | DQS0_c_A | DQ5_A | VSS | | | VSS | DQ13_A | DQS1_c_A | DQ10_A | VSS |
| F | VDD1 | DQ3_A | VDDQ | DQ4_A | VDD2 | | | VDD2 | DQ12_A | VDDQ | DQ11_A | VDD1 |
| G | VSS | ODT(ca)_A | VSS | VDD1 | VSS | | | VSS | VDD1 | VSS | ZQ2 | VSS |
| H | VDD2 | CA0_A | CS1_A | CS0_A | VDD2 | | | VDD2 | CA2_A | CA3_A | CA4_A | VDD2 |
| J | VSS | CA1_A | VSS | CKE0_A | CKE1_A | | | CK_t_A | CK_c_A | VSS | CA5_A | VSS |
| K | VDD2 | VSS | VDD2 | VSS | CS2_A | | | CKE2_A | VSS | VDD2 | VSS | VDD2 |
| L | | | | | | | | | | | | |
| M | | | | | | | | | | | | |
| N | VDD2 | VSS | VDD2 | VSS | CS2_B | | | CKE2_B | VSS | VDD2 | VSS | VDD2 |
| P | VSS | CA1_B | VSS | CKE0_B | CKE1_B | | | CK_t_B | CK_c_B | VSS | CA5_B | VSS |
| R | VDD2 | CA0_B | CS1_B | CS0_B | VDD2 | | | VDD2 | CA2_B | CA3_B | CA4_B | VDD2 |
| T | VSS | ODT(ca)_B | VSS | VDD1 | VSS | | | VSS | VDD1 | VSS | RESET_n | VSS |
| U | VDD1 | DQ3_B | VDDQ | DQ4_B | VDD2 | | | VDD2 | DQ12_B | VDDQ | DQ11_B | VDD1 |
| V | VSS | DQ2_B | DQS0_c_B | DQ5_B | VSS | | | VSS | DQ13_B | DQS1_c_B | DQ10_B | VSS |
| W | VDDQ | VSS | DQS0_t_B | VSS | VDDQ | | | VDDQ | VSS | DQS1_t_B | VSS | VDDQ |
| Y | VSS | DQ1_B | DMI0_B | DQ6_B | VSS | | | VSS | DQ14_B | DMI1_B | DQ9_B | VSS |
| AA | DNU | DQ0_B | VDDQ | DQ7_B | VDDQ | | | VDDQ | DQ15_B | VDDQ | DQ8_B | DNU |
| AB | DNU | DNU | VSS | VDD2 | VSS | | | VSS | VDD2 | VSS | DNU | DNU |

NOTE 1 0.8 mm pitch (X-axis), 0.65 mm pitch (Y-axis), 22 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT(ca)_x balls are wired to ODT(ca)_x pads of Rank 0 DRAM die. ODT(ca)_x pads for other ranks (if present) are disabled in the package.

NOTE 4 ZQ2, CKE2_A, CKE2_B, CS2_A, and CS2_B balls are reserved for 3-rank package. For 1-rank and 2-rank package those balls are NC.

NOTE 5 Die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 6 Package requires dual channel die or functional equivalent of single channel die-stack.

2.2.5 203 ball Discrete Two-Channel FBGA (top view) using MO-311

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
|----|--------|-------|--------|--------|--------|--------|----------|---|---|----|----|----|----|
| A | DNU | DNU | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | | | A |
| B | DNU | DQ0_A | DQ3_A | VSS | DQ4_A | VSS | VDD2 | | | | | | B |
| C | DQ1_A | VSS | VSS | DQ5_A | VSS | DQ7_A | DQS0_t_A | | | | | | C |
| D | DQ2_A | VSS | DMI0_A | VSS | DQ6_A | VSS | DQS0_c_A | | | | | | D |
| E | | | | | | | | | | | | | |
| F | | | | | | | | | | | | | |
| G | DQ13_A | VSS | VSS | VSS | VSS | VSS | VDDQ | | | | | | G |
| H | DMI1_A | VSS | VSS | DQ14_A | VSS | DQ15_A | VDDQ | | | | | | H |
| J | DQ11_A | VSS | VSS | VSS | DQ12_A | VDDQ | DQS1_c_A | | | | | | J |
| K | DQ10_A | VSS | DQ8_A | DQ9_A | VSS | VDDQ | DQS1_t_A | | | | | | K |
| L | VSS | VSS | VSS | VSS | VSS | VDDQ | VDDQ | | | | | | L |
| M | DQ10_B | VSS | DQ8_B | DQ9_B | VSS | VDDQ | DQS1_t_B | | | | | | M |
| N | DQ11_B | VSS | VSS | VSS | DQ12_B | VDDQ | DQS1_c_B | | | | | | N |
| P | DMI1_B | VSS | VSS | DQ14_B | VSS | DQ15_B | VDDQ | | | | | | P |
| R | DQ13_B | VSS | VSS | VSS | VSS | VSS | VDDQ | | | | | | R |
| T | | | | | | | | | | | | | |
| U | | | | | | | | | | | | | |
| V | DQ2_B | VSS | DMI0_B | VSS | DQ6_B | VSS | DQS0_c_B | | | | | | V |
| W | DQ1_B | VSS | VSS | DQ5_B | VSS | DQ7_B | DQS0_t_B | | | | | | W |
| Y | DNU | DQ0_B | DQ3_B | VSS | DQ4_B | VSS | VDD2 | | | | | | Y |
| AA | DNU | DNU | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | | | AA |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |

NOTE 1 0.8 mm pitch (X-axis), 0.65mm pitch (Y-axis), 21 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package.

NOTE 4 ZQ2_A, CKE2_A, CKE2_B, CS2_A, and CS2_B balls are reserved for 3 rank package, and for 1 rank and 2 rank package those balls are NC.

NOTE 5 Die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 6 Package requires dual channel die or functional equivalent of single channel die-stack.

2.2.6 432 ball x64 HDI Discrete Package, 0.50mm x 0.50mm (MO-313)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | |
|----|---|-------|----------|----------|-------|---------|---|---------|--------|----------|----------|---------|------|----|------|-------|----------|----------|-------|---------|----|---------|--------|----------|----------|--------|------|----|
| A | VDDQ | VDD1 | VDDQ | VDDQ | VDDQ | VDD2 | | VDD2 | VDDQ | VDDQ | VDDQ | VDD1 | VDDQ | | VDDQ | VDD1 | VDDQ | VDDQ | VDDQ | VDD2 | | VDD2 | VDDQ | VDDQ | VDDQ | VDD1 | VDDQ | A |
| B | VDDQ | VDD1 | DQ0_A | VSS | CA0_A | VDD2 | | VDD2 | CA4_A | VSS | DQ8_A | VDD1 | VDDQ | | VDDQ | VDD1 | DQ0_C | VSS | CA0_C | VDD2 | | VDD2 | CA4_C | VSS | DQ8_C | VDD1 | VDDQ | B |
| C | VDDQ | DQ1_A | VSS | DQ5_A | VSS | CA2_A | | CA3_A | VSS | DQ13_A | VSS | DQ9_A | VDDQ | | VDDQ | DQ1_C | VSS | DQ5_C | VSS | CA2_C | | CA3_C | VSS | DQ13_C | VSS | DQ9_C | VDDQ | C |
| D | VDDQ | VSS | DQ4_A | VSS | CA1_A | VDD2 | | VDD2 | CA5_A | VSS | DQ12_A | VSS | VDDQ | | VDDQ | VSS | DQ4_C | VSS | CA1_C | VDD2 | | VDD2 | CA5_C | VSS | DQ12_C | VSS | VDDQ | D |
| E | VDDQ | DQ2_A | VSS | DQ6_A | VSS | CLK_L_A | | CLK_c_A | VSS | DQ14_A | VSS | DQ10_A | VDDQ | | VDDQ | DQ2_C | VSS | DQ6_C | VSS | CLK_L_C | | CLK_c_C | VSS | DQ14_C | VSS | DQ10_C | VDDQ | E |
| F | VDDQ | VSS | DQ50_t_A | VSS | CS1_A | VDD2 | | VDD2 | CKE0_A | VSS | DQ51_L_A | VSS | VDDQ | | VDDQ | VSS | DQ50_L_C | VSS | CS1_C | VDD2 | | VDD2 | CKE0_C | VSS | DQ51_L_C | VSS | VDDQ | F |
| G | VDDQ | DQ3_A | VSS | DQ50_c_A | VSS | CS0_A | | CKE1_A | VSS | DQ51_c_A | VSS | DQ11_A | VDDQ | | VDDQ | DQ3_C | VSS | DQ50_c_C | VSS | CS0_C | | CKE1_C | VSS | DQ51_c_C | VSS | DQ11_C | VDDQ | G |
| H | VDDQ | VSS | DMI0_A | VSS | DQ7_A | VDD2 | | VDD2 | DQ15_A | VSS | DMI1_A | VSS | VDDQ | | VDDQ | VSS | DMI0_C | VSS | DQ7_C | VDD2 | | VDD2 | DQ15_C | VSS | DMI1_C | VSS | VDDQ | H |
| J | VDDQ | ZQ3_A | ZQ2_A | ODT_ca_A | CS3_A | CS2_A | | CKE3_A | CKE2_A | ZQ0_A | VSS | ZQ1_A | VDDQ | | VDDQ | ZQ3_C | ZQ2_C | ODT_ca_C | CS3_C | CS2_C | | CKE3_C | CKE2_C | ZQ0_C | VSS | ZQ1_C | VDDQ | J |
| K | NOTE 1 0.5 mm ball pitch. NOTE 2 432 ball count. NOTE 3 Top View, A1 in top left corner. NOTE 4 ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package. NOTE 5 Package requires dual channel die or functional equivalent of single channel die-stack. Package Channel A and Channel C shall be assigned to die Channel A of different DRAM die. NOTE 6 ZQ2, CKE2_A, CKE2_B, CS2_A, and CS2_B balls are reserved for 3-rank package. ZQ3, CKE3_A, CKE3_B, CS3_A, and CS3_B balls are reserved for 4-rank package. For 1-rank and 2-rank package those balls are NC. NOTE 7 Die pad VSS and VSSQ signals are combined to VSS package balls. NOTE 8 Package requires dual channel die or functional equivalent of single channel die-stack. | | | | | | | | | | | | | | | | | | | | | | | | | | K | |
| L | | | | | | | | | | | | | | | | | | | | | | | | | | | | L |
| M | | | | | | | | | | | | | | | | | | | | | | | | | | | | M |
| N | | | | | | | | | | | | | | | | | | | | | | | | | | | | N |
| P | | | | | | | | | | | | | | | | | | | | | | | | | | | | P |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | R |
| T | | | | | | | | | | | | | | | | | | | | | | | | | | | | T |
| V | VDDQ | VSS | VSS | ODT_ca_B | CS3_B | CS2_B | | CKE3_B | CKE2_B | VSS | VSS | RESET_n | VDDQ | | VDDQ | VSS | VSS | ODT_ca_D | CS3_D | CS2_D | | CKE3_D | CKE2_D | VSS | VSS | NC | VDDQ | V |
| W | VDDQ | VSS | DMI0_B | VSS | DQ7_B | VDD2 | | VDD2 | DQ15_B | VSS | DMI1_B | VSS | VDDQ | | VDDQ | VSS | DMI0_D | VSS | DQ7_D | VDD2 | | VDD2 | DQ15_D | VSS | DMI1_D | VSS | VDDQ | W |
| Y | VDDQ | DQ3_B | VSS | DQ50_c_B | VSS | CS0_B | | CKE1_B | VSS | DQ51_c_B | VSS | DQ11_B | VDDQ | | VDDQ | DQ3_D | VSS | DQ50_c_D | VSS | CS0_D | | CKE1_D | VSS | DQ51_c_D | VSS | DQ11_D | VDDQ | Y |
| AA | VDDQ | VSS | DQ50_t_B | VSS | CS1_B | VDD2 | | VDD2 | CKE0_B | VSS | DQ51_t_B | VSS | VDDQ | | VDDQ | DQ2_D | VSS | DQ6_D | VSS | CLK_L_D | | VDD2 | CKE0_D | VSS | DQ51_t_D | VSS | VDDQ | AA |
| AB | VDDQ | DQ2_B | VSS | DQ6_B | VSS | CLK_L_B | | CLK_c_B | VSS | DQ14_B | VSS | DQ10_B | VDDQ | | VDDQ | VSS | DQ4_D | VSS | CA1_D | VDD2 | | CLK_c_D | VSS | DQ14_D | VSS | DQ10_D | VDDQ | AB |
| AC | VDDQ | VSS | DQ4_B | VSS | CA1_B | VDD2 | | VDD2 | CA5_B | VSS | DQ12_B | VSS | VDDQ | | VDDQ | DQ1_D | VSS | DQ5_D | VSS | CA2_D | | VDD2 | CA5_D | VSS | DQ12_D | VSS | VDDQ | AC |
| AD | VDDQ | DQ1_B | VSS | DQ5_B | VSS | CA2_B | | CA3_B | VSS | DQ13_B | VSS | DQ9_B | VDDQ | | VDDQ | VDD1 | DQ0_D | VSS | CA0_D | VDD2 | | CA3_D | VSS | DQ13_D | VSS | DQ9_D | VDDQ | AD |
| AE | VDDQ | VDD1 | DQ0_B | VSS | CA0_B | VDD2 | | VDD2 | CA4_B | VSS | DQ8_B | VDD1 | VDDQ | | VDDQ | VDD1 | VDDQ | VDDQ | VDDQ | VDD2 | | VDD2 | CA4_D | VSS | DQ8_D | VDD1 | VDDQ | AE |
| AF | VDDQ | VDD1 | VDDQ | VDDQ | VDDQ | VDD2 | | VDD2 | VDDQ | VDDQ | VDDQ | VDD1 | VDDQ | | VDDQ | VDD1 | VDDQ | VDDQ | VDDQ | VDD2 | | VDD2 | VDDQ | VDDQ | VDDQ | VDD1 | VDDQ | AF |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | |

2.2.7 324 ball x64 Non HDI Discrete Package

LPDDR4 324 Ball x64 Non HDI Discrete Package, Pitch: 0.8 mm x 0.8 mm; 0.65 mm x 0.65 mm; and 0.65 mm (X-axis) x 0.8 mm (Y-axis) pitch using MO-315.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--|
| A | DNU | DNU | VDD Q | DQ0_B | VDD2 | DQ1_B | VDD Q | CA0_B | CA1_B | CA0_A | VDD Q | DQ1_A | VDD2 | DQ0_A | VDD Q | DNU | DNU | | |
| B | DNU | DQS0_T_B | DQS0_C_B | VSS | DQ3_B | VSS | DQ2_B | VDD Q | CKE0_B | CKE0_A | VDD Q | DQ3_A | VSS | DQ2_A | VSS | DQS0_C_A | DQS0_T_A | DNU | |
| C | VDD Q | DQ5_B | VSS | DQ4_B | VSS | DMI0_B | VDD Q | CKE1_B | VSS | VSS | CKE1_A | VDD Q | DMI0_A | VSS | DQ4_A | VSS | DQ5_A | VDD Q | |
| D | DQ7_B | VSS | DQ13_B | VDD2 | DQ6_B | VSS | ODT_CA_B | VDD2 | CK_T_B | CK_T_A | VDD2 | ODT_CA_A | VSS | DQ6_A | VDD2 | DQ13_A | VSS | DQ7_A | |
| E | VDD2 | DQ14_B | VSS | DQ12_B | VDD2 | CS0_B | VSS | VDD2 | CK_C_B | CK_C_A | VDD2 | VSS | CS0_A | VDD2 | DQ12_A | VSS | DQ14_A | VDD2 | |
| F | DQ15_B | VSS | DQS1_C_B | VSS | VDD2 | CS1_B | VSS | CA2_B | CA2_A | VSS | CS1_A | VDD2 | VSS | VSS | DQS1_C_A | VSS | DQ15_A | | |
| G | VDD Q | DMI1_B | VDD Q | DQS1_T_B | VSS | VSS | VDD2 | CA3_B | VSS | VSS | CA3_A | VDD2 | VSS | VSS | DQS1_T_A | VDD Q | DMI1_A | VDD Q | |
| H | DQ11_B | VDD Q | DQ10_B | VDD2 | RESE_T_N | VSS | ZQ1_A | VDD2 | CA4_B | CA4_A | VDD2 | ZQ0_A | VSS | NC | VDD2 | DQ10_A | VDD Q | DQ11_A | |
| J | VDD1 | DQ8_B | VSS | DQ9_B | VDD2 | NC | VSS | CA5_B | VDD2 | VDD2 | CA5_A | VSS | NC | VDD2 | DQ9_A | VSS | DQ8_A | VDD1 | |
| K | VDD1 | DQ8_C | VSS | DQ9_C | VDD2 | NC | VSS | CA5_C | VDD2 | VDD2 | CA5_D | VSS | NC | VDD2 | DQ9_D | VSS | DQ8_D | VDD1 | |
| L | DQ11_C | VDD Q | DQ10_C | VDD2 | NC | VSS | ZQ0_C | VDD2 | CA4_C | CA4_D | VDD2 | ZQ1_C | VSS | NC | VDD2 | DQ10_D | VDD Q | DQ11_D | |
| M | VDD Q | DMI1_C | VDD Q | DQS1_T_C | VSS | VSS | VDD2 | CA3_C | VSS | VSS | CA3_D | VDD2 | VSS | VSS | DQS1_T_D | VDD Q | DMI1_D | VDD Q | |
| N | DQ15_C | VSS | DQS1_C_C | VSS | VSS | VDD2 | CS1_C | VSS | CA2_C | CA2_D | VSS | CS1_D | VDD2 | VSS | VSS | DQS1_C_D | VSS | DQ15_D | |
| P | VDD2 | DQ14_C | VSS | DQ12_C | VDD2 | CS0_C | VSS | VDD2 | CK_C_C | CK_C_D | VDD2 | VSS | CS0_D | VDD2 | DQ12_D | VSS | DQ14_D | VDD2 | |
| R | DQ7_C | VSS | DQ13_C | VDD2 | DQ6_C | VSS | ODT_CA_C | VDD2 | CK_T_C | CK_T_D | VDD2 | ODT_CA_D | VSS | DQ6_D | VDD2 | DQ13_D | VSS | DQ7_D | |
| T | VDD Q | DQ5_C | VSS | DQ4_C | VSS | DMI0_C | VDD Q | CKE1_C | VSS | VSS | CKE1_D | VDD Q | DMI0_D | VSS | DQ4_D | VSS | DQ5_D | VDD Q | |
| U | DNU | DQS0_T_C | DQS0_C_C | VSS | DQ3_C | VSS | DQ2_C | VDD Q | CKE0_C | CKE0_D | VDD Q | DQ2_D | VSS | DQ3_D | VSS | DQS0_C_D | DQS0_T_D | DNU | |
| V | DNU | DNU | VDD Q | DQ0_C | VDD2 | DQ1_C | VDD Q | CA0_C | CA1_C | CA0_D | VDD Q | DQ1_D | VDD2 | DQ0_D | VDD Q | DNU | DNU | DNU | |

NOTE 1 Mix pitch: 0.8 mm x 0.8 mm; 0.65 mm x 0.65 mm; & 0.65 mm (X-axis) x 0.8 mm (Y-axis) pitch

NOTE 2 18 Rows; 18 Column; 324 Balls; Package Size: 14.5 mm x 14.5 mm

NOTE 3 Top View, A1 in top left corner

NOTE 4 Package channel ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package.

NOTE 5 Package Channel a and Channel c shall be assigned to die Channel A of different DRAM die.

NOTE 6 Die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 7 Package requires dual channel die or functional equivalent of single channel die-stack.

2.2.8 275 ball MCP Two-Channel FBGA (top view) using MO-276

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | |
|----|-----|-----|--------|------|--------|--------|--------|--------|----------|----|----|----|----|----|----|----|----|----|----|----|----|
| A | DNU | DNU | DQ0_A | VSS | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | | | | | | | | | A |
| B | DNU | | DQ1_A | VSS | VSS | VSS | DQ4_A | VSS | VDD2 | | | | | | | | | | | | B |
| C | | | DQ2_A | VSS | VSS | DQ5_A | VSS | DQ7_A | DQS0_t_A | | | | | | | | | | | | C |
| D | | | DQ3_A | VSS | DMI0_A | VSS | DQ6_A | VSS | DQS0_c_A | | | | | | | | | | | | D |
| E | | | | | | | | | | | | | | | | | | | | | |
| F | | | | | | | | | | | | | | | | | | | | | |
| G | | | DQ13_A | VSS | VSS | VSS | VSS | VSS | VDDQ | | | | | | | | | | | | G |
| H | | | DMI1_A | VSS | VSS | DQ14_A | VSS | DQ15_A | VDDQ | | | | | | | | | | | | H |
| J | | | DQ11_A | VSS | VSS | VSS | DQ12_A | VDDQ | DQS1_c_A | | | | | | | | | | | | J |
| K | | | DQ10_A | VSS | DQ8_A | DQ9_A | VSS | VDDQ | DQS1_t_A | | | | | | | | | | | | K |
| L | | | | | | VSS | VSS | VDDQ | VDDQ | | | | | | | | | | | | L |
| M | | | VSS | VSS | VSS | VSS | VCC | VCC | VSSm | | | | | | | | | | | | M |
| N | | | VSF1 | VSF3 | VSF5 | VSF7 | VSF9 | VCCQ | VSSm | | | | | | | | | | | | N |
| P | | | NC | NC | NC | NC | NC | VCCQ | VCCQ | | | | | | | | | | | | P |
| R | | | VSF2 | VSF4 | VSF6 | VSF8 | NC | VCCQ | VSSm | | | | | | | | | | | | R |
| T | | | VSS | VSS | VSS | VSS | VCC | VCC | VSSm | | | | | | | | | | | | T |
| U | | | | | | VSS | VSS | VDDQ | VDDQ | | | | | | | | | | | | U |
| V | | | DQ10_B | VSS | DQ8_B | DQ9_B | VSS | VDDQ | DQS1_t_B | | | | | | | | | | | | V |
| W | | | DQ11_B | VSS | VSS | VSS | DQ12_B | VDDQ | DQS1_c_B | | | | | | | | | | | | W |
| Y | | | DMI1_B | VSS | VSS | DQ14_B | VSS | DQ15_B | VDDQ | | | | | | | | | | | | Y |
| AA | | | DQ13_B | VSS | VSS | VSS | VSS | VSS | VDDQ | | | | | | | | | | | | AA |
| AB | | | | | | | | | | | | | | | | | | | | | AB |
| AC | | | | | | | | | | | | | | | | | | | | | AC |
| AD | | | DQ3_B | VSS | DMI0_B | VSS | DQ6_B | VSS | DQS0_c_B | | | | | | | | | | | | AD |
| AE | | | DQ2_B | VSS | VSS | DQ5_B | VSS | DQ7_B | DQS0_t_B | | | | | | | | | | | | AE |
| AF | DNU | DNU | DQ1_B | VSS | VSS | VSS | DQ4_B | VSS | VDD2 | | | | | | | | | | | | AF |
| AG | DNU | DNU | DQ0_B | VSS | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | | | | | | | | | AG |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | |

NOTE 1 0.5 mm pitch, 27 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package.

NOTE 4 ZQ2_A, CKE2_A, CKE2_B, CS2_A, and CS2_B balls are reserved for 3 rank package, and for 1 rank and 2 rank package those balls are NC.

NOTE 5 DRAM die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 6 The flash ball-out supports eMMC 5.x.

NOTE 7 Vendor specific function (VSF) - this terminal should not have any external electrical connections, but it may have an internal connection. The terminal may be routed to provide accessibility and may be used for general purpose vendor specific operations.

NOTE 8 Package requires dual channel die or functional equivalent of single channel die-stack.

2.2.9 254 ball e•MMC MCP Two-Channel FBGA (top view) using MO-276

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | | |
|----|------|--------|--------|--------|--------|--------|--------|----------|----------|----|----|----|-----------|--------|-------|---------|------|------|----|---|
| A | DNU | DNU | DQ0_A | VDD1 | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | VDDQ | VDDQ | VDD1 | VDD1 | DNU | DNU | A | |
| B | DNU | | DQ1_A | VSS | VDDQ | VSS | DQ4_A | VSS | VDD2 | | | | VDD2 | VDD2 | VDD1 | ZQ0 | | DNU | B | |
| C | | | DQ2_A | VSS | VSS | DQ5_A | VSS | DQ7_A | DQS0_t_A | | | | CA2_A | VSS | CA5_A | ZQ1 | | | C | |
| D | | | DQ3_A | VSS | DMI0_A | VSS | DQ6_A | VSS | DQS0_c_A | | | | CA3_A | VSS | VSS | ZQ2 | | | D | |
| E | | | | | | | | | | | | | CA4_A | VSS | CS0_A | CKE0_A | | | E | |
| F | | | | | | | | | | | | | CA1_A | VSS | CS1_A | CKE1_A | | | F | |
| G | | | DQ13_A | VSS | VSS | VSS | VDD2 | VDD2 | VDD2 | | | | VSS | CA0_A | VSS | CLK_c_A | | | G | |
| H | | | DMI1_A | VSS | VDDQ | DQ14_A | VSS | DQ15_A | VDDQ | | | | VSS | CS2_A | VSS | CLK_t_A | | | H | |
| J | | | DQ11_A | VDDQ | VDDQ | VSS | DQ12_A | VDDQ | DQS1_c_A | | | | ODT(ca)_A | CKE2_A | VCCQ | VCCQ | VCCQ | | J | |
| K | VDD2 | DQ10_A | VSS | DQ8_A | DQ9_A | VSS | VSS | DQS1_t_A | | | | | VSSm | VSSm | VCCQ | VSSm | NC | | K | |
| L | | | | | | | VDD2 | VDD2 | VDD2 | | | | VSSm | DAT7 | DAT6 | VSSm | VSSm | VDDI | | L |
| M | | | VSF1 | VSF3 | VSF5 | VSF7 | VSF9 | VSSm | CMD | | | | DS | VSSm | VSSm | DAT1 | DAT4 | VCC | | M |
| N | | | VSF2 | VSF4 | VSF6 | VSF8 | NC | VSSm | RST_n | | | | VSSm | DAT2 | DAT5 | VSSm | VSSm | VCC | | N |
| P | | | | | | VDD2 | VDD2 | VDD2 | | | | | CLK | VSSm | VSSm | DAT3 | DAT0 | VCC | | P |
| R | VDD2 | DQ10_B | VSS | DQ8_B | DQ9_B | VSS | VSS | DQS1_t_B | | | | | VCCQ | VCCQ | VSSm | VSSm | VSSm | | R | |
| T | | DQ11_B | VDDQ | VDDQ | VSS | DQ12_B | VDDQ | DQS1_c_B | | | | | ODT(ca)_B | CKE2_B | VCCQ | VCCQ | NC | | T | |
| U | | DMI1_B | VSS | VDDQ | DQ14_B | VSS | DQ15_B | VDDQ | | | | | VSS | CS2_B | VSS | CLK_t_B | | | U | |
| V | | DQ13_B | VSS | VSS | VSS | VDD2 | VDD2 | VDD2 | | | | | VSS | CA0_B | VSS | CLK_c_B | | | V | |
| W | | | | | | | | | | | | | CA1_B | VSS | CS1_B | CKE1_B | | | W | |
| Y | | | | | | | | | | | | | CA4_B | VSS | CS0_B | CKE0_B | | | Y | |
| AA | | DQ3_B | VSS | DMI0_B | VSS | DQ6_B | VSS | DQS0_c_B | | | | | CA3_B | VSS | VSS | RESET_n | | | AA | |
| AB | | DQ2_B | VSS | VSS | DQ5_B | VSS | DQ7_B | DQS0_t_B | | | | | CA2_B | VSS | CA5_B | NC | | | AB | |
| AC | DNU | | DQ1_B | VSS | VDDQ | VSS | DQ4_B | VSS | VDD2 | | | | VDD2 | VDD2 | VDD1 | NC | | DNU | AC | |
| AD | DNU | DNU | DQ0_B | VDD1 | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | VDDQ | VDDQ | VDD1 | VDD1 | DNU | DNU | AD | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | | |

NOTE 1 0.5 mm pitch, 24 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package.

NOTE 4 ZQ2, CKE2_A, CKE2_B, CS2_A, and CS2_B balls are reserved for 3 rank package, and for 1 rank and 2 rank package those balls are NC.

NOTE 5 The flash ball-out supports e•MMC 5.x.

NOTE 6 DRAM die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 7 Package requires dual channel die or functional equivalent of single channel die-stack.

NOTE 8 Vendor specific function (VSF) - this terminal should not have any external electrical connections, but it may have an internal connection. The terminal may be routed to provide accessibility and may be used for general purpose vendor specific operations.

2.2.10 254 ball UFS MCP Two-Channel FBGA (top view) using MO-276

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | |
|----|------|--------|--------|-------|--------|--------|--------|----------|----------|----|----|----|-----------|---------|---------|---------|---------|------|----|
| A | DNU | DNU | DQ0_A | VDD1 | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | VDDQ | VDDQ | VDD1 | VDD1 | DNU | DNU | A |
| B | DNU | | DQ1_A | VSS | VDDQ | VSS | DQ4_A | VSS | VDD2 | | | | VDD2 | VDD2 | VDD1 | ZQ0 | | DNU | B |
| C | | | DQ2_A | VSS | VSS | DQ5_A | VSS | DQ7_A | DQS0_t_A | | | | CA2_A | VSS | CA5_A | ZQ1 | | | C |
| D | | | DQ3_A | VSS | DMI0_A | VSS | DQ6_A | VSS | DQS0_c_A | | | | CA3_A | VSS | VSS | ZQ2 | | | D |
| E | | | | | | | | | | | | | CA4_A | VSS | CS0_A | CKE0_A | | | E |
| F | | | | | | | | | | | | | CA1_A | VSS | CS1_A | CKE1_A | | | F |
| G | | | DQ13_A | VSS | VSS | VSS | VDD2 | VDD2 | VDD2 | | | | VSS | CA0_A | VSS | CLK_c_A | | | G |
| H | | | DMI1_A | VSS | VDDQ | DQ14_A | VSS | DQ15_A | VDDQ | | | | VSS | CS2_A | VSS | CLK_t_A | | | H |
| J | | | DQ11_A | VDDQ | VDDQ | VSS | DQ12_A | VDDQ | DQS1_c_A | | | | ODT(ca)_A | CKE2_A | VCCQ2 | VCCQ2 | VCCQ2 | | J |
| K | VDD2 | DQ10_A | VSS | DQ8_A | DQ9_A | VSS | VSS | DQS1_t_A | | | | | VSSm | VSSm | VCCQ2 | VSSm | VDDIQ_2 | | K |
| L | | | | | | | VDD2 | VDD2 | VDD2 | | | | VSSm | DIN1_c | DIN1_t | VSSm | VSSm | VDDI | L |
| M | | | NC | VSF1 | VSF3 | VSF5 | RFU | VSSm | RFU | | | | RST_n | VSSm | VSSm | DIN0_c | DIN0_t | VCC | M |
| N | | | NC | VSF2 | VSF4 | VSF6 | RFU | VSSm | RFU | | | | VSSm | DOUT1_c | DOUT1_t | VSSm | VSSm | VCC | N |
| P | | | | | | | VDD2 | VDD2 | VDD2 | | | | REF_CLK | VSSm | VSSm | DOUT0_c | DOUT0_t | VCC | P |
| R | VDD2 | DQ10_B | VSS | DQ8_B | DQ9_B | VSS | VSS | DQS1_t_B | | | | | VCCQ | VCCQ | VSSm | VSSm | VSSm | | R |
| T | | DQ11_B | VDDQ | VDDQ | VSS | DQ12_B | VDDQ | DQS1_c_B | | | | | ODT(ca)_B | CKE2_B | VCCQ | VCCQ | VDDIQ | | T |
| U | | DMI1_B | VSS | VDDQ | DQ14_B | VSS | DQ15_B | VDDQ | | | | | VSS | CS2_B | VSS | CLK_t_B | | | U |
| V | | DQ13_B | VSS | VSS | VSS | VDD2 | VDD2 | VDD2 | | | | | VSS | CA0_B | VSS | CLK_c_B | | | V |
| W | | | | | | | | | | | | | CA1_B | VSS | CS1_B | CKE1_B | | | W |
| Y | | | | | | | | | | | | | CA4_B | VSS | CS0_B | CKE0_B | | | Y |
| AA | | | DQ3_B | VSS | DMI0_B | VSS | DQ6_B | VSS | DQS0_c_B | | | | CA3_B | VSS | VSS | RESET_n | | | AA |
| AB | | | DQ2_B | VSS | VSS | DQ5_B | VSS | DQ7_B | DQS0_t_B | | | | CA2_B | VSS | CA5_B | NC | | | AB |
| AC | DNU | | DQ1_B | VSS | VDDQ | VSS | DQ4_B | VSS | VDD2 | | | | VDD2 | VDD2 | VDD1 | NC | | DNU | AC |
| AD | DNU | DNU | DQ0_B | VDD1 | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | VDDQ | VDDQ | VDD1 | VDD1 | DNU | DNU | AD |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | |

NOTE 1 0.5 mm pitch, 24 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package.

NOTE 4 ZQ2, CKE2_A, CKE2_B, CS2_A, and CS2_B balls are reserved for 3 rank package, and for 1 rank and 2 rank package those balls are NC.

NOTE 5 DRAM die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 6 Package requires dual channel die or functional equivalent of single channel die-stack.

NOTE 7 Vendor specific function (VSF) - this terminal should not have any external electrical connections, but it may have an internal connection. The terminal may be routed to provide accessibility and may be used for general purpose vendor specific operations.

2.2.11 254 ball e-MMC MCP One Channel FBGA (top view) using MO-276

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | | |
|----|-----|--------|--------|--------|--------|--------|--------|----------|----------|----|----|----|-----------|--------|-------|---------|------|------|----|---|
| A | DNU | DNU | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | NC | NC | DNU | DNU | A | |
| B | DNU | | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | NC | ZQ0 | | DNU | B | |
| C | | | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | NC | ZQ1 | | | C | |
| D | | | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | NC | ZQ2 | | | D | |
| E | | | | | | | | | | | | | NC | NC | NC | NC | | | E | |
| F | | | | | | | | | | | | | NC | NC | NC | NC | | | F | |
| G | | | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | NC | NC | | | G | |
| H | | | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | NC | NC | | | H | |
| J | | | NC | NC | NC | NC | NC | NC | NC | | | | NC | NC | VCCQ | VCCQ | VCCQ | | J | |
| K | | NC | NC | | | | VSSm | VSSm | VCCQ | VSSm | NC | | K | |
| L | | | | | | NC | NC | NC | | | | | VSSm | DAT7 | DAT6 | VSSm | VSSm | VDDI | | L |
| M | | VSF1 | VSF3 | VSF5 | VSF7 | VSF9 | VSSm | CMD | | | | | DS | VSSm | VSSm | DAT1 | DAT4 | VCC | | M |
| N | | VSF2 | VSF4 | VSF6 | VSF8 | NC | VSSm | RST_n | | | | | VSSm | DAT2 | DAT5 | VSSm | VSSm | VCC | | N |
| P | | | | | VDD2 | VDD2 | VDD2 | | | | | | CLK | VSSm | VSSm | DAT3 | DAT0 | VCC | | P |
| R | | VDD2 | DQ10_B | VSS | DQ8_B | DQ9_B | VSS | VSS | DQS1_t_B | | | | | VCCQ | VCCQ | VSSm | VSSm | VSSm | | R |
| T | | DQ11_B | VDDQ | VDDQ | VSS | DQ12_B | VDDQ | DQS1_c_B | | | | | ODT(ca)_B | CKE2_B | VCCQ | VCCQ | NC | | T | |
| U | | DMI1_B | VSS | VDDQ | DQ14_B | VSS | DQ15_B | VDDQ | | | | | VSS | CS2_B | VSS | CLK_t_B | | | U | |
| V | | DQ13_B | VSS | VSS | VSS | VDD2 | VDD2 | VDD2 | | | | | VSS | CA0_B | VSS | CLK_c_B | | | V | |
| W | | | | | | | | | | | | | CA1_B | VSS | CS1_B | CKE1_B | | | W | |
| Y | | | | | | | | | | | | | CA4_B | VSS | CS0_B | CKE0_B | | | Y | |
| AA | | DQ3_B | VSS | DM10_B | VSS | DQ6_B | VSS | DQS0_c_B | | | | | CA3_B | VSS | VSS | RESET_n | | | AA | |
| AB | | DQ2_B | VSS | VSS | DQ5_B | VSS | DQ7_B | DQS0_t_B | | | | | CA2_B | VSS | CA5_B | NC | | | AB | |
| AC | DNU | | DQ1_B | VSS | VDDQ | VSS | DQ4_B | VSS | VDD2 | | | | VDD2 | VDD2 | VDD1 | NC | | DNU | AC | |
| AD | DNU | DNU | DQ0_B | VDD1 | VDD2 | VDDQ | VDDQ | VDD2 | VDD1 | | | | VDDQ | VDDQ | VDD1 | VDD1 | DNU | DNU | AD | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | | |

NOTE 1 0.5 mm pitch, 24 rows.

NOTE 2 Top View, A1 in top left corner.

NOTE 3 ODT(ca)_[x] balls are wired to ODT(ca)_[x] pads of Rank 0 DRAM die. ODT(ca)_[x] pads for other ranks (if present) are disabled in the package.

NOTE 4 ZQ2, CKE2_B, and CS2_B balls are reserved for 3 rank package, and for 1 rank and 2 rank package those balls are NC.

NOTE 5 The flash ball-out supports e-MMC 5.x.

NOTE 6 DRAM die pad VSS and VSSQ signals are combined to VSS package balls.

NOTE 7 Vendor specific function (VSF) - this terminal should not have any external electrical connections, but it may have an internal connection. The terminal may be routed to provide accessibility and may be used for general purpose vendor specific operations.

2.3 Package Ballout

Two Byte-Mode LPDDR4 SDRAM's can be logically combined into a Standard LPDDR4 SDRAM. A Standard device is a x16x2channel SDRAM as defined in JESD209-4. The inputs are ganged and the DQ busses from the two devices are assigned individually to the 16-bit channels. This approach allows for high-density packages, but requires consideration of input loading.

Packages for Standard and Byte-Mode devices share the same ballmaps. This section describes internal wiring changes and system considerations when using packages containing Byte-Mode devices.

Three different die combinations are supported:

- 1) Standard - Packages configured with only Standard LPDDR4 die
- 2) Byte-Mode - Packages configured with only Byte-Mode LPDDR4 die
- 3) Mixed - Packages configured with both Standard and Byte-Mode LPDDR4 die. In this mixed configuration, some ranks contain only Standard die and other ranks contain only Byte-Mode die (See package configuration example in Figure 1).

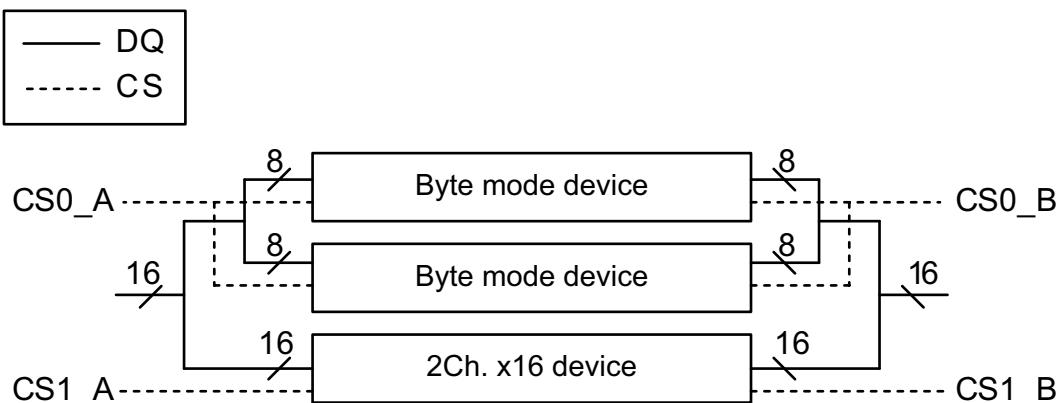


Figure 1 — Mixed package configuration example

2.4 ZQ Wiring

Standard LPDDR4 package ballmaps allocate one ZQ ball per die. Byte-Mode packages potentially support more die for higher package memory density. In order to use ballmaps developed for Standard LPDDR4, an alternate ZQ ball wiring strategy is employed when packages contain Byte-Mode devices as shown in Figure 1.

Since this wiring strategy for Byte-Mode and Mixed packages shares a single ZQ resistor between ranks and channels, applications must ensure that the ZQCals do not overlap between the dies sharing the resistor.

- Applications shall ensure that ZQCAL_Start commands to one rank on any dies sharing a ZQ resistor must complete (tZQCAL satisfied) prior to issuing a ZQCAL_Start command to a different rank tied to the resistor. (Applications can satisfy this requirement, for example, by either:
 - Issuing ZQCAL_Start commands simultaneously to both DRAM channels
 - Issuing ZQCAL_Start commands to one DRAM channel only
- DRAM shall ensure that ZQCAL_Start can be sent independently to the two channels on a die. If a ZQCAL_Start command is received while a ZQ calibration is in progress on the die, the second ZQCAL_Start command will be ignored and the in progress calibration will not be interrupted.

(See 4.31.3, ZQ External Resistor, Tolerance, and Capacitive Loading, for more information.)

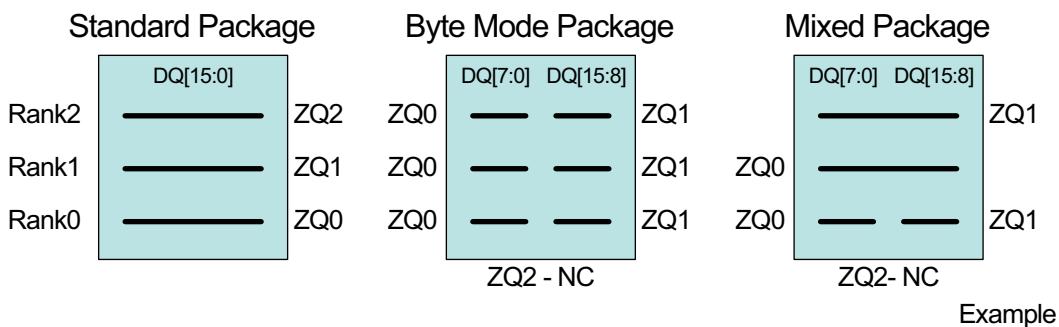


Figure 2 — ZQ Wiring Overview

2.4.1 Specific wiring notes for dual channel (x32) LPDDR4 packages

1. For packages using only standard devices
 - ZQ0 is connected to rank 0 DRAM
 - ZQ1 is connected to rank 1 DRAM (if present)
 - ZQ2 is connected to rank 2 DRAM (if present)
2. For packages using only byte-mode devices
 - ZQ0 is connected to all lower byte [7:0] or upper byte [15:8] DRAM(s)
 - ZQ1 is connected to opposite byte of all DRAM(s) from ZQ0
 - ZQ2 is NC
3. For packages using both standard and byte-mode devices
 - ZQ0 is connected to all lower byte [7:0] or upper byte [15:8] DRAM(s)
 - ZQ1 is connected to opposite byte of all DRAM(s) from ZQ0
 - Standard DRAM(s) may be connected to either ZQ0 or ZQ1
 - ZQ2 is NC

Multi-rank packages containing Byte Mode devices place additional loading on the I/O and power topologies and therefore may not be appropriate for all application environments.

2.5 Pad Definition and Description

Table 1 — Pad Definition and Description

| Symbol | Type | Description |
|---|-----------|---|
| CK_t_A, CK_c_A, CK_t_B, CK_c_B | Input | Clock: CK_t and CK_c are differential clock inputs. All address, command, and control input signals are sampled on the crossing of the positive edge of CK_t and the negative edge of CK_c. AC timings for CA parameters are referenced to CK. Each channel (A & B) has its own clock pair. |
| CKE_A CKE_B | Input | Clock Enable: CKE HIGH activates and CKE LOW deactivates the internal clock circuits, input buffers, and output drivers. Power-saving modes are entered and exited via CKE transitions. CKE is part of the command code. Each channel (A & B) has its own CKE signal. |
| CS_A CS_B | Input | Chip Select: CS is part of the command code. Each channel (A & B) has its own CS signal. |
| CA[5:0]_A CA[5:0]_B | Input | Command/Address Inputs: CA signals provide the Command and Address inputs according to the Command Truth Table. Each channel (A&B) has its own CA signals. |
| ODT_CA_A ODT_CA_B | Input | CA ODT Control: The ODT_CA pin is used in conjunction with the Mode Register to turn on/off the On-Die-Termination for CA pins. |
| DQ[15:0]_A, DQ[15:0]_B | I/O | Data Input/Output: Bi-direction data bus. |
| DQS[1:0]_t_A, DQS[1:0]_c_A, DQS[1:0]_t_B, DQS[1:0]_c_B | I/O | Data Strobe: DQS_t and DQS_c are bi-directional differential output clock signals used to strobe data during a READ or WRITE. The Data Strobe is generated by the DRAM for a READ and is edge-aligned with Data. The Data Strobe is generated by the Memory Controller for a WRITE and must arrive prior to Data. Each byte of data has a Data Strobe signal pair. Each channel (A & B) has its own DQS strobes. |
| DMI[1:0]_A, DMI[1:0]_B | I/O | Data Mask Inversion: DMI is a bi-directional signal which is driven HIGH when the data on the data bus is inverted, or driven LOW when the data is in its normal state. Data Inversion can be disabled via a mode register setting. Each byte of data has a DMI signal. Each channel (A & B) has its own DMI signals. This signal is also used along with the DQ signals to provide write data masking information to the DRAM. The DMI pin function - Data Inversion or Data mask - depends on Mode Register setting. |
| ZQ | Reference | Calibration Reference: Used to calibrate the output drive strength and the termination resistance. There is one ZQ pin per die. The ZQ pin shall be connected to VDDQ through a $240\Omega \pm 1\%$ resistor. |
| VDDQ, VDD1, VDD2 | Supply | Power Supplies: Isolated on the die for improved noise immunity. |
| VSS, VSSQ | GND | Ground Reference: Power supply ground reference |
| RESET_n | Input | RESET: When asserted LOW, the RESET_n signal resets all channels of the die. There is one RESET_n pad per die. |

NOTE 1 "_A" and "_B" indicate DRAM channel "_A" pads are present in all devices. "_B" pads are present in dual channel SDRAM devices only.

3 Functional Description

LPDDR4-SDRAM is a high-speed synchronous DRAM device internally configured with either 1 or 2 channels. Each channel is comprised of 8-banks with from 2 Gb to 16 Gb per channel density. The configuration for channel density that is greater than 16Gb is still TBD¹.

These devices contain the following number of bits:

Single-channel SDRAM devices contain the following number of bits:

- 2 Gb has 2,147,483,648 bits
- 3 Gb has 3,221,225,472 bits
- 4 Gb has 4,294,967,296 bits
- 6 Gb has 6,442,450,944 bits
- 8 Gb has 8,589,934,592 bits
- 12 Gb has 12,884,901,888 bits
- 16 Gb has 17,179,869,184 bits

Dual-channel SDRAM devices contain the following number of bits:

- 4Gb has 4,294,967,296 bits
- 6Gb has 6,442,450,944 bits
- 8Gb has 8,589,934,592 bits
- 12Gb has 12,884,901,888 bits
- 16Gb has 17,179,869,184 bits
- 24Gb has 25,769,803,776 bits
- 32Gb has 34,359,738,368 bits

LPDDR4 devices use a 2 or 4 clocks architecture on the Command/Address (CA) bus to reduce the number of input pins in the system. The 6-bit CA bus contains command, address, and bank information. Each command uses 1, 2 or 4 clock cycle, during which command information is transferred on the positive edge of the clock. See command truth table for details.

These devices use a double data rate architecture on the DQ pins to achieve high speed operation. The double data rate architecture is essentially an 16n prefetch architecture with an interface designed to transfer two data bits per DQ every clock cycle at the I/O pins. A single read or write access for the LPDDR4 SDRAM effectively consists of a single 16n-bit wide, one clock cycle data transfer at the internal DRAM core and eight corresponding n-bit wide, one half-clock-cycle data transfers at the I/O pins. Read and write accesses to the LPDDR4 SDRAMs are burst oriented; accesses start at a selected location and continue for a programmed number of locations in a programmed sequence. Accesses begin with the registration of an Activate command, which is then followed by a Read, Write or Mask Write command. The address and BA bits registered coincident with the Activate command are used to select the row and the bank to be accessed. The address bits registered coincident with the Read, Write or Mask Write command are used to select the bank and the starting column location for the burst access.

Prior to normal operation, the LPDDR4 SDRAM must be initialized. The following section provides detailed information covering device initialization, register definition, command description and device operation.

NOTE 1 As of publication of this document, under discussion by the formulating committee.

3.1 LPDDR4 SDRAM Addressing

Table 2 — LPDDR4 SDRAM Addressing for Dual Channel SDRAM Device

| Memory Density (per Die) | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb | 24Gb | 32Gb |
|--------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|-------------------------------------|
| Memory Density (per channel) | 2Gb | 3Gb | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb |
| Configuration | 16Mb x 16DQ x 8 banks x 2 channels | 24Mb x 16DQ x 8 banks x 2 channels | 32Mb x 16DQ x 8 banks x 2 channels | 48Mb x 16DQ x 8 banks x 2 channels | 64Mb x 16DQ x 8 banks x 2 channels | 96Mb x 16DQ x 8 banks x 2 channels | 128Mb x 16DQ x 8 banks x 2 channels |
| Number of Channels (per die) | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Number of Banks (per Channel) | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Array Pre-Fetch (bits, perchannel) | 256 | 256 | 256 | 256 | 256 | 256 | 256 |
| Number of Rows (per Channel) | 16,384 | 24,576 | 32,768 | 49,152 | 65,536 | 98,304 | 131,072 |
| Number of Columns (fetch boundaries) | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| Page Size (Bytes) | 2048 | 2048 | 2048 | 2048 | 2048 | 2048 | 2048 |
| Channel Density (Bits per channel) | 2,147,483,648 | 3,221,225,472 | 4,294,967,296 | 6,442,450,944 | 8,589,934,592 | 12,884,901,888 | 17,179,869,184 |
| Total Density (Bits per die) | 4,294,967,296 | 6,442,450,944 | 8,589,934,592 | 12,884,901,888 | 17,179,869,184 | 25,769,803,776 | 34,359,738,368 |
| Bank Address | BA0 - BA2 |
| x16 | Row Addresses | R0 - R13 | R0 - R14 (R13=0 when R14=1) | R0 - R14 | R0 - R15 (R14=0 when R15=1) | R0 - R15 | R0 - R16 (R15=0 when R16=1) |
| | Column Addresses | C0 - C9 |
| Burst Starting Address Boundary | 64 - bit |

NOTE 1 The lower two column addresses (C0 - C1) are assumed to be “zero” and are not transmitted on the CA bus.

NOTE 2 Row and Column address values on the CA bus that are not used for a particular density be at valid logic levels.

NOTE 3 For non - binary memory densities,only quarter of the row address space is invalid. When the MSB address bit is “HIGH”, then the MSB - 1 address bit must be “LOW”.

NOTE 4 The row address input which violates restriction described in note 3 in this table may result in undefined or vendor specific behavior. Consult memory vendor for more information.

3.1 LPDDR4 SDRAM Addressing (cont'd)

Table 3 — LPDDR4 SDRAM Addressing For Single Channel SDRAM Device

| Memory Density (per channel) | 2Gb | 3Gb | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb |
|--------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|-------------------------------------|-------------------------------------|
| Configuration | 16Mb x 16DQ x 8 banks x 1 channels | 24Mb x 16DQ x 8 banks x 1 channels | 32Mb x 16DQ x 8 banks x 1 channels | 48Mb x 16DQ x 8 banks x 1 channels | 64Mb x 16DQ x 8 banks x 1 channels | TBD x 16DQ x TBD banks x 1 channels | TBD x 16DQ x TBD banks x 1 channels |
| Number of Channels (per die) | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of Banks (per Channel) | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Array Pre-Fetch (bits, perchannel) | 256 | 256 | 256 | 256 | 256 | 256 | 256 |
| Number of Rows (per Channel) | 16,384 | 24,576 | 32,768 | 49,152 | 65,536 | TBD | TBD |
| Number of Columns (fetch boundaries) | 64 | 64 | 64 | 64 | 64 | TBD | TBD |
| Page Size (Bytes) | 2048 | 2048 | 2048 | 2048 | 2048 | TBD | TBD |
| Channel Density (Bits per channel) | 2,147,483,648 | 3,221,225,472 | 4,294,967,296 | 6,442,450,944 | 8,589,934,592 | 12,884,901,888 | 17,179,869,184 |
| Total Density (Bits per die) | 2,147,483,648 | 3,221,225,472 | 4,294,967,296 | 6,442,450,944 | 8,589,934,592 | 12,884,901,888 | 17,179,869,184 |
| Bank Address | BA0 - BA2 | TBD | TBD |
| X16 | Row Addresses | R0 - R13 | R0 - R14 (R13=0 when R14=1) | R0 - R14 | R0 - R15 (R14=0 when R15=1) | R0 - R15 | TBD |
| | Column Addresses | C0 - C9 | C0 - C9 | C0 - C9 | C0 - C9 | TBD | TBD |
| Burst Starting Address Boundary | 64 - bit | 64 - bit |

NOTE 1 The lower two column addresses (C0 - C1) are assumed to be "zero" and are not transmitted on the CA bus.

NOTE 2 Row and Column address values on the CA bus that are not used for a particular density be at valid logic levels.

NOTE 3 For non - binary memory densities, only half of the row address space is valid. When the MSB address bit is "HIGH", then the MSB - 1 address bit must be "LOW".

NOTE 4 The row address input which violates restriction described in note 3 may result in undefined or vendor specific behavior. Consult memory vendor for more information.

3.2 Simplified LPDDR4 State Diagram

LPDDR4-SDRAM state diagram provides a simplified illustration of allowed state transitions and the related commands to control them. For a complete definition of the device behavior, the information provided by the state diagram should be integrated with the truth tables and timing specification.

The truth tables provide complementary information to the state diagram, they clarify the device behavior and the applied restrictions when considering the actual state of all the banks.

For the command definition, see clause 4, Command Definition and Timing Diagram.

3.2 Simplified LPDDR4 State Diagram (cont'd)

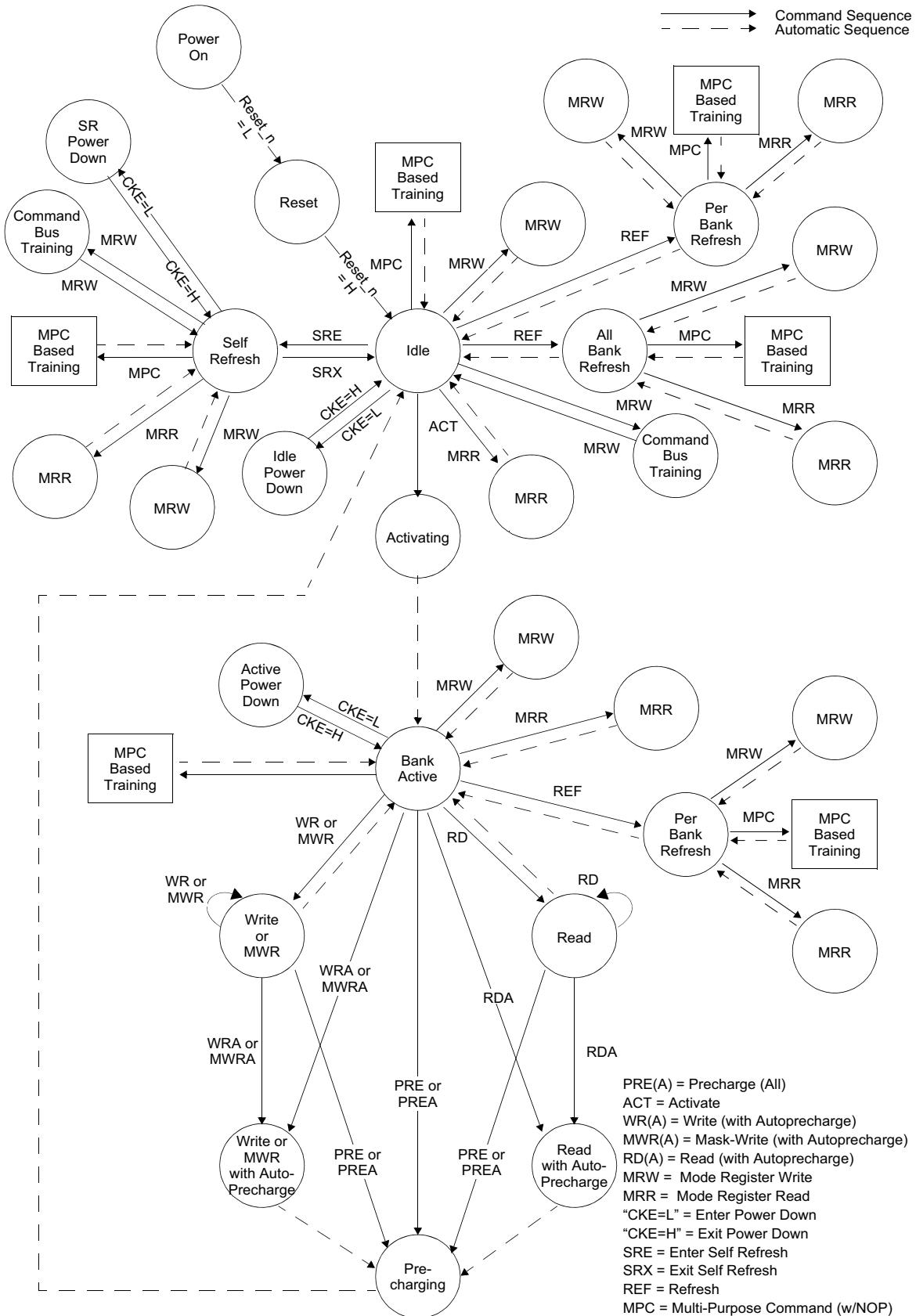
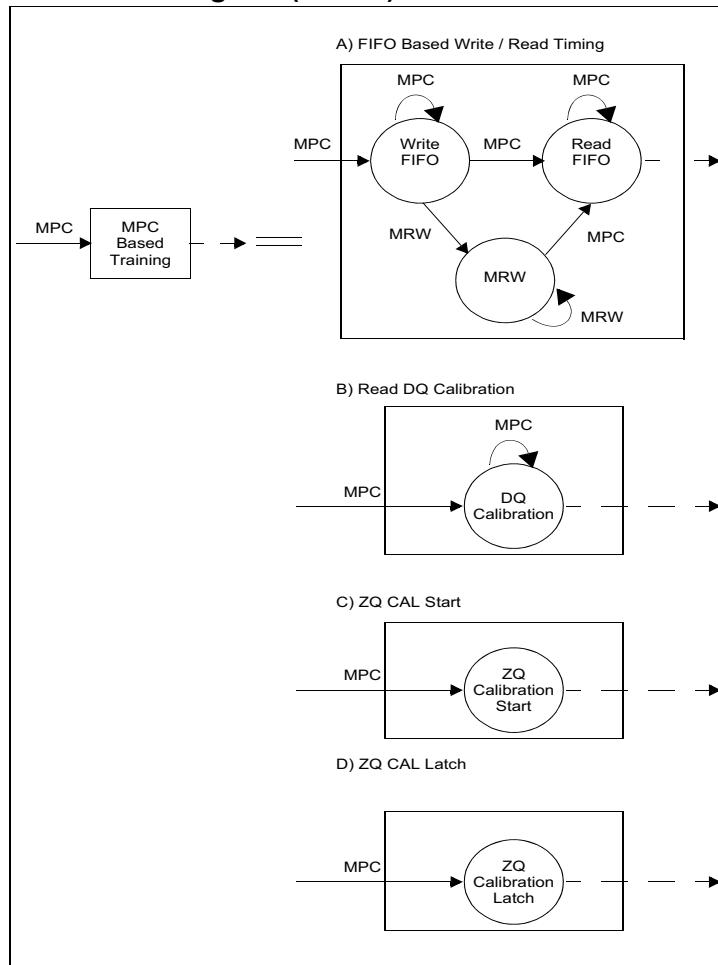


Figure 3 — LPDDR4:Simplified Bus Interface State Diagram -1

3.2 Simplified LPDDR4 State Diagram (cont'd)



NOTE 1 From the Self Refresh state the device can enter Power-Down, MRR, MRW, or MPC states. See the section on Self Refresh for more information.

NOTE 2 In IDLE state, all banks are precharged.

NOTE 3 In the case of a MRW command to enter a training mode, the state machine will not automatically return to the IDLE state at the conclusion of training.

See the applicable training section for more information.

NOTE 4 In the case of a MPC command to enter a training mode, the state machine may not automatically return to the IDLE state at the conclusion of training.

See the applicable training section for more information.

NOTE 5 This simplified State Diagram is intended to provide an overview of the possible state transitions and the commands to control them. In particular, situations involving more than one bank, the enabling or disabling of on-die termination, and some other events are not captured in full detail.

NOTE 6 States that have an "automatic return" and can be accessed from more than one prior state (Ex. MRW from either Idle or Active states) will return to the state from when they were initiated (Ex. MRW from Idle will return to Idle).

NOTE 7 The RESET_n pin can be asserted from any state, and will cause the SDRAM to go to the Reset State. The diagram shows RESET applied from the Power-On as an example, but the Diagram should not be construed as a restriction on RESET_n.

Figure 4 — LPDDR4:Simplified Bus Interface State Diagram -2

3.3 Power-up, Initialization and Power-off Procedure

For power-up and reset initialization, in order to prevent DRAM from functioning improperly, default values of the following MR settings are defined as Table 4.

Table 4 — MRS defaults settings

| Item | MRS | Default Setting | Description |
|-------------------------------|--------------|---------------------|--|
| FSP-OP/WR | MR13 OP[7:6] | 00 _B | FSP-OP/WR[0] are enabled |
| WLS | MR2 OP[6] | 0 _B | Write Latency Set 0 is selected |
| WL | MR2 OP[5:3] | 000 _B | WL = 4 |
| RL | MR2 OP[2:0] | 000 _B | RL = 6, nRTP=8 |
| nWR | MR1 OP[6:4] | 000 _B | nWR = 6 |
| DBI-WR/RD | MR3 OP[7:6] | 00 _B | Write & Read DBI are disabled |
| CA ODT | MR11 OP[6:4] | 000 _B | CA ODT is disabled |
| DQ ODT | MR11 OP[2:0] | 000 _B | DQ ODT is disabled |
| V _{REF} (CA) Setting | MR12 OP[6] | 1 _B | V _{REF} (CA) Range[1] enabled |
| V _{REF} (CA) Value | MR12 OP[5:0] | 001101 _B | Range1 : 27.2% of V _{DD2} |
| V _{REF} (DQ) Setting | MR14 OP[6] | 1 _B | V _{REF} (DQ) Range[1] enabled |
| V _{REF} (DQ) Value | MR14 OP[5:0] | 001101 _B | Range1 : 27.2% of V _{DDQ} |

3.3.1 Voltage Ramp and Device Initialization

The following sequence shall be used to power up the LPDDR4 device. Unless specified otherwise, these steps are mandatory. Note that the power-up sequence of all channels must proceed simultaneously.

1. While applying power (after Ta), RESET_n is recommended to be LOW ($\leq 0.2 \times V_{DD2}$) and all other inputs must be between VILmin and VIHmax. The device outputs remain at High-Z while RESET_n is held LOW. Power supply voltage ramp requirements are provided in Table 5. V_{DD1} must ramp at the same time or earlier than V_{DD2}. V_{DD2} must ramp at the same time or earlier than V_{DDQ}.

Table 5 — Voltage Ramp Conditions

| After | Applicable Conditions |
|---------------|---|
| Ta is reached | V _{DD1} must be greater than V _{DD2} |
| | V _{DD2} must be greater than V _{DDQ} - 200 mV |

NOTE 1 Ta is the point when any power supply first reaches 300 mV.

NOTE 2 Voltage ramp conditions in Table 5 apply between Ta and power-off (controlled or uncontrolled).

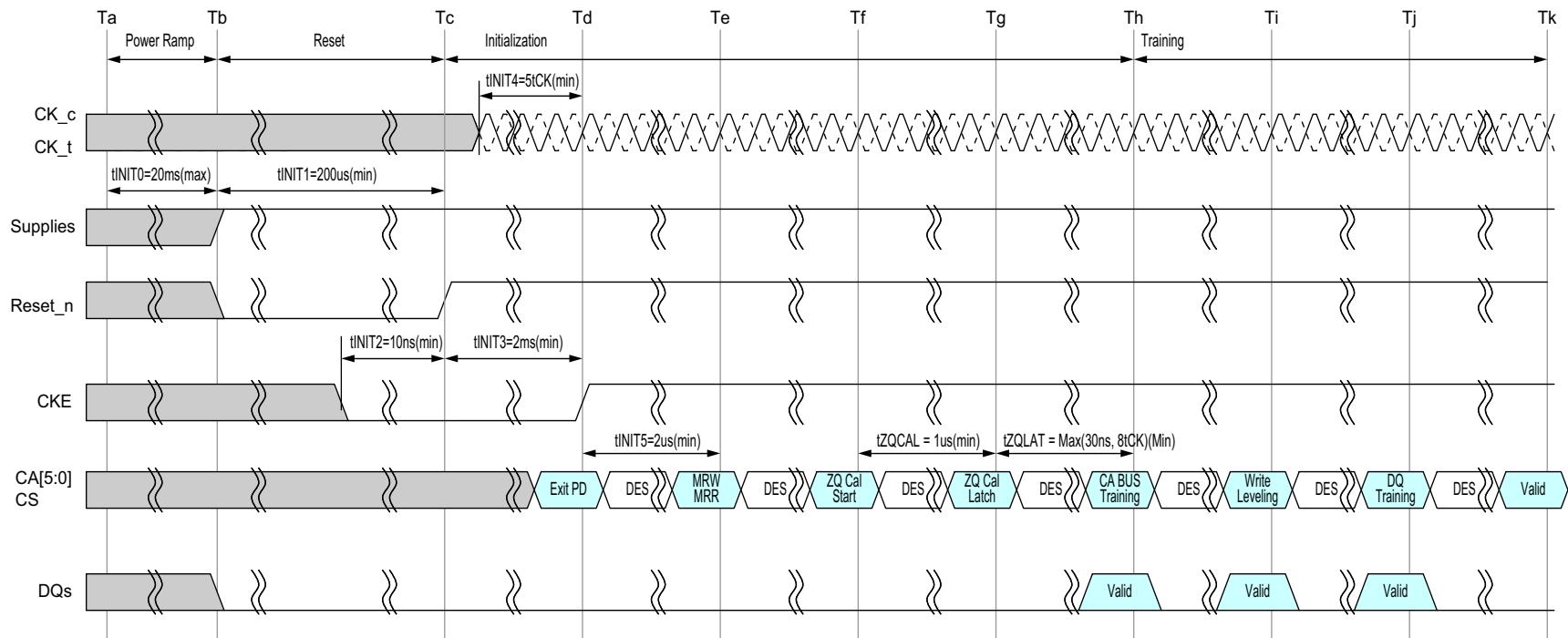
NOTE 3 Tb is the point at which all supply and reference voltages are within their defined ranges.

NOTE 4 Power ramp duration tINIT0 (Tb-Ta) must not exceed 20ms.

NOTE 5 The voltage difference between any of V_{SS} and V_{SSQ} pins must not exceed 100 mV.

2. Following the completion of the voltage ramp (Tb), RESET_n must be maintained LOW. DQ, DMI, DQS_t and DQS_c voltage levels must be between V_{SSQ} and V_{DDQ} during voltage ramp to avoid latch-up. CKE, CK_t, CK_c, CS_n and CA input levels must be between V_{SS} and V_{DD2} during voltage ramp to avoid latch-up.
3. Beginning at Tb, RESET_n must remain LOW for at least tINIT1(Tc), after which RESET_n can be deasserted to HIGH(Tc). At least 10ns before RESET_n de-assertion, CKE is required to be set LOW. All other input signals are "Don't Care".

3.3.1 Voltage Ramp and Device Initialization (cont'd)



NOTES : 1. Training is optional and may be done at the system architects discretion. The training sequence after ZQ_CAL Latch(Th, Sequence7~9) in Figure 5 is simplified recommendation and actual training sequence may vary depending on systems.

Figure 5 — Power Ramp and Initialization Sequence

- After RESET_n is de-asserted(T_c), wait at least t_{INIT3} before activating CKE. Clock(CK_t, CK_c) is required to be started and stabilized for t_{INIT4} before CKE goes active(T_d). CS is required to be maintained LOW when controller activates CKE.
- After setting CKE high, wait minimum of t_{INIT5} to issue any MRR or MRW commands(T_e). For both MRR and MRW commands, the clock frequency must be within the range defined for $tCKb$. Some AC parameters (for example, $tDQSCK$) could have relaxed timings (such as $tDQSCKb$) before the system is appropriately configured.
- After completing all MRW commands to set the Pull-up, Pull-down and Rx termination values, the DRAM controller can issue ZQCAL Start command to the memory(T_f). This command is used to calibrate VOH level and output impedance over process, voltage and temperature. In systems where more than one LPDDR4 DRAM devices share one external ZQ resistor, the controller must not overlap the ZQ calibration sequence of each LPDDR4 device. ZQ calibration sequence is completed after t_{ZQCAL} (T_g) and the ZQCAL Latch command must be issued to update the DQ drivers and DQ+CA ODT to the calibrated values.

3.3.1 Voltage Ramp and Device Initialization (cont'd)

7. After tZQLAT is satisfied (Th) the command bus (internal V_{REF}(CA), CS, and CA) should be trained for high-speed operation by issuing an MRW command (Command Bus Training Mode). This command is used to calibrate the device's internal V_{REF} and align CS/CA with CK for high-speed operation. The LPDDR4 device will power-up with receivers configured for low-speed operations, and V_{REF}(CA) set to a default factory setting. Normal device operation at clock speeds higher than tCKb may not be possible until command bus training has been completed.

NOTE The command bus training MRW command uses the CA bus as inputs for the calibration data stream, and outputs the results asynchronously on the DQ bus. See 4.29, (item 1.), MRW for information on how to enter/exit the training mode.

8. After command bus training, DRAM controller must perform write leveling. Write leveling mode is enabled when MR2 OP[7] is high (Ti). See 4.31, Mode Register Write-WR Leveling Mode, for detailed description of write leveling entry and exit sequence. In write leveling mode, the DRAM controller adjusts write DQS_t_c timing to the point where the LPDDR4 device recognizes the start of write DQ data burst with desired write latency.
9. After write leveling, the DQ Bus (internal V_{REF}(DQ), DQS, and DQ) should be trained for high-speed operation using the MPC training commands and by issuing MRW commands to adjust V_{REF}(DQ)(Tj). The LPDDR4 device will power-up with receivers configured for low-speed operations and V_{REF}(DQ) set to a default factory setting. Normal device operation at clock speeds higher than tCKb should not be attempted until DQ Bus training has been completed. The MPC Read Calibration command is used together with MPC FIFO Write/Read commands to train DQ bus without disturbing the memory array contents. See DQ Bus Training section for detailed DQ Bus Training sequence.
10. At Tk the LPDDR4 device is ready for normal operation, and is ready to accept any valid command. Any more registers that have not previously been set up for normal operation should be written at this time.

Table 6 — Initialization Timing Parameters

| Parameter | Value | | Unit | Comment |
|-----------|-----------------|-----------|------|---|
| | Min | Max | | |
| tINIT0 | - | 20 | ms | Maximum voltage-ramp time |
| tINIT1 | 200 | - | us | Minimum RESET_n LOW time after completion of voltage ramp |
| tINIT2 | 10 | - | ns | Minimum CKE low time before RESET_n high |
| tINIT3 | 2 | - | ms | Minimum CKE low time after RESET_n high |
| tINIT4 | 5 | - | tCK | Minimum stable clock before first CKE high |
| tINIT5 | 2 | - | us | Minimum idle time before first MRW/MRR command |
| tZQCAL | 1 | - | us | ZQ calibration time |
| tZQLAT | Max(30ns, 8tCK) | - | ns | ZQCAL latch quiet time. |
| tCKb | Note *1,2 | Note *1,2 | ns | Clock cycle time during boot |

NOTE 1 Min tCKb guaranteed by DRAM test is 18 ns.

NOTE 2 The system may boot at a higher frequency than dictated by min tCKb. The higher boot frequency is system dependent.

3.3.2 Reset Initialization with Stable Power

The following sequence is required for RESET at no power interruption initialization.

1. Assert RESET_n below $0.2 \times V_{DD2}$ anytime when reset is needed. RESET_n needs to be maintained for minimum tPW_RESET. CKE must be pulled LOW at least 10 ns before de-asserting RESET_n.
2. Repeat steps 4 to 10 in 3.3.1.

Table 7 — Reset Timing Parameter

| Parameter | Value | | Unit | Comment |
|-----------|-------|-----|------|---|
| | Min | Max | | |
| tPW_RESET | 100 | - | ns | Minimum RESET_n low Time for Reset Initialization with stable power |

3.3.3 Power-off Sequence

The following procedure is required to power off the device.

While powering off, CKE must be held LOW ($\leq 0.2 \times V_{DD2}$) and all other inputs must be between VILmin and VIHmax. The device outputs remain at High-Z while CKE is held LOW. DQ, DMI, DQS_t and DQS_c voltage levels must be between V_{SSQ} and V_{DDQ} during voltage ramp to avoid latch-up. RESET_n, CK_t, CK_c, CS and CA input levels must be between V_{SS} and V_{DD2} during voltage ramp to avoid latch-up.

Tx is the point where any power supply drops below the minimum value specified.

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

Table 8 — Power Supply Conditions

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

The voltage difference between any of V_{SS} , V_{SSQ} pins must not exceed 100 mV.

3.3.4 Uncontrolled Power-Off Sequence

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

At Tx, when the power supply drops below the minimum values specified, all power supplies must be turned off and all power supply current capacity must be at zero, except any static charge remaining in the system.

After Tz (the point at which all power supplies first reach 300mV), the device must power off. During this period the relative voltage between power supplies is uncontrolled. V_{DD1} and V_{DD2} must decrease with a slope lower than 0.5 V/ μ s between Tx and Tz.

An uncontrolled power-off sequence can occur a maximum of 400 times over the life of the device.

Table 9 — Timing Parameters Power Off

| Symbol | Value | | Unit | Comment |
|--------|-------|-----|------|-----------------------------|
| | Min | Max | | |
| tPOFF | - | 2 | s | Maximum Power-off ramp item |

3.4 Mode Register Definition

Table 10 shows the mode registers for LPDDR4 SDRAM. Each register is denoted as "R" if it can be read but not written, "W" if it can be written but not read, and "R/W" if it can be read and written. A Mode Register Read command is used to read a mode register. A Mode Register Write command is used to write a mode register.

Table 10 — Mode Register Assignment in LPDDR4 SDRAM

| MR# | OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-----|----------|----------------|--------------|---|-----------------------|-----------|----------|--------------|
| 0 | CATR | RFU | RFU | RZQI | | RFU | RFU | Refresh mode |
| 1 | RPST | | nWR (for AP) | | RD-PRE | WR-PRE | | BL |
| 2 | WR Lev | WLS | | WL | | | RL | |
| 3 | DBI-WR | DBI-RD | | PDDS | | PPRP | WR PST | PU-CAL |
| 4 | TUF | Thermal Offset | | PPRE | SR Abort | | | Refresh Rate |
| 5 | | | | LPDDR4 Manufacturer ID | | | | |
| 6 | | | | Revision ID-1 | | | | |
| 7 | | | | Revision ID-2 | | | | |
| 8 | IO Width | | | Density | | | Type | |
| 9 | | | | Vendor Specific Test Register | | | | |
| 10 | | | | RFU | | | ZQ-Reset | |
| 11 | RFU | | CA ODT | | RFU | | DQ ODT | |
| 12 | RFU | VR-CA | | | V _{REF} (CA) | | | |
| 13 | FSP-OP | FSP-WR | DMD | RRO | VRCG | VRO | RPT | CBT |
| 14 | RFU | VR(dq) | | | V _{REF} (DQ) | | | |
| 15 | | | | Lower-Byte Invert Register for DQ Calibration | | | | |
| 16 | | | | PASR Bank Mask | | | | |
| 17 | | | | PASR Segment Mask | | | | |
| 18 | | | | DQS Oscillator Count - LSB | | | | |
| 19 | | | | DQS Oscillator Count - MSB | | | | |
| 20 | | | | Upper-Byte Invert Register for DQ Calibration | | | | |
| 21 | | | | RFU | | | | |
| 22 | RFU | ODTD-CA | ODTE-CS | ODTE-CK | SOC ODT | | | |
| 23 | | | | DQS interval timer run time setting | | | | |
| 24 | TRR Mode | TRR Mode BAn | | | Unlimited MAC | MAC Value | | |
| 25 | | | | PPR Resource | | | | |
| 26 | | | | RFU | | | | |
| 27 | | | | RFU | | | | |
| 28 | | | | RFU | | | | |
| 29 | | | | RFU | | | | |
| 30 | | | | Reserved for testing - SDRAM will ignore | | | | |
| 31 | | | | RFU | | | | |
| 32 | | | | DQ Calibration Pattern "A" (default = 5AH) | | | | |
| 33 | | | | RFU | | | | |
| 34 | | | | RFU | | | | |
| 35 | | | | RFU | | | | |
| 36 | | | | RFU | | | | |
| 37 | | | | RFU | | | | |
| 38 | | | | RFU | | | | |
| 39 | | | | Reserved for testing - SDRAM will ignore | | | | |
| 40 | | | | DQ Calibration Pattern "B" (default = 3CH) | | | | |

MR0 Register Information (MA[5:0] = 00_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|-------|-------|-------|-------|-------|--------------|--------------|
| CATR | RFU | RFU | | RZQI | RFU | Latency Mode | Refresh mode |

| Function | Register Type | Operand | Data | Notes |
|--------------------------------------|---------------|---------|---|---------|
| Refresh mode | Read-only | OP[0] | 0 _B : Both legacy & modified refresh mode supported 1 _B : Only modified refresh mode supported | |
| Latency Mode | | OP[1] | 0 _B : Device supports normal latency 1 _B : Device supports byte mode latency | 6,7 |
| RZQI (Built-in Self-Test for RZQ) | | OP[4:3] | 00 _B : RZQ Self-Test Not Supported 01 _B : ZQ pin may connect to V _{SSQ} or float 10 _B : ZQ-pin may short to V _{DDQ} 11 _B : ZQ-pin Self-Test Completed, no error condition detected (ZQ-pin may not connect to V _{SSQ} or float, nor short to V _{DDQ}) | 1,2,3,4 |
| CATR (CA Terminating Rank) | | OP[7] | 0 _B : CA for this rank is not terminated 1 _B : Vendor specific | 5 |

NOTE 1 RZQI MR value, if supported, will be valid after the following sequence:

- a. Completion of MPC ZQCAL Start command to either channel.
 - b. Completion of MPC ZQCAL Latch command to either channel then tZQLAT is satisfied.
- RZQI value will be lost after Reset.

NOTE 2 If the ZQ-pin is connected to V_{SSQ} to set default calibration, OP[4:3] shall be set to 01_B. If the ZQ-pin is not connected to V_{SSQ}, either OP[4:3] = 01_B or OP[4:3] = 10_B might indicate a ZQ-pin assembly error. It is recommended that the assembly error is corrected.

NOTE 3 In the case of possible assembly error, the LPDDR4-SDRAM device will default to factory trim settings for RON, and will ignore ZQ Calibration commands. In either case, the device may not function as intended.

NOTE 4 If ZQ Self-Test returns OP[4:3] = 11_B, the device has detected a resistor connected to the ZQ-pin. However, this result cannot be used to validate the ZQ resistor value or that the ZQ resistor tolerance meets the specified limits (i.e., 240Ω ± 1%).

NOTE 5 CATR functionality is Vendor specific. CATR can either indicate the connection status of the ODTCA pad for the die or whether CA for the rank is terminated. Consult the vendor device datasheet for details.

NOTE 6 See byte mode addendum spec for byte mode latency details.

NOTE 7 Byte mode latency for 2Ch. x16 device is only allowed when it is stacked in a same package with byte mode device.

MR1 Register Information (MA[5:0] = 01_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|--------------|-------|-------|--------|--------|-------|-------|
| RPST | nWR (for AP) | | | RD-PRE | WR-PRE | BL | |

| Function | Register Type | Operand | Data | Notes |
|---|---------------|---|---|-------|
| BL (Burst Length) | Write-only | OP[1:0] | 00 _B : BL=16 Sequential (default) 01 _B : BL=32 Sequential 10 _B : BL=16 or 32 Sequential (on-the-fly) All Others: Reserved | 1,7 |
| WR-PRE (WR Pre-amble Length) | | OP[2] | 0 _B : Reserved 1 _B : WR Pre-amble = 2*tCK | 5,6 |
| RD-PRE (RD Pre-amble Type) | | OP[3] | 0 _B : RD Pre-amble = Static (default) 1 _B : RD Pre-amble = Toggle | 3,5,6 |
| nWR (Write-Recovery for Auto-Precharge commands) | OP[6:4] | 000 _B : nWR = 6 (default) 001 _B : nWR = 10 010 _B : nWR = 16 011 _B : nWR = 20 100 _B : nWR = 24 101 _B : nWR = 30 110 _B : nWR = 34 111 _B : nWR = 40 | | 2,5,6 |
| RPST (RD Post-Amble Length) | OP[7] | 0 _B : RD Post-amble = 0.5*tCK (default) 1 _B : RD Post-amble = 1.5*tCK | | 4,5,6 |

NOTE 1 Burst length on-the-fly can be set to either BL=16 or BL=32 by setting the "BL" bit in the command operands. See the Command Truth Table.

NOTE 2 The programmed value of nWR is the number of clock cycles the LPDDR4-SDRAM device uses to determine the starting point of an internal Precharge operation after a Write burst with AP (auto-precharge) enabled. (Ref. See Latency Code Frequency Table for allowable Frequency Ranges for RL/WL/nWR, available in next revision of this document.)

NOTE 3 For Read operations this bit must be set to select between a "toggling" pre-amble and a "Non-toggling" Pre-amble. See 4.5, Read Preamble and Postamble, for a drawing of each type of pre-amble.

NOTE 4 OP[7] provides an optional READ post-amble with an additional rising and falling edge of DQS_t. The optional postamble cycle is provided for the benefit of certain memory controllers.

NOTE 5 There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.

NOTE 6 There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

NOTE 7 Supporting the two physical registers for Burst Length: MR1 OP[1:0] as optional feature. Applications requiring support of both vendor options shall assure that both FSP-OP[0] and FSP-OP[1] are set to the same code. Refer to vendor datasheets for detail.

Table 11 — Burst Sequence for READ

| Burst Length | Burst Type | C4 | C3 | C2 | C1 | C0 | Burst Cycle Number and Burst Address Sequence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--------------|------------|----|----|----|----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | | | | | |
| 16 | SEQ | V | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | | | | | | | | | | | | | | | | |
| | | V | 0 | 1 | 0 | 0 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | | | | | | | | | | | | | | | | |
| | | V | 1 | 0 | 0 | 0 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | | | | | | | | | | | | | |
| | | V | 1 | 1 | 0 | 0 | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | | | | | | | | | | | | | | | | |
| 32 | SEQ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F |
| | | 0 | 0 | 1 | 0 | 0 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 |
| | | 0 | 1 | 0 | 0 | 0 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| | | 0 | 1 | 1 | 0 | 0 | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B |
| | | 1 | 0 | 0 | 0 | 0 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
| | | 1 | 0 | 1 | 0 | 0 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 |
| | | 1 | 1 | 0 | 0 | 0 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 8 | 9 | A | B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | | 1 | 1 | 1 | 0 | 0 | 1C | 1D | 1E | 1F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | C | D | E | F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B |

NOTE 1 C0-C1 are assumed to be '0', and are not transmitted on the command bus.

NOTE 2 The starting burst address is on 64-bit (4n) boundaries.

Table 12 — Burst Sequence for Write

| Burst Length | Burst Type | C4 | C3 | C2 | C1 | C0 | Burst Cycle Number and Burst Address Sequence | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--------------|------------|----|----|----|----|----|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | | | | | |
| 16 | SEQ | V | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | | | | | | | | | | | | | | | |
| 32 | SEQ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 1A | 1B | 1C | 1D | 1E | 1F |

NOTE 1 C0-C1 are assumed to be '0', and are not transmitted on the command bus.

NOTE 2 The starting address is on 256-bit (16n) boundaries for Burst length 16.

NOTE 3 The starting address is on 512-bit (32n) boundaries for Burst length 32.

NOTE 4 C2-C3 shall be set to '0' for all Write operations.

MR2 Register Information (MA[5:0] = 02_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|--------|-------|-------|-------|-------|-------|-------|-------|
| WR Lev | WLS | | WL | | | RL | |

| Function | Register Type | Operand | Data | Notes |
|----------------------------|---------------|---------|---|-------|
| RL (Read latency) | | OP[2:0] | RL & nRTP for DBI-RD Disabled (MR3 OP[6]=0 _B) 000 _B : RL=6, nRTP = 8 (Default) 001 _B : RL=10, nRTP = 8 010 _B : RL=14, nRTP = 8 011 _B : RL=20, nRTP = 8 100 _B : RL=24, nRTP = 10 101 _B : RL=28, nRTP = 12 110 _B : RL=32, nRTP = 14 111 _B : RL=36, nRTP = 16 RL & nRTP for DBI-RD Enabled (MR3 OP[6]=1 _B) 000 _B : RL=6, nRTP = 8 001 _B : RL=12, nRTP = 8 010 _B : RL=16, nRTP = 8 011 _B : RL=22, nRTP = 8 100 _B : RL=28, nRTP = 10 101 _B : RL=32, nRTP = 12 110 _B : RL=36, nRTP = 14 111 _B : RL=40, nRTP = 16 | 1,3,4 |
| WL (Write latency) | Write-only | OP[5:3] | WL Set "A" (MR2 OP[6]=0 _B) 000 _B : WL=4 (Default) 001 _B : WL=6 010 _B : WL=8 011 _B : WL=10 100 _B : WL=12 101 _B : WL=14 110 _B : WL=16 111 _B : WL=18 WL Set "B" (MR2 OP[6]=1 _B) 000 _B : WL=4 001 _B : WL=8 010 _B : WL=12 011 _B : WL=18 100 _B : WL=22 101 _B : WL=26 110 _B : WL=30 111 _B : WL=34 | 1,3,4 |
| WLS (Write Latency Set) | | OP[6] | 0 _B : WL Set "A" (default) 1 _B : WL Set "B" | 1,3,4 |
| WR LEV (Write Leveling) | | OP[7] | 0 _B : Disabled (default) 1 _B : Enabled | 2 |

Notes:

1. (Ref. See Latency Code Frequency Table for allowable Frequency Ranges for RL/WL/nWR/nRTP, available in next revision of this document).
2. After a MRW to set the Write Leveling Enable bit (OP[7]=1B), the LPDDR4-SDRAM device remains in the MRW state until another MRW command clears the bit (OP[7]=0B). No other commands are allowed until the Write Leveling Enable bit is cleared.
3. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
4. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

MR3 Register Information (MA[5:0] = 03_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|--------|--------|-------|-------|-------|-------|--------|--------|
| DBI-WR | DBI-RD | PDDS | | | PPRP | WR PST | PU-CAL |

| Function | Register Type | Operand | Data | Notes |
|---------------------------------------|---------------|---------|---|-------|
| PU-Cal (Pull-up Calibration Point) | Write-only | OP[0] | 0 _B : V _{DDQ} /2.5 1 _B : V _{DDQ} /3 (default) | 1,4 |
| WR PST(WR Post-Amble Length) | | OP[1] | 0 _B : WR Post-amble = 0.5*tCK (default) 1 _B : WR Post-amble = 1.5*tCK(Vendor specific function) | 2,3,5 |
| Post Package Repair Protection | | OP[2] | 0 _B : PPR protection disabled (default) 1 _B : PPR protection enabled | 6 |
| PDDS (Pull-Down Drive Strength) | | OP[5:3] | 000 _B : RFU 001 _B : RZQ/1 010 _B : RZQ/2 011 _B : RZQ/3 100 _B : RZQ/4 101 _B : RZQ/5 110 _B : RZQ/6 (default) 111 _B : Reserved | 1,2,3 |
| DBI-RD (DBI-Read Enable) | | OP[6] | 0 _B : Disabled (default) 1 _B : Enabled | 2,3 |
| DBI-WR (DBI-Write Enable) | | OP[7] | 0 _B : Disabled (default) 1 _B : Enabled | 2,3 |

Notes:

1. All values are "typical". The actual value after calibration will be within the specified tolerance for a given voltage and temperature. Re-calibration may be required as voltage and temperature vary.
2. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
3. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.
4. For dual channel devices, PU-CAL setting is required as the same value for both Ch.A and Ch.B before issuing ZQ Cal start command.
5. Refer to the supplier data sheet for vendor specific function. 1.5*tCK apply > 1.6GHz clock.
6. If MR3 OP[2] is set to 1b then PPR protection mode is enabled. The PPR Protection bit is a sticky bit and can only be set to 0b by a power on reset.
MR4 OP[4] controls entry to PPR Mode. If PPR protection is enabled then DRAM will not allow writing of 1 to MR4 OP[4].

MR4 Register Information (MA[5:0] = 04_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|----------------|-------|-------|----------|-------|--------------|-------|
| TUF | Thermal Offset | | PPRE | SR Abort | | Refresh Rate | |

| Function | Register Type | Operand | Data | | Notes |
|--|---------------|---------|---|--|-------------------|
| Refresh Rate | Read | OP[2:0] | 000_B : SDRAM Low temperature operating limit exceeded 001_B : 4x refresh 010_B : 2x refresh 011_B : 1x refresh (default) 100_B : 0.5x refresh 101_B : 0.25x refresh, no de-rating 110_B : 0.25x refresh, with de-rating 111_B : SDRAM High temperature operating limit exceeded | | 1,2,3,4, 7,8,9 |
| SR Abort (Self Refresh Abort) | Write | OP[3] | 0_B : Disable (default) 1_B : Enable | | 9,11 |
| PPRE (Post-package repair entry/exit) | Write | OP[4] | 0_B : Exit PPR mode (default) 1_B : Enter PPR mode | | 5,9 |
| Thermal Offset (Vender Specific Function) | Write | OP[6:5] | 00_B : No offset, 0~5°C gradient (default) 01_B : 5°C offset, 5~10°C gradient 10_B : 10°C offset, 10~15°C gradient 11_B : Reserved | | 10 |
| TUF (Temperature Update Flag) | Read | OP[7] | 0_B : No change in OP[2:0] since last MR4 read (default) 1_B : Change in OP[2:0] since last MR4 read | | 6,7,8 |

Notes:

1. The refresh rate for each MR4-OP[2:0] setting applies to tREFI, tREFIpb, and tREFW. OP[2:0]=011_B corresponds to a device temperature of 85 °C. Other values require either a longer (2x, 4x) refresh interval at lower temperatures, or a shorter (0.5x, 0.25x) refresh interval at higher temperatures. If OP[2]=1_B, the device temperature is greater than 85 °C.
2. At higher temperatures (>85 °C), AC timing derating may be required. If derating is required the LPDDR4-SDRAM will set OP[2:0]=110_B. See derating timing requirements in 10.3, Table 131.
3. DRAM vendors may or may not report all of the possible settings over the operating temperature range of the device. Each vendor guarantees that their device will work at any temperature within the range using the refresh interval requested by their device.
4. The device may not operate properly when OP[2:0]=000_B or 111_B.
5. Post-package repair can be entered or exited by writing to OP[4].
6. When OP[7]=1, the refresh rate reported in OP[2:0] has changed since the last MR4 read. A mode register read from MR4 will reset OP[7] to '0'.
7. OP[7] = 0 at power-up. OP[2:0] bits are valid after initialization sequence(Te).
8. See the section on “temperature Sensor” for information on the recommended frequency of reading MR4.
9. OP[6:3] bits that can be written in this register. All other bits will be ignored by the DRAM during a MRW to this register.
10. Refer to the supplier data sheet for vender specific function.
11. Self Refresh abort feature is available for higher density devices starting with 12Gb device.

MR5 Register Information (MA[5:0] = 05_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|------------------------|-------|-------|-------|-------|-------|-------|-------|
| LPDDR4 Manufacturer ID | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|------------------------|---------------|---------|--|-------|
| LPDDR4 Manufacturer ID | Read-only | OP[7:0] | See JEP166, LPDDR4 Manufacturer ID Codes | |

MR6 Register Information (MA[7:0] = 06_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|---------------|-------|-------|-------|-------|-------|-------|-------|
| Revision ID-1 | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|----------------------|---------------|---------|--|-------|
| LPDDR4 Revision ID-1 | Read-only | OP[7:0] | 00000000 _B : A-version 00000001 _B : B-version | 1 |

NOTE 1 MR6 is vendor specific.

MR7 Register Information (MA[7:0] = 07_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|---------------|-------|-------|-------|-------|-------|-------|-------|
| Revision ID-2 | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|----------------------|---------------|---------|--|-------|
| LPDDR4 Revision ID-2 | Read-only | OP[7:0] | 00000000 _B : A-version 00000001 _B : B-version | 1 |

NOTE 1 MR7 is vendor specific.

MR8 Register Information (MA[5:0] = 08_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------|---------|-------|-------|-------|-------|-------|-------|
| IO Width | Density | | | | | Type | |

| Function | Register Type | Operand | Data | Notes |
|----------|---------------|---------|---|-------|
| Type | Read-only | OP[1:0] | 00 _B : S16 SDRAM (16n pre-fetch) All Others: Reserved | |
| Density | | OP[5:2] | 0000 _B : 4Gb dual channel die / 2Gb single channel die 0001 _B : 6Gb dual channel die / 3Gb single channel die 0010 _B : 8Gb dual channel die / 4Gb single channel die 0011 _B : 12Gb dual channel die / 6Gb single channel die 0100 _B : 16Gb dual channel die / 8Gb single channel die 0101 _B : 24Gb dual channel die / 12Gb single channel die 0110 _B : 32Gb dual channel die / 16Gb single channel die All Others: Reserved | |
| IO Width | | OP[7:6] | 00 _B : x16 (per channel) All Others: Reserved | |

MR9 Register Information (MA[7:0] = 09_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------------------------------|-------|-------|-------|-------|-------|-------|-------|
| Vendor Specific Test Register | | | | | | | |

NOTE 1 Only 00_H should be written to this register.

MR10 Register Information (MA[7:0] = 0A_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|-------|-------|-------|-------|-------|-------|----------|
| RFU | | | | | | | ZQ-Reset |

| Function | Register Type | Operand | Data | Notes |
|----------|---------------|---------|--|-------|
| ZQ-Reset | Write-only | OP[0] | 0 _B : Normal Operation (Default) 1 _B : ZQ Reset | 1,2 |

NOTE 1 See Table 76, ZQCal Timing Parameters for calibration latency and timing.

NOTE 2 If the ZQ-pin is connected to V_{DDQ} through R_{ZQ}, either the ZQ calibration function or default calibration (via ZQ-Reset) is supported. If the ZQ-pin is connected to V_{SS}, the device operates with default calibration, and ZQ calibration commands are ignored. In both cases, the ZQ connection shall not change after power is applied to the device.

MR11 Register Information (MA[5:0] = 0B_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------|--------|-------|-------|----------|--------|-------|-------|
| DQ ODTnt | CA ODT | | | DQ ODTnt | DQ ODT | | |

| Function | Register Type | Operand | Data | Notes |
|--|---------------|---------|--|---------|
| DQ ODT (DQ Bus Receiver On-Die-Termination) | | OP[2:0] | 000_B : Disable (Default) 001_B : RZQ/1 010_B : RZQ/2 011_B : RZQ/3 100_B : RZQ/4 101_B : RZQ/5 110_B : RZQ/6 111_B : RFU | 1,2,3 |
| DQ ODTnt (DQ Bus Receiver On-Die Termination for non-target DRAM) | Write-only | OP[7,3] | 00_B : Disable (Default) 01_B : RZQ/3 10_B : RZQ/5 11_B : RZQ/6 | 1,2,3,4 |
| CA ODT (CA Bus Receiver On-Die-Termination) | | OP[6:4] | 000_B : Disable (Default) 001_B : RZQ/1 010_B : RZQ/2 011_B : RZQ/3 100_B : RZQ/4 101_B : RZQ/5 110_B : RZQ/6 111_B : RFU | 1,2,3 |

NOTE 1 All values are "typical". The actual value after calibration will be within the specified tolerance for a given voltage and temperature. Re-calibration may be required as voltage and temperature vary.

NOTE 2 There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.

NOTE 3 There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

NOTE 4 ODT for non-target DRAM is optional.

MR12 Register Information ($MA[5:0] = 0C_H$)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|-------|-------|-------|-------|-----------------------|-------|-------|
| RFU | VR-CA | | | | V _{REF} (CA) | | |

| Function | Register Type | Operand | Data | Notes |
|--|----------------|---------|--|---------------|
| V _{REF} (CA) (V _{REF} (CA) Setting) | Read/ Write | OP[5:0] | 000000 _B : -- Thru -- 110010 _B : See table below All Others: Reserved | 1,2,3, 5,6 |
| VR-CA (V _{REF} (CA) Range) | | OP[6] | 0 _B : V _{REF} (CA) Range[0] enabled 1 _B : V _{REF} (CA) Range[1] enabled (default) | 1,2,4, 5,6 |

NOTE 1 This register controls the V_{REF}(CA) levels. Refer to Table 13 - VREF Settings for Range[0] and Range[1] for actual voltage of V_{REF}(CA).

NOTE 2 A read to this register places the contents of OP[7:0] on DQ[7:0]. Any RFU bits and unused DQ's shall be set to '0'. See the section on MRR Operation.

NOTE 3 A write to OP[5:0] sets the internal V_{REF}(CA) level for FSP[0] when MR13 OP[6]=0_B, or sets FSP[1] when MR13 OP[6]=1_B. The time required for V_{REF}(CA) to reach the set level depends on the step size from the current level to the new level. See the section on V_{REF}(CA) training for more information.

NOTE 4 A write to OP[6] switches the LPDDR4-SDRAM between two internal V_{REF}(CA) ranges. The range (Range[0] or Range[1]) must be selected when setting the V_{REF}(CA) register. The value, once set, will be retained until overwritten, or until the next power-on or RESET event.

NOTE 5 There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.

NOTE 6 There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

Table 13 — V_{REF} Settings for Range[0] and Range[1]

| Function | Operand | Range[0] Values (% of V _{DD2}) | Range[1] Values (% of V _{DD2}) | Notes | |
|------------------------------------|---------|--|--|---------------------------------------|-----------------------------|
| V _{REF} Settings for MR12 | OP[5:0] | 000000 _B : 10.0% | 011010 _B : 20.4% | 000000 _B : 22.0% | 011010 _B : 32.4% |
| | | 000001 _B : 10.4% | 011011 _B : 20.8% | 000001 _B : 22.4% | 011011 _B : 32.8% |
| | | 000010 _B : 10.8% | 011100 _B : 21.2% | 000010 _B : 22.8% | 011100 _B : 33.2% |
| | | 000011 _B : 11.2% | 011101 _B : 21.6% | 000011 _B : 23.2% | 011101 _B : 33.6% |
| | | 000100 _B : 11.6% | 011110 _B : 22.0% | 000100 _B : 23.6% | 011110 _B : 34.0% |
| | | 000101 _B : 12.0% | 011111 _B : 22.4% | 000101 _B : 24.0% | 011111 _B : 34.4% |
| | | 000110 _B : 12.4% | 100000 _B : 22.8% | 000110 _B : 24.4% | 100000 _B : 34.8% |
| | | 000111 _B : 12.8% | 100001 _B : 23.2% | 000111 _B : 24.8% | 100001 _B : 35.2% |
| | | 001000 _B : 13.2% | 100010 _B : 23.6% | 001000 _B : 25.2% | 100010 _B : 35.6% |
| | | 001001 _B : 13.6% | 100011 _B : 24.0% | 001001 _B : 25.6% | 100011 _B : 36.0% |
| | | 001010 _B : 14.0% | 100100 _B : 24.4% | 001010 _B : 26.0% | 100100 _B : 36.4% |
| | | 001011 _B : 14.4% | 100101 _B : 24.8% | 001011 _B : 26.4% | 100101 _B : 36.8% |
| | | 001100 _B : 14.8% | 100110 _B : 25.2% | 001100 _B : 26.8% | 100110 _B : 37.2% |
| | | 001101 _B : 15.2% | 100111 _B : 25.6% | 001101 _B : 27.2% (Default) | 100111 _B : 37.6% |
| | | 001110 _B : 15.6% | 101000 _B : 26.0% | 001110 _B : 27.6% | 101000 _B : 38.0% |
| | | 001111 _B : 16.0% | 101001 _B : 26.4% | 001111 _B : 28.0% | 101001 _B : 38.4% |
| | | 010000 _B : 16.4% | 101010 _B : 26.8% | 010000 _B : 28.4% | 101010 _B : 38.8% |
| | | 010001 _B : 16.8% | 101011 _B : 27.2% | 010001 _B : 28.8% | 101011 _B : 39.2% |
| | | 010010 _B : 17.2% | 101100 _B : 27.6% | 010010 _B : 29.2% | 101100 _B : 39.6% |
| | | 010011 _B : 17.6% | 101101 _B : 28.0% | 010011 _B : 29.6% | 101101 _B : 40.0% |
| | | 010100 _B : 18.0% | 101110 _B : 28.4% | 010100 _B : 30.0% | 101110 _B : 40.4% |
| | | 010101 _B : 18.4% | 101111 _B : 28.8% | 010101 _B : 30.4% | 101111 _B : 40.8% |
| | | 010110 _B : 18.8% | 110000 _B : 29.2% | 010110 _B : 30.8% | 110000 _B : 41.2% |
| | | 010111 _B : 19.2% | 110001 _B : 29.6% | 010111 _B : 31.2% | 110001 _B : 41.6% |
| | | 011000 _B : 19.6% | 110010 _B : 30.0% | 011000 _B : 31.6% | 110010 _B : 42.0% |
| | | 011001 _B : 20.0% | All Others: Reserved | 011001 _B : 32.0% | All Others: Reserved |

NOTE 1 These values may be used for MR12 OP[5:0] to set the V_{REF}(CA) levels in the LPDDR4-SDRAM.

NOTE 2 The range may be selected in the MR12 register by setting OP[6] appropriately.

NOTE 3 The MR12 registers represents either FSP[0] or FSP[1]. Two frequency-set-points each for CA and DQ are provided to allow for faster switching between terminated and un-terminated operation, or between different high frequency setting which may use different terminations values.

MR13 Register Information (MA[5:0] = 0D_H)

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

| Function | Register Type | Operand | Data | Notes |
|--|---------------|---------|--|-------|
| CBT (Command Bus Training) | Write-only | OP[0] | 0_B: Normal Operation (default) 1_B: Command Bus Training Mode Enabled | 1 |
| RPT (Read Preamble Training Mode) | | OP[1] | 0_B: Disable (default) 1_B: Enable | |
| VRO (V _{REF} Output) | | OP[2] | 0_B: Normal operation (default) 1_B: Output the V _{REF} (CA) and V _{REF} (DQ) values on DQ bits | 2 |
| VRCG (V _{REF} Current Generator) | | OP[3] | 0_B: Normal Operation (default) 1_B: V _{REF} Fast Response (high current) mode | 3 |
| RRO Refresh rate option | | OP[4] | 0_B: Disable codes 001 and 010 in MR4 OP[2:0] 1_B: Enable all codes in MR4 OP[2:0] | 4, 5 |
| DMD (Data Mask Disable) | | OP[5] | 0_B: Data Mask Operation Enabled (default) 1_B: Data Mask Operation Disabled | 6 |
| FSP-WR (Frequency Set Point Write/Read) | | OP[6] | 0_B: Frequency-Set-Point[0] (default) 1_B: Frequency-Set-Point [1] | 7 |
| FSP-OP (Frequency Set Point Operation Mode) | | OP[7] | 0_B: Frequency-Set-Point[0] (default) 1_B: Frequency-Set-Point [1] | 8 |

Notes:

1. A write to set OP[0]=1 causes the LPDDR4-SDRAM to enter the Command Bus Training mode. When OP[0]=1 and CKE goes LOW, commands are ignored and the contents of CA[5:0] are mapped to the DQ bus. CKE must be brought HIGH before doing a MRW to clear this bit (OP[0]=0) and return to normal operation. See the Command Bus Training section for more information.
2. When set, the LPDDR4-SDRAM will output the V_{REF}(CA) and V_{REF}(DQ) voltages on DQ pins. Only the “active” frequency-set-point, as defined by MR13 OP[7], will be output on the DQ pins. This function allows an external test system to measure the internal V_{REF} levels. The DQ pins used for V_{REF} output are vendor specific.
3. When OP[3]=1, the V_{REF} circuit uses a high-current mode to improve V_{REF} settling time.
4. MR13 OP4 RRO bit is valid only when MR0 OP0 = 1. For LPDDR4 devices with MR0 OP0 = 0, MR4 OP[2:0] bits are not dependent on MR13 OP4.
5. When OP[4] = 0, only 001b and 010b in MR4 OP[2:0] are disabled. LPDDR4 devices must report 011b instead of 001b or 010b in this case. Controller should follow the refresh mode reported by MR4 OP[2:0], regardless of RRO setting. TCSR function does not depend on RRO setting.
6. When enabled (OP[5]=0B) data masking is enabled for the device. When disabled (OP[5]=1B), masked write command is illegal. See 4.16, LPDDR4 Data Mask (DM) and Data Bus Inversion (DBIdc) Function.
7. FSP-WR determines which frequency-set-point registers are accessed with MRW commands for the following functions such as V_{REF}(CA) Setting, V_{REF}(CA) Range, V_{REF}(DQ) Setting, V_{REF}(DQ) Range. For more information, refer to 4.30, Frequency Set Point.
8. FSP-OP determines which frequency-set-point register values are currently used to specify device operation for the following functions such as V_{REF}(CA) Setting, V_{REF}(CA) Range, V_{REF}(DQ) Setting, V_{REF}(DQ) Range. For more information, refer to 4.30 Frequency Set Point section.

MR14 Register Information (MA[5:0] = 0E_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|--------|-------|-------|-------|-----------------------|-------|-------|
| RFU | VR(DQ) | | | | V _{REF} (DQ) | | |

| Function | Register Type | Operand | Data | | Notes |
|--|----------------|---------|--|--|---------------|
| V _{REF} (DQ) (V _{REF} (DQ) Setting) | Read/ Write | OP[5:0] | 000000 _B : -- Thru -- 110010 _B : See table below All Others: Reserved | | 1,2,3, 5,6 |
| VR(dq) (V _{REF} (DQ) Range) | | OP[6] | 0 _B : V _{REF} (DQ) Range[0] enabled 1 _B : V _{REF} (DQ) Range[1] enabled (default) | | 1,2,4, 5,6 |

Notes:

1. This register controls the V_{REF}(DQ) levels for Frequency-Set-Point[1:0]. Values from either VR(DQ)[0] or VR(dq)[1] may be selected by setting OP[6] appropriately.
2. A read (MRR) to this register places the contents of OP[7:0] on DQ[7:0]. Any RFU bits and unused DQ's shall be set to '0'. See the section on MRR Operation.
3. A write to OP[5:0] sets the internal V_{REF}(DQ) level for FSP[0] when MR13 OP[6]=0B, or sets FSP[1] when MR13 OP[6]=1B. The time required for V_{REF}(DQ) to reach the set level depends on the step size from the current level to the new level. See the section on V_{REF}(DQ) training for more information.
4. A write to OP[6] switches the LPDDR4-SDRAM between two internal V_{REF}(DQ) ranges. The range (Range[0] or Range[1]) must be selected when setting the V_{REF}(DQ) register. The value, once set, will be retained until overwritten, or until the next power-on or RESET event.
5. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
6. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.

Table 14 — V_{REF} Settings for Range[0] and Range[1]

| Function | Operand | Range[0] Values (% of V _{DDQ}) | Range[1] Values (% of V _{DDQ}) | Notes | |
|------------------------------------|---------|--|--|---------------------------------------|-----------------------------|
| V _{REF} Settings for MR14 | OP[5:0] | 000000 _B : 10.0% | 011010 _B : 20.4% | 000000 _B : 22.0% | 011010 _B : 32.4% |
| | | 000001 _B : 10.4% | 011011 _B : 20.8% | 000001 _B : 22.4% | 011011 _B : 32.8% |
| | | 000010 _B : 10.8% | 011100 _B : 21.2% | 000010 _B : 22.8% | 011100 _B : 33.2% |
| | | 000011 _B : 11.2% | 011101 _B : 21.6% | 000011 _B : 23.2% | 011101 _B : 33.6% |
| | | 000100 _B : 11.6% | 011110 _B : 22.0% | 000100 _B : 23.6% | 011110 _B : 34.0% |
| | | 000101 _B : 12.0% | 011111 _B : 22.4% | 000101 _B : 24.0% | 011111 _B : 34.4% |
| | | 000110 _B : 12.4% | 100000 _B : 22.8% | 000110 _B : 24.4% | 100000 _B : 34.8% |
| | | 000111 _B : 12.8% | 100001 _B : 23.2% | 000111 _B : 24.8% | 100001 _B : 35.2% |
| | | 001000 _B : 13.2% | 100010 _B : 23.6% | 001000 _B : 25.2% | 100010 _B : 35.6% |
| | | 001001 _B : 13.6% | 100011 _B : 24.0% | 001001 _B : 25.6% | 100011 _B : 36.0% |
| | | 001010 _B : 14.0% | 100100 _B : 24.4% | 001010 _B : 26.0% | 100100 _B : 36.4% |
| | | 001011 _B : 14.4% | 100101 _B : 24.8% | 001011 _B : 26.4% | 100101 _B : 36.8% |
| | | 001100 _B : 14.8% | 100110 _B : 25.2% | 001100 _B : 26.8% | 100110 _B : 37.2% |
| | | 001101 _B : 15.2% | 100111 _B : 25.6% | 001101 _B : 27.2% (Default) | 100111 _B : 37.6% |
| | | 001110 _B : 15.6% | 101000 _B : 26.0% | 001110 _B : 27.6% | 101000 _B : 38.0% |
| | | 001111 _B : 16.0% | 101001 _B : 26.4% | 001111 _B : 28.0% | 101001 _B : 38.4% |
| | | 010000 _B : 16.4% | 101010 _B : 26.8% | 010000 _B : 28.4% | 101010 _B : 38.8% |
| | | 010001 _B : 16.8% | 101011 _B : 27.2% | 010001 _B : 28.8% | 101011 _B : 39.2% |
| | | 010010 _B : 17.2% | 101100 _B : 27.6% | 010010 _B : 29.2% | 101100 _B : 39.6% |
| | | 010011 _B : 17.6% | 101101 _B : 28.0% | 010011 _B : 29.6% | 101101 _B : 40.0% |
| | | 010100 _B : 18.0% | 101110 _B : 28.4% | 010100 _B : 30.0% | 101110 _B : 40.4% |
| | | 010101 _B : 18.4% | 101111 _B : 28.8% | 010101 _B : 30.4% | 101111 _B : 40.8% |
| | | 010110 _B : 18.8% | 110000 _B : 29.2% | 010110 _B : 30.8% | 110000 _B : 41.2% |
| | | 010111 _B : 19.2% | 110001 _B : 29.6% | 010111 _B : 31.2% | 110001 _B : 41.6% |
| | | 011000 _B : 19.6% | 110010 _B : 30.0% | 011000 _B : 31.6% | 110010 _B : 42.0% |
| | | 011001 _B : 20.0% | All Others: Reserved | 011001 _B : 32.0% | All Others: Reserved |

Notes:

- These values may be used for MR14 OP[5:0] to set the V_{REF}(DQ) levels in the LPDDR4-SDRAM.
- The range may be selected in the MR14 register by setting OP[6] appropriately.
- The MR14 registers represents either FSP[0] or FSP[1]. Two frequency-set-points each for CA and DQ are provided to allow for faster switching between terminated and un-terminated operation, or between different high frequency setting which may use different terminations values.

1,2,3

MR15 Register Information (MA[5:0] = 0F_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|---|-------|-------|-------|-------|-------|-------|-------|
| Lower-Byte Invert Register for DQ Calibration | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|--------------------------------------|---------------|---------|--|-------|
| Lower-Byte Invert for DQ Calibration | Write-only | OP[7:0] | <p>The following values may be written for any operand OP[7:0], and will be applied to the corresponding DQ locations DQ[7:0] within a byte lane:</p> <p>0_B: Do not invert</p> <p>1_B: Invert the DQ Calibration patterns in MR32 and MR40</p> <p>Default value for OP[7:0]=55_H</p> | 1,2,3 |

Notes:

1. This register will invert the DQ Calibration pattern found in MR32 and MR40 for any single DQ, or any combination of DQ's. Example: If MR15 OP[7:0]=00010101B, then the DQ Calibration patterns transmitted on DQ[7,6,5,3,1] will not be inverted, but the DQ Calibration patterns transmitted on DQ[4,2,0] will be inverted.
2. DMI[0] is not inverted, and always transmits the “true” data contained in MR32/MR40.
3. No Data Bus Inversion (DBI) function is enacted during DQ Read Calibration, even if DBI is enabled in MR3-OP[6].

Table 15 — MR15 Invert Register Pin Mapping

| PIN | DQ0 | DQ1 | DQ2 | DQ3 | DMI0 | DQ4 | DQ5 | DQ6 | DQ7 |
|------|-----|-----|-----|-----|-----------|-----|-----|-----|-----|
| MR15 | OP0 | OP1 | OP2 | OP3 | NO-Invert | OP4 | OP5 | OP6 | OP7 |

MR16 Register Information (MA[5:0] = 10_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------------|-------|-------|-------|-------|-------|-------|-------|
| PASR Bank Mask | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|----------------|---------------|---------|---|-------|
| Bank[7:0] Mask | Write-only | OP[7:0] | 0 _B : Bank Refresh enabled (default) : Unmasked 1 _B : Bank Refresh disabled : Masked | 1 |

| OP[n] | Bank Mask | 8-Bank SDRAM |
|-------|-----------|--------------|
| 0 | xxxxxx1 | Bank 0 |
| 1 | xxxxxx1x | Bank 1 |
| 2 | xxxxx1xx | Bank 2 |
| 3 | xxxx1xxx | Bank 3 |
| 4 | xxx1xxxx | Bank 4 |
| 5 | xx1xxxxx | Bank 5 |
| 6 | x1xxxxxx | Bank 6 |
| 7 | 1xxxxxxx | Bank 7 |

Notes:

1. When a mask bit is asserted (OP[n]=1), refresh to that bank is disabled.
2. PASR bank-masking is on a per-channel basis. The two channels on the die may have different bank masking in dual channel devices.

MR17 Register Information (MA[5:0] = 11_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------------------|-------|-------|-------|-------|-------|-------|-------|
| PASR Segment Mask | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|-------------------|---------------|---------|---|-------|
| PASR Segment Mask | Write-only | OP[7:0] | 0 _B : Segment Refresh enabled (default) 1 _B : Segment Refresh disabled | |

| Segment | OP[n] | Segment Mask | 2Gb per channel | 3Gb per channel | 4Gb per channel | 6Gb per channel | 8Gb per channel | 12Gb per channel | 16Gb per channel |
|---------|-------|--------------|------------------|-----------------|------------------|------------------|------------------|------------------|------------------|
| | | | R13:R11 | R14:R12 | R14:R12 | R15:R13 | R15:R13 | R16:R14 | R16:R14 |
| 0 | 0 | xxxxxx1 | | | | 000 _B | | | |
| 1 | 1 | xxxxxx1x | | | | 001 _B | | | |
| 2 | 2 | xxxxx1xx | | | | 010 _B | | | |
| 3 | 3 | xxx1xxx | | | | 011 _B | | | |
| 4 | 4 | xx1xxxxx | | | | 100 _B | | | |
| 5 | 5 | xx1xxxxx | | | | 101 _B | | | |
| 6 | 6 | x1xxxxxx | 110 _B | Not Allowed | 110 _B | Not Allowed | 110 _B | Not Allowed | 110 _B |
| 7 | 7 | 1xxxxxxx | 111 _B | | 111 _B | | 111 _B | | 111 _B |

Notes:

1. This table indicates the range of row addresses in each masked segment. "X" is don't care for a particular segment.
2. PASR segment-masking is on a per-channel basis. The two channels on the die may have different segment masking in dual channel devices.
3. For 3Gb, 6Gb, and 12Gb per channel densities, OP[7:6] must always be LOW (=00_B).

MR18 Register Information (MA[5:0] = 12_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|
| DQS Oscillator Count - LSB | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|---|---------------|---------|---------------------------------------|-------|
| DQS Oscillator (WR Training DQS Oscillator) | Read-only | OP[7:0] | 0 - 255 LSB DRAM DQS Oscillator Count | 1,2,3 |

Notes:

1. MR18 reports the LSB bits of the DRAM DQS Oscillator count. The DRAM DQS Oscillator count value is used to train DQS to the DQ data valid window. The value reported by the DRAM in this mode register can be used by the memory controller to periodically adjust the phase of DQS relative to DQ.
2. Both MR18 and MR19 must be read (MRR) and combined to get the value of the DQS Oscillator count.
3. A new MPC [Start DQS Oscillator] should be issued to reset the contents of MR18/MR19.

MR19 Register Information (MA[5:0] = 13_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|
| DQS Oscillator Count - MSB | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|---|---------------|---------|-------------------------------------|-------|
| DQS Oscillator (WR Training DQS Oscillator) | Read-only | OP[7:0] | 0-255 MSB DRAM DQS Oscillator Count | 1,2,3 |

Notes:

1. MR19 reports the MSB bits of the DRAM DQS Oscillator count. The DRAM DQS Oscillator count value is used to train DQS to the DQ data valid window. The value reported by the DRAM in this mode register can be used by the memory controller to periodically adjust the phase of DQS relative to DQ.
2. Both MR18 and MR19 must be read (MRR) and combined to get the value of the DQS Oscillator count.
3. A new MPC [Start DQS Oscillator] should be issued to reset the contents of MR18/MR19.

MR20 Register Information (MA[5:0] = 14_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|---|-------|-------|-------|-------|-------|-------|-------|
| Upper-Byte Invert Register for DQ Calibration | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|--------------------------------------|---------------|---------|--|-------|
| Upper-Byte Invert for DQ Calibration | Write-only | OP[7:0] | <p>The following values may be written for any operand OP[7:0], and will be applied to the corresponding DQ locations DQ[15:8] within a byte lane:</p> <p>0_B: Do not invert</p> <p>1_B: Invert the DQ Calibration patterns in MR32 and MR40</p> <p>Default value for OP[7:0] = 55_H</p> | 1,2 |

Notes:

1. This register will invert the DQ Calibration pattern found in MR32 and MR40 for any single DQ, or any combination of DQ's. Example: If MR20 OP[7:0]=00010101B, then the DQ Calibration patterns transmitted on DQ[15,14,13,11,9] will not be inverted, but the DQ Calibration patterns transmitted on DQ[12,10,8] will be inverted.
2. DMI[1] is not inverted, and always transmits the "true" data contained in MR32/MR40.
3. No Data Bus Inversion (DBI) function is enacted during DQ Read Calibration, even if DBI is enabled in MR3-OP[6].

Table 16 - MR20 Invert Register Pin Mapping

| PIN | DQ8 | DQ9 | DQ10 | DQ11 | DMI1 | DQ12 | DQ13 | DQ14 | DQ15 |
|------|-----|-----|------|------|-----------|------|------|------|------|
| MR20 | OP0 | OP1 | OP2 | OP3 | NO-Invert | OP4 | OP5 | OP6 | OP7 |

MR22 Register Information (MA[5:0] = 16_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------------------------|---------|---------|---------|---------|-------|-------|-------|
| ODTD for x8_2ch(Byte) mode | ODTD-CA | ODTE-CS | ODTE-CK | SOC ODT | | | |

| Function | Register Type | Operand | Data | Notes |
|---|---------------|---------|--|---------------|
| SoC ODT (Controller ODT Value for VOH calibration) | | OP[2:0] | 000_B: Disable (Default) 001_B: RZQ/1 010_B: RZQ/2 011_B: RZQ/3 100_B: RZQ/4 101_B: RZQ/5 110_B: RZQ/6 111_B: RFU | 1,2,3 |
| ODTE-CK (CK ODT enabled for non-terminating rank) | Write-only | OP[3] | 0_B: ODT-CK Over-ride Disabled (Default) 1_B: ODT-CK Over-ride Enabled | 2,3,4, 6,8 |
| ODTE-CS (CS ODT enable for non-terminating rank) | | OP[4] | 0_B: ODT-CS Over-ride Disabled (Default) 1_B: ODT-CS Over-ride Enabled | 2,3,5, 6,8 |
| ODTD-CA (CA ODT termination disable) | | OP[5] | 0_B: ODT-CA Obey ODT_CA bond pad (default) 1_B: ODT-CA Disabled | 2,3,6, 7,8 |
| ODTD for x8_2ch(Byte) mode | | OP[7:6] | See x8_2ch (Byte) mode addendum | |

Notes:

1. All values are "typical".
2. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. Only the registers for the set point determined by the state of the FSP-WR bit (MR13 OP[6]) will be written to with an MRW command to this MR address, or read from with an MRR command to this address.
3. There are two physical registers assigned to each bit of this MR parameter, designated set point 0 and set point 1. The device will operate only according to the values stored in the registers for the active set point, i.e., the set point determined by the state of the FSP-OP bit (MR13 OP[7]). The values in the registers for the inactive set point will be ignored by the device, and may be changed without affecting device operation.
4. When OP[3]=1, then the CK signals will be terminated to the value set by MR11-OP[6:4] regardless of the state of the ODT_CA bond pad. This overrides the ODT_CA bond pad for configurations where CA is shared by two or more DRAMs but CK is not, allowing CK to terminate on all DRAMs.
5. When OP[4]=1, then the CS signal will be terminated to the value set by MR11-OP[6:4] regardless of the state of the ODT_CA bond pad. This overrides the ODT_CA bond pad for configurations where CA is shared by two or more DRAMs but CS is not, allowing CS to terminate on all DRAMs.
6. For system configurations where the CK, CS, and CA signals are shared between packages, the package design should provide for the ODT_CA ball to be bonded on the system board outside of the memory package. This provides the necessary control of the ODT function for all die with shared Command Bus signals.
7. When OP[5]=0, CA[5:0] will terminate when the ODT_CA bond pad is HIGH and MR11-OP[6:4] is VALID, and disables termination when ODT_CA is LOW or MR11-OP[6:4] is disabled. When OP[5]=1, termination for CA[5:0] is disabled, regardless of the state of the ODT_CA bond pad or MR11-OP[6:4].
8. To ensure proper operation in a multi-rank configuration, when CA, CK or CS ODT is enabled via MR11 OP[6:4] and also via MR22 or CA-ODT pad setting, the rank providing ODT will continue to terminate the command bus in all DRAM states including Active Self Refresh, Self Refresh Power-down, Active Power-down and Precharge Power-down.

MR23 Register Information (MA[5:0] = 17_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|
| DQS interval timer run time setting | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|-----------------------------|---------------|---------|---|-------|
| DQS interval timer run time | Write-only | OP[7:0] | <p>00000000_B: DQS interval timer stop via MPC Command (Default)</p> <p>00000001_B: DQS timer stops automatically at 16th clocks after timer start</p> <p>00000010_B: DQS timer stops automatically at 32nd clocks after timer start</p> <p>00000011_B: DQS timer stops automatically at 48th clocks after timer start</p> <p>00000100_B: DQS timer stops automatically at 64th clocks after timer start</p> <p>----- Thru -----</p> <p>00111111_B: DQS timer stops automatically at (63X16)th clocks after timer start</p> <p>01XXXXXX_B: DQS timer stops automatically at 2048th clocks after timer start</p> <p>10XXXXXX_B: DQS timer stops automatically at 4096th clocks after timer start</p> <p>11XXXXXX_B: DQS timer stops automatically at 8192nd clocks after timer start</p> | 1, 2 |

Notes:

1. MPC command with OP[6:0]=1001101_B (Stop DQS Interval Oscillator) stops DQS interval timer in case of MR23 OP[7:0] = 00000000_B.
2. MPC command with OP[6:0]=1001101B (Stop DQS Interval Oscillator) is illegal with non-zero values in MR23 OP[7:0].

MR24 Register Information (MA[5:0] = 18_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|----------|--------------|-------|-------|-----------|-----------|-------|-------|
| TRR Mode | TRR Mode BAn | | | Unlimited | MAC Value | | |

| Function | Register Type | Operand | Data | Notes |
|--------------|---------------|---------|---|-------|
| MAC Value | Read-only | OP[2:0] | 000_B : Unknown when bit OP3=0 (Note 1) 001_B : 700K 010_B : 600K 011_B : 500K 100_B : 400K 101_B : 300K 110_B : 200K 111_B : Reserved | |
| | | | 0_B : OP[2:0] define MAC value 1_B : Unlimited MAC value (Note 2, Note 3) | |
| TRR Mode BAn | Write-only | OP[6:4] | 000_B : Bank 0 001_B : Bank 1 010_B : Bank 2 011_B : Bank 3 100_B : Bank 4 101_B : Bank 5 110_B : Bank 6 111_B : Bank 7 | |
| | | | 0_B : Disabled (default) 1_B : Enabled | |

Notes:

1. Unknown means that the device is not tested for tMAC and pass/fail value is unknown.
2. There is no restriction to number of activates.
3. MR24 OP [2:0] is set to zero.

MR25 Register Information (MA[5:0] = 19_H)

Mode Register 25 contains one bit of readout per bank indicating that at least one resource is available for Post Package Repair programming.

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|-------|-------|-------|-------|-------|-------|-------|-------|
| Bank7 | Bank6 | Bank5 | Bank4 | Bank3 | Bank2 | Bank1 | Bank0 |

| Function | Register Type | Operand | Data | Notes |
|--------------|---------------|---------|--|-------|
| PPR Resource | Read-only | OP[7:0] | 0 _B : PPR Resource is not available 1 _B : PPR Resource is available | |

MR30 Register Information (MA[5:0] = 1E_H)

| | | | | | | | |
|--------------|-------|-------|-------|-------|-------|-------|-------|
| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
| Valid 0 or 1 | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|--------------------------|---------------|---------|------------|-------|
| SDRAM will ignore | Write-only | OP[7:0] | Don't care | 1 |

Notes:

1. This register is reserved for testing purposes. The logical data values written to OP[7:0] shall have no effect on SDRAM operation, however timings need to be observed as for any other MR access command.

MR32 Register Information (MA[5:0] = 20_H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|---|-------|-------|-------|-------|-------|-------|-------|
| DQ Calibration Pattern “A” (default = 5A _H) | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|---|---------------|---------|--|-------|
| Return DQ Calibration Pattern MR32 + MR40 | Write | OP[7:0] | X _B : An MPC command with OP[6:0]= 1000011 _B causes the device to return the DQ Calibration Pattern contained in this register and (followed by) the contents of MR40. A default pattern “5A _H ” is loaded at power-up or RESET, or the pattern may be overwritten with a MRW to this register. The contents of MR15 and MR20 will invert the data pattern for a given DQ (See MR15 for more information) | |

MR39 Register Information (MA[5:0] = 27_H)

| | | | | | | | |
|--------------|-------|-------|-------|-------|-------|-------|-------|
| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
| Valid 0 or 1 | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|--------------------------|---------------|---------|------------|-------|
| SDRAM will ignore | Write-only | OP[7:0] | Don't care | 1 |

Notes:

1. This register is reserved for testing purposes. The logical data values written to OP[7:0] shall have no effect on SDRAM operation, however timings need to be observed as for any other MR access command.

MR40 Register Information (MA[5:0] = 28H)

| OP[7] | OP[6] | OP[5] | OP[4] | OP[3] | OP[2] | OP[1] | OP[0] |
|---|-------|-------|-------|-------|-------|-------|-------|
| DQ Calibration Pattern “B” (default = 3C _H) | | | | | | | |

| Function | Register Type | Operand | Data | Notes |
|---|---------------|---------|--|-------|
| Return DQ Calibration Pattern MR32 + MR40 | Write only | OP[7:0] | X _B : A default pattern “3C _H ” is loaded at power-up or RESET, or the pattern may be overwritten with a MRW to this register. See MR32 for more information. | 1,2,3 |

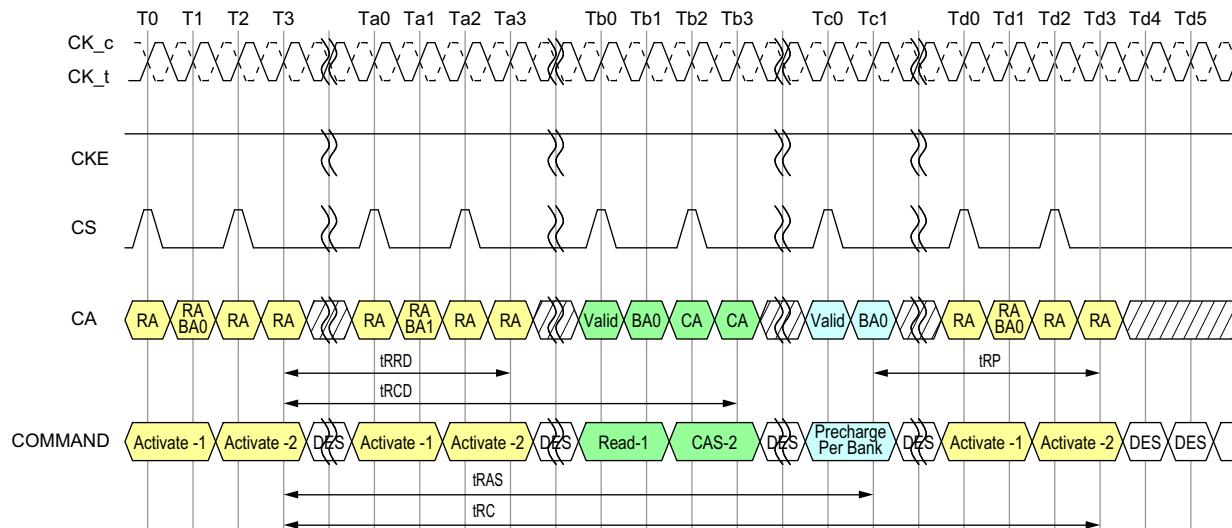
Notes:

1. The pattern contained in MR40 is concatenated to the end of MR32 and transmitted on DQ[15:0] and DMI[1:0] when DQ Read Calibration is initiated via a MPC command. The pattern transmitted serially on each data lane, organized “little endian” such that the low-order bit in a byte is transmitted first. If the data pattern in MR40 is 27_H, then the first bit transmitted will be a '1', followed by '1', '1', '0', '0', '1', '0', and '0'. The bit stream will be 00100111_B.
2. MR15 and MR20 may be used to invert the MR32/MR40 data patterns on the DQ pins. See MR15 and MR20 for more information. Data is never inverted on the DMI[1:0] pins.
3. The data pattern is not transmitted on the DMI[1:0] pins if DBI-RD is disabled via MR3-OP[6].
4. No Data Bus Inversion (DBI) function is enacted during DQ Read Calibration, even if DBI is enabled in MR3-OP[6].

4 Command Definitions and Timing Diagrams

4.1 Activate Command

The ACTIVATE command is composed of two consecutive commands, Activate-1 command and Activate-2. Activate-1 command is issued by holding CS HIGH, CA0 HIGH and CA1 LOW at the first rising edge of the clock and Activate-2 command issued by holding CS HIGH, CA0 HIGH and CA1 HIGH at the first rising edge of the clock. The bank addresses BA0, BA1 and BA2 are used to select desired bank. Row addresses are used to determine which row to activate in the selected bank. The ACTIVATE command must be applied before any READ or WRITE operation can be executed. The device can accept a READ or WRITE command at tRCD after the ACTIVATE command is issued. After a bank has been activated it must be precharged before another ACTIVATE command can be applied to the same bank. The bank active and precharge times are defined as tRAS and tRP respectively. The minimum time interval between ACTIVATE commands to the same bank is determined by the RAS cycle time of the device(tRC). The minimum time interval between ACTIVATE commands to different banks is tRRD.



NOTES : 1. A PRECHARGE command uses tRPab timing for all bank PRECHARGE and tRPpb timing for single-bank PRECHARGE.

In this figure, tRP is used to denote either all bank PRECHARGE or a single-bank PRECHARGE.

DON'T CARE TIME BREAK

Figure 6 — ACTIVATE Command

4.2 8-Bank Device Operation

Certain restrictions on operation of the 8-bank LPDDR4 devices must be observed. There are two rules: One rule restricts the number of sequential ACTIVATE commands that can be issued; the other provides more time for RAS precharge for a PRECHARGE ALL command. The rules are as follows:

8 bank device Sequential Bank Activation Restriction:

No more than 4 banks may be activated (or refreshed, in the case of REFpb) in a rolling tFAW window. The number of clocks in a tFAW period is dependent upon the clock frequency, which may vary. If the clock frequency is not changed over this period, converting clocks is done by dividing tFAW[ns] by tCK[ns], and rounding up to the next integer value. As an example of the rolling window, if RU(tFAW/tCK) is 10 clocks, and an ACTIVATE command is issued in clock n, no more than three further ACTIVATE commands can be issued at or between clock n + 1 and n + 9. REFpb also counts as bank activation for purposes of tFAW. If the clock frequency is changed during the tFAW period, the rolling tFAW window may be calculated in clock cycles by adding up the time spent in each clock period. The tFAW requirement is met when the previous n clock cycles exceeds the tFAW time.

The 8-Bank Device Precharge-All Allowance:

tRP for a PRECHRGAE ALL command must equal tRPab, which is greater than tRPpb.

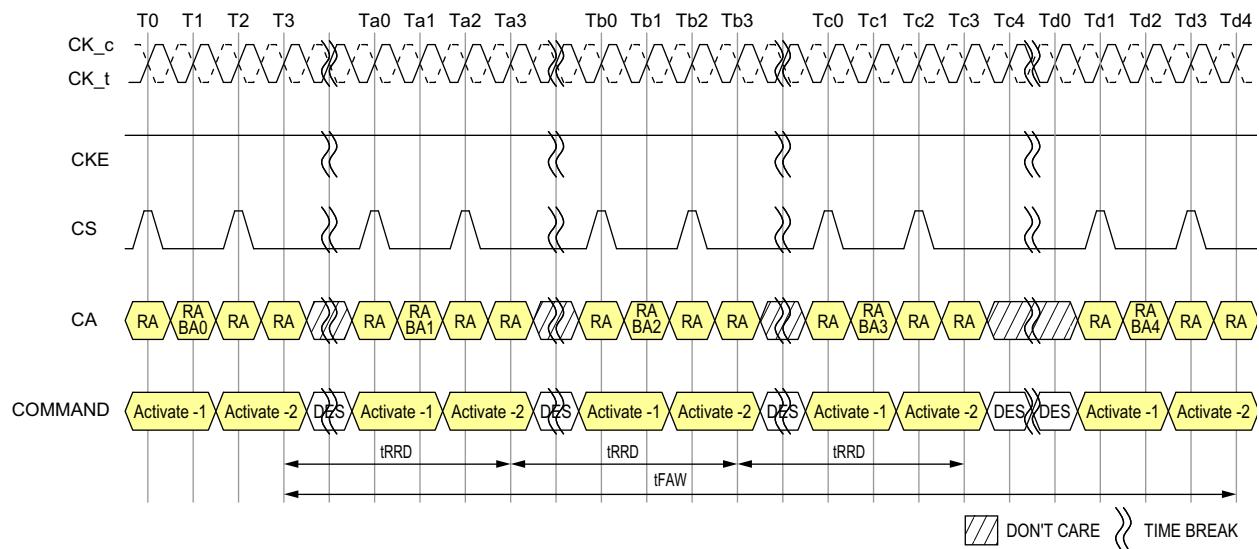


Figure 7 — tFAW Timing

4.3 Core Timing

Table 17 — Core AC Timing

| Parameter | Symbol | Min/ Max | Data Rate | | | | | | | | Unit | |
|---|--------|-------------|---|------|------|------|------|------|----------------------------------|------|----------|--|
| Core Parameters | | | 533 | 1066 | 1600 | 2133 | 2667 | 3200 | 3733 | 4267 | | |
| ACTIVATE-to-ACTIVATE command period (same bank) | tRC | MIN | tRAS + tRPab (with all bank precharge) tRAS + tRPpb (with per bank precharge) | | | | | | | | ns | |
| Minimum Self Refresh Time (Entry to Exit) | tSR | MIN | max(15ns, 3nCK) | | | | | | | | ns | |
| Self Refresh exit to next valid command delay | tXSR | MIN | max(tRFCab + 7.5ns, 2nCK) | | | | | | | | ns | |
| Exit Power-Down to next valid command delay | tXP | MIN | max(7.5ns, 5nCK) | | | | | | | | ns | |
| CAS-to-CAS delay | tCCD | MIN | 8 | | | | | | | | tCK(avg) | |
| Internal READ to PRECHARGE command delay | tRTP | MIN | max(7.5ns, 8nCK) | | | | | | | | ns | |
| RAS-to-CAS delay | tRCD | MIN | max(18ns, 4nCK) | | | | | | | | ns | |
| Row precharge time (single bank) | tRPpb | MIN | max(18ns, 4nCK) | | | | | | | | ns | |
| Row precharge time (all banks) | tRPab | MIN | max(21ns, 4nCK) | | | | | | | | ns | |
| Row active time | tRAS | MIN | max(42ns, 3nCK) | | | | | | | | ns | |
| | | MAX | Min(9 * tREFI * Refresh Rate, 70.2) us (Refresh Rate is specified by MR4, OP[2:0]) | | | | | | | | - | |
| WRITE recovery time | tWR | MIN | max(18ns, 6nCK) | | | | | | | | ns | |
| WRITE-to-READ delay | tWTR | MIN | max(10ns, 8nCK) | | | | | | | | ns | |
| Active bank-A to active bank-B | tRRD | MIN | max(10ns, 4nCK) | | | | | | Max(7.5ns, 4nCK) ² | ns | | |
| Precharge to Precharge Delay ¹ | tPPD | MIN | 4 | | | | | | | | tCK | |
| Four-bank ACTIVATE window | tFAW | MIN | 40 | | | | | | 30 ² | | ns | |

NOTE 1 Precharge to precharge timing restriction does not apply to Auto-Precharge commands.

NOTE 2 Devices supporting 4267 Mbps specification shall support these timings at lower data rates.

4.4 Read and Write Access Operations

After a bank has been activated, a read or write command can be executed. This is accomplished by asserting CKE asynchronously, with CS and CA[5:0] set to the proper state (see Command Truth Table) at a rising edge of CK.

The LPDDR4-SDRAM provides a fast column access operation. A single Read or Write command will initiate a burst read or write operation, where data is transferred to/from the DRAM on successive clock cycles. Burst interrupts are not allowed, but the optimal burst length may be set on the fly (see command truth table).

4.5 Read Preamble and Postamble

The DQS strobe for the LPDDR4-SDRAM requires a pre-amble prior to the first latching edge (the rising edge of DQS_t with DATA "valid"), and it requires a post-amble after the last latching edge. The pre-amble and post-amble lengths are set via mode register writes (MRW).

For READ operations the pre-amble is $2*tCK$, but the pre-amble is static (no-toggle) or toggling, selectable via mode register.

LPDDR4 will have a DQS Read post-amble of $0.5*tCK$ (or extended to $1.5*tCK$). Standard DQS post-amble will be $0.5*tCK$ driven by the DRAM for Reads. A mode register setting instructs the DRAM to drive an additional (extended) one cycle DQS Read post-amble. The drawings below show examples of DQS Read post-amble for both standard ($tRPST$) and extended ($tRPSTE$) post-amble operation.

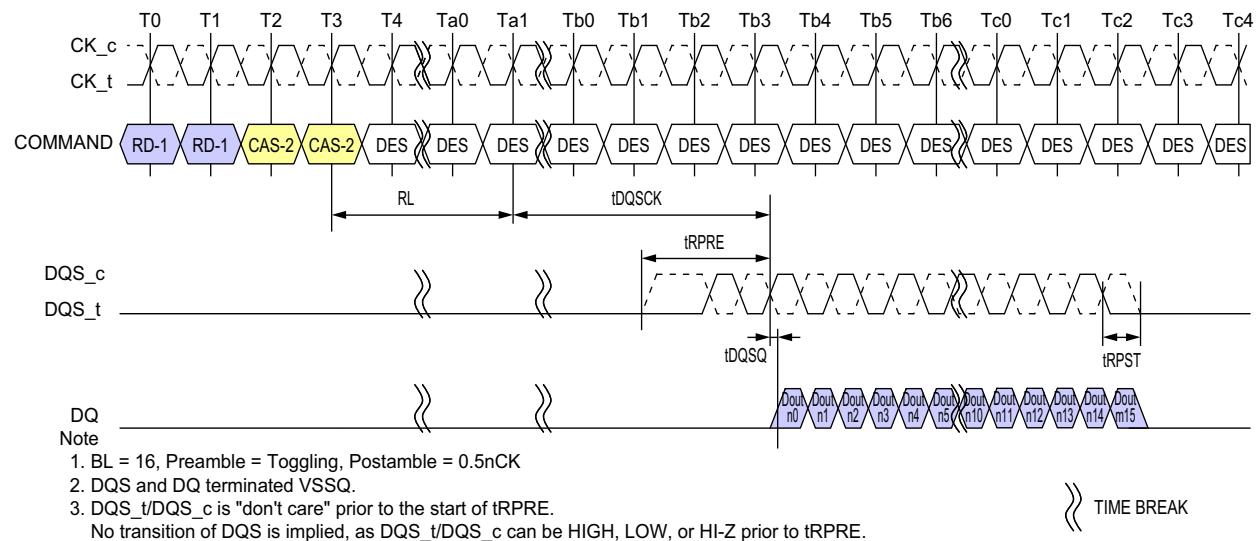


Figure 8 — DQS Read Preamble and Postamble: Toggling Preamble and 0.5nCK Postamble

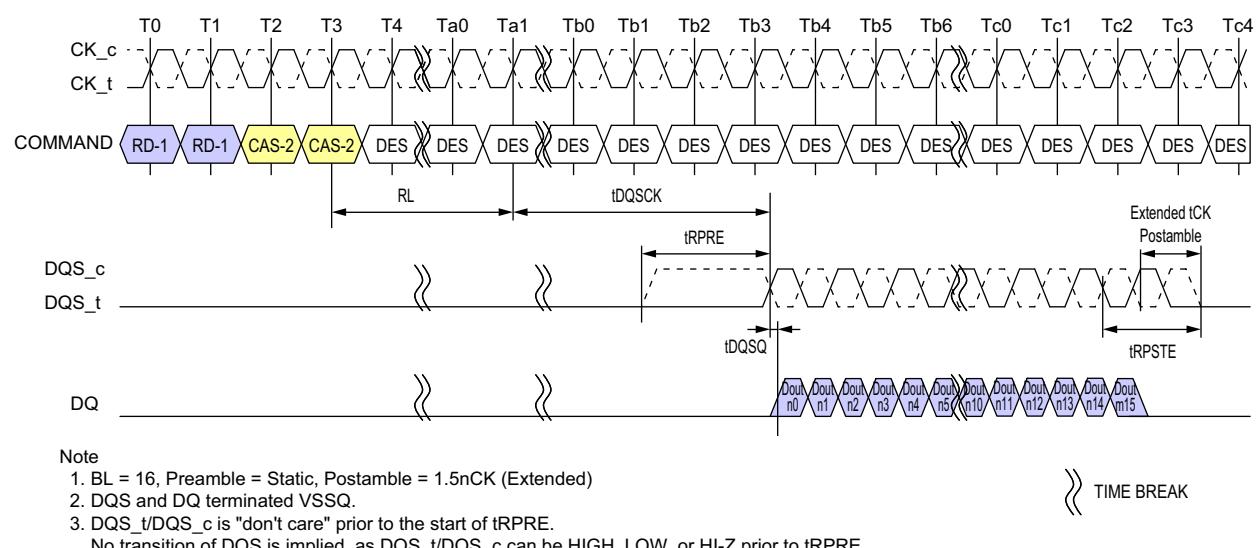


Figure 9 — DQS Read Preamble and Postamble: Static Preamble and 1.5nCK Postamble

4.6 Burst Read Operation

A burst Read command is initiated with CS, and CA[5:0] asserted to the proper state at the rising edge of CK, as defined by the Command Truth Table. The command address bus inputs determine the starting column address for the burst. The two low-order address bits are not transmitted on the CA bus and are implied to be “0”, so that the starting burst address is always a multiple of four (ex. 0x0, 0x4, 0x8, 0xC). The read latency (RL) is defined from the last rising edge of the clock that completes a read command (Ex: the second rising edge of the CAS-2 command) to the rising edge of the clock from which the tDQSCK delay is measured. The first valid data is available $RL * tCK + tDQSCK + tDQSQ$ after the rising edge of Clock that completes a read command. The data strobe output is driven tRPRE before the first valid rising strobe edge. The first data-bit of the burst is synchronized with the first valid (i.e., post-preamble) rising edge of the data strobe. Each subsequent data out appears on each DQ pin, edge-aligned with the data strobe. At the end of a burst the DQS signals are driven for another half cycle post-amble, or for a 1.5-cycle postamble if the programmable post-amble bit is set in the mode register. The RL is programmed in the mode registers. Pin timings for the data strobe are measured relative to the cross-point of DQS_t and DQS_c.

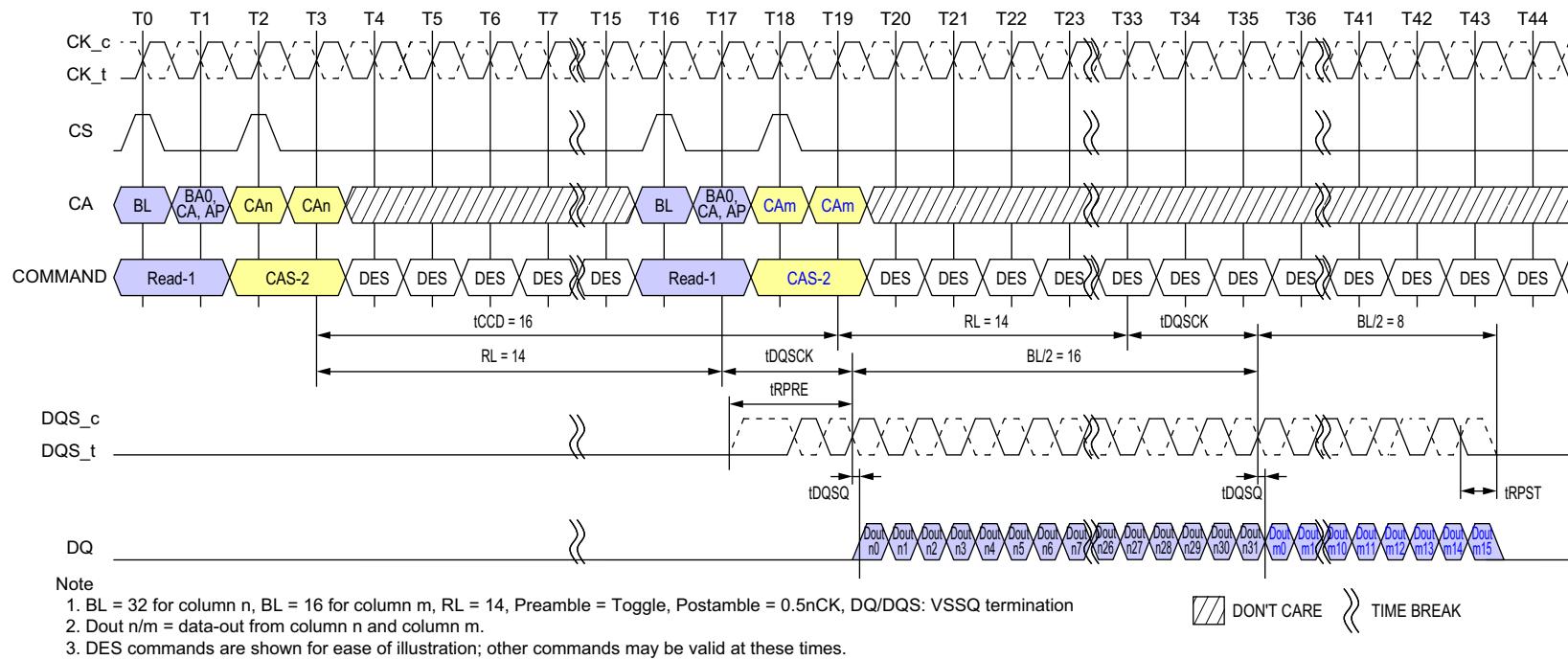
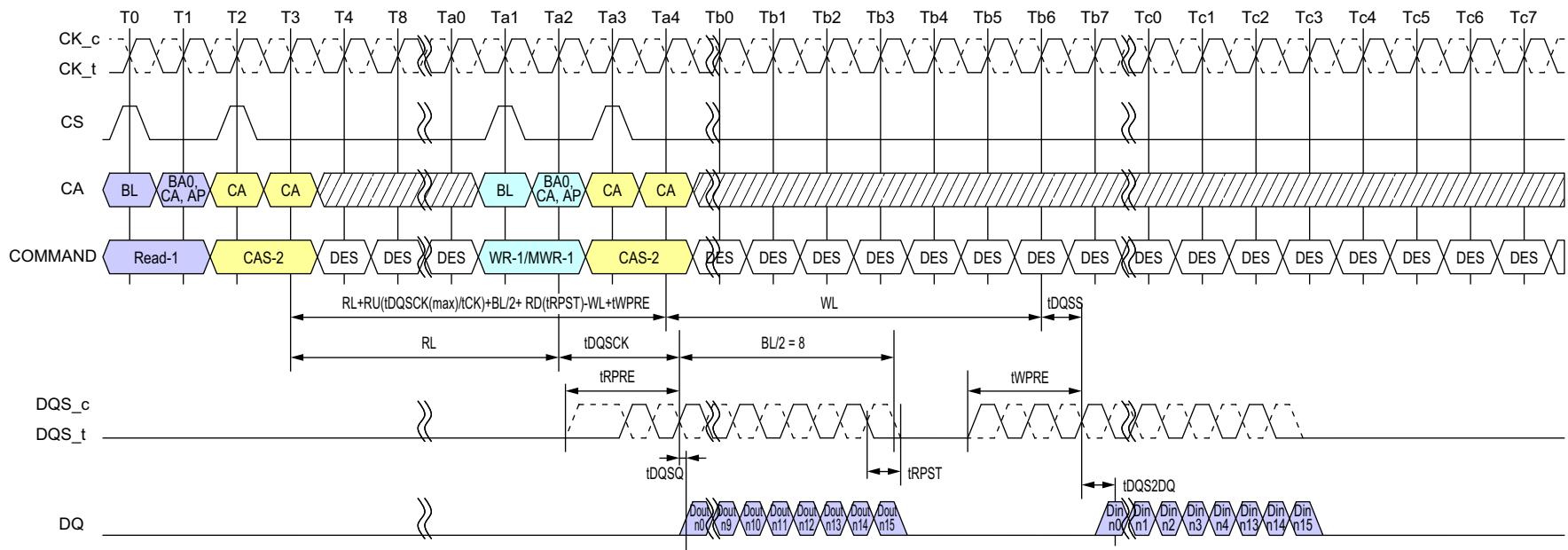


Figure 10 — Burst Read Timing



Note

1. BL=16, Read Preamble = Toggle, Read Postamble = 0.5nCK, Write Preamble = 2nCK, Write Postamble = 0.5nCK, DQ/DQS: VSSQ termination
2. Dout n = data-out from column n and Din n = data-in to column n
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 11 — Burst Read followed by Burst Write or Burst Mask Write

The minimum time from a Burst Read command to a Write or MASK WRITE command is defined by the read latency (RL) and the burst length (BL). Minimum READ-to-WRITE or MASK WRITE latency is $RL+RU(tDQSK(\max)/tCK)+BL/2+RD(tRPST)-WL+tWPRE$.

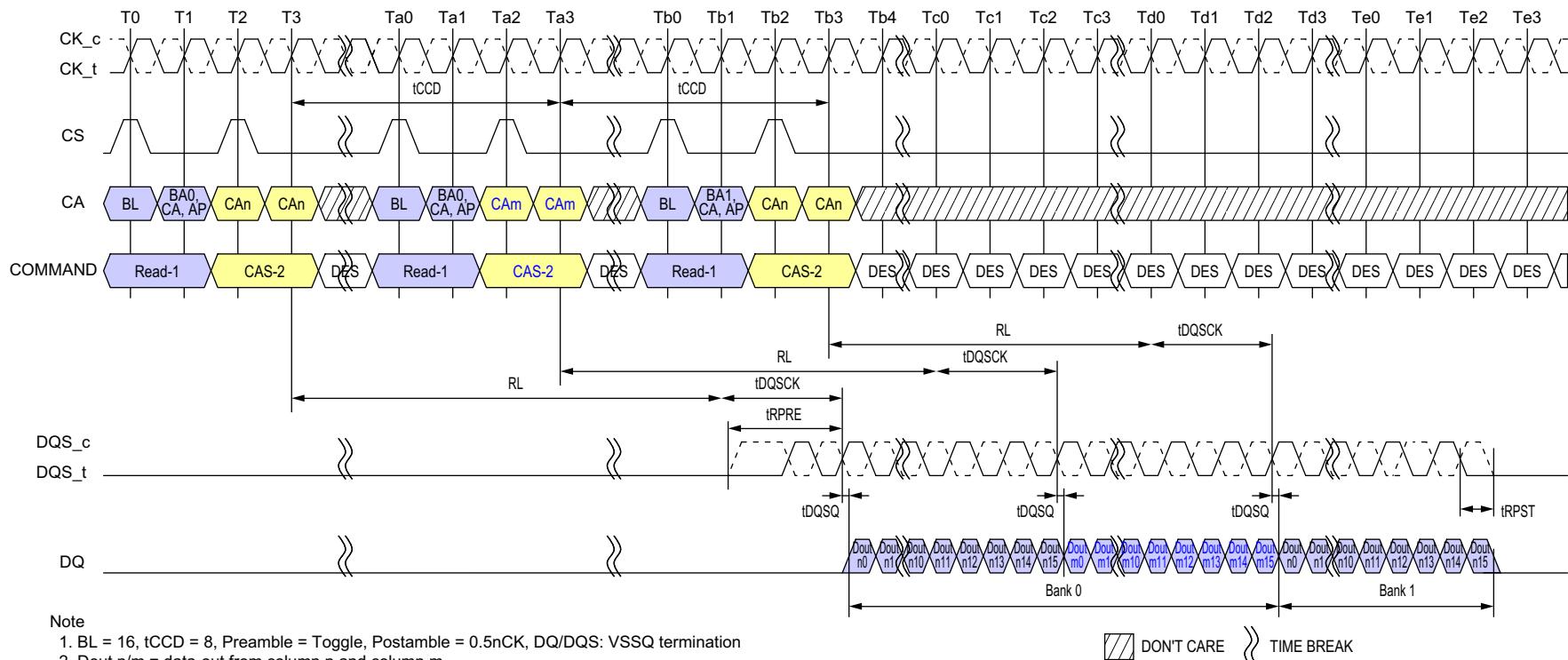


Figure 12 — Seamless Burst Read

The seamless Burst READ operation is supported by placing a READ command at every tCCD(Min) interval for BL16 (or every $2 \times$ tCCD(Min) for BL32). The seamless Burst READ can access any open bank.

4.7 Read Timing

The read timing is shown in Figure 13.

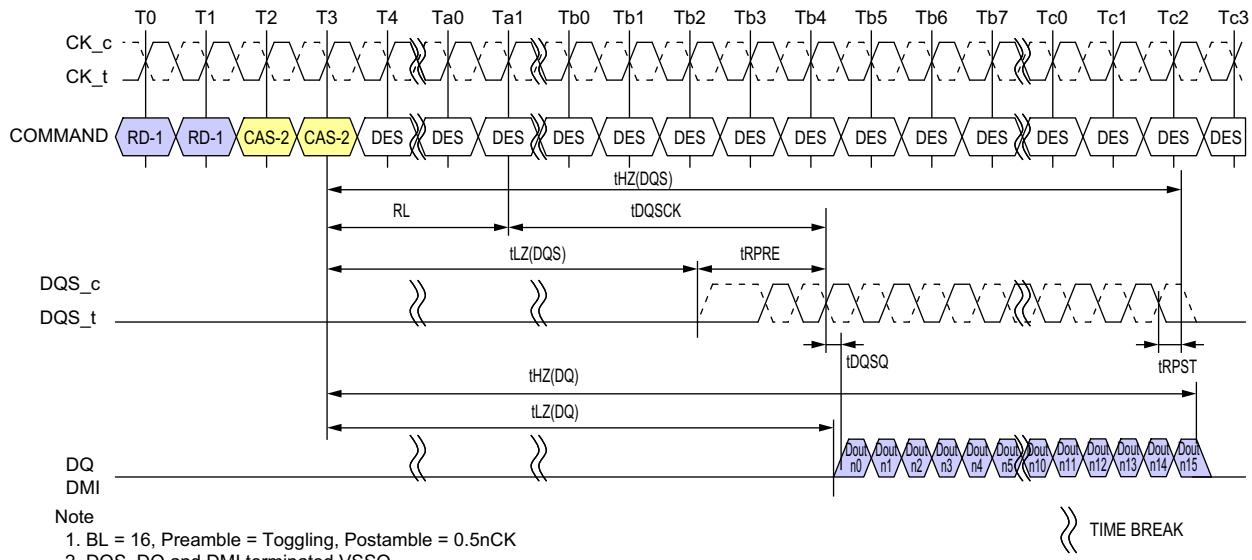


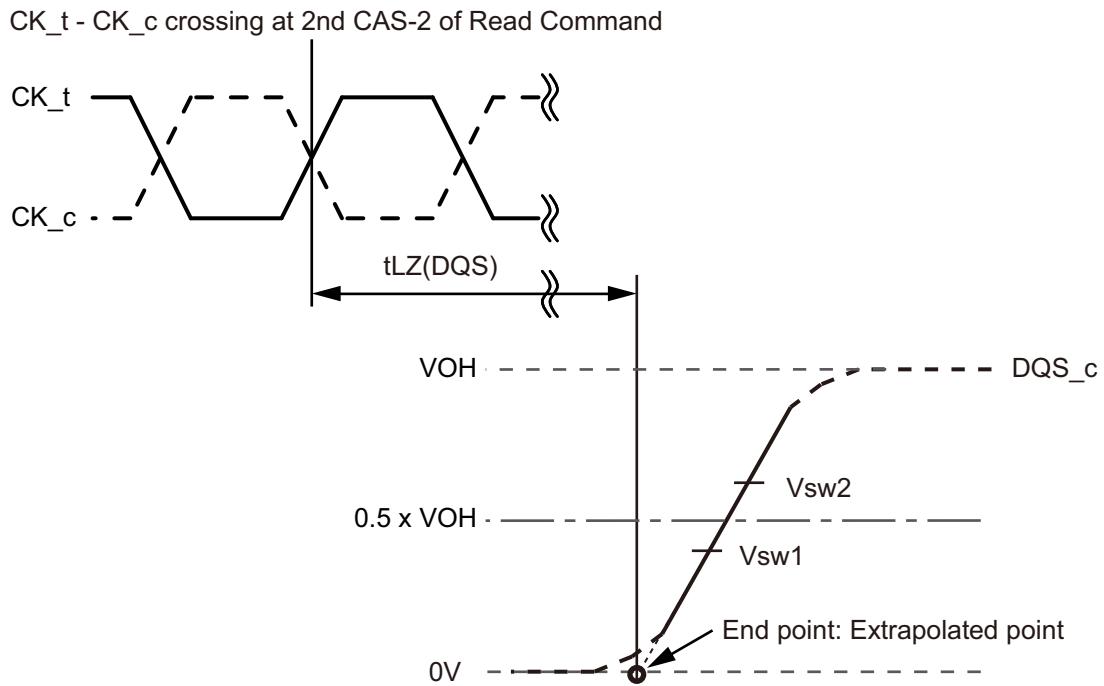
Figure 13 — Read Timing

4.6 tLZ(DQS), tLZ(DQ), tHZ(DQS), tHZ(DQ) Calculation

tHZ and tLZ transitions occur in the same time window as valid data transitions. These parameters are referenced to a specific voltage level that specifies when the device output is no longer driving tHZ(DQS) and tHZ(DQ), or begins driving tLZ(DQS), tLZ(DQ). The actual voltage measurement points are not critical as long as the calculation is consistent. The parameters tLZ(DQS), tLZ(DQ), tHZ(DQS), and tHZ(DQ) are defined as single ended.

This section shows a method to calculate the point when the device is no longer driving tHZ(DQS) and tHZ(DQ), or begins driving tLZ(DQS), tLZ(DQ), by measuring the signal at two different voltages. The actual voltage measurement points are not critical as long as the calculation is consistent. The parameters tLZ(DQS), tLZ(DQ), tHZ(DQS), and tHZ(DQ) are defined as single ended.

4.7.1 tLZ(DQS) and tHZ(DQS) Calculation for ATE(Automatic Test Equipment)

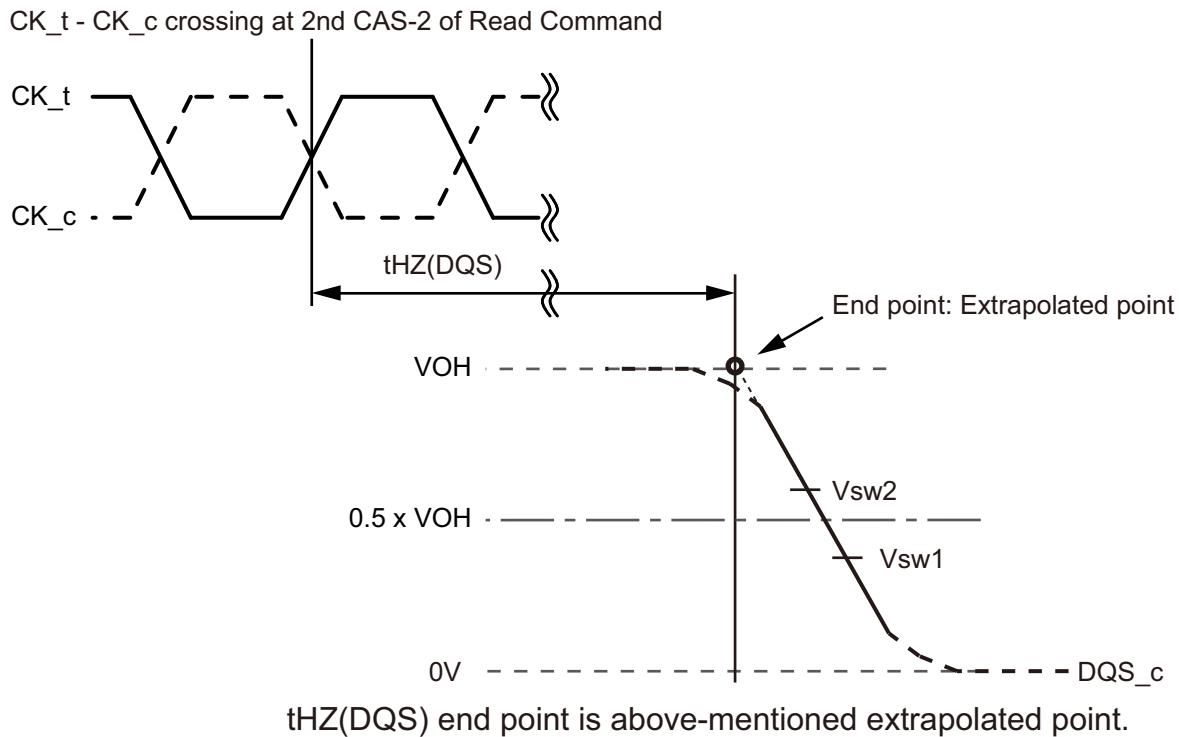


$t_{LZ}(DQS)$ end point is above-mentioned extrapolated point.

Note

1. Conditions for Calibration: Pull Down Driver $R_{on} = 40\text{ohm}$, $VOH = VDDQ/3$
2. Termination condition for DQS_t and DQS_C = 50ohm to VSSQ.
3. The VOH level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances.
Use the actual VOH value for t_{HZ} and t_{LZ} measurements.

Figure 14 — $t_{LZ}(DQS)$ method for calculating transitions and end point



Note

1. Conditions for Calibration: Pull Down Driver Ron = 40ohm, VOH = VDDQ/3
2. Termination condition for DQS_t and DQS_C = 50ohm to VSSQ.
3. The VOH level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances.
Use the actual VOH value for tHZ and tLZ measurements.

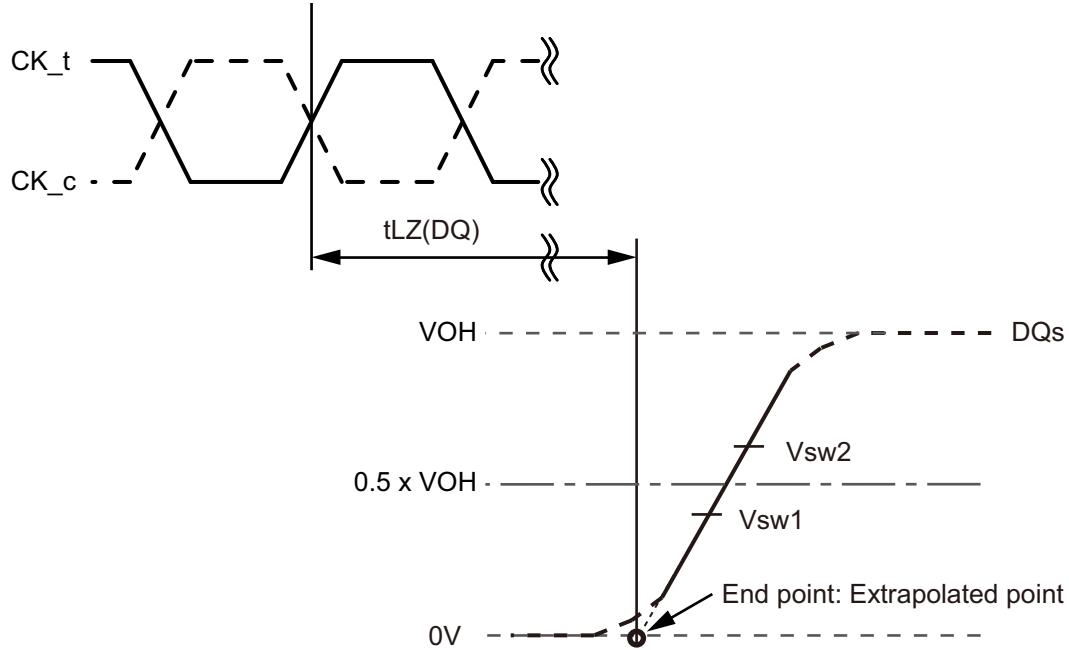
Figure 15 — tHZ(DQS) method for calculating transitions and end point

Table 18 — Reference Voltage for tLZ(DQS), tHZ(DQS) Timing Measurements

| Measured Parameter | Measured Parameter Symbol | Vsw1[V] | Vsw2[V] | Note |
|---|---------------------------|-----------|-----------|------|
| DQS _c low-impedance time from CK _t , CK _c | tLZ(DQS) | 0.4 x VOH | 0.6 x VOH | |
| DQS _c high impedance time from CK _t , CK _c | tHZ(DQS) | 0.4 x VOH | 0.6 x VOH | |

4.7.2 tLZ(DQ) and tHZ(DQ) Calculation for ATE(Automatic Test Equipment)

CK_t - CK_c crossing at 2nd CAS-2 of Read Command

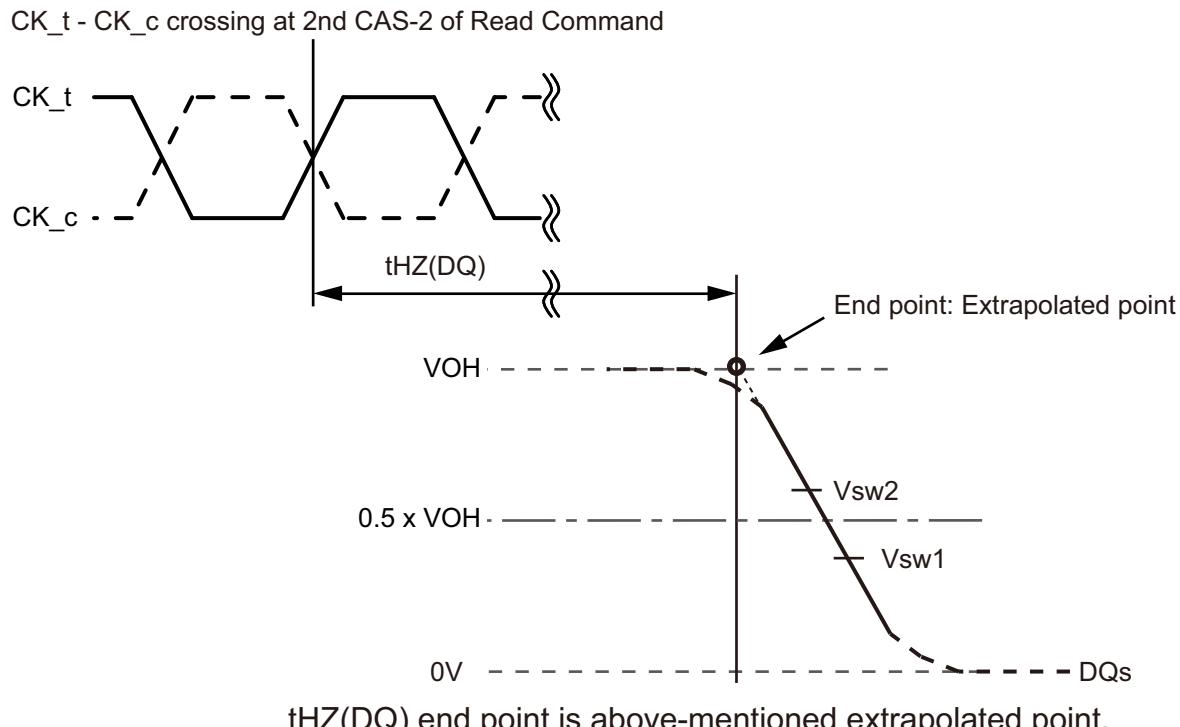


tLZ(DQ) end point is above-mentioned extrapolated point.

Note

1. Conditions for Calibration: Pull Down Driver Ron = 40ohm, VOH = VDDQ/3
2. Termination condition for DQ and DMI = 50ohm to VSSQ.
3. The VOH level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances.
Use the actual VOH value for tHZ and tLZ measurements.

Figure 16 — tLZ(DQ) method for calculating transitions and end point



Note

1. Conditions for Calibration: Pull Down Driver Ron = 40ohm, VOH = VDDQ/3
2. Termination condition for DQ and DMI = 50ohm to VSSQ.
3. The VOH level depends on MR22 OP[2:0] and MR3 OP[0] settings as well as device tolerances.
Use the actual VOH value for tHZ and tLZ measurements.

Figure 17 — tHZ(DQ) method for calculating transitions and end point

Table 19 — Reference Voltage for tLZ(DQ), tHZ(DQ) Timing Measurements

| Measured Parameter | Measured Parameter Symbol | Vsw1[V] | Vsw2[V] | Note |
|---|---------------------------|-----------|-----------|------|
| DQ low-impedance time from CK _t , CK _c | tLZ(DQ) | 0.4 x VOH | 0.6 x VOH | |
| DQ high impedance time from CK _t , CK _c | tHZ(DQ) | 0.4 x VOH | 0.6 x VOH | |

4.7.3 tRPRE Calculation for ATE(Automatic Test Equipment)

The method for calculating differential pulse widths for tRPRE is shown in Figure 18 and Figure 19.

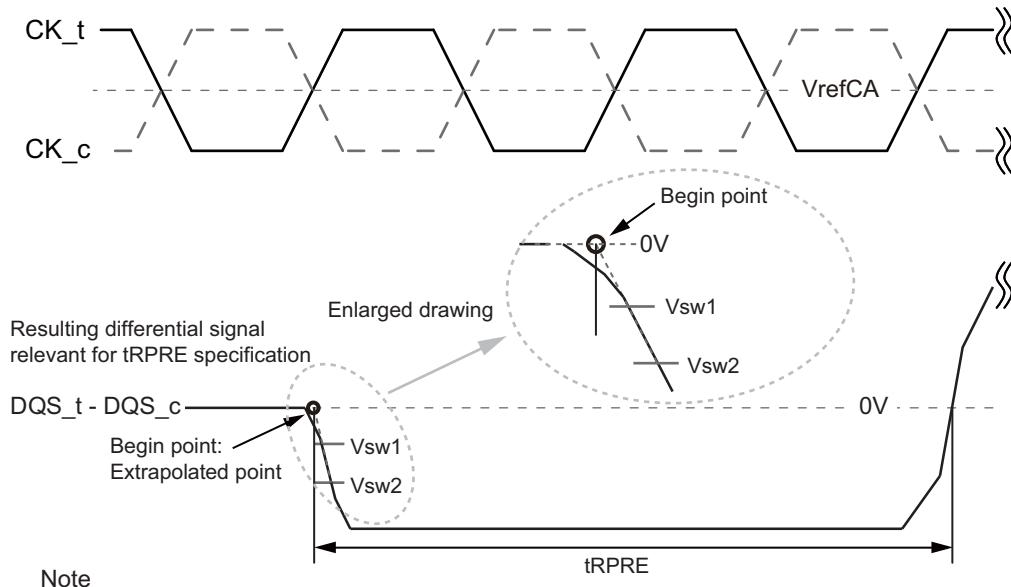


Figure — 18 Method for calculating tRPRE transitions and endpoints

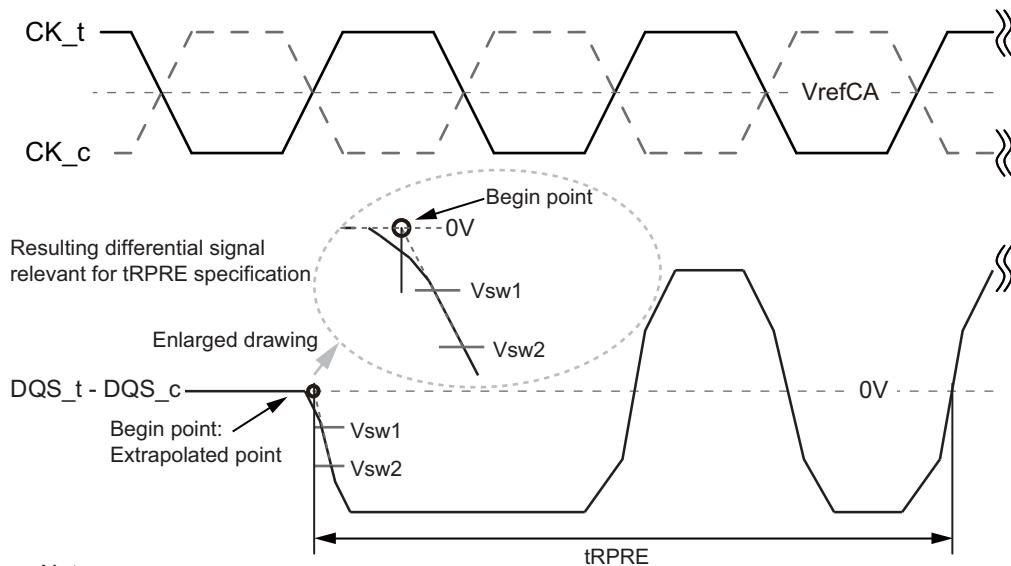


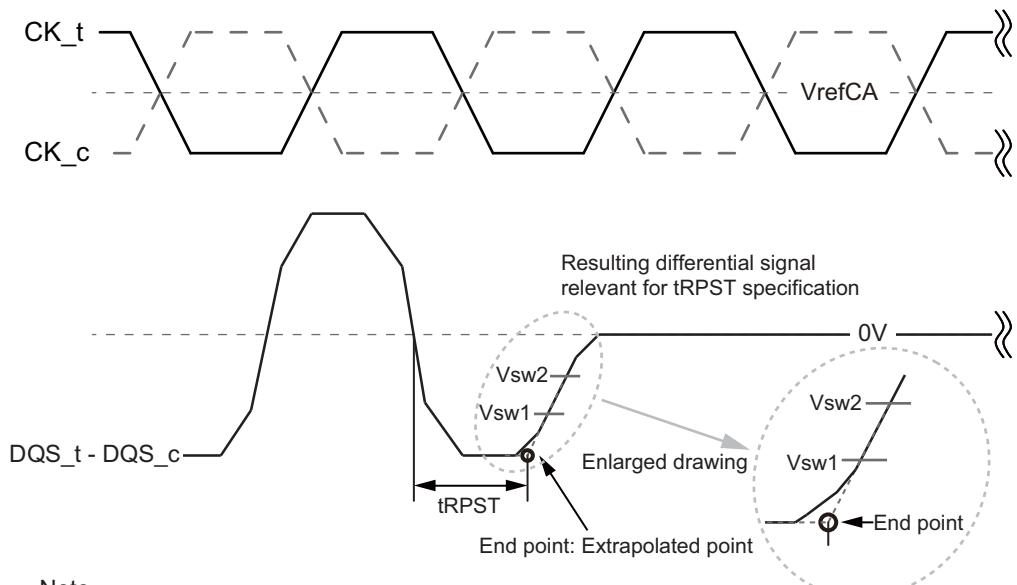
Figure — 19 Method for calculating tRPRE transitions and endpoints

Table 20 — Reference Voltage for tRPRE Timing Measurements

| Measured Parameter | Measured Parameter Symbol | Vsw1[V] | Vsw2[V] | Note |
|--|---------------------------|--------------|--------------|------|
| DQS _t , DQS _c differential Read Preamble | tRPRE | -(0.3 x VOH) | -(0.7 x VOH) | |

4.7.4 tRPST Calculation for ATE(Automatic Test Equipment)

The method for calculating differential pulse widths for tRPST is shown in Figure 20.



Note

1. Conditions for Calibration: Pull Down Driver Ron = 40ohm, VOH = VDDQ/3.
2. Termination condition for DQS_t, DQS_c, DQ and DMI = 50ohm to VSSQ.
3. Read Postamble: 0.5tCK
4. The method for calculating differential pulse widths for 1.5 tCK Postamble is same as 0.5 tCK Postamble.

Figure — 20 Method for calculating tRPST transitions and endpoints

Table 21 — Reference Voltage for tRPST Timing Measurements

| Measured Parameter | Measured Parameter Symbol | Vsw1[V] | Vsw2[V] | Note |
|--|---------------------------|--------------|--------------|------|
| DQS_t, DQS_c differential Read Postamble | tRPST | -(0.7 x VOH) | -(0.3 x VOH) | |

Table 22 — Read AC Timing

4.8 tDQSCK Timing Table

Table 23 — tDQSCK Timing Table

| Parameter | Symbol | Min | Max | Unit | Notes |
|---|-------------|-----|-----|-------|-------|
| DQS Output Access Time from CK_t/CK_c | tDQSCK | 1.5 | 3.5 | ns | 1 |
| DQS Output Access Time from CK_t/CK_c - Temperature Variation | tDQSCK_temp | - | 4 | ps/°C | 2 |
| DQS Output Access Time from CK_t/CK_c - Voltage Variation | tDQSCK_volt | - | 7 | ps/mV | 3 |

NOTE 1 Includes DRAM process, voltage and temperature variation. It includes the AC noise impact for frequencies > 20 MHz and max voltage of 45 mV pk-pk from DC-20 MHz at a fixed temperature on the package. The voltage supply noise must comply to the component Min-Max DC Operating conditions.

NOTE 2 tDQSCK_temp max delay variation as a function of Temperature.

NOTE 3 tDQSCK_volt max delay variation as a function of DC voltage variation for V_{DDQ} and V_{DD2} . tDQSCK_volt should be used to calculate timing variation due to V_{DDQ} and V_{DD2} noise < 20 MHz. Host controller do not need to account for any variation due to V_{DDQ} and V_{DD2} noise > 20 MHz. The voltage supply noise must comply to the component Min-Max DC Operating conditions. The voltage variation is defined as the Max[abs{tDQSCKmin@V1-tDQSCKmax@V2}, abs{tDQSCKmax@V1-tDQSCKmin@V2}]/abs{V1-V2}. For tester measurement $V_{DDQ} = V_{DD2}$ is assumed.

4.8.1 CK to DQS Rank to Rank variation

Table 24 — tDQSCK_rank2rank Timing Table

| Parameter | Symbol | Min/Max | | | | | | | Unit | Note |
|----------------------------------|------------------|---------|------|------|------|------|------|------|------|------|
| Read Timing | | | 1600 | 1866 | 2133 | 2400 | 3200 | 4267 | | |
| CK to DQS Rank to Rank variation | tDQSCK_rank2rank | Max | | | | | | 1.0 | ns | 1,2 |

NOTE 1 The same voltage and temperature are applied to tDQS2CK_rank2rank.

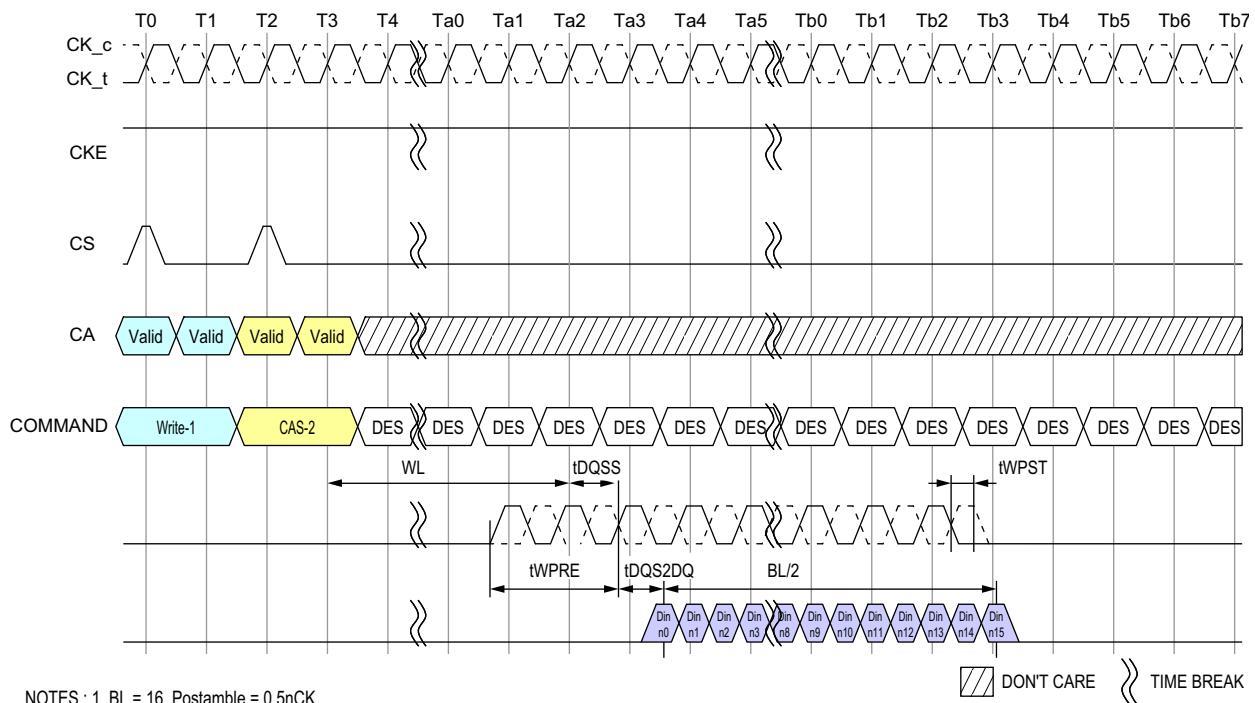
NOTE 2 tDQSCK_rank2rank parameter is applied to multi-ranks per byte lane within a package consisting of the same design dies.

4.9 Write Preamble and Postamble

The DQS strobe for the LPDDR4-SDRAM requires a pre-amble prior to the first latching edge (the rising edge of DQS_t with DATA "valid"), and it requires a post-amble after the last latching edge. The pre-amble and post-amble lengths are set via mode register writes (MRW).

For WRITE operations, a $2*t_{CK}$ pre-amble is required at all operating frequencies.

LPDDR4 will have a DQS Write post-amble of $0.5*t_{CK}$ or extended to $1.5*t_{CK}$. Standard DQS post-amble will be $0.5*t_{CK}$ driven by the memory controller for Writes. A mode register setting instructs the DRAM to drive an additional (extended) one cycle DQS Write post-amble. The drawings below show examples of DQS Write post-amble for both standard (t_{WPST}) and extended (t_{WPSTE}) post-amble operation.



NOTES : 1. BL = 16, Postamble = 0.5nCK

2. DQS and DQ terminated VSSQ

3. DQS_t/DQS_c is "don't care" prior to the start of tWPRE.

No transition of DQS is implied, as DQS_t/DQS_c can be HIGH, LOW, or HI-Z prior to tWPRE.

Figure 21 — DQS Write Preamble and Postamble: 0.5nCK Postamble

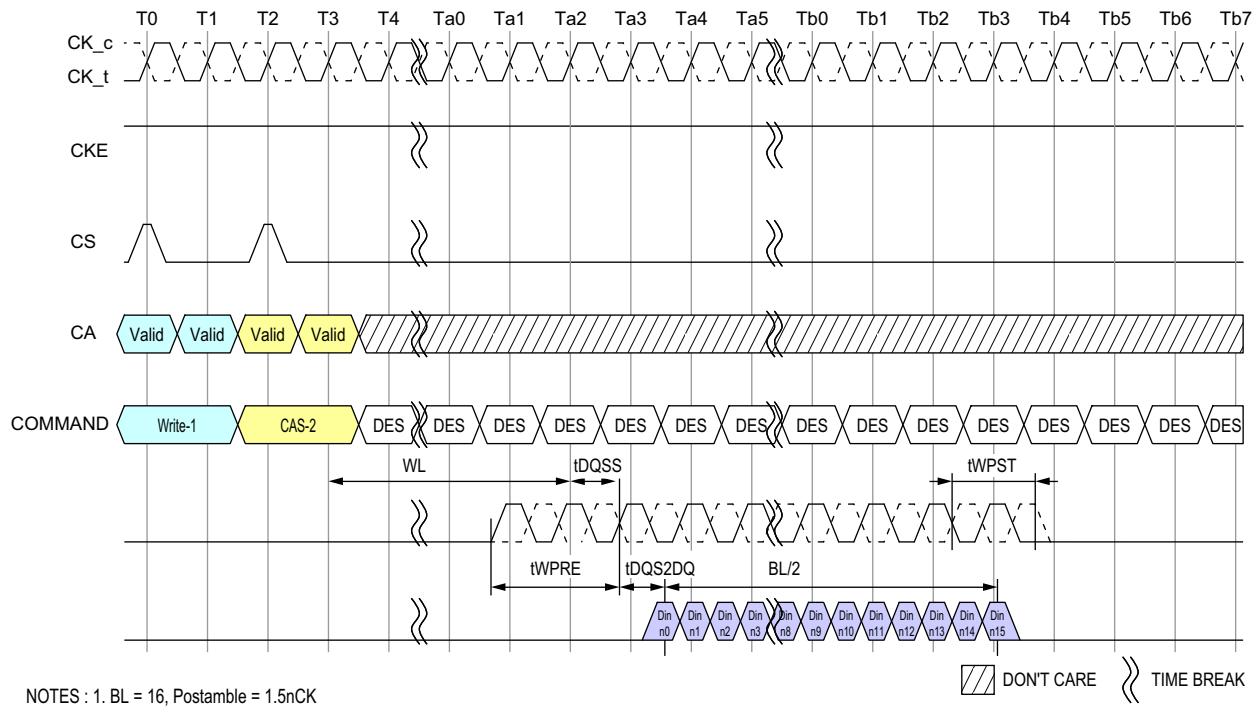
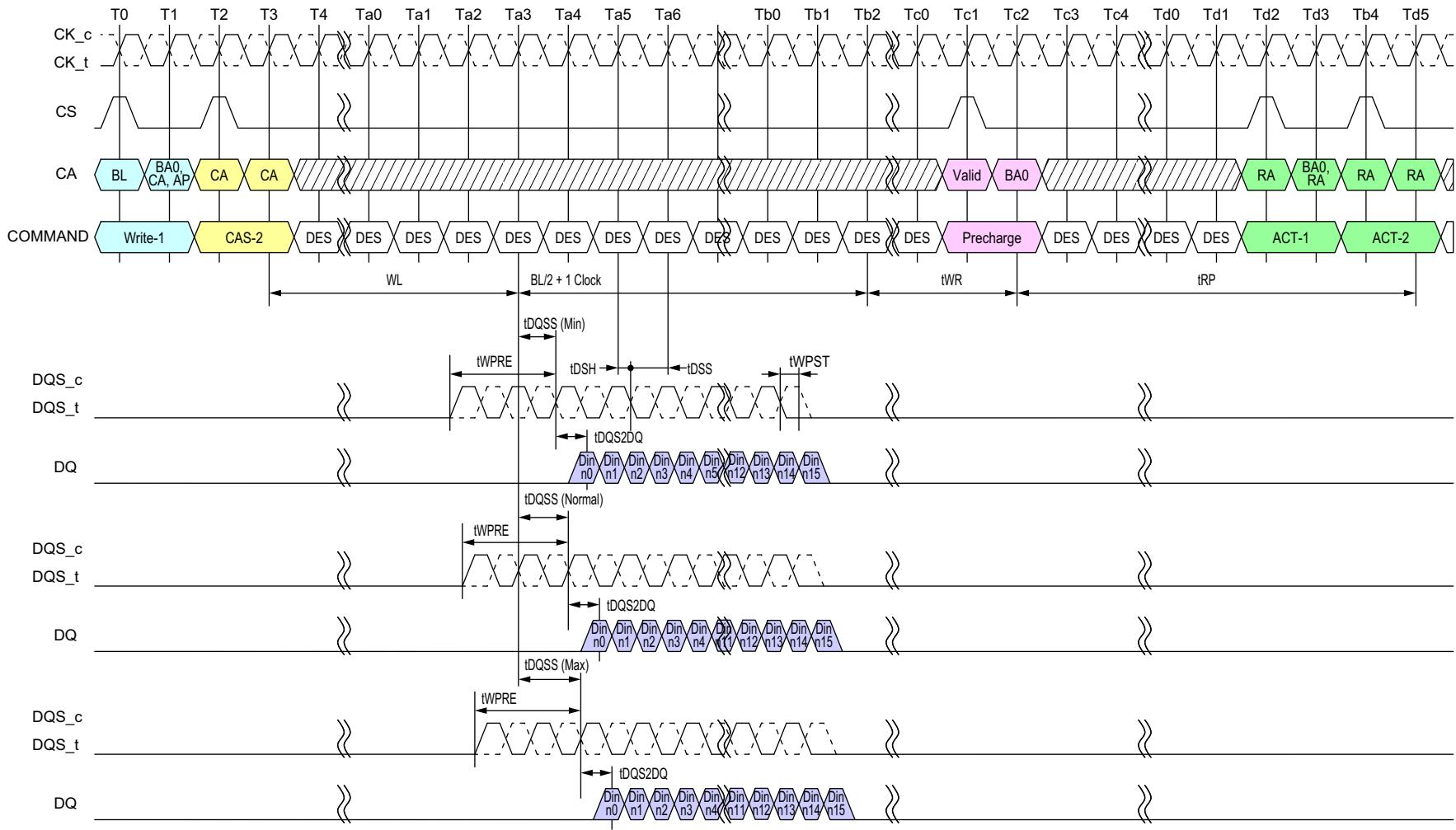


Figure 22 — DQS Write Preamble and Postamble: 1.5nCK Postamble

4.10 Burst Write Operation

A burst WRITE command is initiated with CS, and CA[5:0] asserted to the proper state at the rising edge of CK, as defined by the Command Truth Table. Column addresses C[3:2] should be driven LOW for Burst WRITE commands, and column addresses C[1:0] are not transmitted on the CA bus (and are assumed to be zero), so that the starting column burst address is always aligned with a 32B boundary. The write latency (WL) is defined from the last rising edge of the clock that completes a write command (Ex: the second rising edge of the CAS-2 command) to the rising edge of the clock from which tDQSS is measured. The first valid "latching" edge of DQS must be driven $WL * tCK + tDQSS$ after the rising edge of Clock that completes a write command.

The LPDDR4-SDRAM uses an un-matched DQS-DQ path for lower power, so the DQS-strobe must arrive at the SDRAM ball prior to the DQ signal by the amount of tDQS2DQ. The DQS-strobe output is driven tWPRE before the first valid rising strobe edge. The tWPRE pre-amble is required to be $2 \times tCK$. The DQS strobe must be trained to arrive at the DQ pad center-aligned with the DQ-data. The DQ-data must be held for tDIVW (data input valid window) and the DQS must be periodically trained to stay centered in the tDIVW window to compensate for timing changes due to temperature and voltage variation. Burst data is captured by the SDRAM on successive edges of DQS until the 16 or 32 bit data burst is complete. The DQS-strobe must remain active (toggling) for tWPST (WRITE post-amble) after the completion of the burst WRITE. After a burst WRITE operation, tWR must be satisfied before a PRECHARGE command to the same bank can be issued. Pin input timings are measured relative to the cross point of DQS_t and DQS_c.

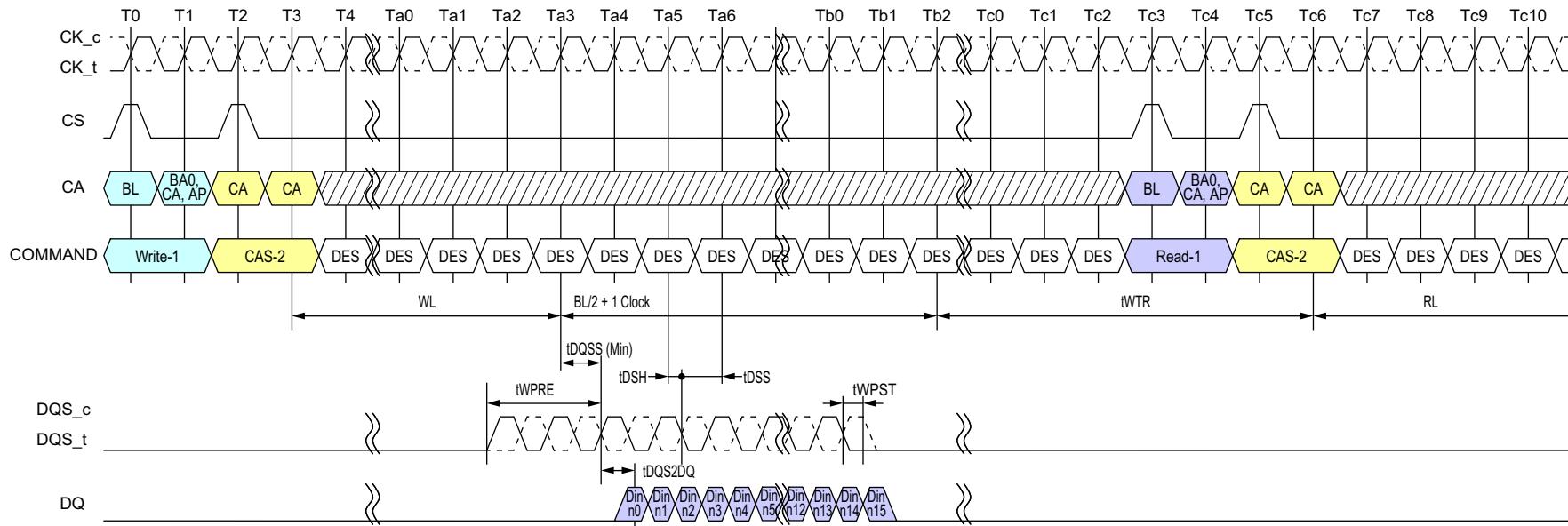


Note

1. BL=16, Write Postamble = 0.5nCK, DQ/DQS: VSSQ termination
2. Din n = data-in to columnn n
3. The minimum number of clock cycles from the burst write command to the burst read command for any bank is $[WL + 1 + BL/2 + RU(tWR/tCK)]$.
4. tWR starts at the rising edge of CK after the last latching edge of DQS.
5. DES commands are shown for ease of illustration; other commands may be valid at these times.

DON'T CARE TIME BREAK

Figure 23 - Burst Write Operation



Note

1. BL=16, Write Postamble = 0.5nCK, DQ/DQS: VSSQ termination
 2. Din n = data-in to columnm n
 3. The minimum number of clock cycles from the burst write command to the burst read command for any bank is $[WL + 1 + BL/2 + RU(tWTR/tCK)]$.
 4. tWTR starts at the rising edge of CK after the last latching edge of DQS.
 5. DES commands are shown for ease of illustration; other commands may be valid at these times.



Figure 24 - Burst Write Followed by Burst Read

4.11 Write Timing

The write timing is shown in Figure 25.

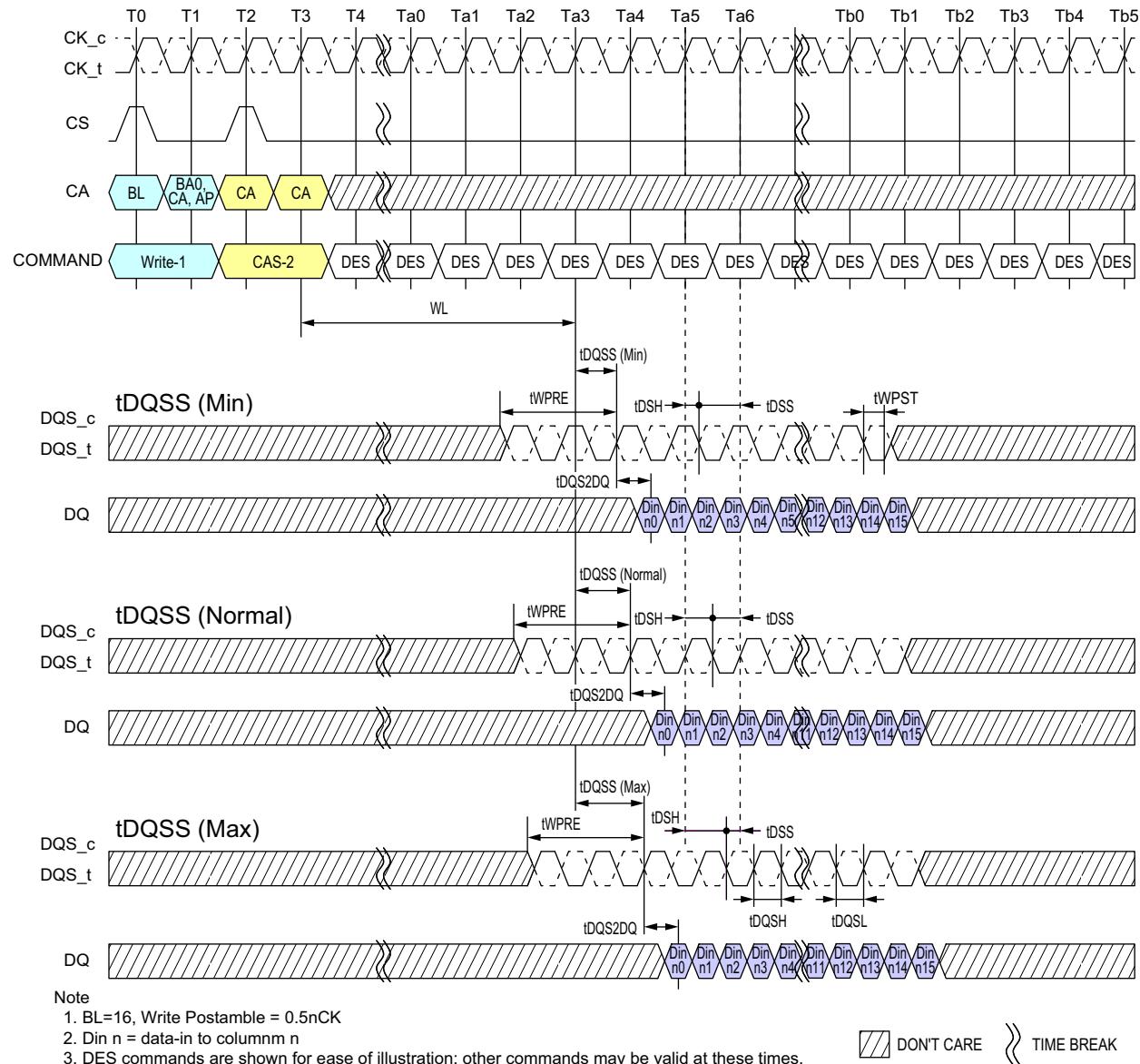
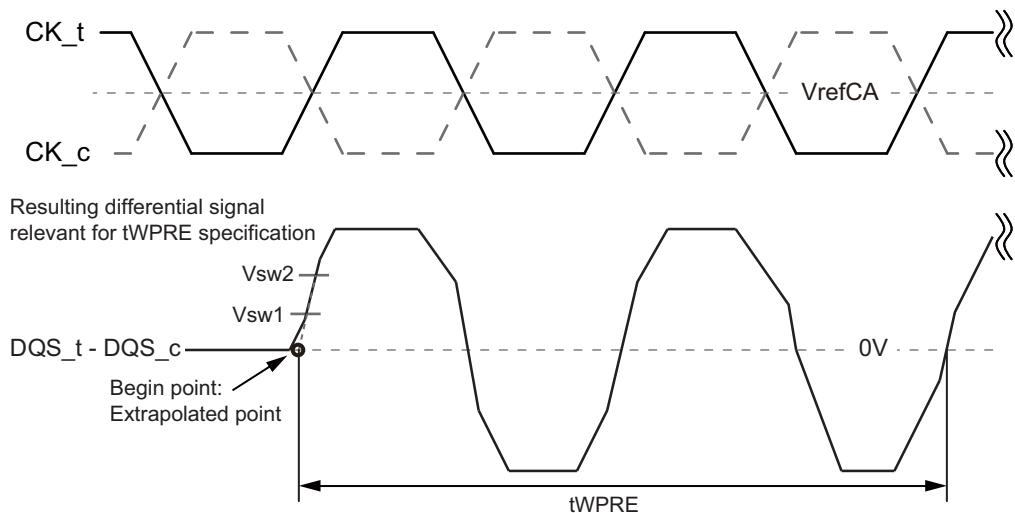


Figure 25 — Write Timing

4.11.1 tWPRE Calculation for ATE(Automatic Test Equipment)

The method for calculating differential pulse widths for tWPRE is shown in Figure 26.



Note

- Termination condition for DQS_t, DQS_c, DQ and DMI = 50ohm to VSSQ.

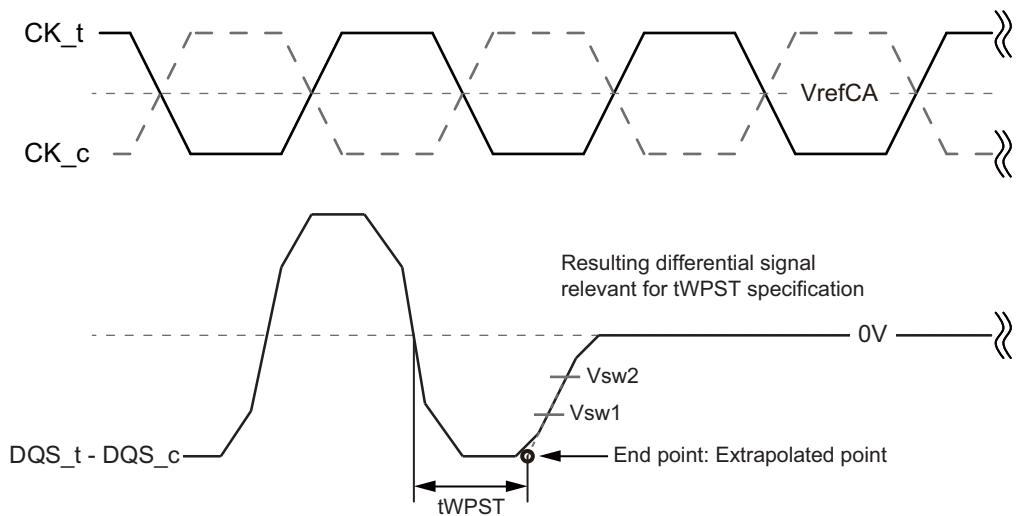
Figure 26 — Method for calculating tWPRE transitions and endpoints

Table 25 — Reference Voltage for tWPRE Timing Measurements

| Measured Parameter | Measured Parameter Symbol | V _{sw1} [V] | V _{sw2} [V] | Note |
|---|---------------------------|----------------------|----------------------|------|
| DQS _t , DQS _c differential WRITE Preamble | tWPRE | VIHL_AC x 0.3 | VIHL_AC x 0.7 | |

4.11.2 tWPST Calculation for ATE(Automatic Test Equipment)

The method for calculating differential pulse widths for tWPST is shown in Figure 27.



Note

1. Termination condition for DQS_t, DQS_c, DQ and DMI = 50ohm to VSSQ.
2. Write Postamble: 0.5tCK
3. The method for calculating differential pulse widths for 1.5 tCK Postamble is same as 0.5 tCK Postamble.

Figure 27 — Method for calculating tWPST transitions and endpoints

Table 26 — Reference Voltage for tWPST Timing Measurements

| Measured Parameter | Measured Parameter Symbol | Vsw1[V] | Vsw2[V] | Note |
|---|---------------------------|-------------------|-------------------|------|
| DQS_t, DQS_c differential WRITE Postamble | tWPST | - (VIHL_AC x 0.7) | - (VIHL_AC x 0.3) | |

Table 27 — Write AC Timing

| Parameter | Symbol | Min/Max | Data Rate | | | | | | | | Unit | Note |
|------------------------------------|--------|---------|-----------|------|------|------|------|------|------|------|----------|------|
| Write Timing | | | 533 | 1066 | 1600 | 2133 | 2667 | 3200 | 3733 | 4267 | | |
| Write command to 1st DQS latching | tDQSS | Min | 0.75 | | | | | | | | tCK(avg) | |
| | | Max | 1.25 | | | | | | | | | |
| DQS input high-level | tDQSH | Min | 0.4 | | | | | | | | tCK(avg) | |
| DQS input low-level width | tDQSL | Min | 0.4 | | | | | | | | tCK(avg) | |
| DQS falling edge to CK setup time | tDSS | Min | 0.2 | | | | | | | | tCK(avg) | |
| DQS falling edge hold time from CK | tDSH | Min | 0.2 | | | | | | | | tCK(avg) | |
| Write preamble | tWPRE | Min | 1.8 | | | | | | | | tCK(avg) | |
| 0.5 tCK Write postamble | tWPST | Min | 0.4 | | | | | | | | tCK(avg) | 1 |
| 1.5 tCK Write postamble | tWPST | Min | 1.4 | | | | | | | | tCK(avg) | 1 |

NOTE 1 The length of Write Postamble depends on MR3 OP1 setting.

4.12 Read and Write Latencies

Table 28 — Read and Write Latencies

| Read Latency | | Write Latency | | nWR | nRTP | Lower Clock Frequency Limit [MHz] | Upper Clock Frequency Limit [MHz] | Notes |
|--------------|--------|---------------|-------|-----|------|-----------------------------------|-----------------------------------|-----------------|
| No DBI | w/ DBI | Set A | Set B | | | | | |
| 6 | 6 | 4 | 4 | 6 | 8 | 10 | 266 | 1,2,3,4 ,5,6 |
| 10 | 12 | 6 | 8 | 10 | 8 | 266 | 533 | |
| 14 | 16 | 8 | 12 | 16 | 8 | 533 | 800 | |
| 20 | 22 | 10 | 18 | 20 | 8 | 800 | 1066 | |
| 24 | 28 | 12 | 22 | 24 | 10 | 1066 | 1333 | |
| 28 | 32 | 14 | 26 | 30 | 12 | 1333 | 1600 | |
| 32 | 36 | 16 | 30 | 34 | 14 | 1600 | 1866 | |
| 36 | 40 | 18 | 34 | 40 | 16 | 1866 | 2133 | |

NOTE 1 The LPDDR4 SDRAM device should not be operated at a frequency above the Upper Frequency Limit, or below the Lower Frequency Limit, shown for each RL, WL, nRTP, or nWR value.

NOTE 2 DBI for Read operations is enabled in MR3 OP[6]. When MR3 OP[6]=0, then the "No DBI" column should be used for Read Latency. When MR3 OP[6]=1, then the "w/DBI" column should be used for Read Latency.

NOTE 3 Write Latency Set "A" and Set "B" is determined by MR2 OP[6]. When MR2 OP[6]=0, then Write Latency Set "A" should be used. When MR2 OP[6]=1, then Write Latency Set "B" should be used.

NOTE 4 The programmed value of nWR is the number of clock cycles the LPDDR4 SDRAM device uses to determine the starting point of an internal Precharge operation after a Write burst with AP (Auto Pre-charge). It is determined by RU(tWR/tCK).

NOTE 5 The programmed value of nRTP is the number of clock cycles the LPDDR4 SDRAM device uses to determine the starting point of an internal Precharge operation after a Read burst with AP (Auto-Precharge). It is determined by RU(tRTP/tCK).

NOTE 6 nRTP shown in this table is valid for BL16 only. For BL32, the SDRAM will add 8 clocks to the nRTP value before starting a precharge.

4.13 Write and Masked Write operation DQS controls (WDQS Control)

LPDDR4-SDRAMs support write and masked write operations with the following DQS controls. Before and after Write and Masked Write operations are issued, DQS_t/DQS_c is required to have a sufficient voltage gap to make sure the write buffers operating normally without any risk of metastability.

The LPDDR4-SDRAM is supported by either of two WDQS control modes (4.13.1, and 4.13.2).

Mode 1: Read Based Control

Mode 2 : WDQS_on / WDQS_off definition based control

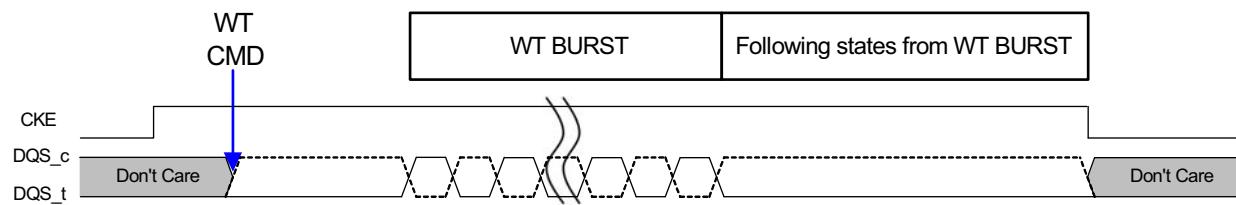
Regardless of ODT enable/disable, WDQS related timing described in 4.13 does not allow any change of existing command timing constraints for all read/write operations. In case of any conflict or ambiguity on the command timing constraints caused by what is specified in 4.13, the specifications defined in 4.38, Table 74 (or 4.13.1, and 4.13.2) should have higher priority than WDQS control requirements.

Some legacy products may not provide WDQS control described below. However, in order to prevent the write preamble related failure, it is strongly recommended to support either of two WDQS controls to LPDDR4-SDRAMs. In the case of legacy SoC which may not provide WDQS control modes, it is required to consult DRAM vendors to guarantee the write / masked write operation appropriately.

4.13.1 WDQS Control Mode 1 - Read Based Control

The LPDDR4-SDRAM needs to be guaranteed the differential WDQS, but the differential WDQS can be controlled as described below. WDQS control requirements here can be ignored while differential read DQS is operated or while DQS hands over from Read to Write and vice versa.

1. At the time a write / masked write command is issued, SoC makes the transition from driving DQS_c high to driving differential DQS_t/DQS_c, followed by normal differential burst on DQS pins.
2. At the end of postamble of write /masked write burst, SoC resumes driving DQS_c high through the subsequent states except for DQS toggling and DQS turn around time of WT-RD and RD-WT as long as CKE is high.
3. When CKE is low, the state of DQS_t and DQS_c is allowed to be “Don’t Care”.



4.13.2 WDQS Control Mode 2 - WDQS_on/off

After write / masked write command is issued, DQS_t and DQS_c required to be differential from WDQS_on, and DQS_t and DQS_c can be “Don’t Care” status from WDQS_off of write / masked write command. When ODT is enabled, WDQS_on and WDQS_off timing is located in the middle of the operations. When host disables ODT, WDQS_on and WDQS_off constraints conflict with tRTW. The timing does not conflict when ODT is enabled because WDQS_on and WDQS_off timing is covered in ODTLon and ODTLoff. However, regardless of ODT on/off, WDQS_on/off timing below does not change any command timing constraints for all read and write operations. In order to prevent the conflict, WDQS_on/off requirement can be ignored when WDQS_on/off timing is overlapped with read operation period including Read burst period and tRPST or overlapped with turn-around time (RD-WT or WT-RD). In addition, the period during DQS toggling caused by Read and Write can be counted as WDQS_on/off.

Parameters

- WDQS_on: the max delay from write / masked write command to differential DQS_t and DQS_c.
- WDQS_off : the min delay for DQS_t and DQS_c differential input after the last write / masked write command.
- WDQS_Exception : the period where WDQS_on and WDQS_off timing is overlapped with read operation or with DQS turn around (RD-WT, WT-RD).
 - WDQS_Exception @ ODT disable = max (WL-WDQS_on+tDQSTA- tWPRE - n*tCK, 0 tCK)
where RD to WT command gap = tRTW(min)@ODT disable + n*tCK
 - WDQS_Exception @ ODT enable = tDQSTA

Table 29 — WDQS_on / WDQS_off Definition

| WL | | nWR | nRTP | WDQS_on (max) | | WDQS_off (min) | | Lower Clock Frequency Limit (>) | Upper Clock Frequency Limit (≤) |
|-------|-------|-----|------|---------------|-------|----------------|-------|---------------------------------|---------------------------------|
| Set A | Set B | | | Set A | Set B | Set A | Set B | | |
| 4 | 4 | 6 | 8 | 0 | 0 | 15 | 15 | 10 | 266 |
| 6 | 8 | 10 | 8 | 0 | 0 | 18 | 20 | 266 | 533 |
| 8 | 12 | 16 | 8 | 0 | 6 | 21 | 25 | 533 | 800 |
| 10 | 18 | 20 | 8 | 4 | 12 | 24 | 32 | 800 | 1066 |
| 12 | 22 | 24 | 10 | 4 | 14 | 27 | 37 | 1066 | 1333 |
| 14 | 26 | 30 | 12 | 6 | 18 | 30 | 42 | 1333 | 1600 |
| 16 | 30 | 34 | 14 | 6 | 20 | 33 | 47 | 1600 | 1866 |
| 18 | 34 | 40 | 16 | 8 | 24 | 36 | 52 | 1866 | 2133 |
| nCK | nCK | nCK | nCK | nCK | nCK | nCK | nCK | MHz | MHz |

NOTE 1 WDQS_on/off requirement can be ignored when WDQS_on/off timing is overlapped with read operation period including Read burst period and tRPST or overlapped with turn-around time (RD-WT or WT-RD).

NOTE 2 The period during which DQS is toggling because of a Read or Write can be counted as part of the WDQS_on/off requirement.

Table 30 — WDQS_on / WDQS_off Allowable Variation Range

| | Min | Max | Unit |
|----------|-------|------|----------|
| WDQS_On | -0.25 | 0.25 | tCK(avg) |
| WDQS_Off | -0.25 | 0.25 | tCK(avg) |

Table 31 — DQS turn around parameter

| Parameter | Description | Value | Unit | Note |
|-----------|---|-------|------|------|
| tDQSTA | Turn-around time RDQS to WDQS for WDQS control case | TBD | - | 1 |

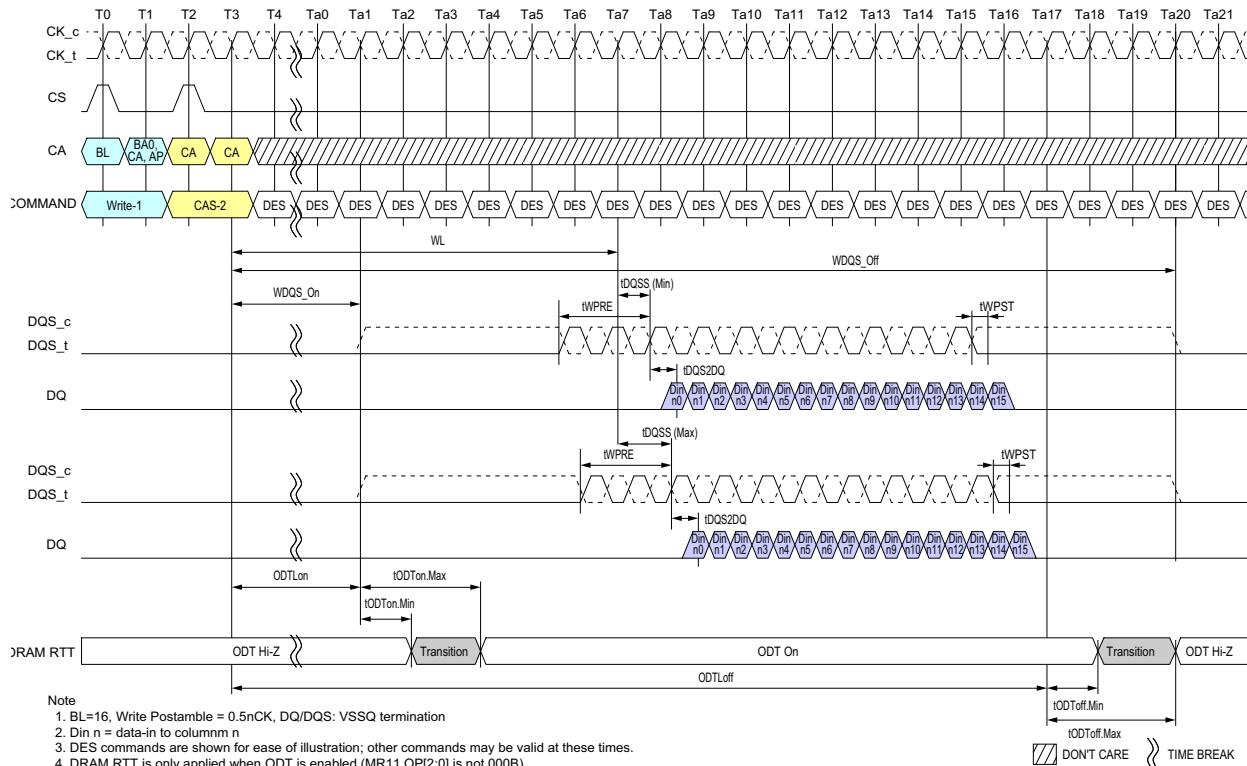


Figure 28 — Burst Write Operation

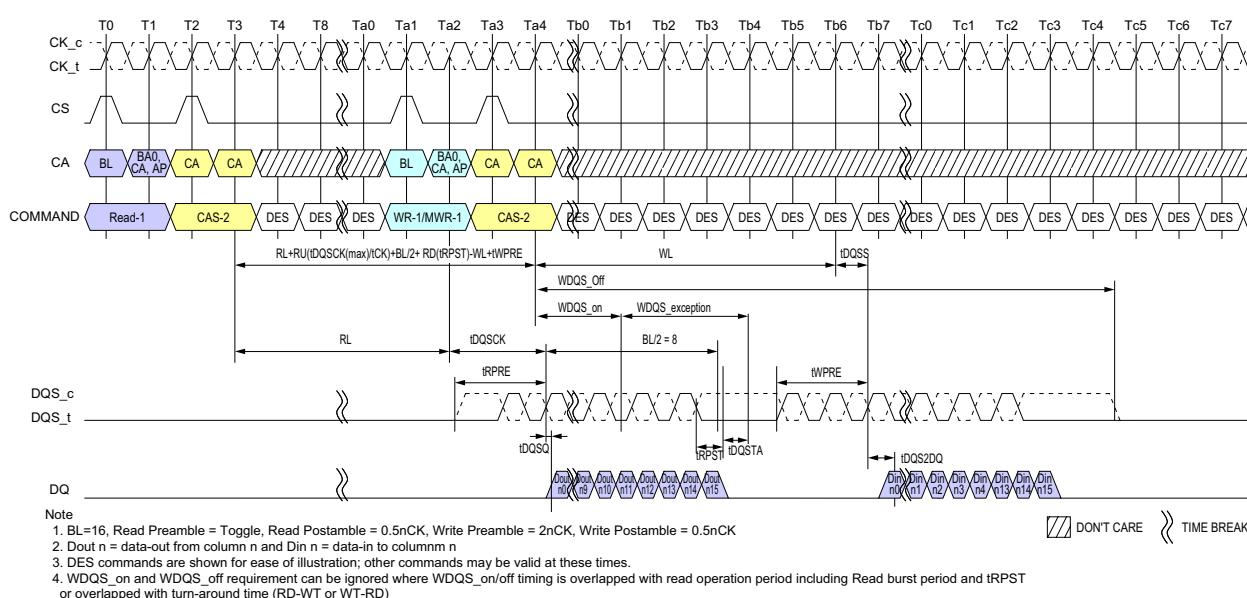


Figure 29 — Burst Read followed by Burst Write or Burst Mask Write (ODT Disable)

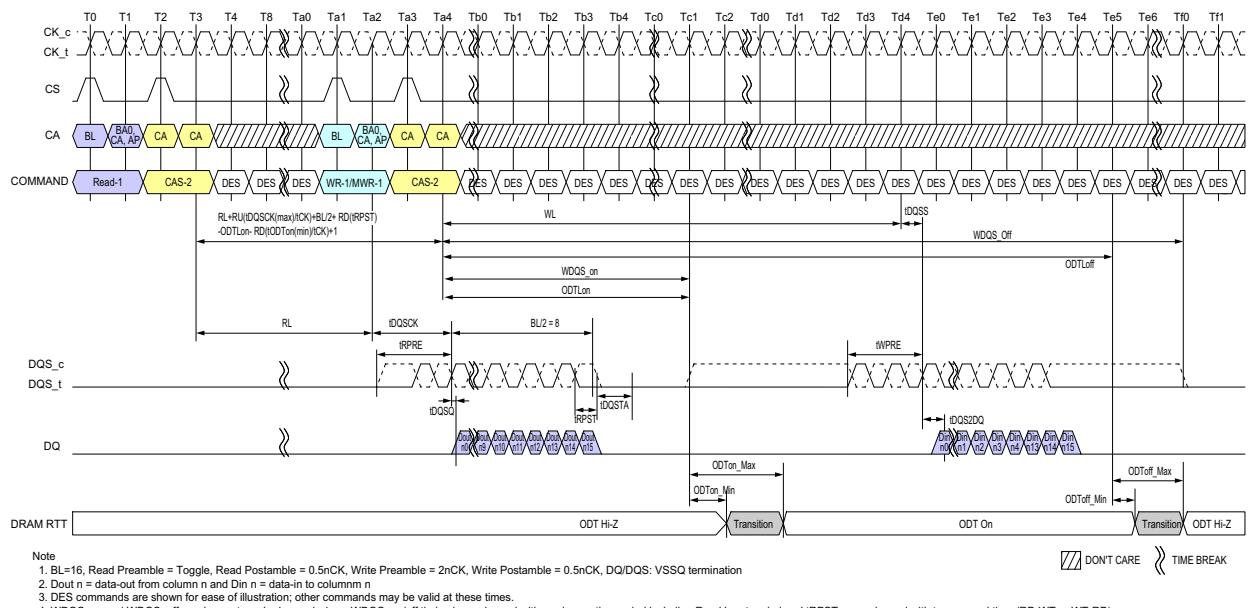


Figure 30 — Burst Read followed by Burst Write or Burst Mask Write (ODT Enable)

4.14 Postamble and Preamble merging behavior

The DQS strobe for the device requires a preamble prior to the first latching edge (the rising edge of DQS_t with data valid), and it requires a postamble after the last latching edge. The preamble and postamble options are set via Mode Register Write commands.

In Read to Read or Write to Write operations with tCCD=BL/2, postamble for 1st command and preamble for 2nd command will disappear to create consecutive DQS latching edge for seamless burst operations.

But in the case of Read to Read or Write to Write operations with command interval of tCCD+1,tCCD+2, etc., they will not completely disappear because it's not seamless burst operations.

Timing diagrams in this material describe Postamble and Preamble merging behavior in Read to Read or Write to Write operations with tCCD+n.

4.14.1 Read to Read Operation

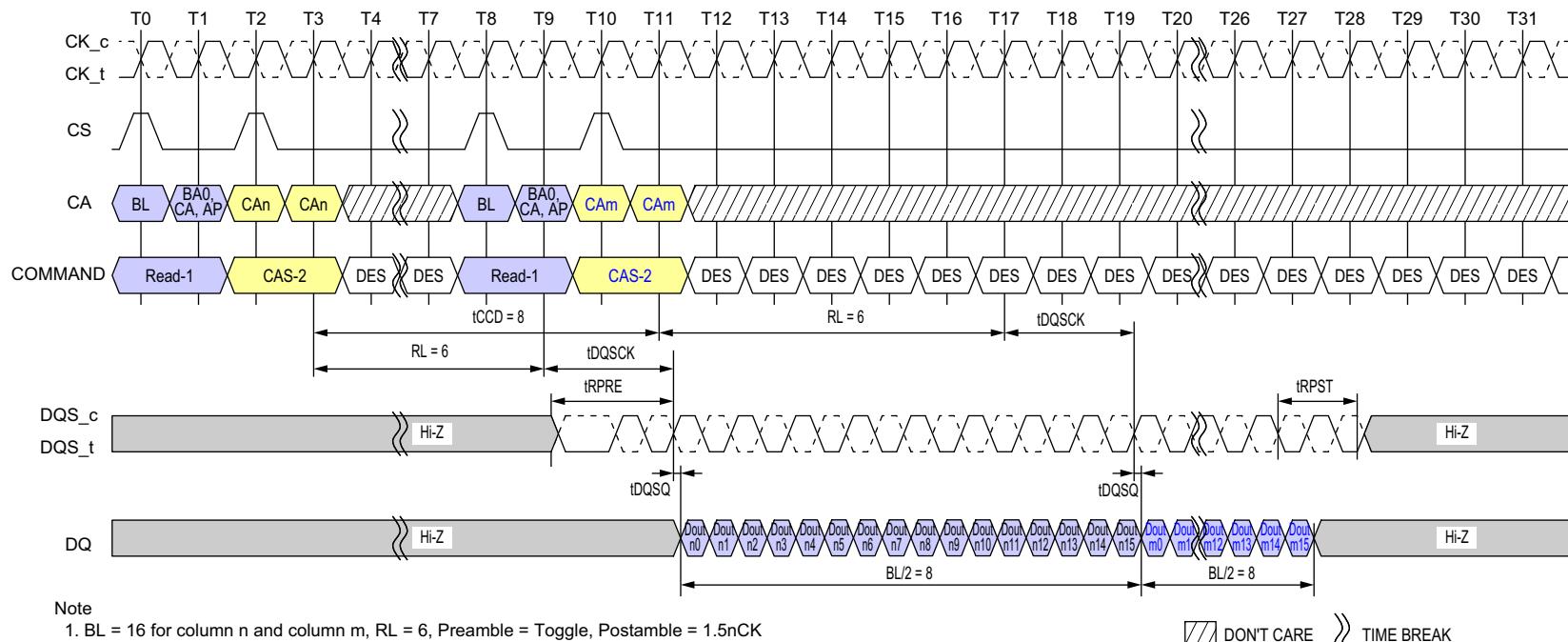


Figure 31 — Seamless Reads Operation: tCCD = Min, Preamble = Toggle, 1.5nCK Postamble

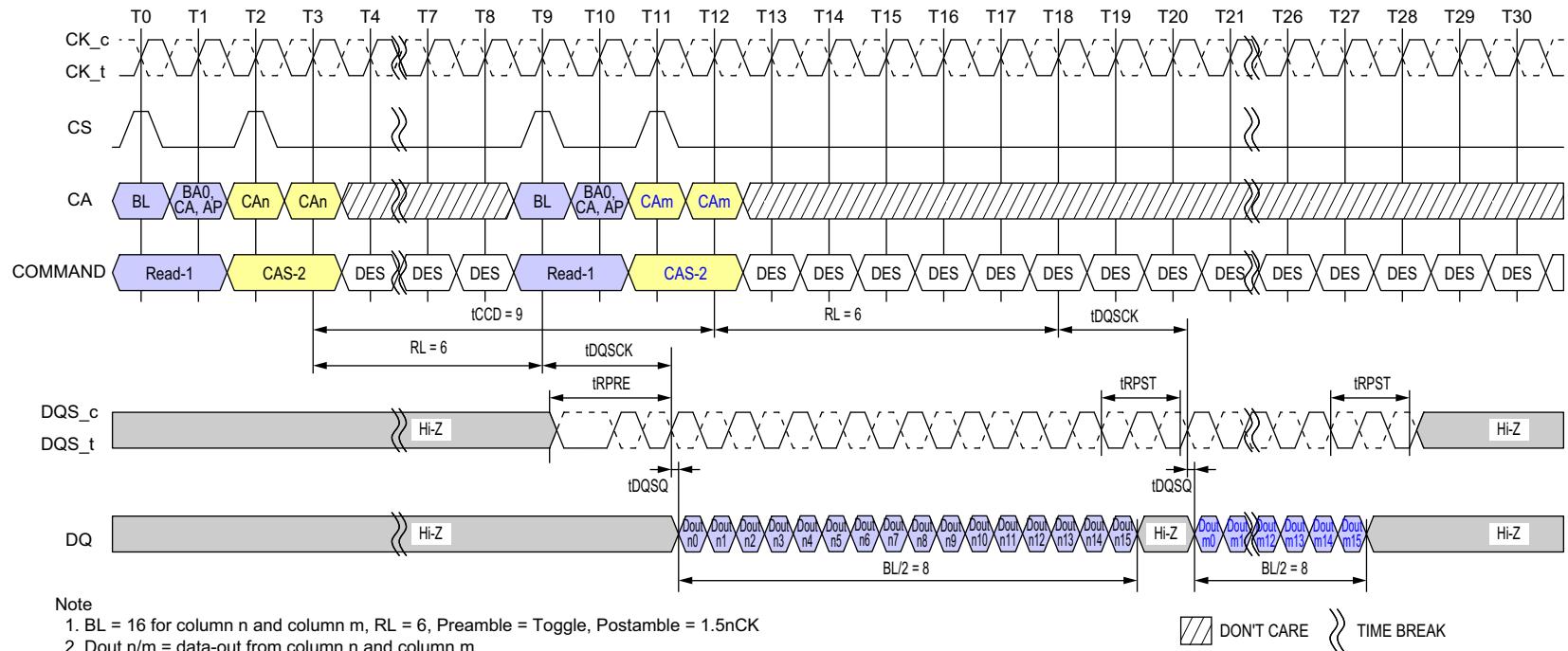


Figure 32 — Consecutive Reads Operation: tCCD = Min +1, Preamble = Toggle, 1.5nCK Postamble

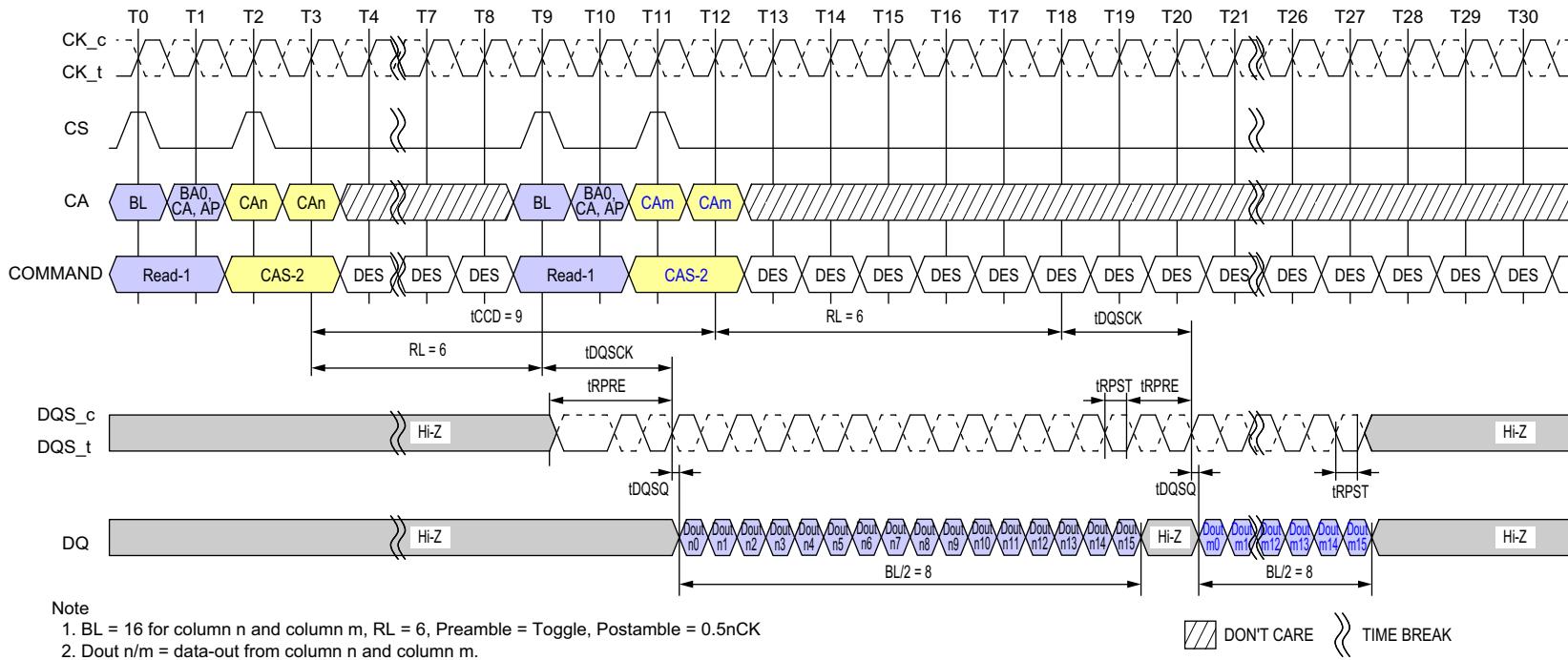
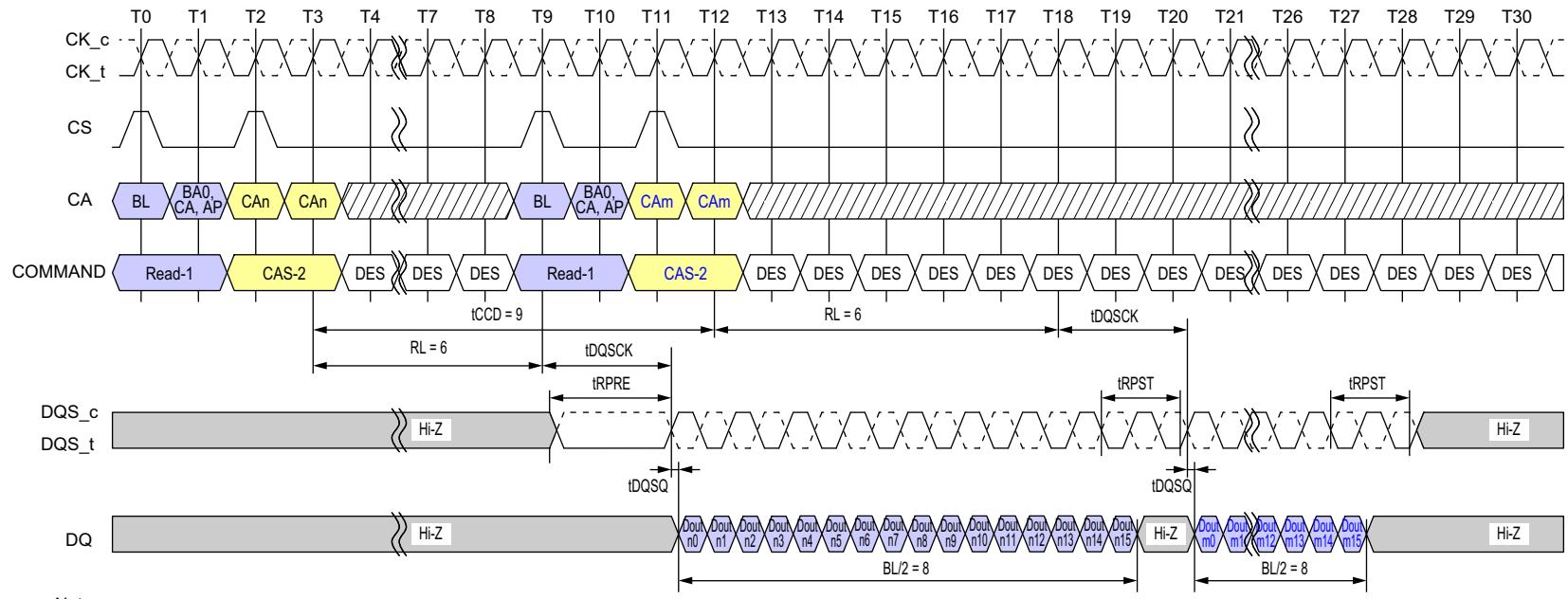


Figure 33 — Consecutive Reads Operation: tCCD = Min +1, Preamble = Toggle, 0.5nCK Postamble



Note

1. BL = 16 for column n and column m, RL = 6, Preamble = Static, Postamble = 1.5nCK
2. Dout n/m = data-out from column n and column m.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

\square/\square DON'T CARE \circlearrowright TIME BREAK

Figure 34 — Consecutive Reads Operation: tCCD = Min +1, Preamble = Static, 1.5nCK Postamble

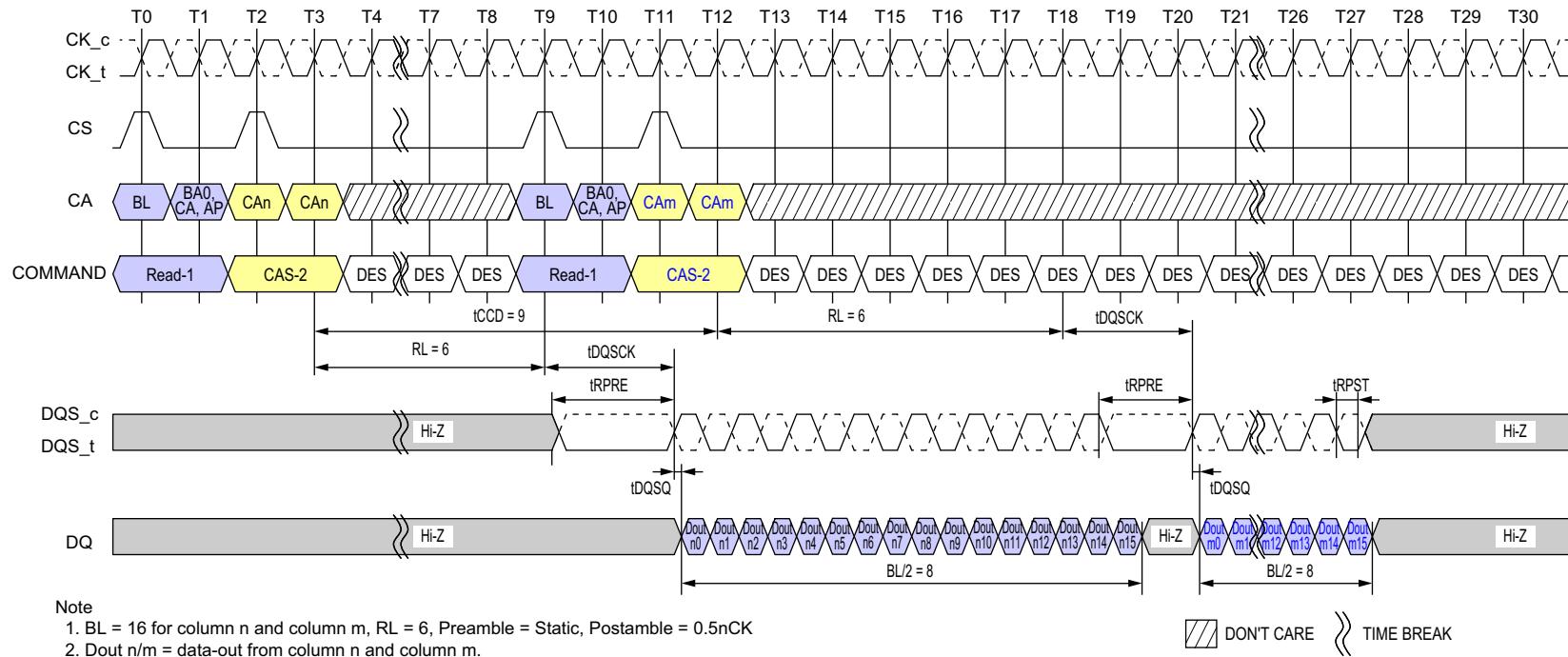


Figure 35 — Consecutive Reads Operation: tCCD = Min +1. Preamble = Static. 0.5nCK Postamble

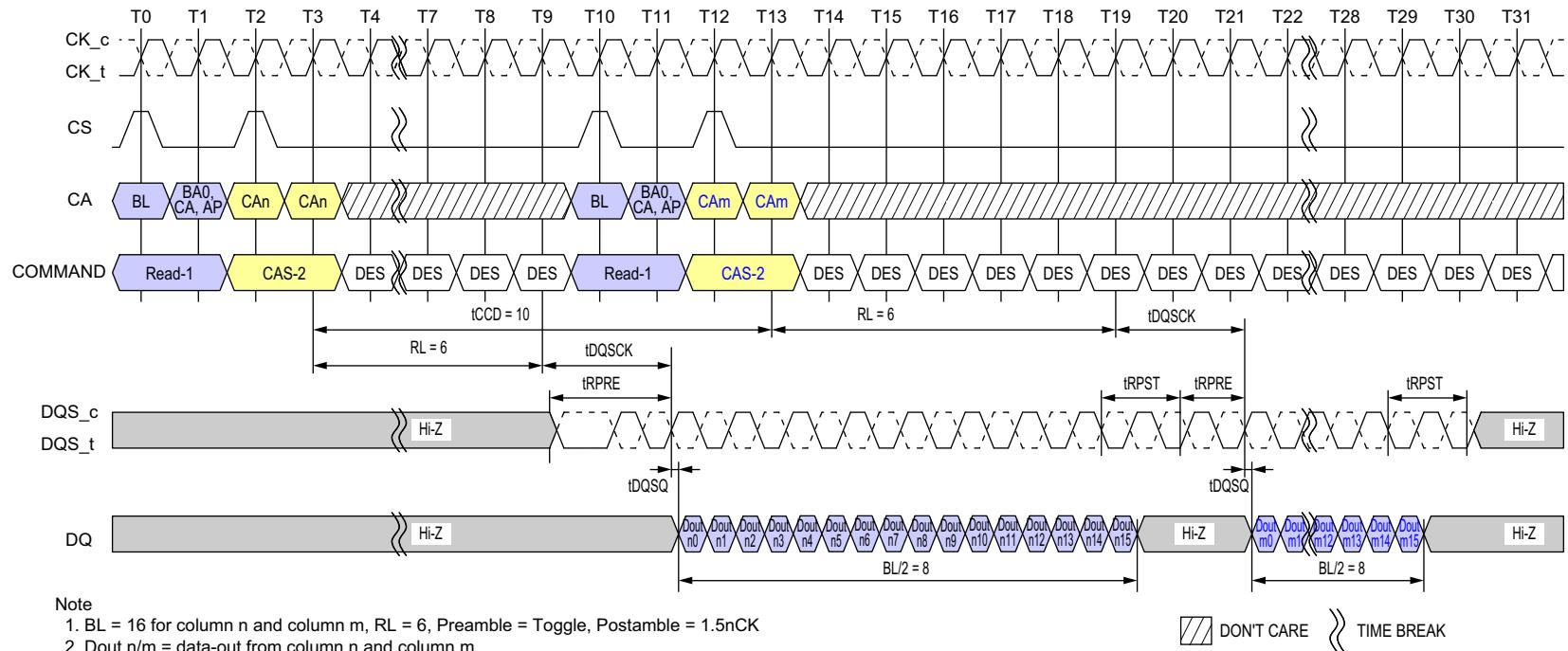
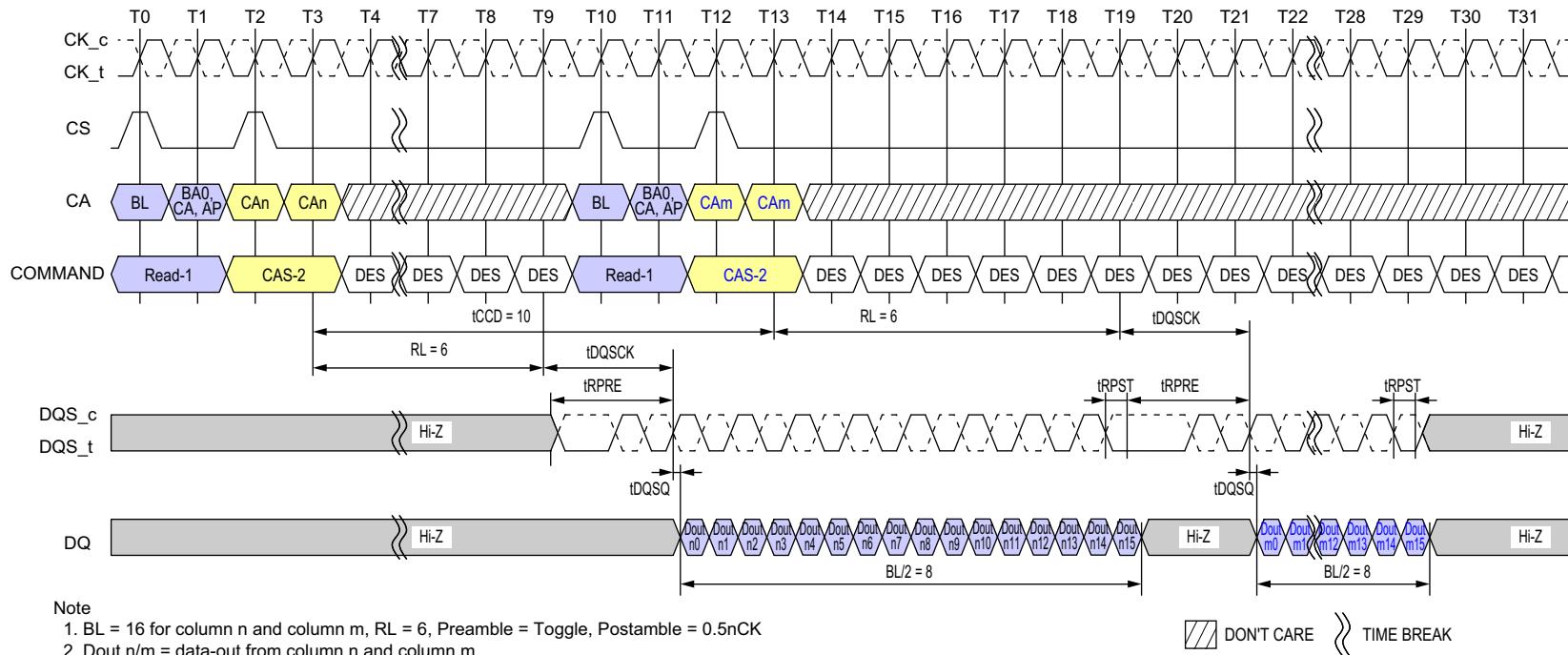


Figure 36 — Consecutive Reads Operation: tCCD = Min +2, Preamble = Toggle, 1.5nCK Postamble



Note

1. BL = 16 for column n and column m, RL = 6, Preamble = Toggle, Postamble = 0.5nCK
2. Dout n/m = data-out from column n and column m.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

DON'T CARE TIME BREAK

Figure 37 — Consecutive Reads Operation: tCCD = Min +2, Preamble = Toggle, 0.5nCK Postamble

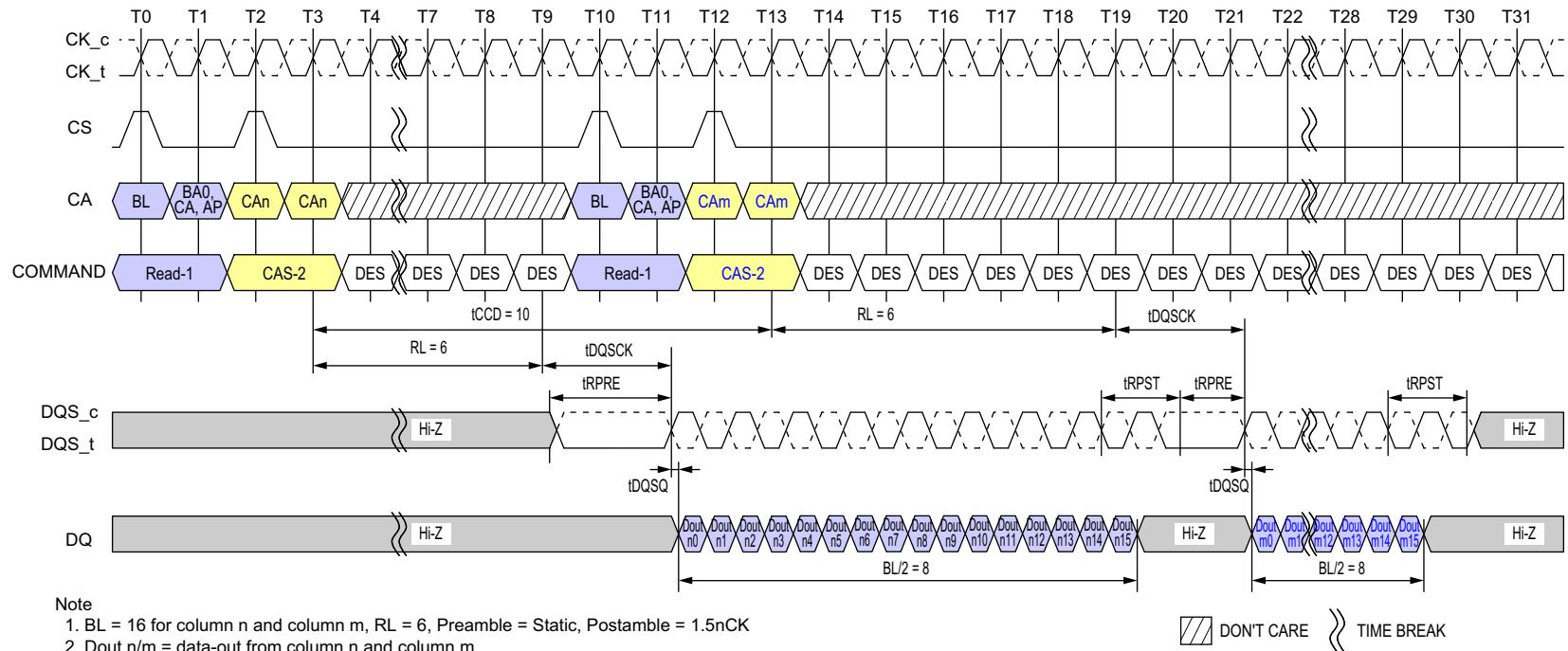
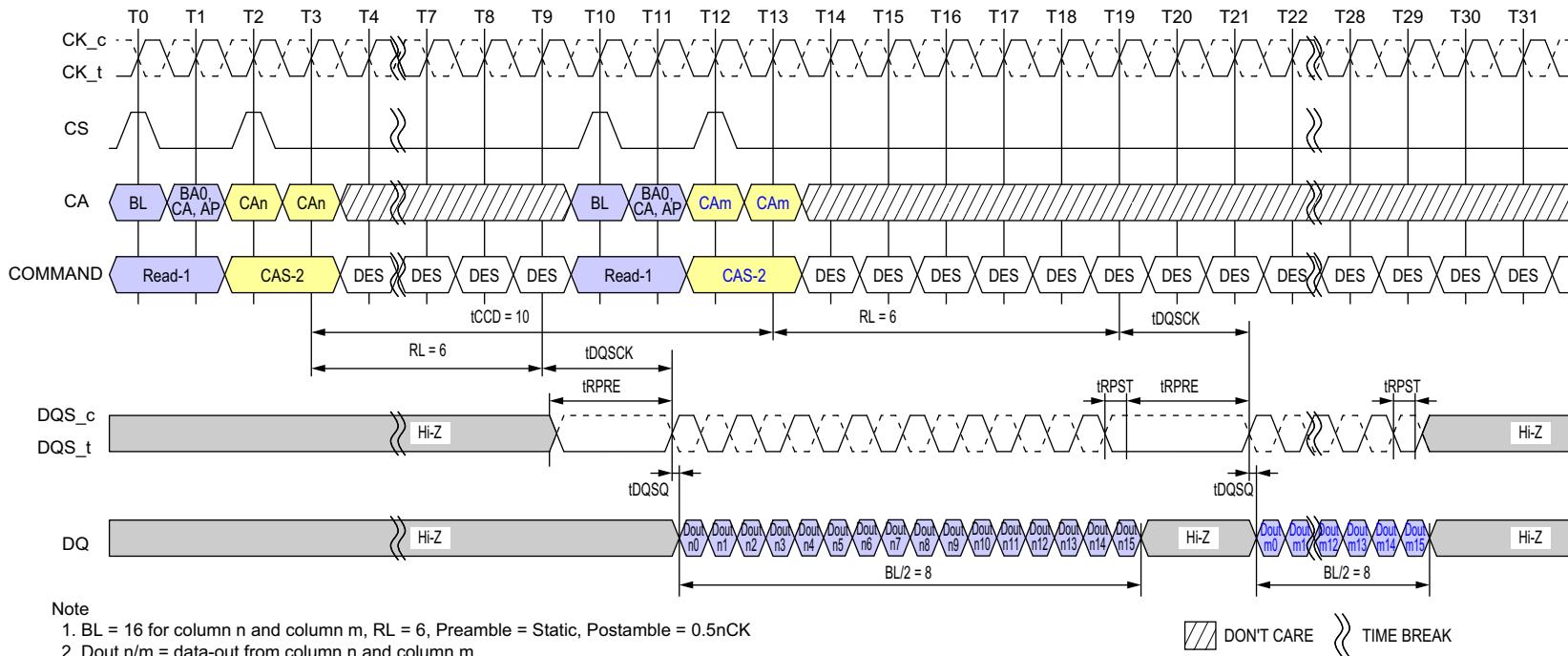


Figure 38 — Consecutive Reads Operation: tCCD = Min +2, Preamble = Static, 1.5nCK Postamble



Note

1. BL = 16 for column n and column m, RL = 6, Preamble = Static, Postamble = 0.5nCK
2. Dout n/m = data-out from column n and column m.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

DON'T CARE TIME BREAK

Figure 39 — Consecutive Reads Operation: tCCD = Min +2, Preamble = Static, 0.5nCK Postamble

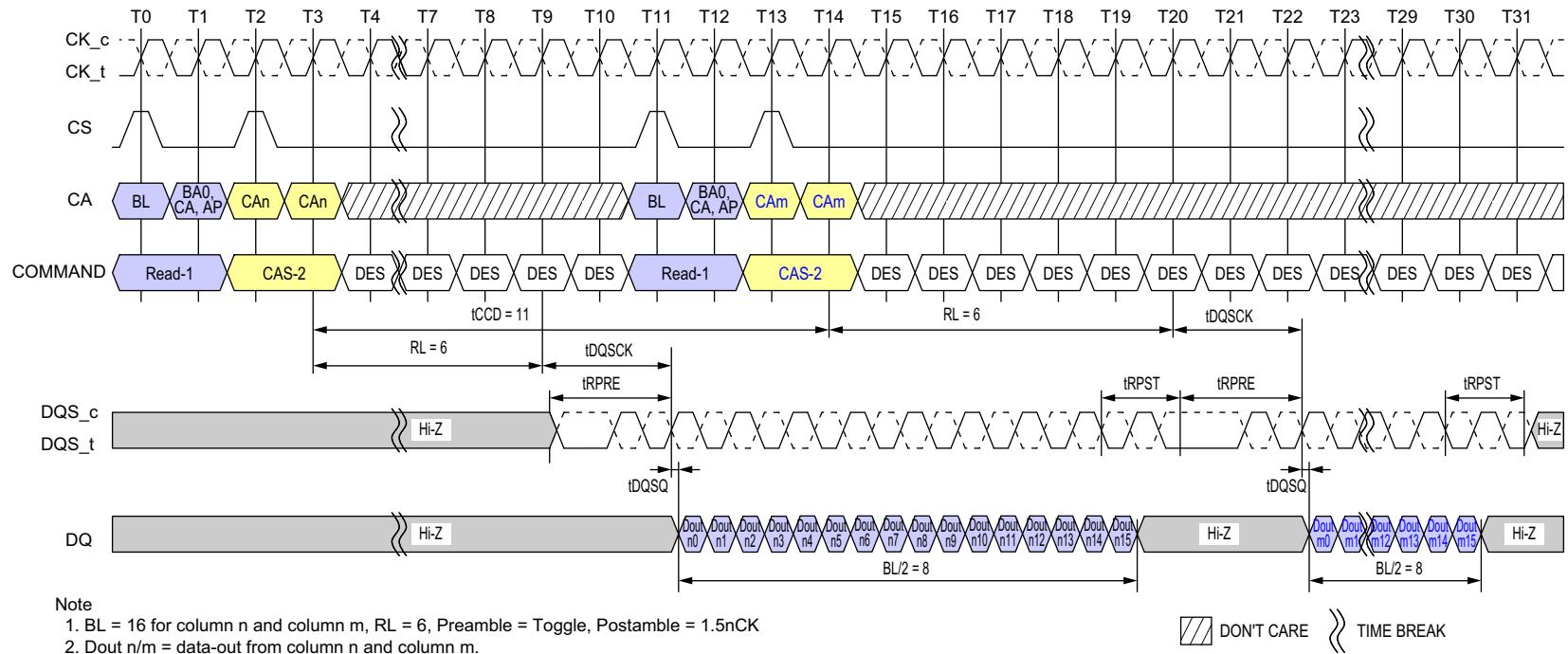


Figure 40 — Consecutive Reads Operation: tCCD = Min +3, Preamble = Toggle, 1.5nCK Postamble

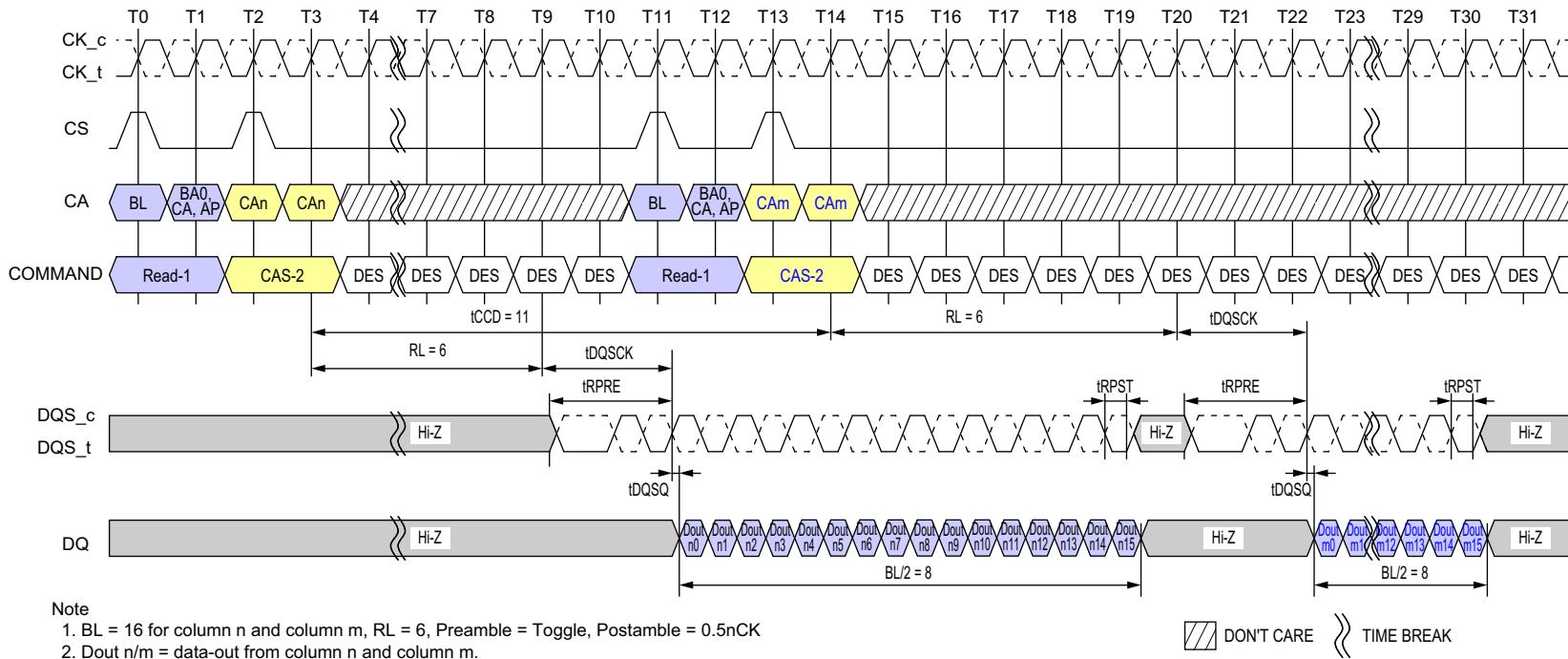


Figure 41 — Consecutive Reads Operation: tCCD = Min +3, Preamble = Toggle, 0.5nCK Postamble

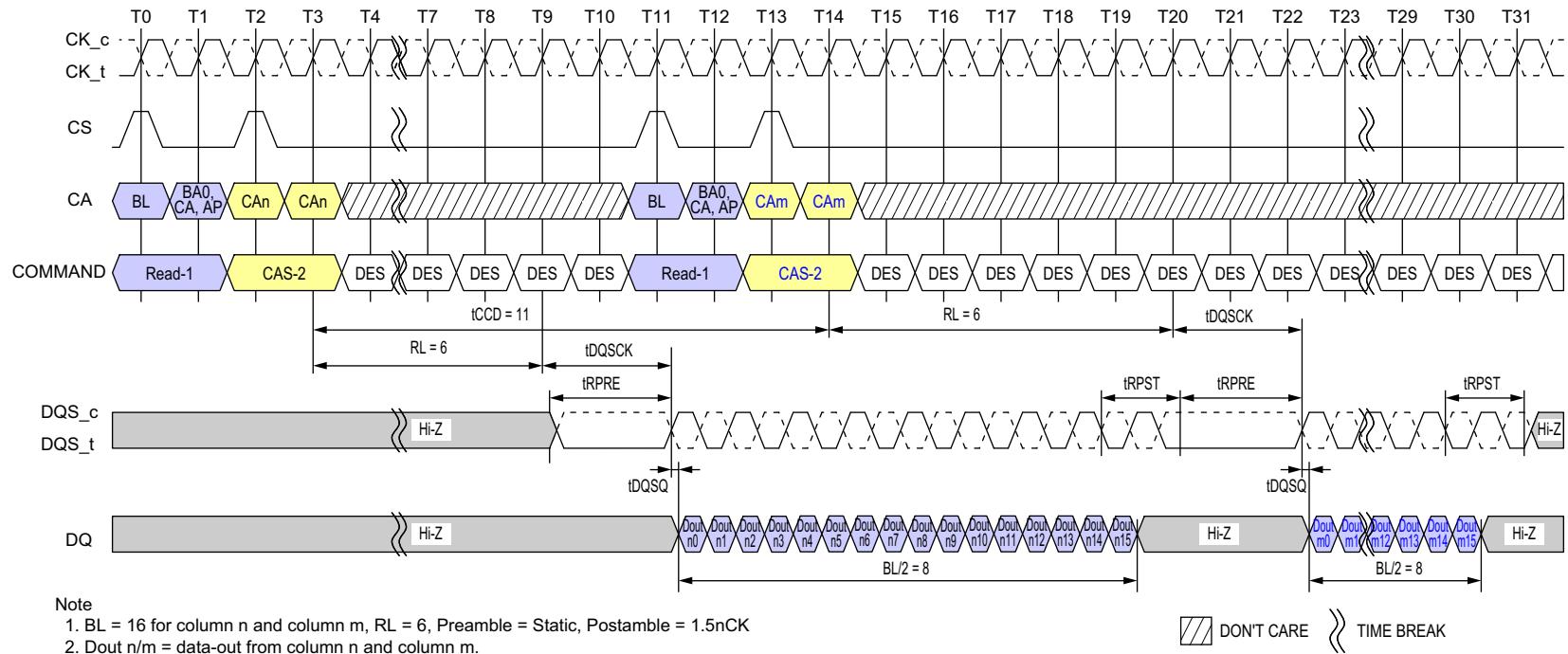
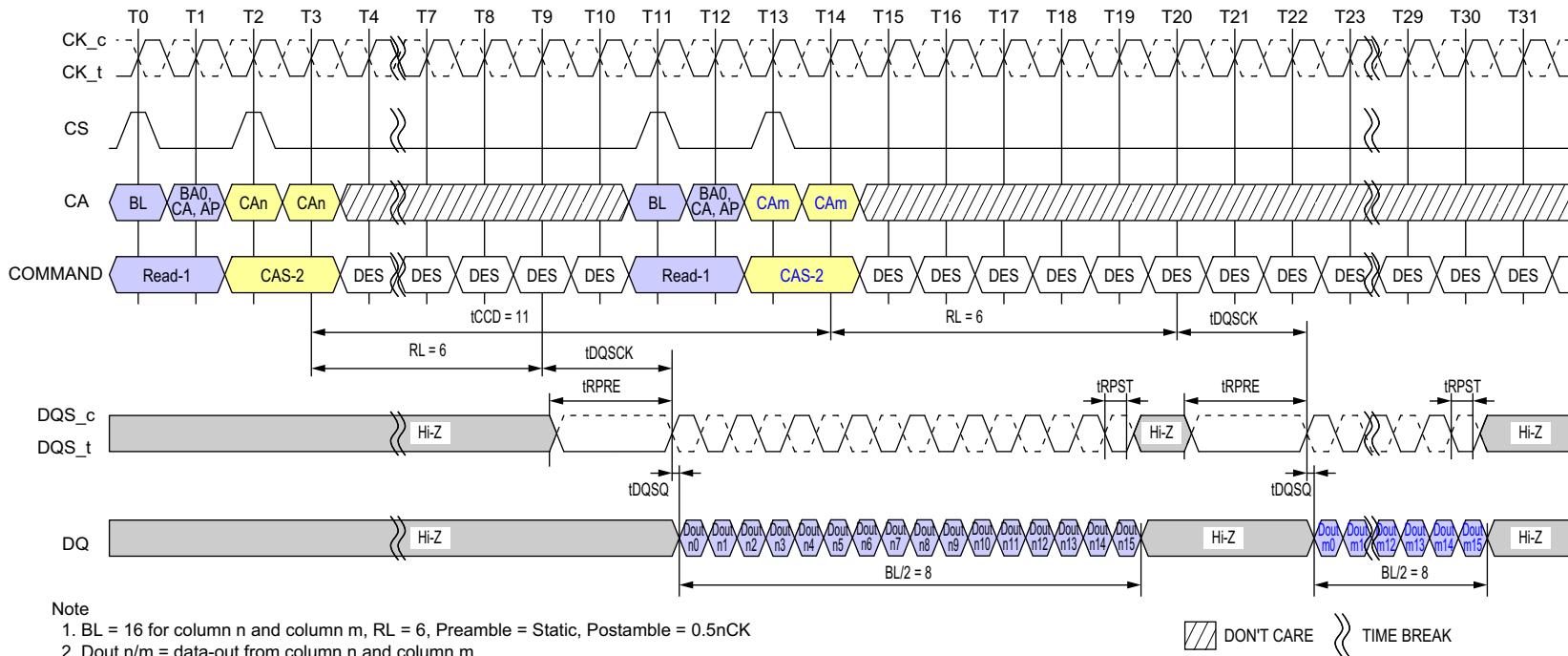


Figure 42 — Consecutive Reads Operation: tCCD = Min +3, Preamble = Static, 1.5nCK Postamble



Note

1. BL = 16 for column n and column m, RL = 6, Preamble = Static, Postamble = 0.5nCK
2. Dout n/m = data-out from column n and column m.
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

DON'T CARE TIME BREAK

Figure 43 — Consecutive Reads Operation: tCCD = Min +3, Preamble = Static, 0.5nCK Postamble

4.14.2 Write to Write Operation

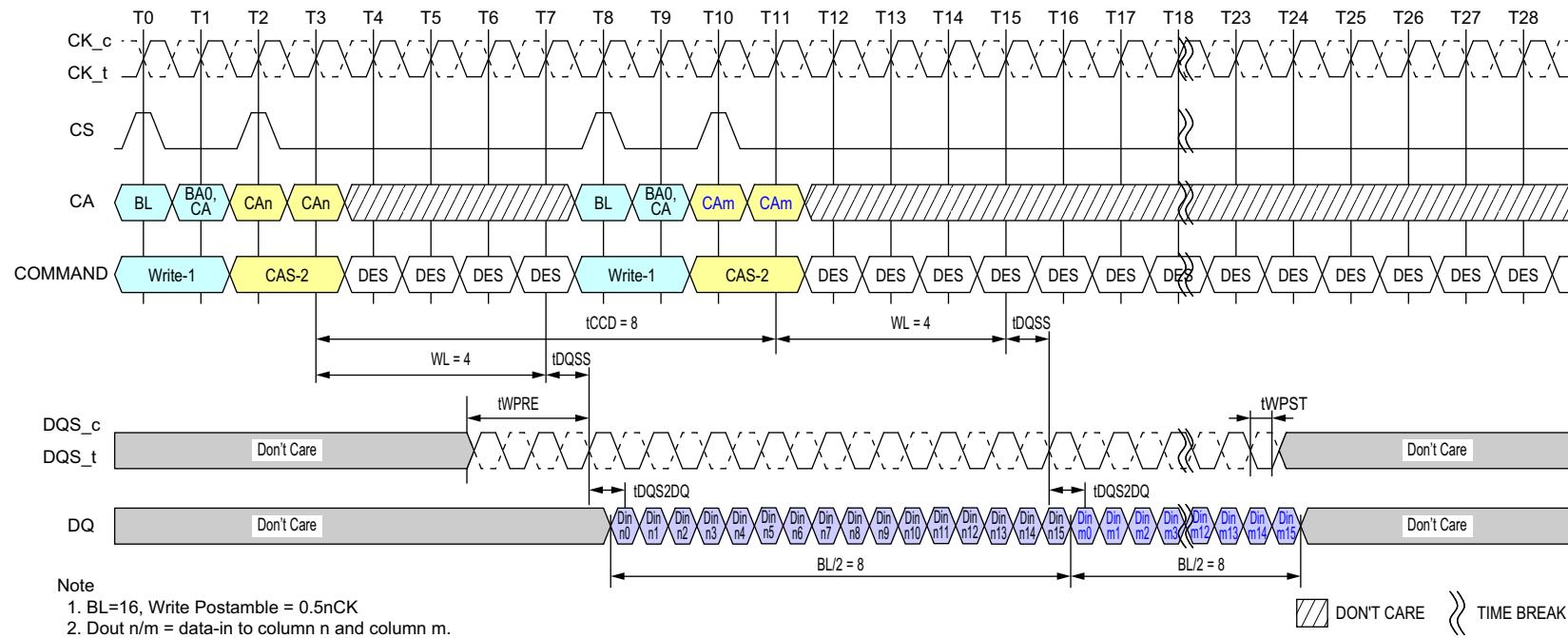


Figure 44 — Seamless Writes Operation: $tCCD = \text{Min}, 0.5nCK$ Postamble

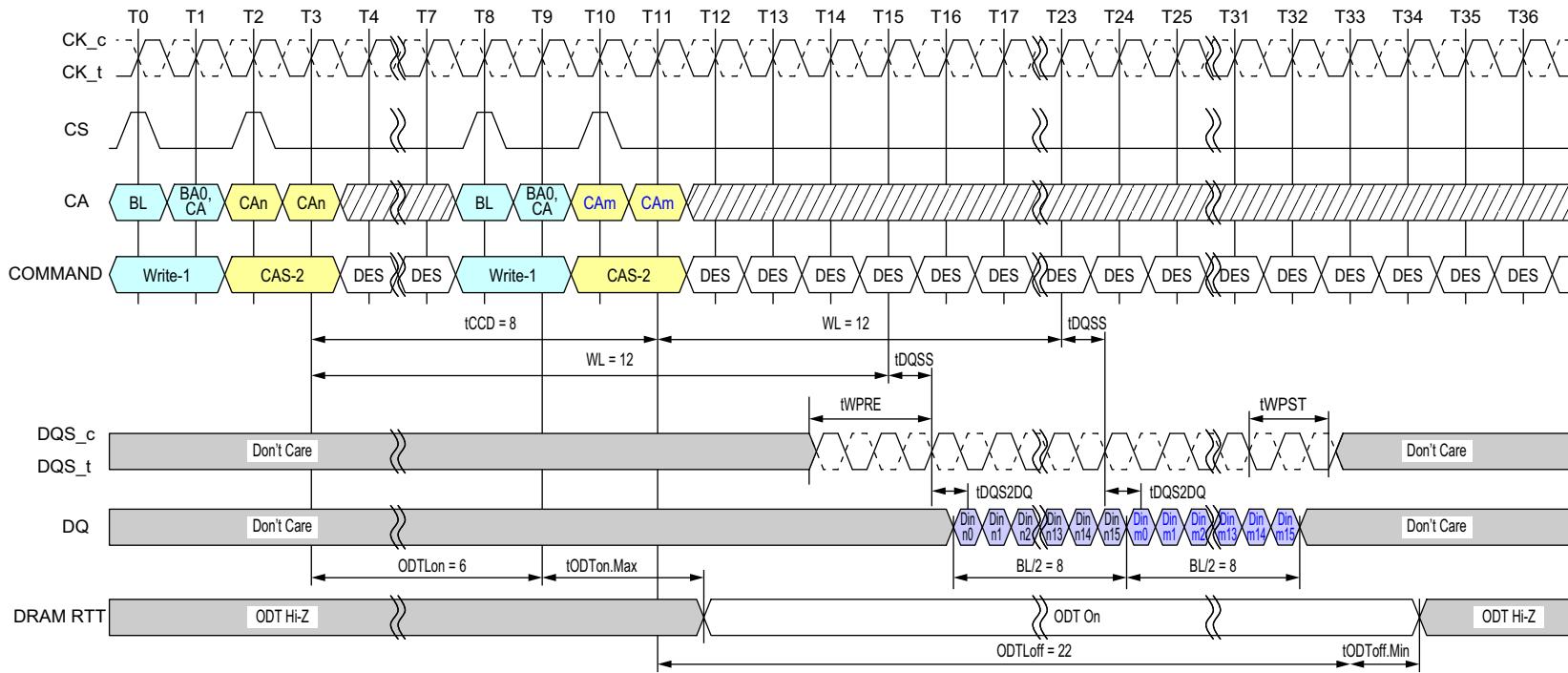


Figure 45 — Seamless Writes Operation: tCCD = Min, 1.5nCK Postamble, 533MHz < Clock Freq. ≤ 800MHz, ODT Worst Timing Case

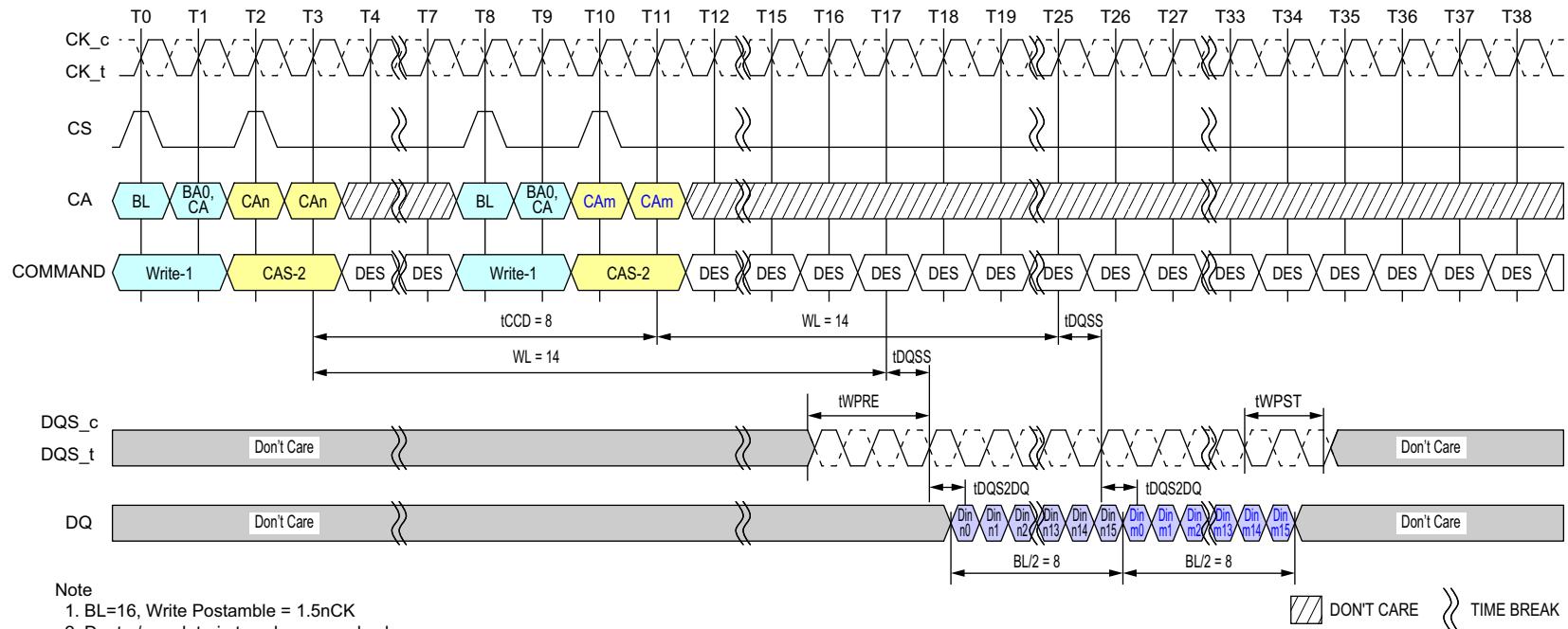
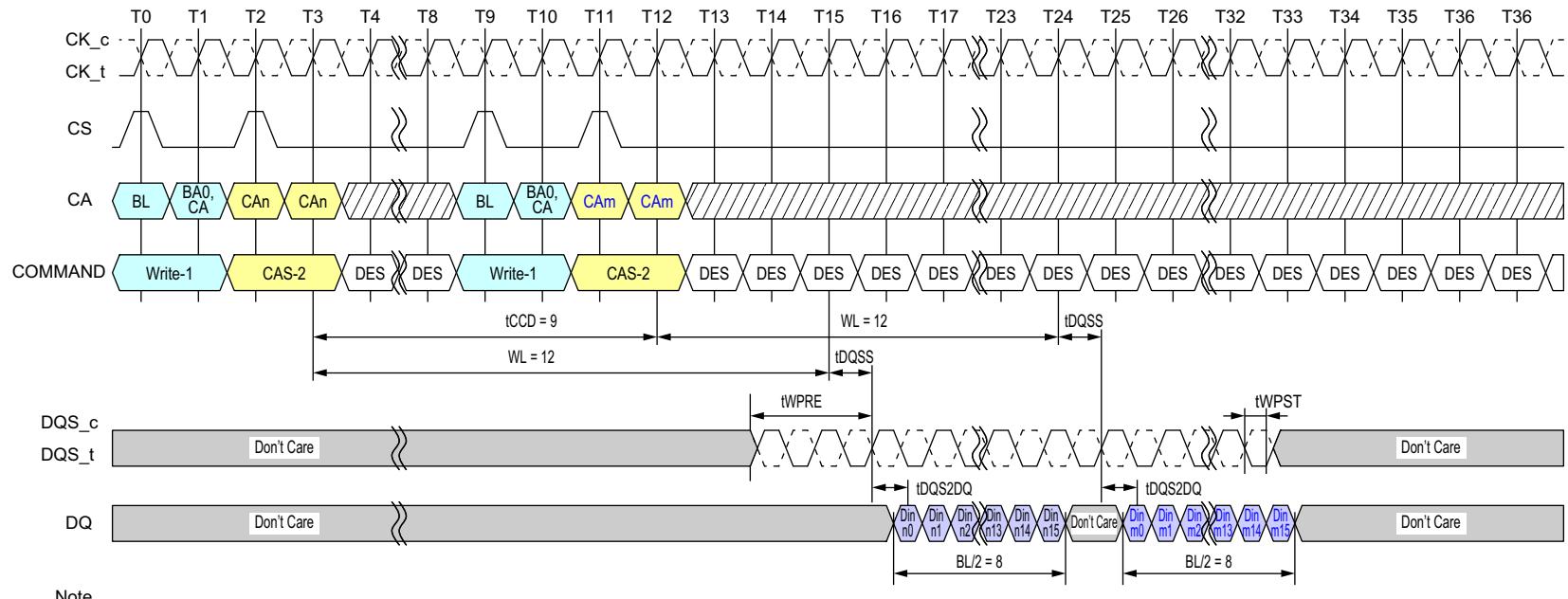


Figure 46 — Seamless Writes Operation: tCCD = Min, 1.5nCK Postamble



Note

1. BL=16, Write Postamble = 0.5nCK
 2. Dout n/m = data-in to column n and column m.
 3. DES commands are shown for ease of illustration; other commands may be valid at these times.

DON'T CARE TIME BREAK

Figure 47 — Consecutive Writes Operation: tCCD = Min + 1, 0.5nCK Postamble

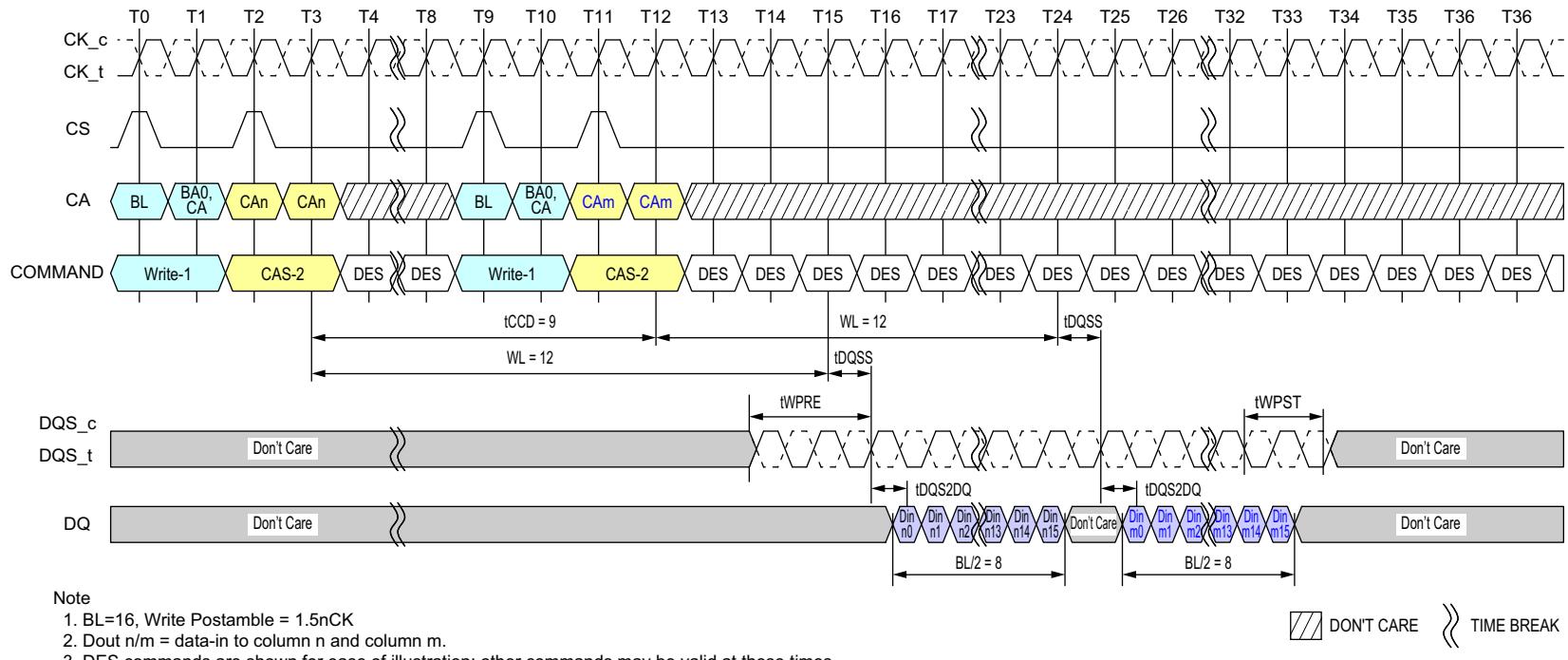


Figure 48 — Consecutive Writes Operation: tCCD = Min + 1, 1.5nCK Postamble

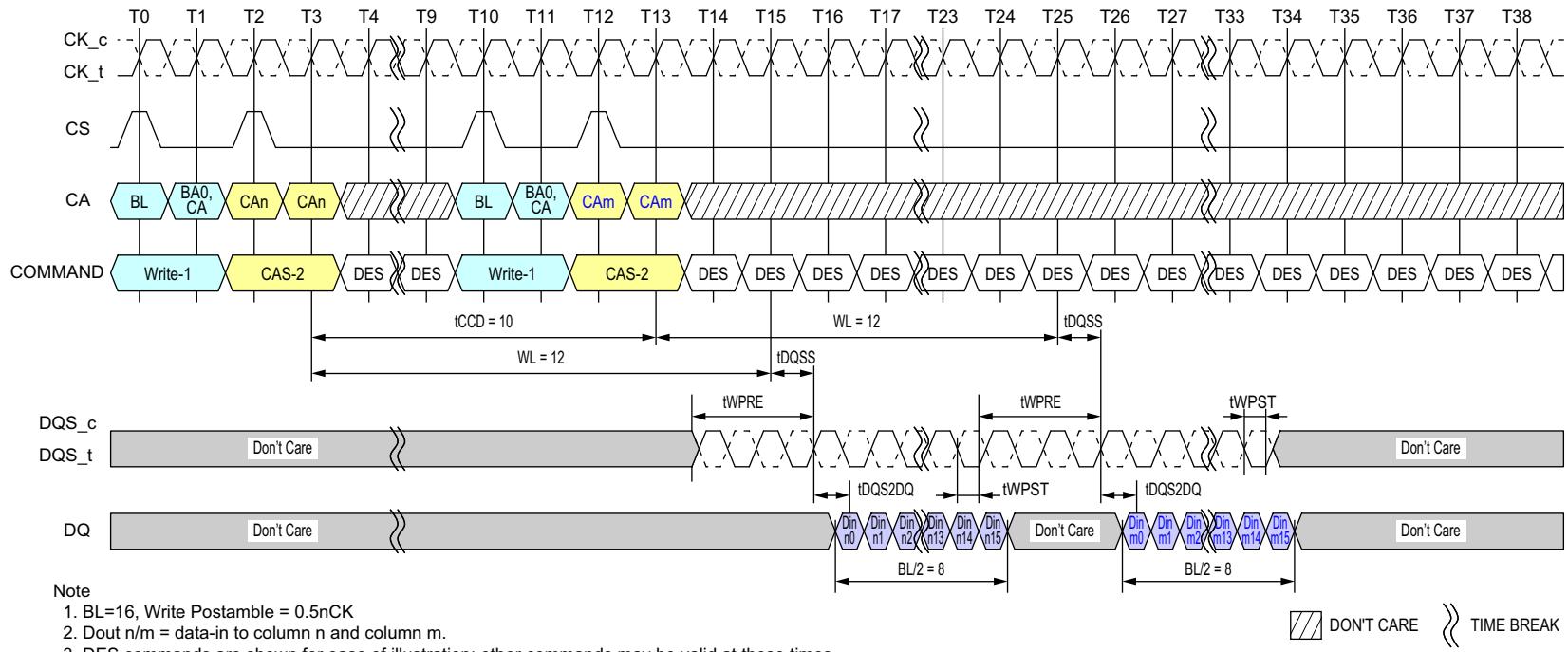


Figure 49 — Consecutive Writes Operation: tCCD = Min + 2, 0.5nCK Postamble

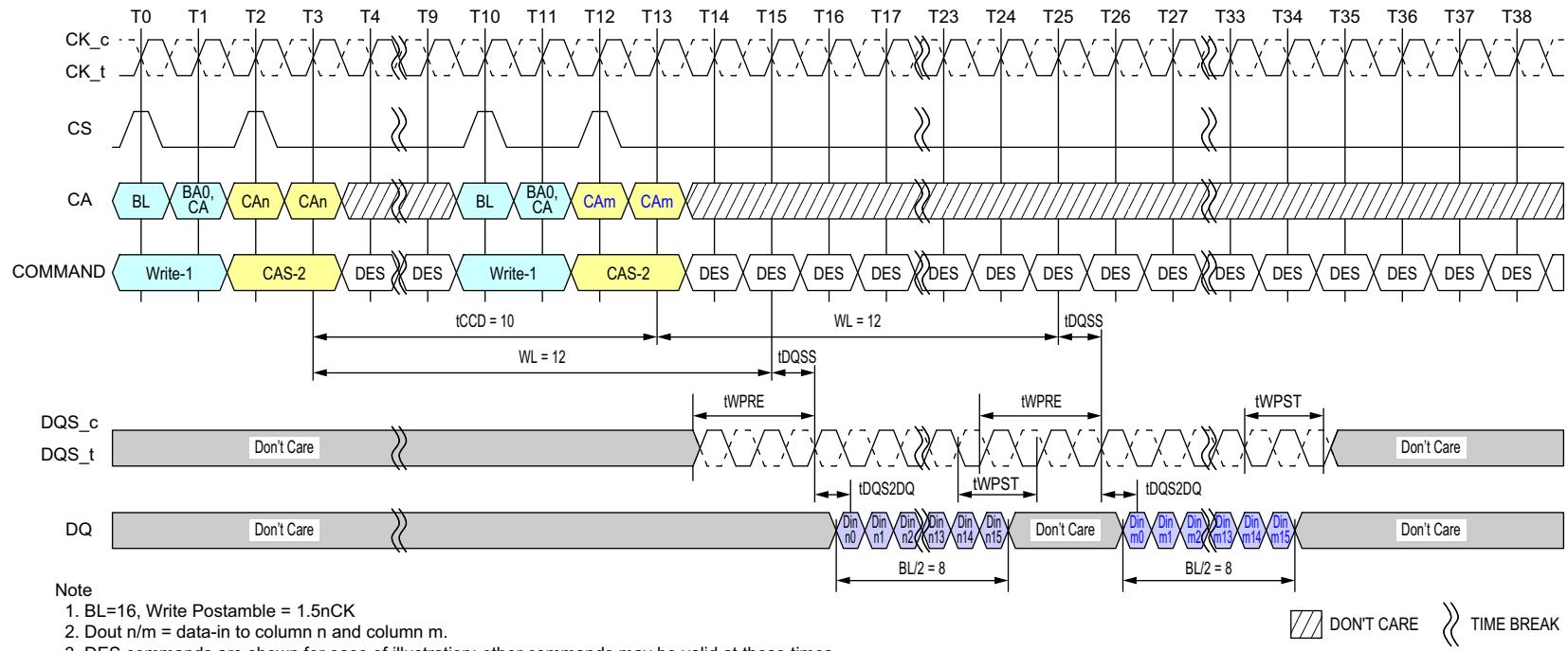


Figure 50 — Consecutive Writes Operation: tCCD = Min + 2, 1.5nCK Postamble

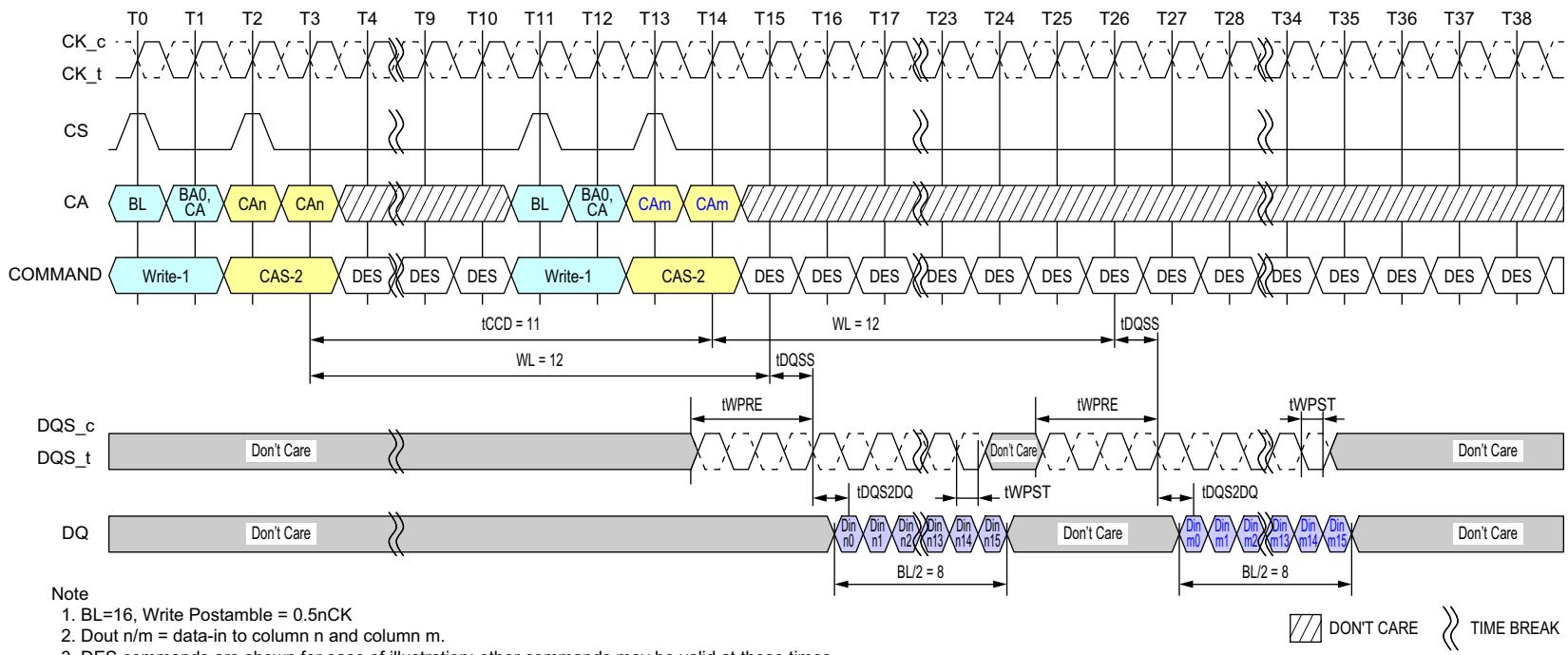


Figure 51 — Consecutive Writes Operation: tCCD = Min + 3, 0.5nCK Postamble

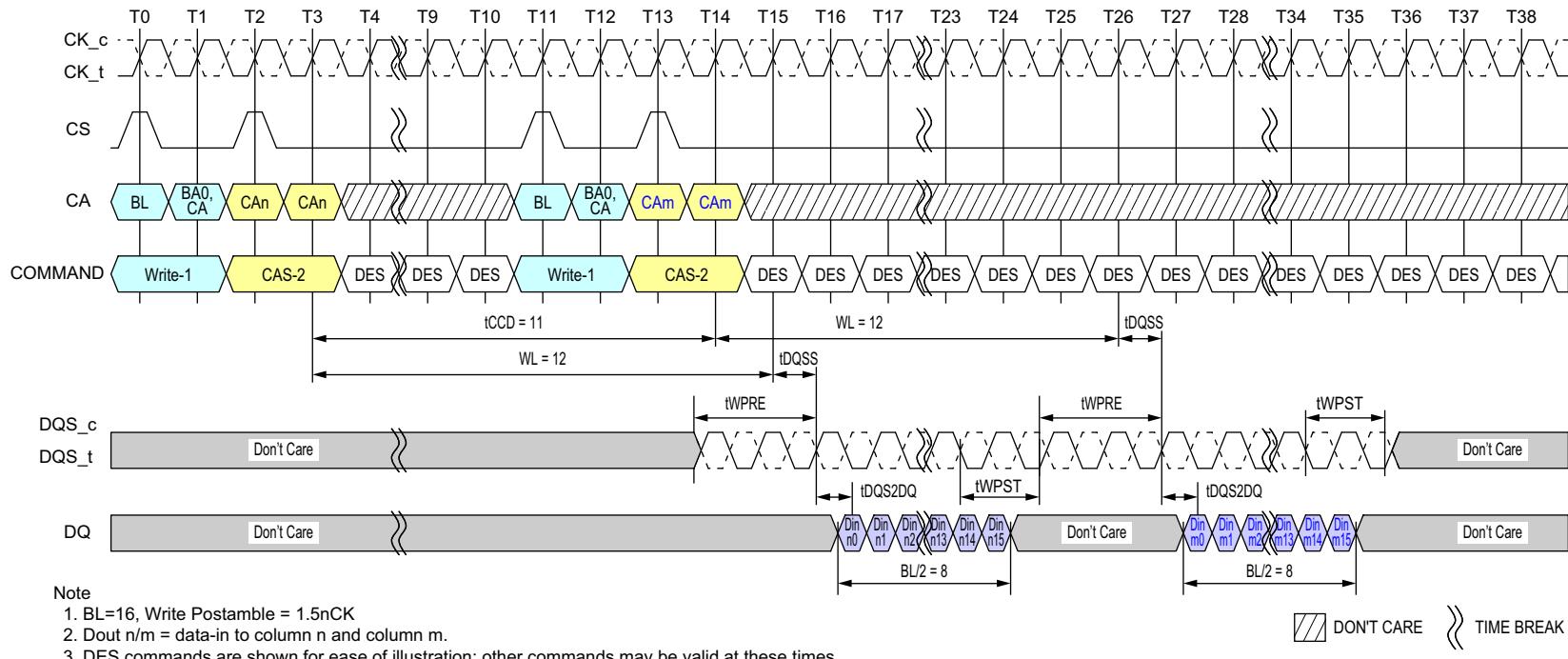


Figure 52 — Consecutive Writes Operation: tCCD = Min + 3, 1.5nCK Postamble

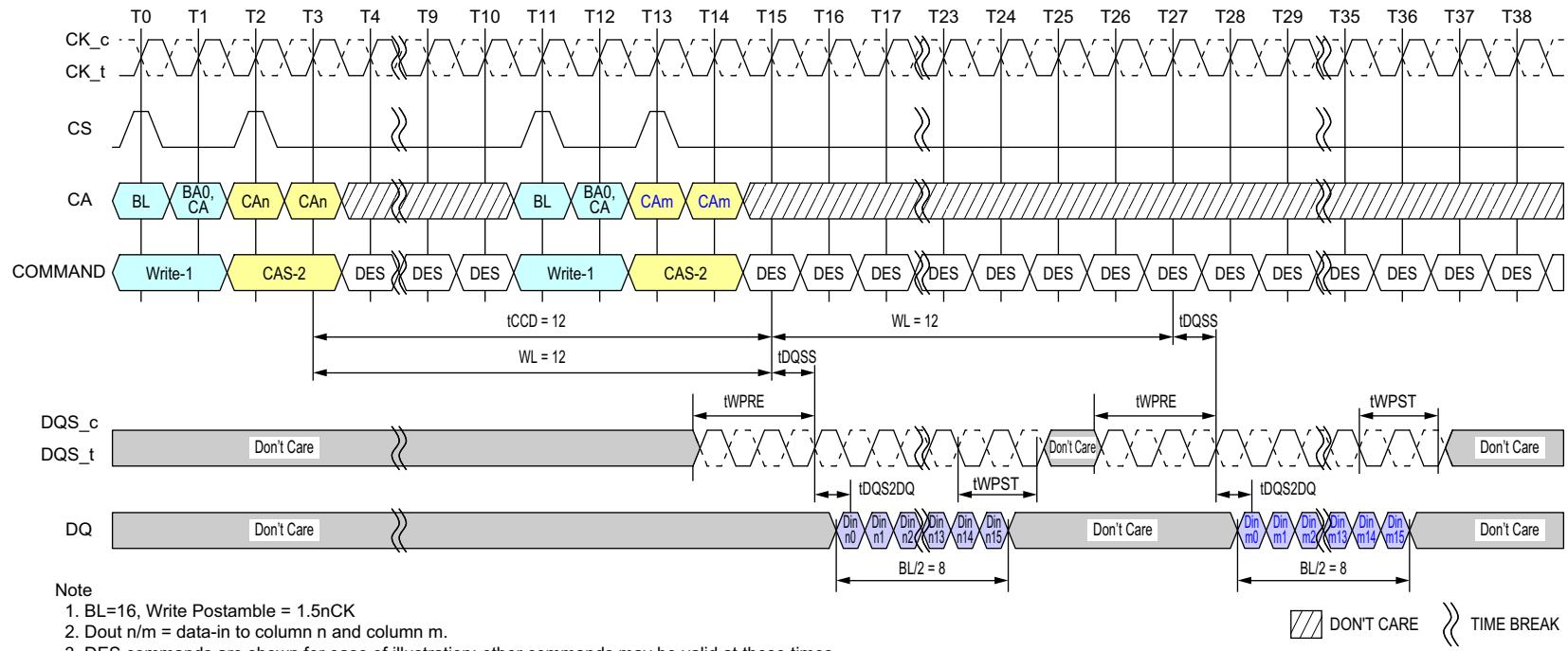
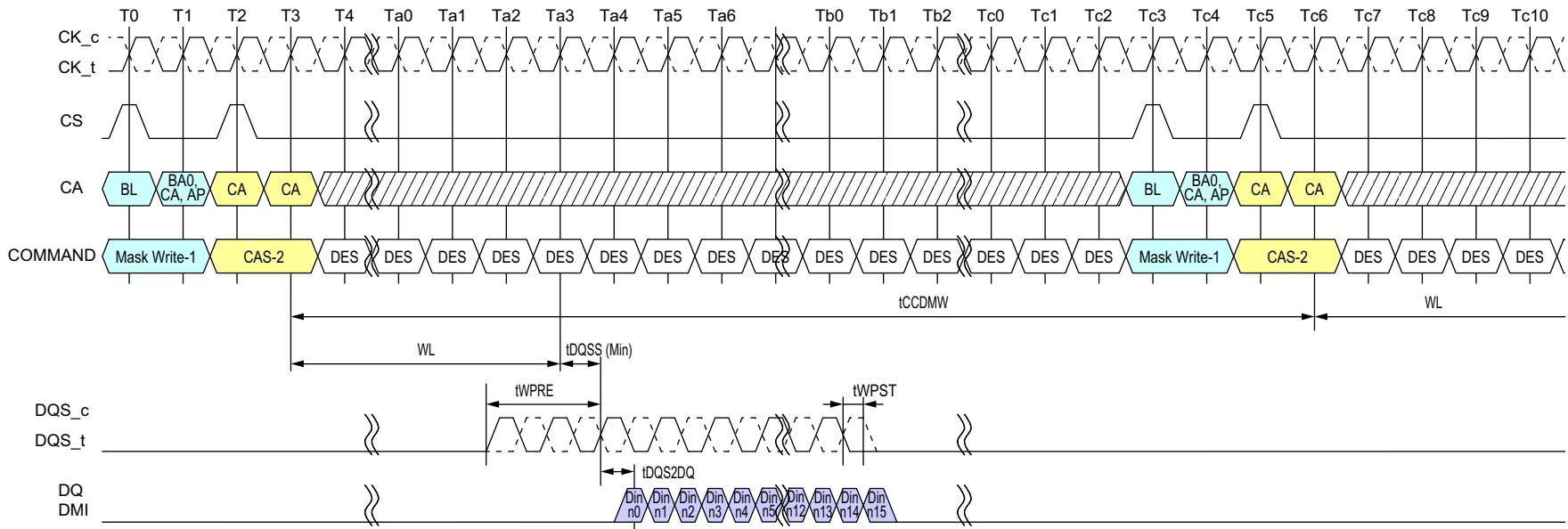


Figure 53 — Consecutive Writes Operation: tCCD = Min + 4, 1.5nCK Postamble

4.15 MASKED WRITE OPERATION

The LPDDR4-SDRAM requires that Write operations which include a byte mask anywhere in the burst sequence must use the Masked Write command. This allows the DRAM to implement efficient data protection schemes based on larger data blocks. The Masked Write-1 command is used to begin the operation, followed by a CAS-2 command. A Masked Write command to the same bank cannot be issued until tCCDMW later, to allow the LPDDR4-SDRAM to finish the internal Read-Modify-Write. One Data Mask-Invert (DMI) pin is provided per byte lane, and the Data Mask-Invert timings match data bit (DQ) timing. See the section on "Data Mask Invert" for more information on the use of the DMI signal.

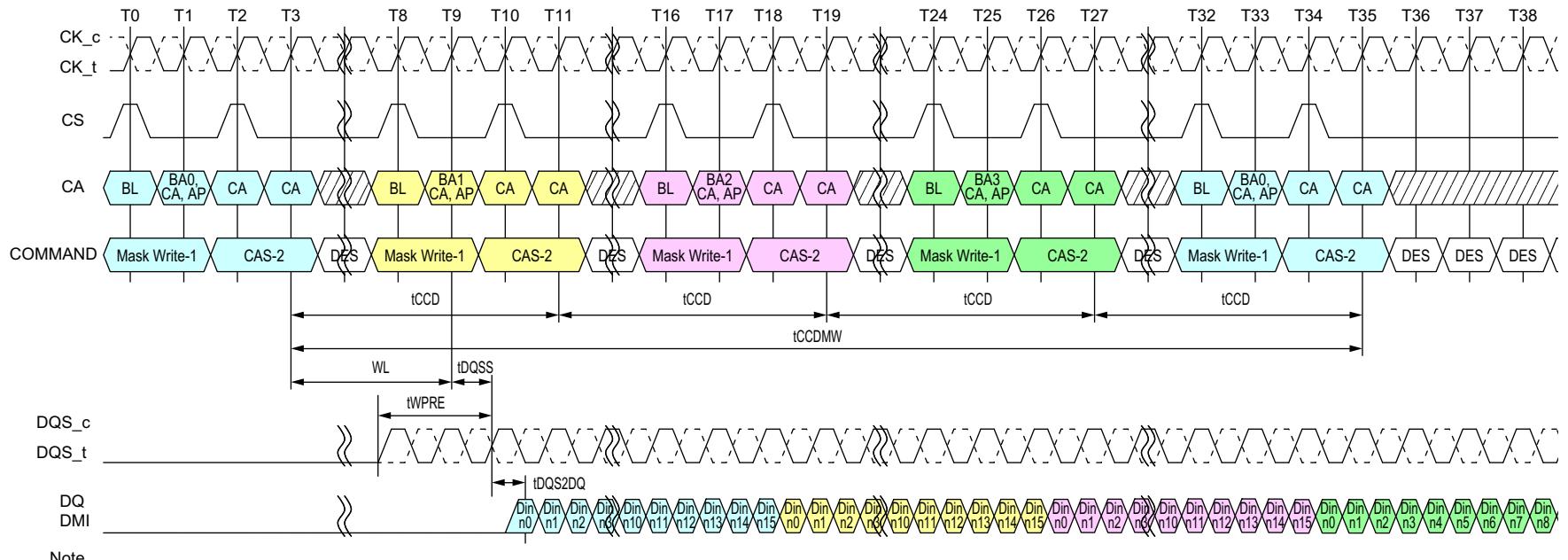


Note

1. BL=16, Write Postamble = 0.5nCK, DQ/DQS: VSSQ termination
2. Din n = data-in to column n
3. Mask-Write supports only BL16 operations. For BL32 configuration, the system needs to insert only 16 bit wide data for masked write operation.
4. DES commands are shown for ease of illustration; other commands may be valid at these time.

DON'T CARE TIME BREAK

Figure 54 — Masked Write Command - Same Bank



Note

1. BL=16, DQ/DQS/DMI: VSSQ termination
2. Din n = data-in to column n
3. Mask-Write supports only BL16 operations. For BL32 configuration, the system needs to insert only 16 bit wide data for masked write operation.
4. DES commands are shown for ease of illustration; other commands may be valid at these time.

DON'T CARE TIME BREAK

Figure 55 — Masked Write Command - Different Bank

4.15.1 Masked Write Timing constraints for BL16

Table 32 — Timing constraints for Same bank: DQ ODT is Disabled

| Next CMD Current CMD | Active | Read (BL=16 or 32) | Write (BL=16 or 32) | Masked Write | Precharge |
|-------------------------|-------------------------------|----------------------------|--|--|------------------------------|
| Active | illegal | RU(tRCD/tCK) | RU(tRCD/tCK) | RU(tRCD/tCK) | RU(tRAS/tCK) |
| Read with BL = 16 | illegal | 8 ¹⁾ | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | BL/2+max{(8,RU(tRTP/tCK)}-8 |
| Read with BL = 32 | illegal | 16 ²⁾ | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | BL/2+max{(8,RU(tRTP/tCK)}-8 |
| Write with BL = 16 | illegal | WL+1+BL/2 +RU(tWTR/tCK) | 8 ¹⁾ | tCCDMW ³⁾ | WL+ 1 + BL/2+RU(tWR/tCK) |
| Write with BL = 32 | illegal | WL+1+BL/2 +RU(tWTR/tCK) | 16 ²⁾ | tCCDMW +8 ⁴⁾ | WL+ 1 + BL/2+RU(tWR/tCK) |
| Masked Write | illegal | WL+1+BL/2 +RU(tWTR/tCK) | tCCD | tCCDMW ³⁾ | WL+ 1 + BL/2 +RU(tWR/tCK) |
| Precharge | RU(tRP/tCK), RU(tRPab/tCK) | illegal | illegal | illegal | 4 |

NOTE 1 In the case of BL = 16, tCCD is 8*tCK.

NOTE 2 In the case of BL = 32, tCCD is 16*tCK.

NOTE 3 tCCDMW = 32*tCK (4*tCCD at BL=16)

NOTE 4 Write with BL=32 operation has 8*tCK longer than BL =16.

NOTE 5 tRPST values depend on MR1-OP[7] respectively.

Table 33 — Timing constraints for Same bank: DQ ODT is Enabled

| Next CMD Current CMD | Active | Read (BL=16 or 32) | Write (BL=16 or 32) | Masked Write | Precharge |
|-------------------------|---------|-----------------------|---|---|-----------------------------|
| Read with BL = 16 | illegal | 8 ¹⁾ | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | BL/2+max{(8,RU(tRTP/tCK)}-8 |
| Read with BL = 32 | illegal | 16 ²⁾ | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | BL/2+max{(8,RU(tRTP/tCK)}-8 |

NOTE 1 In the case of BL = 16, tCCD is 8*tCK.

NOTE 2 In the case of BL = 32, tCCD is 16*tCK.

NOTE 3 The rest of the timing is same as DQ ODT is Disable case.

NOTE 4 tRPST values depend on MR1-OP[7] respectively.

Table 34 — Timing constraints for Different bank: DQ ODT is Disabled

| Next CMD Current CMD | Active | Read (BL=16 or 32) | Write (BL=16 or 32) | Masked Write | Precharge |
|-------------------------|--------------|----------------------------|--|--|-----------|
| Active | RU(tRRD/tCK) | 4 | 4 | 4 | 2 |
| Read with BL = 16 | 4 | 8 ¹⁾ | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | 2 |
| Read with BL = 32 | 4 | 16 ²⁾ | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | RL+RU(tDQSCK(max)/tCK) +BL/2-WL+tWPRE+RD(tRPST) | 2 |
| Write with BL = 16 | 4 | WL+1+BL/2 +RU(tWTR/tCK) | 8 ¹⁾ | 8 ¹⁾ | 2 |
| Write with BL = 32 | 4 | WL+1+BL/2 +RU(tWTR/tCK) | 16 ²⁾ | 16 ²⁾ | 2 |
| Masked Write | 4 | WL+1+BL/2 +RU(tWTR/tCK) | 8 ¹⁾ | 8 ¹⁾ | 2 |
| Precharge | 4 | 4 | 4 | 4 | 4 |

NOTE 1 In the case of BL = 16, tCCD is 8*tCK.

NOTE 2 In the case of BL = 32, tCCD is 16*tCK.

NOTE 3 tRPST values depend on MR1-OP[7] respectively.

Table 35 — Timing constraints for Different bank: DQ ODT is Enabled

| Next CMD Current CMD | Active | Read (BL=16 or 32) | Write (BL=16 or 32) | Masked Write | Precharge |
|-------------------------|--------|-----------------------|---|---|-----------|
| Read with BL = 16 | 4 | 8 ¹⁾ | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | 2 |
| Read with BL = 32 | 4 | 16 ²⁾ | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | RL+RU(tDQSCK(max)/ tCK)+BL/2+RD(tRPST)- ODTLon-RD(tODTon,min/tCK) | 2 |

NOTE 1 In the case of BL = 16, tCCD is 8*tCK.

NOTE 2 In the case of BL = 32, tCCD is 16*tCK.

NOTE 3 The rest of the timing is same as DQ ODT is Disable case.

NOTE 4 tRPST values depend on MR1-OP[7] respectively.

4.16 LPDDR4 Data Mask (DM) and Data Bus Inversion (DBIdc) Function

LPDDR4 SDRAM supports the function of Data Mask and Data Bus inversion. Details are as follows:.

- LPDDR4 device supports Data Mask (DM) function for Write operation.
- LPDDR4 device supports Data Bus Inversion (DBIdc) function for Write and Read operation.
- LPDDR4 supports DM and DBIdc function with a byte granularity.
- DBIdc function during Write or Masked Write can be enabled or disabled through MR3 OP[7].
- DBIdc function during Read can be enabled or disabled through MR3 OP[6].
- DM function during Masked Write can be enabled or disabled through MR13 OP[5].
- LPDDR4 device has one Data Mask Inversion (DMI) signal pin per byte; total of 2 DMI signals per channel.
- DMI signal is a bi-directional DDR signal and is sampled along with the DQ signals for Read and Write or Masked Write operation.

There are eight possible combinations for LPDDR4 device with DM and DBIdc function. Table 36 describes the functional behavior for all combinations.

Table 36 — Function Behavior of DMI Signal During Write, Masked Write and Read Operation

| DM Function | Write DBIdc Function | Read DBIdc Function | DMI Signal during Write Command | Signal during Masked Write Command | DMI Signal During Read | DMI Signal during MPC WR FIFO | DMI Signal during MPC RD FIFO | DMI Signal during MPC DQ Read Training | DMI Signal During MRR |
|-------------|----------------------|---------------------|---------------------------------|------------------------------------|------------------------|-------------------------------|-------------------------------|--|-----------------------|
| Disable | Disable | Disable | NOTE 1 | NOTE 1, 3 | NOTE 2 | NOTE 1 | NOTE 2 | NOTE 2 | NOTE 2 |
| Disable | Enable | Disable | NOTE 4 | NOTE 3 | NOTE 2 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 2 |
| Disable | Disable | Enable | NOTE 1 | NOTE 3 | NOTE 5 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 12 |
| Disable | Enable | Enable | NOTE 4 | NOTE 3 | NOTE 5 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 12 |
| Enable | Disable | Disable | NOTE 6 | NOTE 7 | NOTE 2 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 2 |
| Enable | Enable | Disable | NOTE 4 | NOTE 8 | NOTE 2 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 2 |
| Enable | Disable | Enable | NOTE 6 | NOTE 7 | NOTE 5 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 12 |
| Enable | Enable | Enable | NOTE 4 | NOTE 8 | NOTE 5 | NOTE 9 | NOTE 10 | NOTE 11 | NOTE 12 |

NOTE 1 DMI input signal is a don't care. DMI input receivers are turned OFF.

NOTE 2 DMI output drivers are turned OFF.

NOTE 3 Masked Write Command is not allowed and is considered an illegal command as DM function is disabled.

NOTE 4 DMI signal is treated as DBI signal and it indicates whether DRAM needs to invert the Write data received on DQs within a byte. The LPDDR4 device inverts Write data received on the DQ inputs in case DMI was sampled HIGH, or leaves the Write data non-inverted in case DMI was sampled LOW.

NOTE 5 The LPDDR4 DRAM inverts Read data on its DQ outputs associated within a byte and drives DMI signal HIGH when the number of '1' data bits within a given byte lane is greater than four; otherwise the DRAM does not invert the read data and drives DMI signal LOW.

NOTE 6 The LPDDR4 DRAM does not perform any mask operation when it receives Write command. During the Write burst associated with Write command, DMI signal must be driven LOW.

NOTE 7 The LPDDR4 DRAM requires an explicit Masked Write command for all masked write operations. DMI signal is treated as DM signal and it indicates which bit time within the burst is to be masked. When DMI signal is HIGH, DRAM masks that bit time across all DQs associated within a byte. All DQ input signals within a byte are don't care (either HIGH or LOW) when DMI signal is HIGH. When DMI signal is LOW, the LPDDR4 DRAM does not perform mask operation and data received on DQ input is written to the array.

NOTE 8 The LPDDR4 DRAM requires an explicit Masked Write command for all masked write operations. The LPDDR4 device masks the Write data received on the DQ inputs if the total count of '1' data bits on DQ[2:7] or DQ[10:15] (for Lower Byte or Upper Byte respectively) is equal to or greater than five and DMI signal is LOW. Otherwise the LPDDR4 DRAM does not perform mask operation and treats it as a legal DBI pattern; DMI signal is treated as DBI signal and data received on DQ input is written to the array.

NOTE 9 DMI signal is treated as a training pattern. The LPDDR4 DRAM does not perform any mask operation and does not invert Write data received on the DQ inputs.

NOTE 10 DMI signal is treated as a training pattern. The LPDDR4 DRAM returns DMI pattern written in WR FIFO.

NOTE 11 DMI signal is treated as a training pattern. For more details, see 4.34, RD DQ Calibration.

NOTE 12 DBI may apply or may not apply during normal MRR. It's vendor specific.

If read DBI is enable with MRS and vendor cannot support the DBI during MRR, DBI pin status should be low.

If read DBI is enable with MRS and vendor can support the DBI during MRR, the LPDDR4 DRAM inverts Mode Register Read data on its DQ outputs associated within a byte and drives DMI signal HIGH when the number of '1' data bits within a given byte lane is greater than four; otherwise the DRAM does not invert the read data and drives DMI signal LOW.

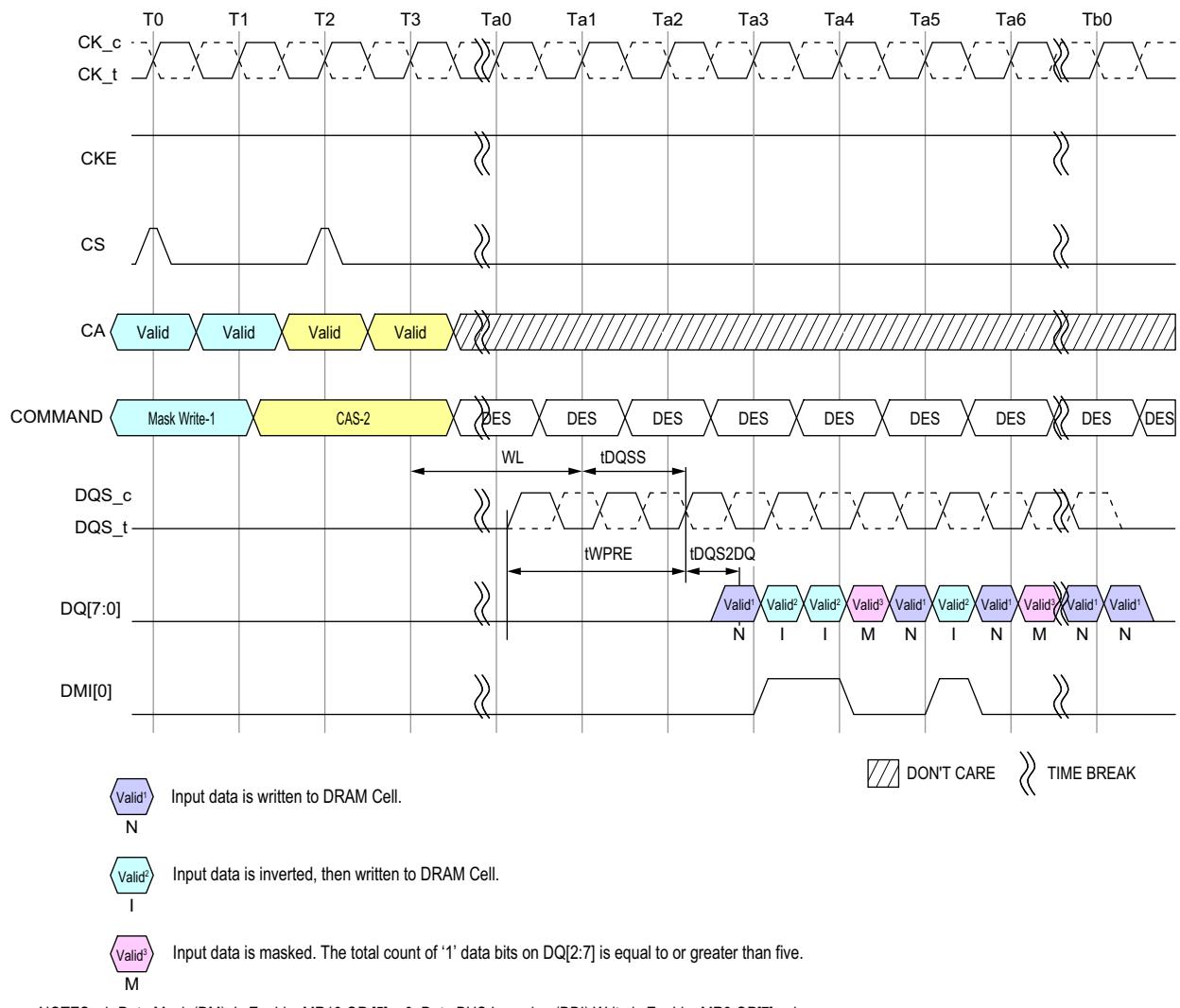
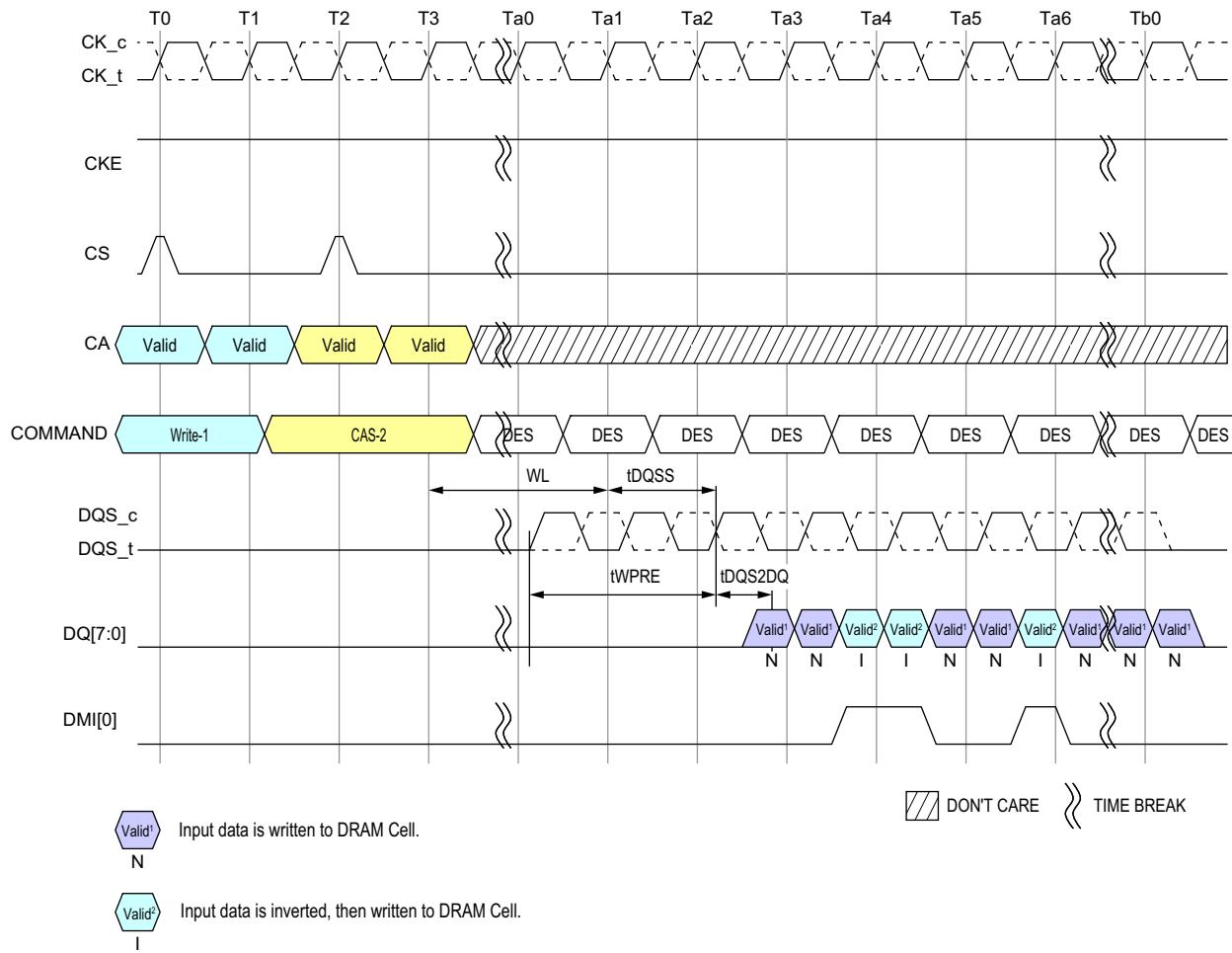


Figure 56 — Masked Write Command w/ Write DBI Enabled; DM Enabled



NOTES : 1. Data Mask (DM) is Disable: MR13 OP [5] = 1, Data BUS Inversion (DBI) Write is Enable: MR3 OP[7] = 1

Figure 57 — Write Command w/ Write DBI Enabled; DM Enabled

4.17 Precharge Operation

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

To ensure that LPDDR4 devices can meet the instantaneous current demands, the row-precharge time for an all bank PRECHARGE (tRPab) is longer than the per bank precharge time (tRPpb).

Table 37 — Precharge Bank Selection

| AB (CA[5], R1) | BA2 (CA[2], R2) | BA1 (CA[1], R2) | BA0 (CA[0], R2) | Precharged Bank(s) |
|---------------------------|----------------------------|----------------------------|----------------------------|-------------------------------|
| 0 | 0 | 0 | 0 | Bank 0 only |
| 0 | 0 | 0 | 1 | Bank 1 only |
| 0 | 0 | 1 | 0 | Bank 2 only |
| 0 | 0 | 1 | 1 | Bank 3 only |
| 0 | 1 | 0 | 0 | Bank 4 only |
| 0 | 1 | 0 | 1 | Bank 5 only |
| 0 | 1 | 1 | 0 | Bank 6 only |
| 0 | 1 | 1 | 1 | Bank 7 only |
| 1 | Valid | Valid | Valid | All Banks |

4.17.1 Burst Read Operation Followed by a Precharge

The PRECHARGE command can be issued as early as BL/2 clock cycles after a READ command, but PRECHARGE cannot be issued until after tRAS is satisfied. A new bank ACTIVATE command can be issued to the same bank after the row PRECHARGE time (tRP) has elapsed. The minimum READ-to-PRECHARGE time must also satisfy a minimum analog time from the 2nd rising clock edge of the CAS-2 command. tRTP begins BL/2 - 8 clock cycles after the READ command. For LPDDR4 READ-to-PRECHARGE timings see Table 38.

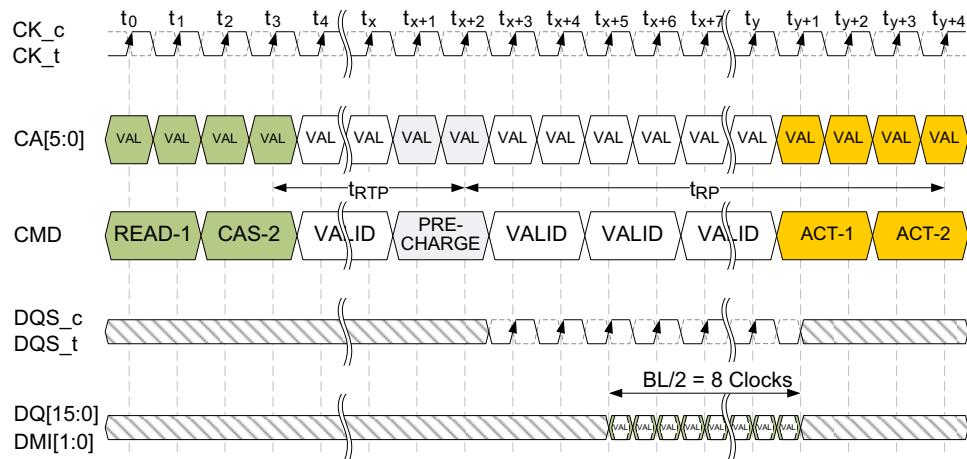


Figure 58 — Burst READ followed by PRECHARGE

(Shown with BL16, 2tCK pre-amble)

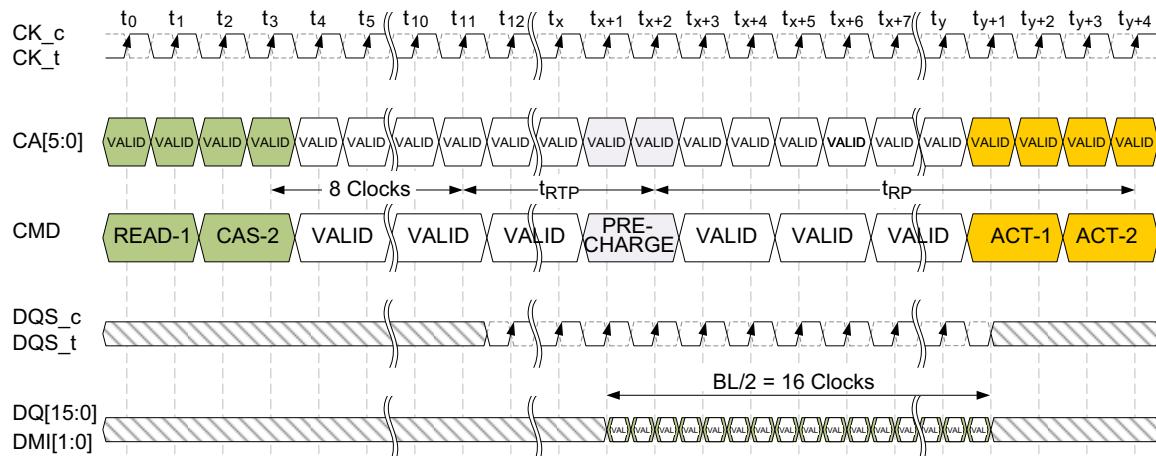


Figure 59 — Burst READ followed by PRECHARGE

(Shown with BL32, 2tCK pre-amble)

4.17.2 Burst WRITE Followed by PRECHARGE

A Write Recovery time (t_{WR}) must be provided before a PRECHARGE command may be issued. This delay is referenced from the next rising edge of CK_t after the last latching DQS clock of the burst.

LPDDR4-SDRAM devices write data to the memory array in prefetch multiples (prefetch=16). An internal WRITE operation can only begin after a prefetch group has been clocked, so t_{WR} starts at the prefetch boundaries. The minimum WRITE-to-PRECHARGE time for commands to the same bank is $WL + BL/2 + 1 + RU(t_{WR}/t_{CK})$ clock cycles.

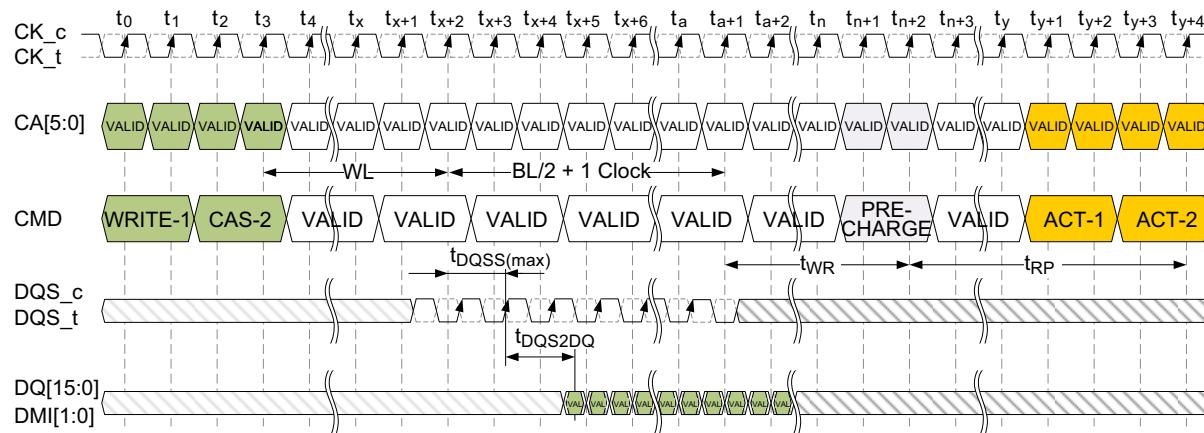


Figure 60 — Burst WRITE Followed by PRECHARGE
(Shown with BL16, 2tCK pre-amble)

4.17.3 Auto-Precharge Operation

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

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

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

4.17.4 Burst READ with Auto-Precharge

If AP is HIGH when a READ command is issued, the READ with Auto-Precharge function is engaged. An internal precharge procedure starts a following delay time after the READ command. And this delay time depends on BL setting.

BL = 16: nRTP

BL = 32: 8nCK + nRTP

For LPDDR4 Auto-Precharge calculations, see Table 38. Following an Auto-Precharge operation, an ACTIVATE command can be issued to the same bank if the following two conditions are both satisfied:

- The RAS precharge time (t_{RP}) has been satisfied from the clock at which the Auto-Precharge began, or
- The RAS cycle time (t_{RC}) from the previous bank activation has been satisfied.

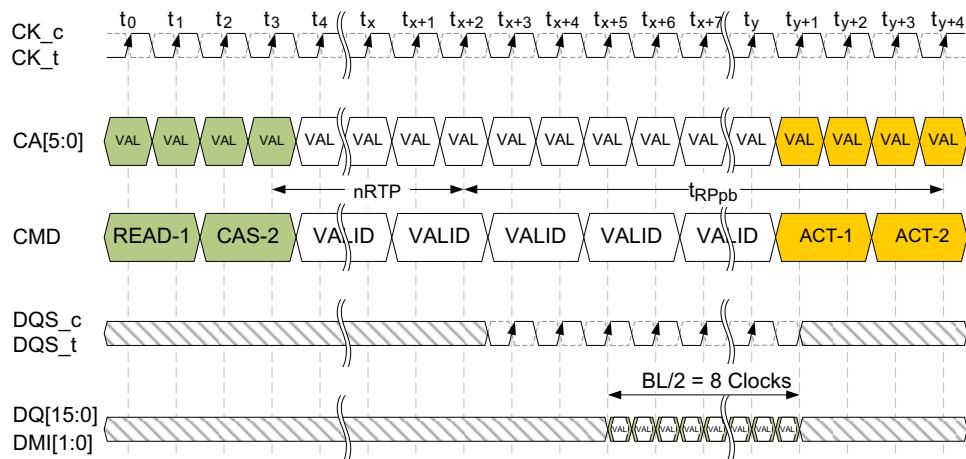


Figure 61 — Burst READ with Auto-Precharge
(Shown with BL16, 2tCK pre-amble)

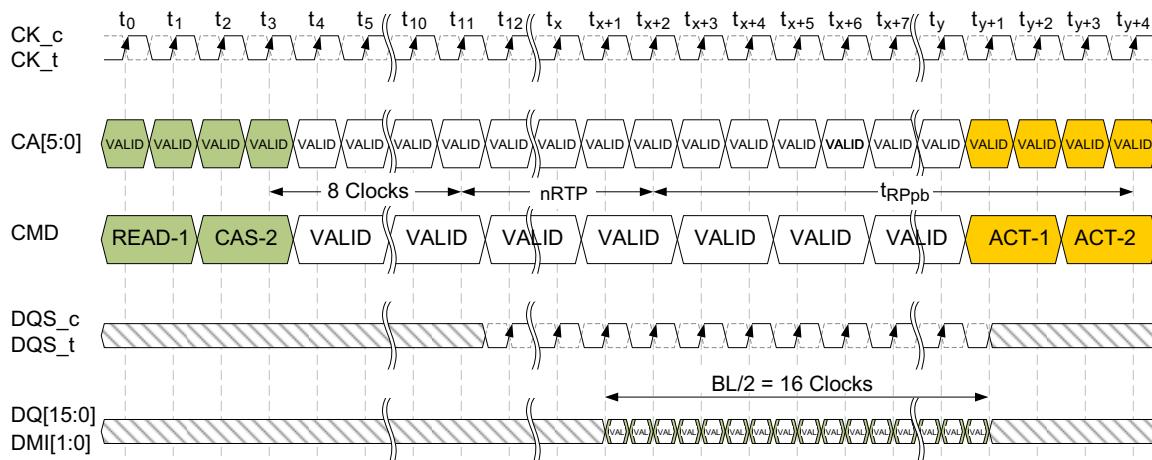


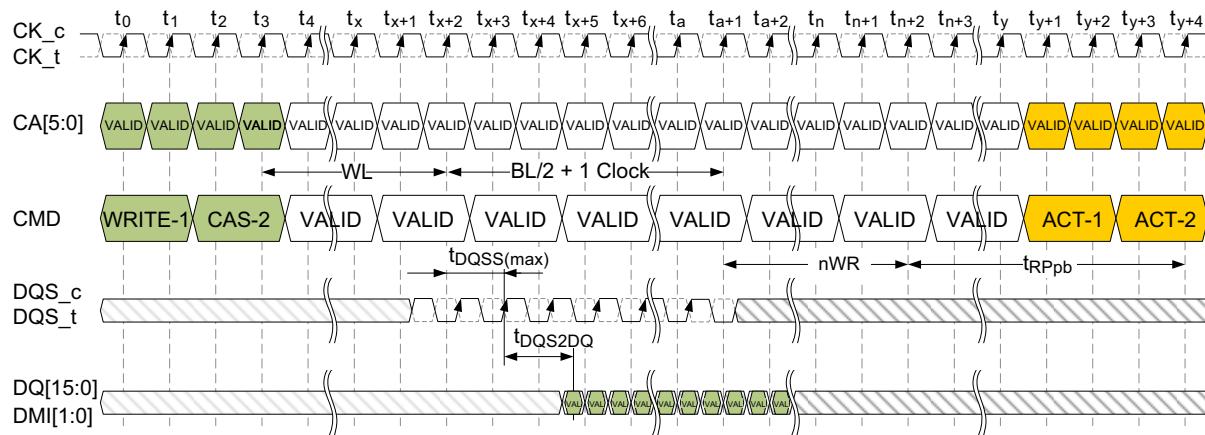
Figure 62 — Burst READ with Auto-Precharge
(Shown with BL32, 2tCK pre-amble)

4.17.5 Burst WRITE with Auto-Precharge

If AP is HIGH when a WRITE command is issued, the WRITE with Auto-Precharge function is engaged. The device starts an Auto-Precharge on the rising edge tWR cycles after the completion of the Burst WRITE.

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

- The RAS precharge time (tRP) has been satisfied from the clock at which the Auto-Precharge began, and
- The RAS cycle time (tRC) from the previous bank activation has been satisfied.



**Figure 63 — Burst WRITE with Auto-Precharge
(Shown with BL16, 2tCK pre-amble)**

4.18 Auto-Precharge Operation

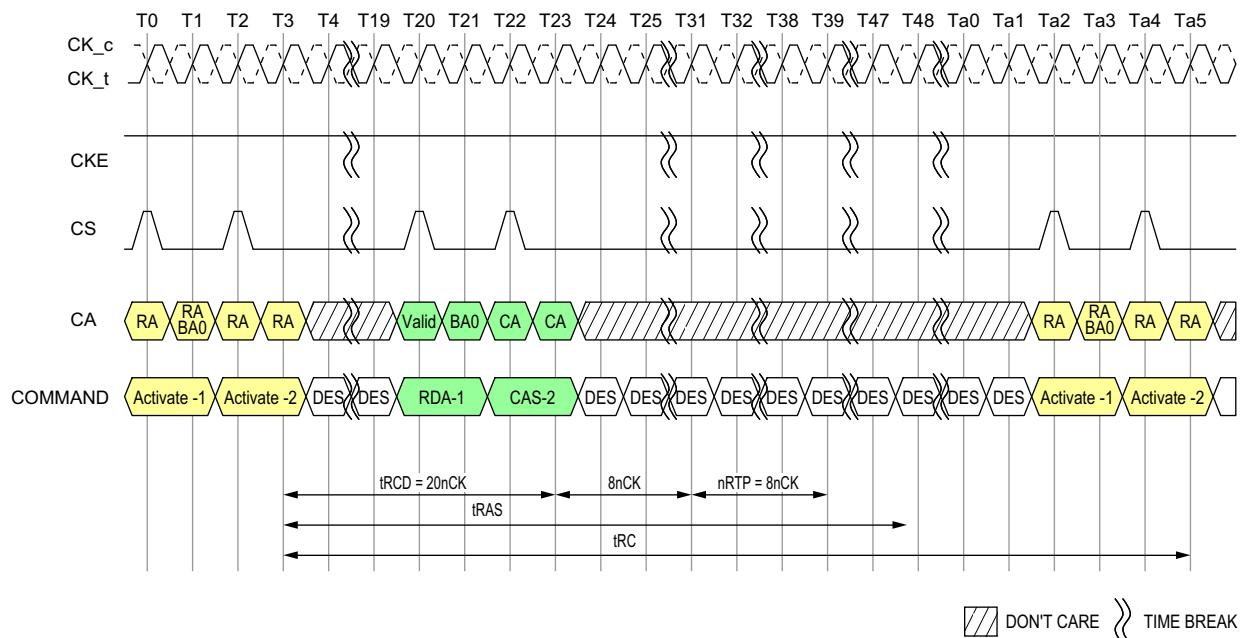
Before a new row can be opened in an active bank, the active bank must be precharged using either the PRECHARGE command or the Auto-Precharge function. When a READ, a WRITE or Masked Write command is issued to the device, the AP bit (CA5) can be set to enable the active bank to automatically begin precharge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

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

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

Read with Auto-Precharge or Write/Mask Write with Auto-Precharge commands may be issued after tRCD has been satisfied. The LPDDR4 SDRAM RAS Lockout feature will schedule the internal precharge to assure that tRAS is satisfied.

tRC needs to be satisfied prior to issuing subsequent Activate commands to the same bank. Figure 64 shows example of RAS lock function.



NOTES : 1. tCK(AVG) = 0.938ns, Data Rate = 2133Mbps, tRCD(Min) = Max(18ns, 4nCK), tRAS(Min) = Max(42ns, 3nCK), nRTP = 8nCK, BL = 32
2. tRCD = 20nCK comes from Roundup(18ns/0.938ns)
3. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 64 — Command Input Timing with RAS lock

4.18.1 Delay time from Write to Read with Auto-Precharge

In the case of write command followed by read with Auto-Precharge, controller must satisfy tWR for the write command before initiating the DRAM internal Auto-Precharge. It means that (tWTR + nRTP) should be equal or longer than (tWR) when BL setting is 16, as well as (tWTR + nRTP + 8nCK) should be equal or longer than (tWR) when BL setting is 32. Refer to the Figure 65 for details.

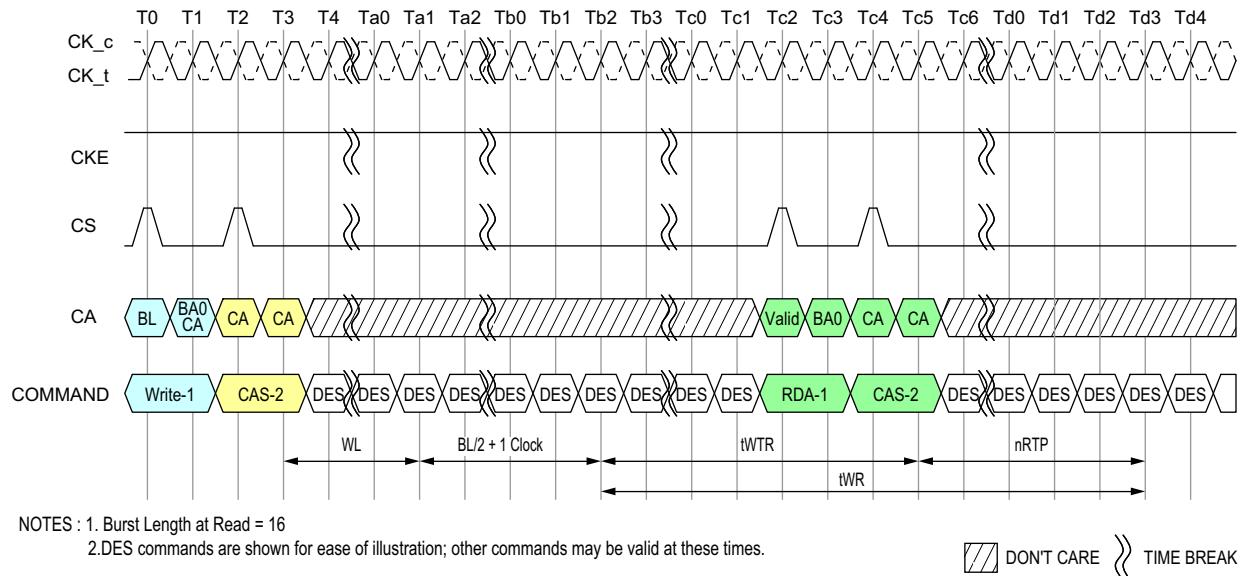


Figure 65 — Delay time from Write to Read with Auto-Precharge

Table 38 — Timing Between Commands (PRECHARGE and Auto-Precharge) : DQ ODT is Disable

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|--------------------|---|---|------|--------|
| READ BL=16 | PRECHARGE (to same bank as Read) | tRTP | tCK | 1,6 |
| | PRECHARGE All | tRTP | tCK | 1,6 |
| READ BL=32 | PRECHARGE (to same bank as Read) | 8tCK + tRTP | tCK | 1,6 |
| | PRECHARGE All | 8tCK + tRTP | tCK | 1,6 |
| READ w/AP BL=16 | PRECHARGE (to same bank as READ w/AP) | nRTP | tCK | 1,10 |
| | PRECHARGE All | nRTP | tCK | 1,10 |
| | Activate (to same bank as READ w/AP) | nRTP + tRPpb | tCK | 1,8,10 |
| | WRITE or WRITE w/AP (same bank) | Illegal | - | |
| | MASK-WR or MASK-WR w/AP (same bank) | Illegal | - | |
| | WRITE or WRITE w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-WL+tWPRE | tCK | 3,4,5 |
| | MASK-WR or MASK-WR w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-WL+tWPRE | tCK | 3,4,5 |
| | READ or READ w/AP (same bank) | Illegal | - | |
| | READ or READ w/AP (different bank) | BL/2 | tCK | 3 |

Table 38 — Timing Between Commands (PRECHARGE and Auto-Precharge) : DQ ODT is Disable (cont'd)

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|---------------------|---|---|------|--------|
| READ w/AP BL=32 | PRECHARGE (to same bank as READ w/AP) | 8tCK + nRTP | tCK | 1,10 |
| | PRECHARGE All | 8tCK + nRTP | tCK | 1,10 |
| | Activate (to same bank as READ w/AP) | 8tCK + nRTP + tRPpb | tCK | 1,8,10 |
| | WRITE or WRITE w/AP (same bank) | Illegal | - | |
| | MASK-WR or MASK-WR w/AP (same bank) | Illegal | - | |
| | WRITE or WRITE w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-WL+tWPRE | tCK | 3,4,5 |
| | MASK-WR or MASK-WR w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-WL+tWPRE | tCK | 3,4,5 |
| | READ or READ w/AP (same bank) | Illegal | - | |
| | READ or READ w/AP (different bank) | BL/2 | tCK | 3 |
| | PRECHARGE (to same bank as WRITE) | WL + BL/2 + tWR + 1 | tCK | 1,7 |
| WRITE BL=16 & 32 | PRECHARGE All | WL + BL/2 + tWR + 1 | tCK | 1,7 |
| | PRECHARGE (to same bank as MASK-WR) | WL + BL/2 + tWR + 1 | tCK | 1,7 |
| MASK-WR BL=16 | PRECHARGE All | WL + BL/2 + tWR + 1 | tCK | 1,7 |

Table 38 — Timing Between Commands (PRECHARGE and Auto-Precharge) : DQ ODT is Disable (cont'd)

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|--------------------------|---|---|------|--------|
| WRITE w/AP BL=16 & 32 | PRECHARGE (to same bank as WRITE w/AP) | WL + BL/2 + nWR + 1 | tCK | 1,11 |
| | PRECHARGE All | WL + BL/2 + nWR + 1 | tCK | 1,11 |
| | ACTIVATE (to same bank as WRITE w/AP) | WL + BL/2 +nWR + 1 + tRPpb | tCK | 1,8,11 |
| | WRITE or WRITE w/AP (same bank) | Illegal | - | |
| | READ or READ w/AP (same bank) | Illegal | - | |
| | WRITE or WRITE w/AP (different bank) | BL/2 | tCK | 3 |
| | MASK-WR or MASK-WR w/AP (different bank) | BL/2 | tCK | 3 |
| | READ or READ w/AP (different bank) | WL + BL/2 + tWTR + 1 | tCK | 3,9 |

Table 38 — Timing Between Commands (PRECHARGE and Auto-Precharge) : DQ ODT is Disable (cont'd)

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|-----------------------|---|---|------|--------|
| MASK-WR w/AP BL=16 | PRECHARGE (to same bank as MASK-WR w/AP) | WL + BL/2 + nWR + 1 | tCK | 1,11 |
| | PRECHARGE All | WL + BL/2 + nWR + 1 | tCK | 1,11 |
| | ACTIVATE (to same bank as MASK-WR w/AP) | WL + BL/2 + nWR + 1 + tRPpb | tCK | 1,8,11 |
| | WRITE or WRITE w/AP (same bank) | Illegal | - | 3 |
| | MASK-WR or MASK-WR w/AP (same bank) | Illegal | - | 3 |
| | WRITE or WRITE w/AP (different bank) | BL/2 | tCK | 3 |
| | MASK-WR or MASK-WR w/AP (different bank) | BL/2 | tCK | 3 |
| | READ or READ w/AP (same bank) | Illegal | - | 3 |
| | READ or READ w/AP (different bank) | WL + BL/2 + tWTR + 1 | tCK | 3,9 |

Table 38 — Timing Between Commands (PRECHARGE and Auto-Precharge) : DQ ODT is Disable (cont'd)

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|---------------|--|---|------|-------|
| PRECHARGE | PRECHARGE (to same bank as PRECHARGE) | 4 | tCK | 1 |
| | PRECHARGE All | 4 | tCK | 1 |
| PRECHARGE All | PRECHARGE | 4 | tCK | 1 |
| | PRECHARGE All | 4 | tCK | 1 |

NOTE 1 For a given bank, the precharge period should be counted from the latest precharge command, whether per bank or all bank, issued to that bank. The precharge period is satisfied tRP after that latest precharge command.

NOTE 2 Any command issued during the minimum delay time as specified in the table above is illegal.

NOTE 3 After READ w/AP, seamless read operations to different banks are supported. After WRITE w/AP or MASK-WR w/AP, seamless write operations to different banks are supported. READ, WRITE, and MASK-WR operations may not be truncated or interrupted.

NOTE 4 tRPST values depend on MR1-OP[7] respectively.

NOTE 5 tWPRE values depend on MR1-OP[2] respectively.

NOTE 6 Minimum Delay between "From Command" and "To Command" in clock cycle is calculated by dividing tRTP(ns) by tCK(ns) and rounding up to the next integer: Minimum Delay[cycles] = Roundup(tRTP[ns] / tCK[ns])

NOTE 7 Minimum Delay between "From Command" and "To Command" in clock cycle is calculated by dividing tWR(ns) by tCK(ns) and rounding up to the next integer: Minimum Delay[cycles] = Roundup(tWR[ns] / tCK[ns])

NOTE 8 Minimum Delay between "From Command" and "To Command" in clock cycle is calculated by dividing tRPpb(ns) by tCK(ns) and rounding up to the next integer: Minimum Delay[cycles] = Roundup(tRPpb[ns] / tCK[ns])

NOTE 9 Minimum Delay between "From Command" and "To Command" in clock cycle is calculated by dividing tWTR(ns) by tCK(ns) and rounding up to the next integer: Minimum Delay[cycles] = Roundup(tWTR[ns] / tCK[ns])

NOTE 10 For Read w/AP the value is nRTP which is defined in Mode Register 2.

NOTE 11 For Write w/AP the value is nWR which is defined in Mode Register 1.

Table 39 — Timing Between Commands (read w/ AP and write command) :DQ ODT is Enabled

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|---------------------|---|---|-------------|--------------|
| READ w/AP BL=16 | WRITE or WRITE w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-ODTLon-RD(tODTon,min/tCK)+1 | tCK | 2, 3 |
| | MASK-WR or MASK-WR w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-ODTLon-RD(tODTon,min/tCK)+1 | tCK | 2, 3 |
| READ w/AP BL=32 | WRITE or WRITE w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-ODTLon-RD(tODTon,min/tCK)+1 | tCK | 2, 3 |
| | MASK-WR or MASK-WR w/AP (different bank) | RL+RU(tDQSCK(max)/tCK)+BL/2+RD(tRPST)-ODTLon-RD(tODTon,min/tCK)+1 | tCK | 2, 3 |

NOTE 1 The rest of the timing about precharge and Auto-Precharge is same as DQ ODT is Disable case.

NOTE 2 After READ w/AP, seamless read operations to different banks are supported. READ, WRITE, and MASK-WR operations may not be truncated or interrupted.

NOTE 3 tRPST values depend on MR1-OP[7] respectively.

4.19 Refresh command

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

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

The bank count is synchronized between the controller and the SDRAM by resetting the bank count to zero. Synchronization can occur upon asserting RESET_n or at every exit from Self Refresh. REFab command also synchronizes the counter between the controller and SDRAM to zero. The SDRAM device can be placed in Self Refresh or a REFab command can be issued at any time without cycling through all eight banks using per bank REFRESH command. After the bank count is synchronized to zero the controller can issue per bank REFRESH commands in any order as described in the previous paragraph.

A REFab command issued when the bank counter is not zero will reset the bank counter to zero and the DRAM will perform refreshes to all banks as indicated by the row counter. If another refresh command (REFab or REFpb) is issued after the REFab command then it uses an incremented value of the row counter. The table below shows examples of both bank and refresh counter increment behavior.

Table 40 — Bank and Refresh counter increment behavior

| # | Command | BA0 | BA1 | BA2 | Refresh Bank # | Bank Counter # | Ref Counter # (Row Address #) |
|----|---------|---------------------|-----|-----|----------------|----------------|-------------------------------|
| 0 | | Reset, SRX or REFab | | | | | To 0 |
| 1 | REFpb | 0 | 0 | 0 | 0 | 0 to 1 | n |
| 2 | REFpb | 0 | 0 | 1 | 1 | 1 to 2 | |
| 3 | REFpb | 0 | 1 | 0 | 2 | 2 to 3 | |
| 4 | REFpb | 0 | 1 | 1 | 3 | 3 to 4 | |
| 5 | REFpb | 1 | 0 | 0 | 4 | 4 to 5 | |
| 6 | REFpb | 1 | 0 | 1 | 5 | 5 to 6 | |
| 7 | REFpb | 1 | 1 | 0 | 6 | 6 to 7 | |
| 8 | REFpb | 1 | 1 | 1 | 7 | 7 to 0 | |
| 9 | REFpb | 1 | 1 | 0 | 6 | 0 to 1 | n + 1 |
| 10 | REFpb | 1 | 1 | 1 | 7 | 1 to 2 | |
| 11 | REFpb | 0 | 0 | 1 | 1 | 2 to 3 | |
| 12 | REFpb | 0 | 1 | 1 | 3 | 3 to 4 | |
| 13 | REFpb | 1 | 0 | 1 | 5 | 4 to 5 | |
| 14 | REFpb | 0 | 1 | 0 | 2 | 5 to 6 | |
| 15 | REFpb | 0 | 0 | 0 | 0 | 6 to 7 | |
| 16 | REFpb | 1 | 0 | 0 | 4 | 7 to 0 | n + 2 |
| 17 | REFpb | 0 | 0 | 0 | 0 | 0 to 1 | |
| 18 | REFpb | 0 | 0 | 1 | 1 | 1 to 2 | |
| 19 | REFpb | 0 | 1 | 0 | 2 | 2 to 3 | |
| 20 | REFab | V | V | V | 0-7 | To 0 | n + 2 |
| 21 | REFpb | 1 | 1 | 0 | 6 | 0 to 1 | n + 3 |
| 22 | REFpb | 1 | 1 | 1 | 7 | 1 to 2 | |

Snip

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

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

- tRFCab has been satisfied after the prior REFab command.
- tRFCpb has been satisfied after the prior REFpb command.
- tRP has been satisfied after the prior PRECHARGE command to that bank.
- tRRD has been satisfied after the prior ACTIVATE command (if applicable, for example after activating a row in a different bank than the one affected by the REFpb command).

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

After issuing REFpb, these conditions must be met:

- tRFCpb must be satisfied before issuing a REFab command.
- tRFCpb must be satisfied before issuing an ACTIVATE command to the same bank.
- tRRD must be satisfied before issuing an ACTIVATE command to a different bank.
- tRFCpb must be satisfied before issuing another REFpb command.

An all bank REFRESH command (REFab) issues a REFRESH command to all banks. All banks must be idle when REFab is issued (for instance, by issuing a PRECHARGE-all command prior to issuing an all bank REFRESH command). REFab also synchronizes the bank count between the controller and the SDRAM to zero. The REFab command must not be issued to the device until the following conditions have been met:

- tRFCab has been satisfied following the prior REFab command.
- tRFCpb has been satisfied following the prior REFpb command.
- tRP has been satisfied following the prior PRECHARGE commands.

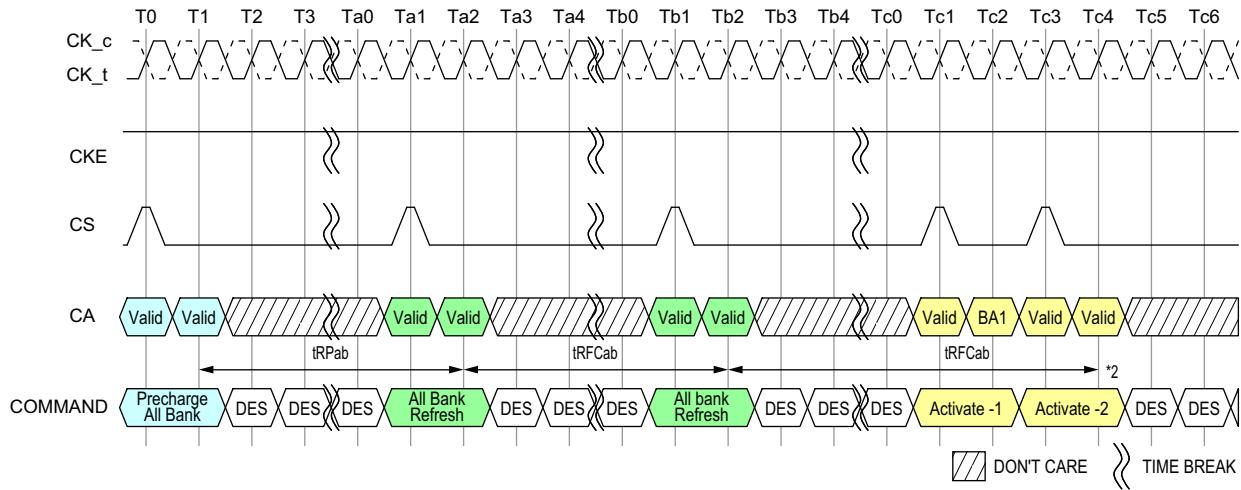
When an all bank refresh cycle has completed, all banks will be idle. After issuing REFab:

- tRFCab latency must be satisfied before issuing an ACTIVATE command.
- tRFCab latency must be satisfied before issuing a REFab or REFpb command.

Table 41 — REFRESH Command Scheduling Separation requirements

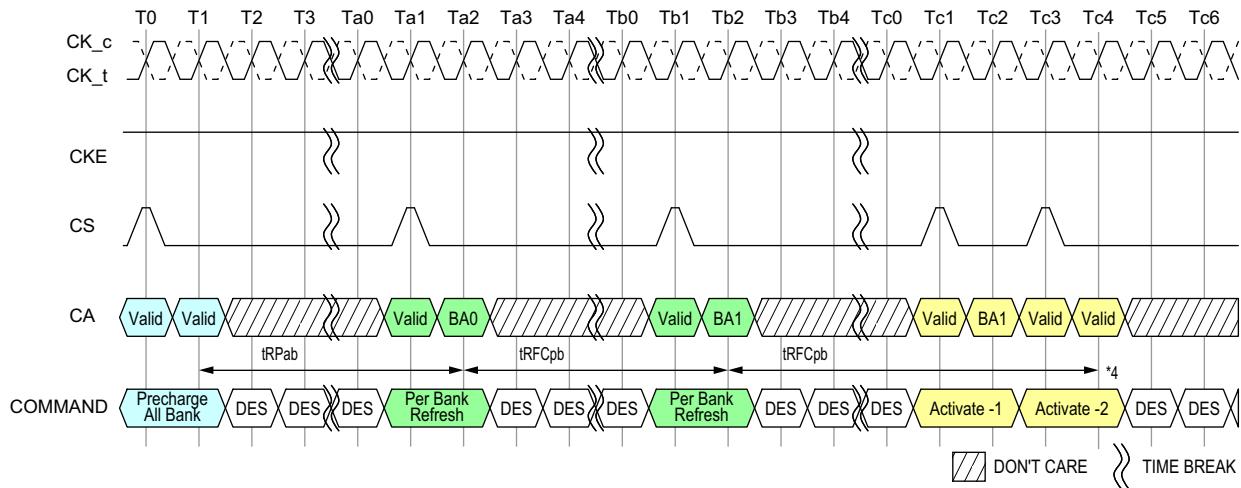
| Symbol | Minimum Delay From | To | Notes |
|--------|--------------------|--|-------|
| tRFCab | REFab | REFab | |
| | | Activate command to any bank | |
| | | REFpb | |
| tRFCpb | REFpb | REFab | |
| | | Activate command to same bank as REFpb | |
| | | REFpb | |
| tRRD | REFpb | Activate command to different bank than REFpb | |
| | Activate | REFpb | 1 |
| | | Activate command to different bank than prior Activate command | |

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



NOTES :
 1. DES commands are shown for ease of illustration; other commands may be valid at these times.
 2. Activate Command is shown as an example. Other commands may be valid provided the timing specification is satisfied.

Figure 66 — All Bank Refresh Operation



NOTES :
 1. DES commands are shown for ease of illustration; other commands may be valid at these times.
 2. In the beginning of this example, the REFpb bank is pointing to bank 0.
 3. Operations to banks other than the bank being refreshed are supported during the t_{RFCpb} period.
 4. Activate Command is shown as an example. Other commands may be valid provided the timing specification is satisfied.

Figure 67 — Per Bank Refresh Operation

In general, a Refresh command needs to be issued to the LPDDR4 SDRAM regularly every tREFI interval. To allow for improved efficiency in scheduling and switching between tasks, some flexibility in the absolute refresh interval is provided. A maximum of 8 Refresh commands can be postponed during operation of the LPDDR4 SDRAM, meaning that at no point in time more than a total of 8 Refresh commands are allowed to be postponed and maximum number of pulled-in or postponed REF command is dependent on refresh rate. It is described in the table below. In case that 8 Refresh commands are postponed in a row, the resulting maximum interval between the surrounding Refresh commands is limited to $9 \times t_{REFI}$. A maximum of 8 additional Refresh commands can be issued in advance ("pulled in"), with each one reducing the number of regular Refresh commands required later by one. Note that pulling in more than 8 Refresh commands in advance does not further reduce the number of regular Refresh commands required later, so that the resulting maximum interval between two surrounding Refresh commands is limited to $9 \times t_{REFI}$.

At any given time, a maximum of 16 REF commands can be issued within $2 \times tREFI$. Self Refresh Mode may be entered with a maximum of eight Refresh commands being postponed. After exiting Self Refresh Mode with one or more Refresh commands postponed, additional Refresh commands may be postponed to the extent that the total number of postponed Refresh commands (before and after the Self Refresh) will never exceed eight. During Self Refresh Mode, the number of postponed or pulled-in REF commands does not change.

And for per bank refresh, a maximum 8×8 per bank refresh commands can be postponed or pulled in for scheduling efficiency. At any given time, a maximum of $2 \times 8 \times 8$ per bank refresh commands can be issued within $2 \times tREFI$.

Table 42 — Legacy Refresh Command Timing Constraints

| MR4 OP[2:0] | Refresh rate | Max. No. of pulled-in or postponed REFab | Max. Interval between two REFab | Max. No. of REFab within max($2xtREFI \times$ refresh rate multiplier, $16xtRFC$) | Per bank Refresh |
|-------------|------------------|--|---------------------------------|---|------------------|
| 000B | Low Temp. Limit | N/A | N/A | N/A | N/A |
| 001B | 4x tREFI | 8 | $9 \times 4 \times tREFI$ | 16 | 1/8 of REFab |
| 010B | 2x tREFI | 8 | $9 \times 2 \times tREFI$ | 16 | 1/8 of REFab |
| 011B | 1x tREFI | 8 | $9 \times tREFI$ | 16 | 1/8 of REFab |
| 100B | 0.5x tREFI | 8 | $9 \times 0.5 \times tREFI$ | 16 | 1/8 of REFab |
| 101B | 0.25x tREFI | 8 | $9 \times 0.25 \times tREFI$ | 16 | 1/8 of REFab |
| 110B | 0.25x tREFI | 8 | $9 \times 0.25 \times tREFI$ | 16 | 1/8 of REFab |
| 111B | High Temp. Limit | N/A | N/A | N/A | N/A |

Table 43 — Modified REFRESH Command Timing Constraints

| MR4 OP[2:0] | Refresh rate | Max. No. of pulled-in or postponed REFab | Max. Interval between two REFab | Max. No. of REFab within max($2xtREFI \times$ refresh rate multiplier, $16xtRFC$) | Per bank Refresh |
|-------------|------------------|--|---------------------------------|---|------------------|
| 000B | Low Temp. Limit | N/A | N/A | N/A | N/A |
| 001B | 4x tREFI | 2 | $3 \times 4 \times tREFI$ | 4 | 1/8 of REFab |
| 010B | 2x tREFI | 4 | $5 \times 2 \times tREFI$ | 8 | 1/8 of REFab |
| 011B | 1x tREFI | 8 | $9 \times tREFI$ | 16 | 1/8 of REFab |
| 100B | 0.5x tREFI | 8 | $9 \times 0.5 \times tREFI$ | 16 | 1/8 of REFab |
| 101B | 0.25x tREFI | 8 | $9 \times 0.25 \times tREFI$ | 16 | 1/8 of REFab |
| 110B | 0.25x tREFI | 8 | $9 \times 0.25 \times tREFI$ | 16 | 1/8 of REFab |
| 111B | High Temp. Limit | N/A | N/A | N/A | N/A |

NOTE 1 For any thermal transition phase where Refresh mode is transitioned to either $2x tREFI$ or $4x tREFI$, DRAM will support the previous postponed refresh requirement provided the number of postponed refreshes is monotonically reduced to meet the new requirement. However, the pulled-in refresh commands in previous thermal phase are not applied in new thermal phase. Entering new thermal phase the controller must count the number of pulled-in refresh commands as zero, regardless of remaining pulled-in refresh commands in previous thermal phase.

NOTE 2 LPDDR4 devices are refreshed properly if memory controller issues refresh commands with same or shorter refresh period than reported by MR4 OP[2:0]. If shorter refresh period is applied, the corresponding requirements from Table apply. For example, when MR4 OP[2:0]=001B, controller can be in any refresh rate from $4xtREFI$ to $0.25x tREFI$. When MR4 OP[2:0]=010B, the only prohibited refresh rate is $4x tREFI$.

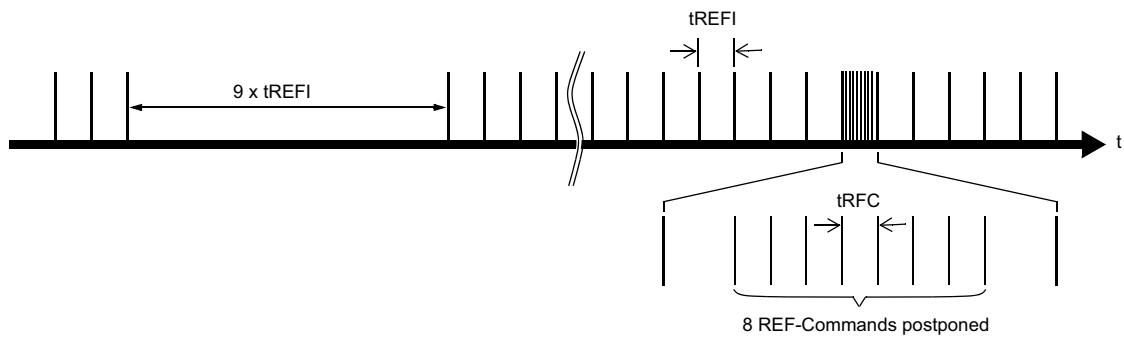


Figure 68 — Postponing Refresh Commands (Example)

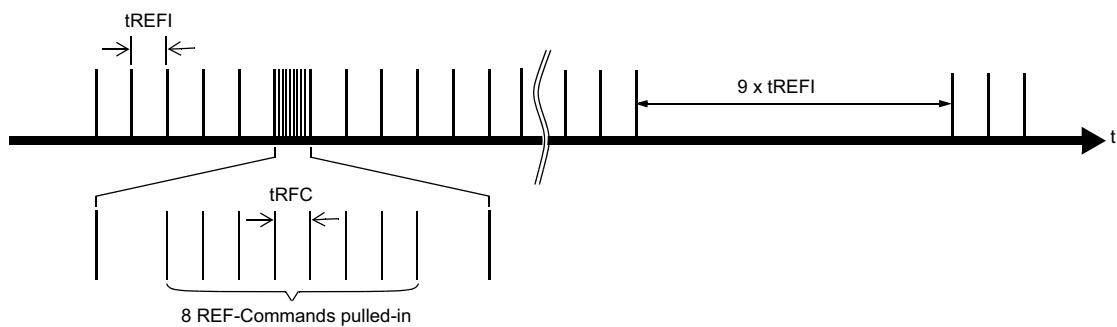


Figure 69 — Pulling-in Refresh Commands (Example)

4.19.1 Burst Read operation followed by Per Bank Refresh

The Per Bank Refresh command can be issued after tRTP + tRPpb from Read command.

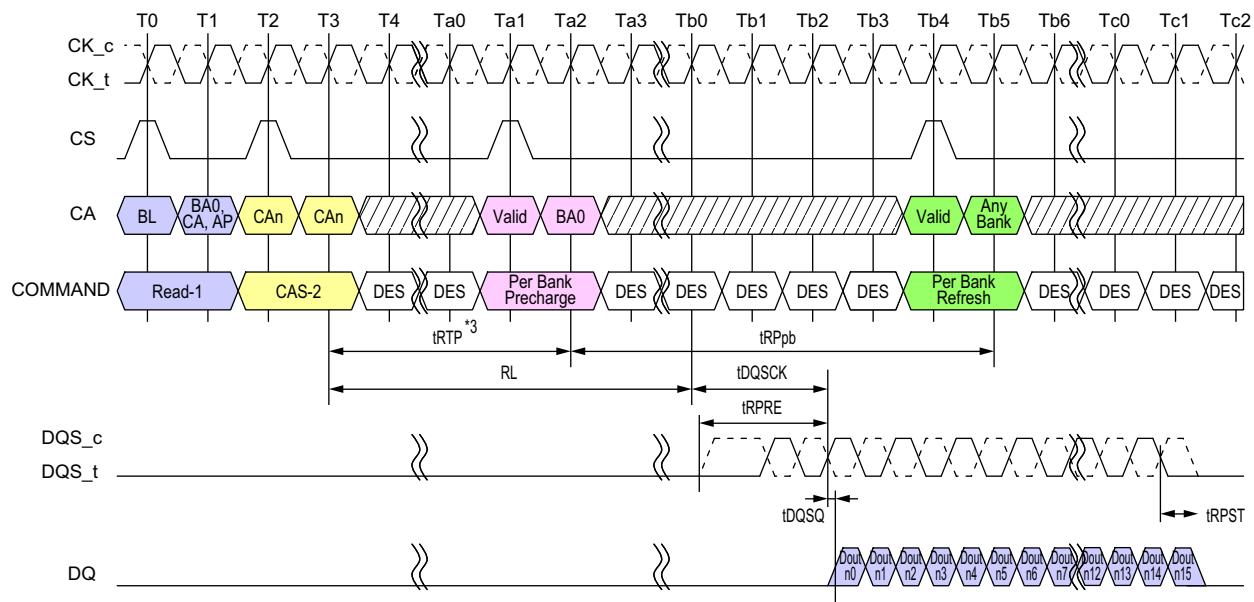


Figure 70 — Burst Read operation followed by Per Bank Refresh

The Per Bank Refresh command can be issued after tRC from Read with Auto Precharge command.

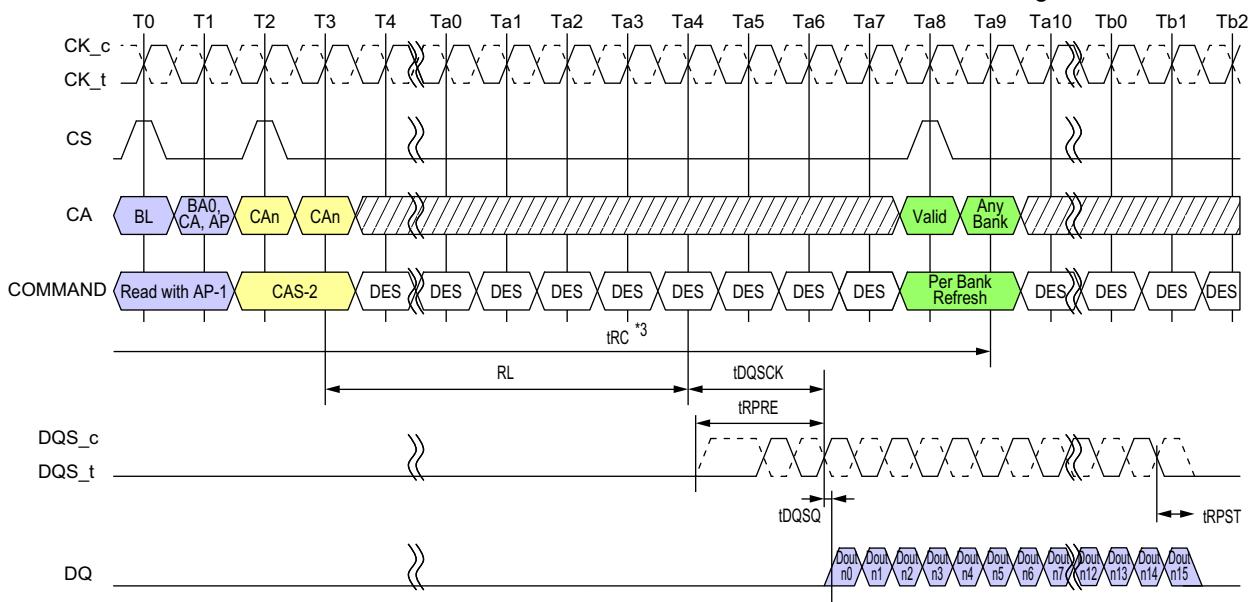


Figure 71 — Burst Read with Auto-Precharge operation followed by Per Bank Refresh

4.20.1 Refresh Requirement

Table 44 — Refresh Requirement Parameters per die for Dual Channel SDRAM devices

| Refresh Requirements | Symbol | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb | 24Gb | 32Gb | Units |
|--|----------|---------|-----|-----|-------|------|------|------|-------|
| Density per Channel | | 2Gb | 3Gb | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb | |
| Number of banks per channel | | | | | 8 | | | | |
| Refresh Window (tREFW) (TCASE ≤ 85°C) | tREFW | | | | 32 | | | | ms |
| Refresh Window (tREFW) (1/2 Rate Refresh) | tREFW | | 16 | | 16 | | TBD | TBD | ms |
| Refresh Window (tREFW) (1/4 Rate Refresh) | tREFW | | 8 | | 8 | | TBD | TBD | ms |
| Required Number of REFRESH Commands in a tREFW window | R | | | | 8192 | | | | - |
| Average Refresh Interval | REFAB | tREFI | | | 3.904 | | | | us |
| | REFPB | tREFIpb | | | 488 | | | | ns |
| Refresh Cycle Time (All Banks) | tRFCab | 130 | 180 | 180 | 280 | 380 | | | ns |
| Refresh Cycle Time (Per Bank) | tRFCpb | 60 | 90 | 90 | 140 | 190 | | | ns |
| Per-bank Refresh to Per-bank Refresh different bank Time | tpbR2pbR | 60 | | | 90 | | | | ns |

Table 45 — Refresh Requirement Parameters per die for Single Channel SDRAM devices

| Refresh Requirements | Symbol | 2Gb | 3Gb | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb | Units |
|---|--------|---------|-------|-----|-------|-----|------|------|-------|
| Density per Channel | | 2Gb | 3Gb | 4Gb | 6Gb | 8Gb | 12Gb | 16Gb | |
| Number of banks per channel | | | 8 | | 8 | | TBD | TBD | |
| Refresh Window (tREFW) (TCASE ≤ 85°C) | tREFW | | 32 | | 32 | | TBD | TBD | ms |
| Refresh Window (tREFW) (1/2 Rate Refresh) | tREFW | | 16 | | 16 | | TBD | TBD | ms |
| Refresh Window (tREFW) (1/4 Rate Refresh) | tREFW | | 8 | | 8 | | TBD | TBD | ms |
| Required Number of REFRESH Commands in a tREFW window | R | | 8192 | | 8192 | | TBD | TBD | - |
| Average Refresh Interval | REFAB | tREFI | 3.904 | | 3.904 | | TBD | TBD | us |
| | REFPB | tREFIpb | 488 | | 488 | | TBD | TBD | ns |
| Refresh Cycle Time (All Banks) | tRFCab | 130 | 180 | 180 | 280 | TBD | TBD | | ns |
| Refresh Cycle Time (Per Bank) | tRFCpb | 60 | 90 | 90 | 140 | TBD | TBD | | ns |

NOTE 1 Refresh for each channel is independent of the other channel on the die, or other channels in a package. Power delivery in the user's system should be verified to make sure the DC operating conditions are maintained when multiple channels are refreshed simultaneously.

NOTE 2 Self Refresh abort feature is available for higher density devices starting with 12 Gb dual channel device and 6 Gb single channel device and tXSR_abort(min) is defined as tRFCpb + 17.5ns.

4.2 Self Refresh Operation

4.21.1 Self Refresh Entry and Exit

The Self Refresh command can be used to retain data in the LPDDR4 SDRAM, the SDRAM retains data without external Refresh command. The device has a built-in timer to accommodate Self Refresh operation. The Self Refresh is entered by Self Refresh Entry Command defined by having CS High, CA0 Low, CA1 Low, CA2 Low; CA3 High; CA4 High, CA5 Valid (Valid that means it is Logic Level, High or Low) for the first rising edge and CS Low, CA0 Valid, CA1 Valid, CA2 Valid, CA3 Valid, CA4 Valid, CA5 Valid at the second rising edge of the clock. Self Refresh command is only allowed when read data burst is completed and SDRAM is idle state.

During Self Refresh mode, external clock input is needed and all input pin of SDRAM are activated. SDRAM can accept the following commands, MRR-1, CAS-2, DES, SRX, MPC, MRW-1, and MRW-2 except PASR Bank/Segment setting.

LPDDR4 SDRAM can operate in Self Refresh in both the standard or elevated temperature ranges. SDRAM will also manage Self Refresh power consumption when the operating temperature changes, lower at low temperature and higher at high temperatures.

For proper Self Refresh operation, power supply pins (VDD1, VDD2 and VDDQ) must be at valid levels. However VDDQ may be turned off during Self Refresh with Power Down after tCKELCK(Max(5ns,5nCK)) is satisfied (Refer to Figure 73 about tCKELCK).

Prior to exiting Self Refresh with Power Down, VDDQ must be within specified limits. The minimum time that the SDRAM must remain in Self Refresh model is tSR,min. Once Self Refresh Exit is registered, only MRR-1, CAS-2, DES, MPC, MRW-1 and MRW-2 except PASR Bank/Segment setting are allowed until tXSR is satisfied.

The use of Self Refresh mode introduces the possibility that an internally timed refresh event can be missed when Self Refresh Exit is registered. Upon exit from Self Refresh, it is required that at least one REFRESH command (8 per bank or 1 all bank) is issued before entry into a subsequent Self Refresh. This REFRESH command is not included in the count of regular refresh commands required by the tREFI interval, and does not modify the postponed or pulled-in refresh counts; the REFRESH command does count toward the maximum refreshes permitted within 2 X tREFI.

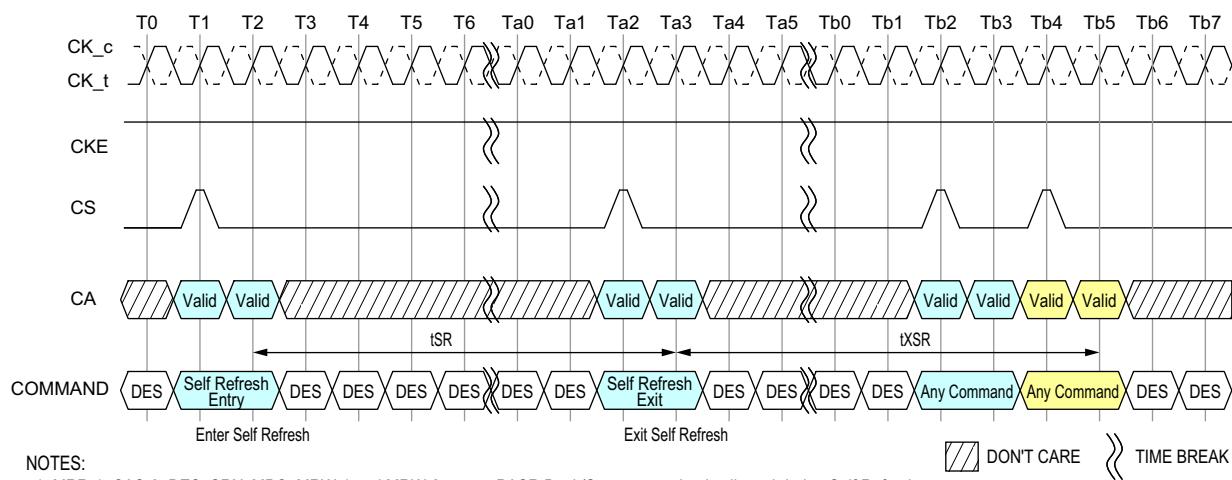


Figure 72 — Self Refresh Entry/Exit Timing

4.21.2 Power Down Entry and Exit during Self Refresh

Entering/Exiting Power Down Mode is allowed during Self Refresh mode in SDRAM. The related timing parameters between Self Refresh Entry/Exit and Power Down Entry/Exit are shown in Figure 73.

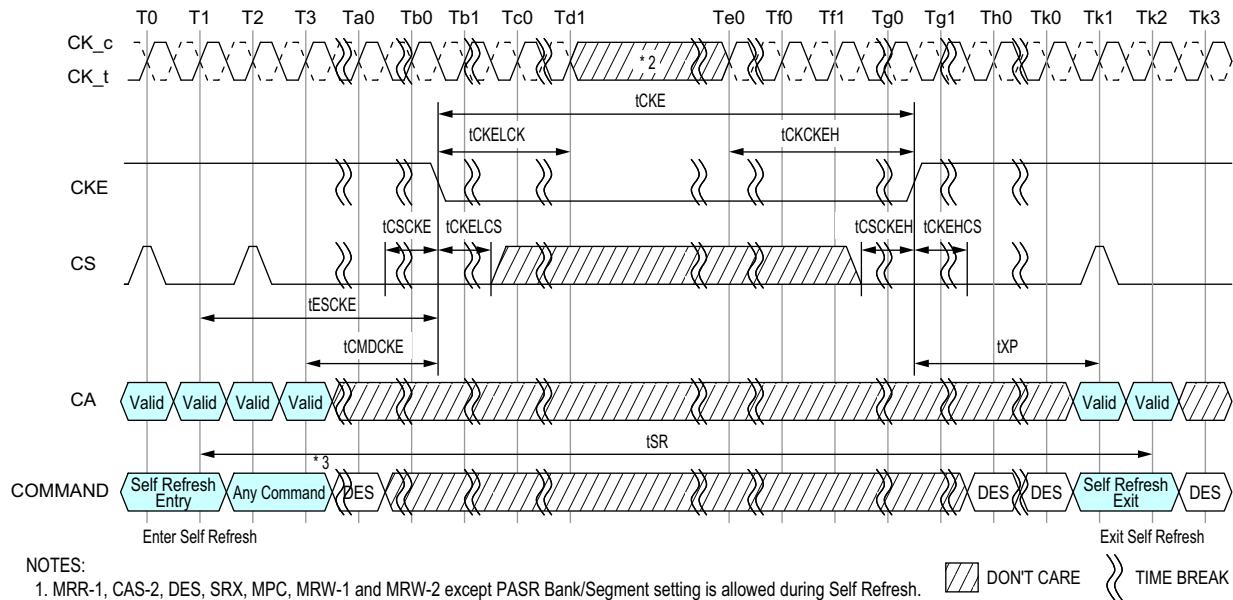


Figure 73 — Self Refresh Entry/Exit Timing with Power Down Entry/Exit

4.21.3 Command input Timing after Power Down Exit

Command input timings after Power Down Exit during Self Refresh mode are shown in Figure 74.

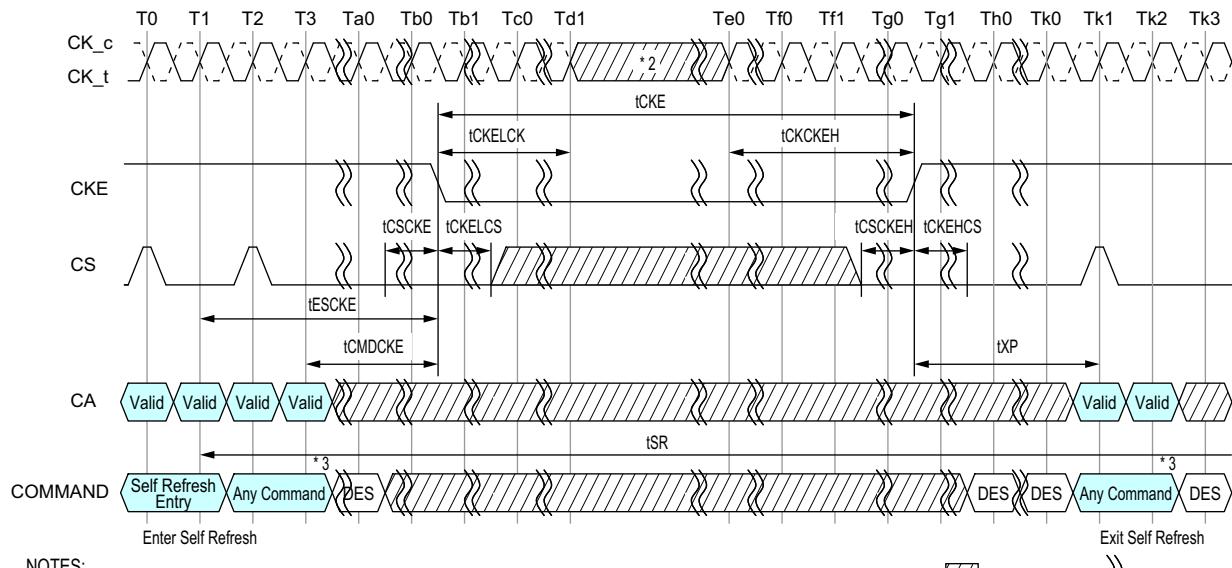


Figure 74 — Command input timings after Power Down Exit during Self Refresh

4.21.4 AC Timing Table

Table 46 — AC Timing Table

| Parameter | Symbol | Min/ Max | Data Rate | Unit | Note |
|---|--------|-------------|------------------------------|------|------|
| Self Refresh Timing | | | | | |
| Delay from SRE command to CKE Input low | tESCKE | Min | Max(1.75ns, 3tCK) | ns | 1 |
| Minimum Self Refresh Time | tSR | Min | Max(15ns, 3tCK) | ns | 1 |
| Exit Self Refresh to Valid commands | tXSR | Min | Max(tRFCab + 7.5ns, 2tCK) | ns | 1,2 |

NOTE 1 Delay time has to satisfy both analog time(ns) and clock count(tCK). It means that tESCKE will not expire until CK has toggled through at least 3 full cycles (3 *tCK) and 1.75ns has transpired. The case which 3tCK is applied to is shown in Figure 75.

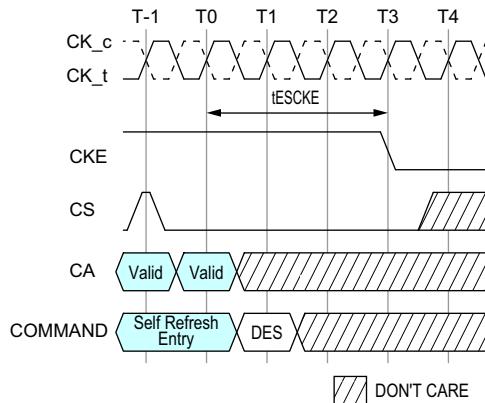


Figure 75 — tESCKE Timing

NOTE 2 MRR-1, CAS-2, DES, MPC, MRW-1 and MRW-2 except PASR Bank/Segment setting are only allowed during this period.

4.22 Self Refresh Abort

If MR4 OP[3] is enabled then DRAM aborts any ongoing refresh during Self Refresh exit and does not increment the internal refresh counter. Controller can issue a valid command after a delay of tXSR_abort instead of tXSR.

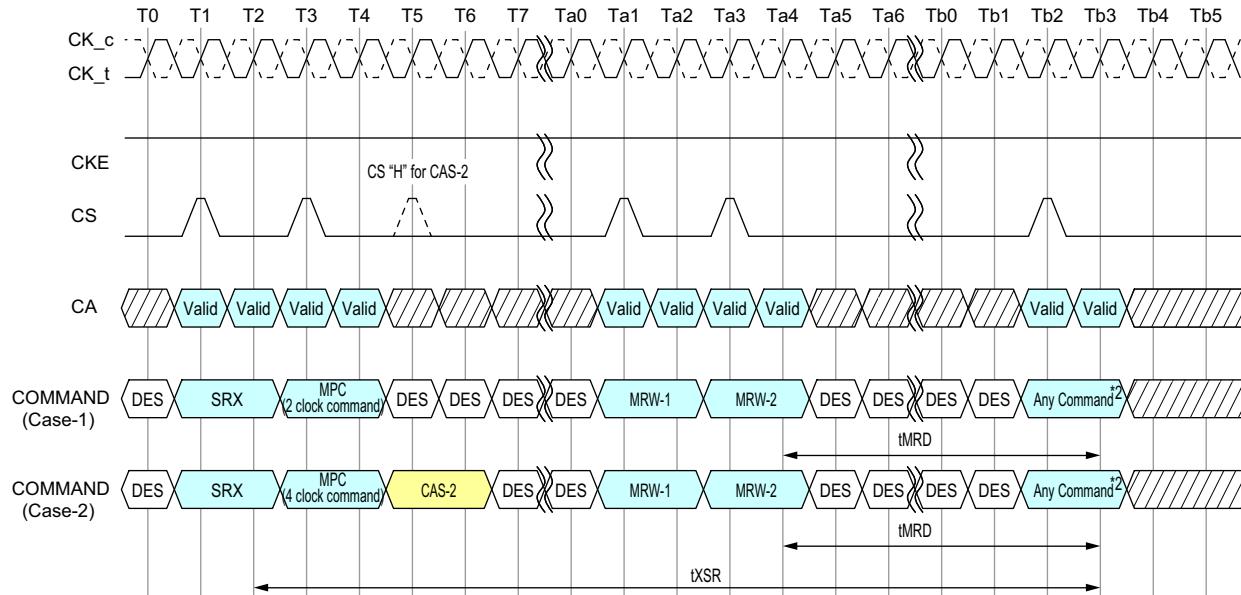
The value of tXSR_abort(min) is defined as tRFCpb + 17.5ns.

Upon exit from Self Refresh mode, the LPDDR4 SDRAM requires a minimum of one extra refresh (8 per bank or 1 all bank) before entry into a subsequent Self Refresh mode. This requirement remains the same irrespective of the setting of the MR bit for Self Refresh abort.

Self Refresh abort feature is available for higher density devices starting with 12 Gb dual channel device and 6 Gb single channel device.

4.23 MRR, MRW, MPC Command during tXSR, tRFC

Mode Register Read (MRR), Mode Register Write (MRW) and Multi-Purpose Command (MPC) can be issued during tXSR period.



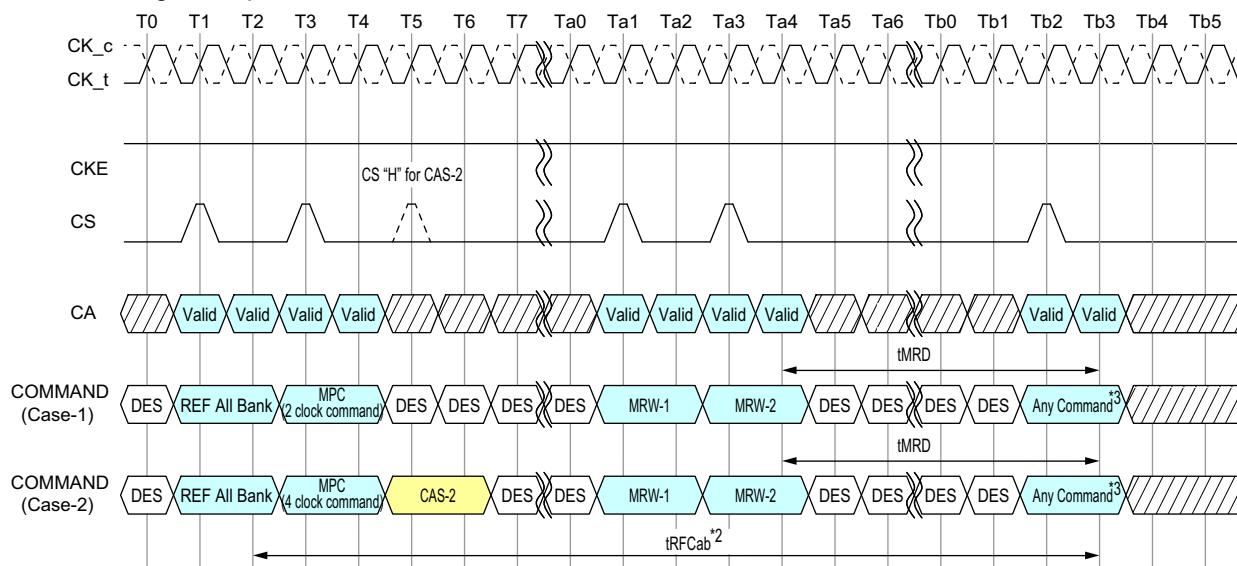
NOTES : 1. MPC and MRW command are shown in figure at this time, Any combination of MRR, MRW and MPC is allowed during tXSR period.

2. Any command also includes MRR, MRW and all MPC command.

DON'T CARE TIME BREAK

Figure 76 — MRR, MRW and MPC Commands Issuing Timing during tXSR

Mode Register Read (MRR), Mode Register Write (MRW) and Multi-Purpose Command (MPC) can be issued during tRFC period.



NOTES : 1. MPC and MRW command are shown in figure at this time, Any combination of MRR, MRW and MPC is allowed during tRFCab or tRFCpb period.

2. Refresh cycle time depends on Refresh command. In case of REF per Bank command issued, Refresh cycle time will be tRFCpb.

3. Any command also includes MRR, MRW and all MPC command.

DON'T CARE TIME BREAK

Figure 77 — MRR, MRW and MPC Commands Issuing Timing during tRFC

4.24 MODE REGISTER READ(MRR)

The Mode Register Read (MRR) command is used to read configuration and status data from the LPDDR4-SDRAM registers. The MRR command is initiated with CS and CA[5:0] in the proper state as defined by the Command Truth Table. The mode register address operands (MA[5:0]) allow the user to select one of 64 registers. The mode register contents are available on the first 4UI's data bits of DQ[7:0] after RL x tCK + tDQSCK + tDQSQ following the MRR command. Subsequent data bits contain valid but undefined content. DQS is toggled for the duration of the Mode Register READ burst. The MRR has a command burst length 16.

MRR operation must not be interrupted.

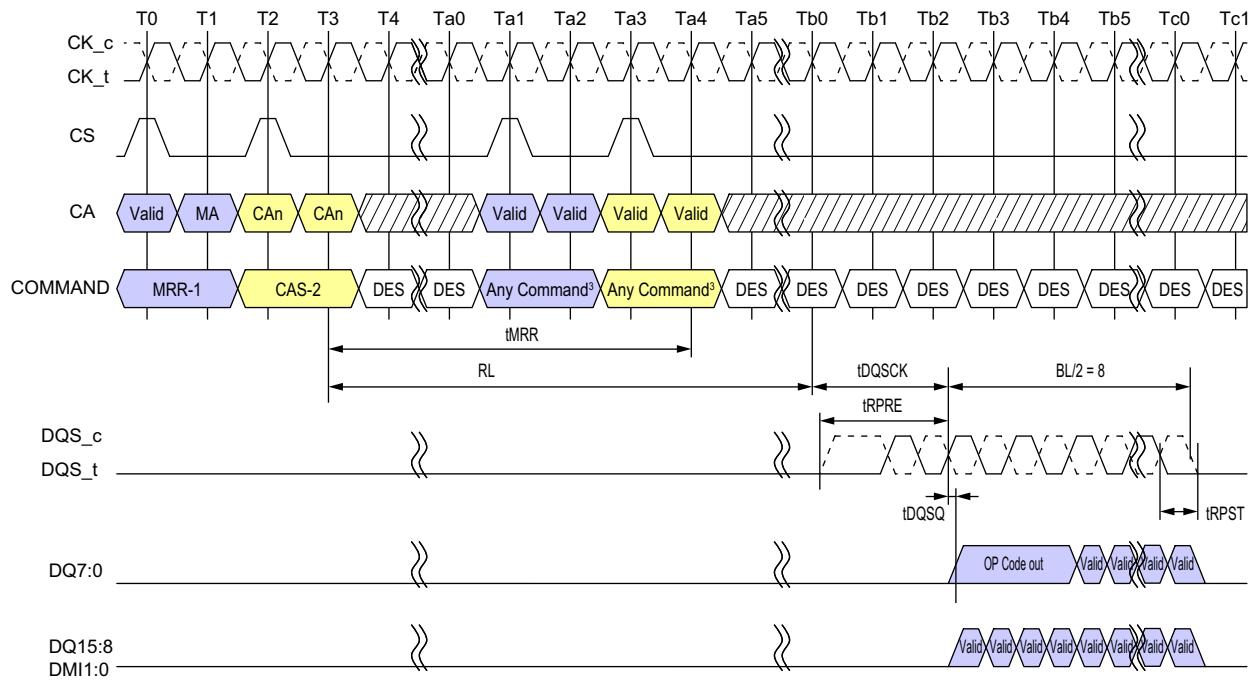
Table 47 — DQ output mapping

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

NOTE 1 MRR data are extended to first 4 UI's for DRAM controller to sample data easily.

NOTE 2 DBI may apply or may not apply during normal MRR. It's vendor specific. If read DBI is enable with MRS and vendor cannot support the DBI during MRR, DMI pin status should be low.

NOTE 3 The read pre-amble and post-amble of MRR are same as normal read.



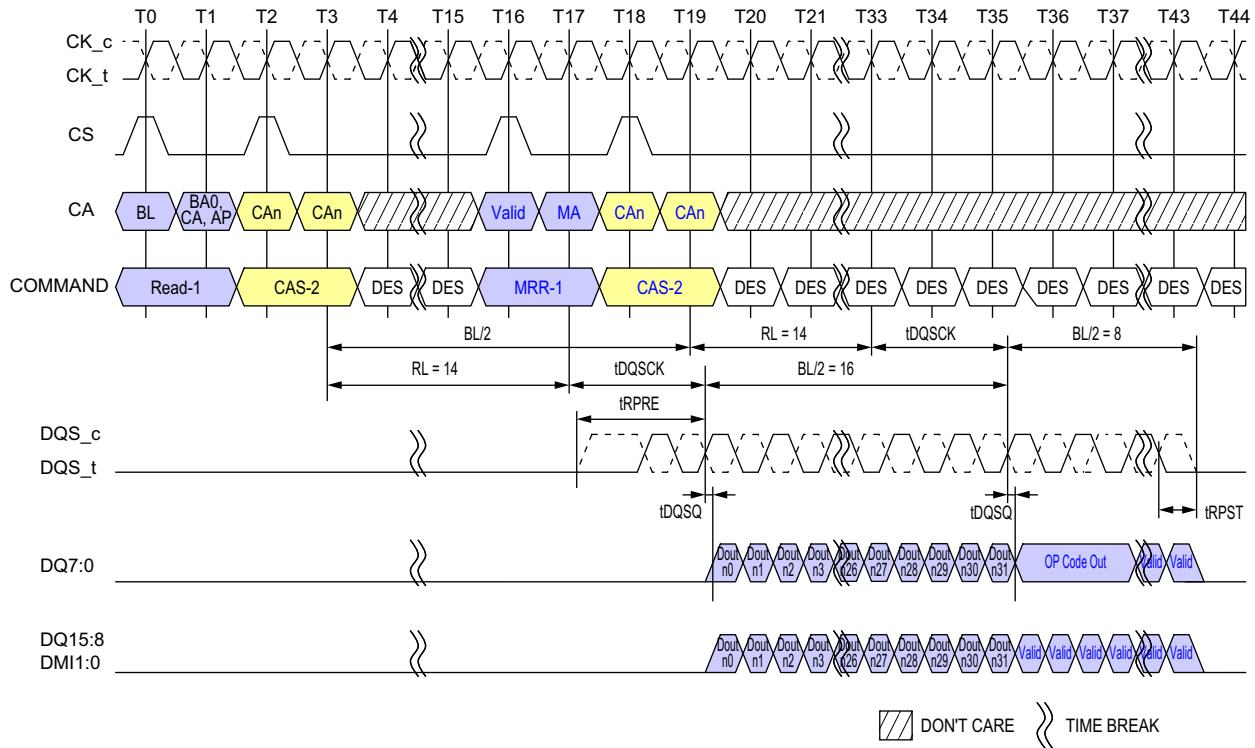
Note

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

Figure 78 — Mode Register Read Operation

4.24.1 MRR after Read and Write command

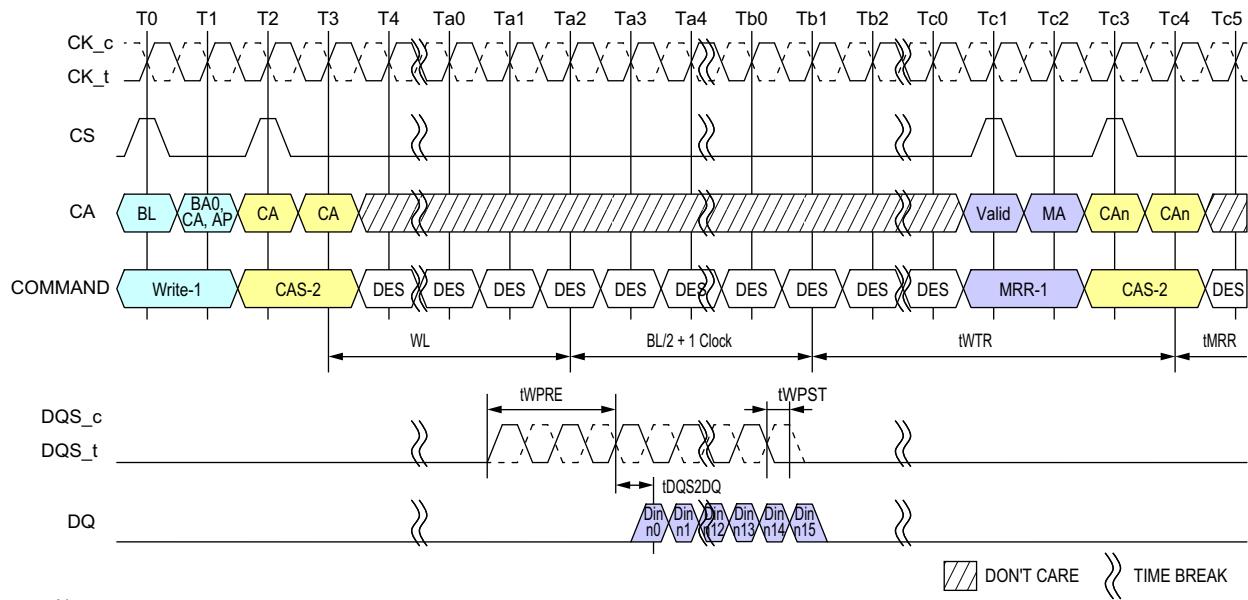
After a prior READ command, the MRR command must not be issued earlier than BL/2 clock cycles, in a similar way WL + BL/2 + 1 + RU(tWTR/tCK) clock cycles after a prior Write, Write with AP, Mask Write, Mask Write with AP and MPC Write FIFO command in order to avoid the collision of Read and Write burst data on SDRAM's internal Data bus.



Note

1. The minimum number of clock cycles from the burst READ command to the MRR command is BL/2.
2. Read BL = 32, MRR BL = 16, RL = 14, Preamble = Toggle, Postamble = 0.5nCK, DBI = Disable, DQ/DQS: VSSQ termination
3. DES commands except tMRR period are shown for ease of illustration; other commands may be valid at these times.

Figure 79 — READ to MRR Timing



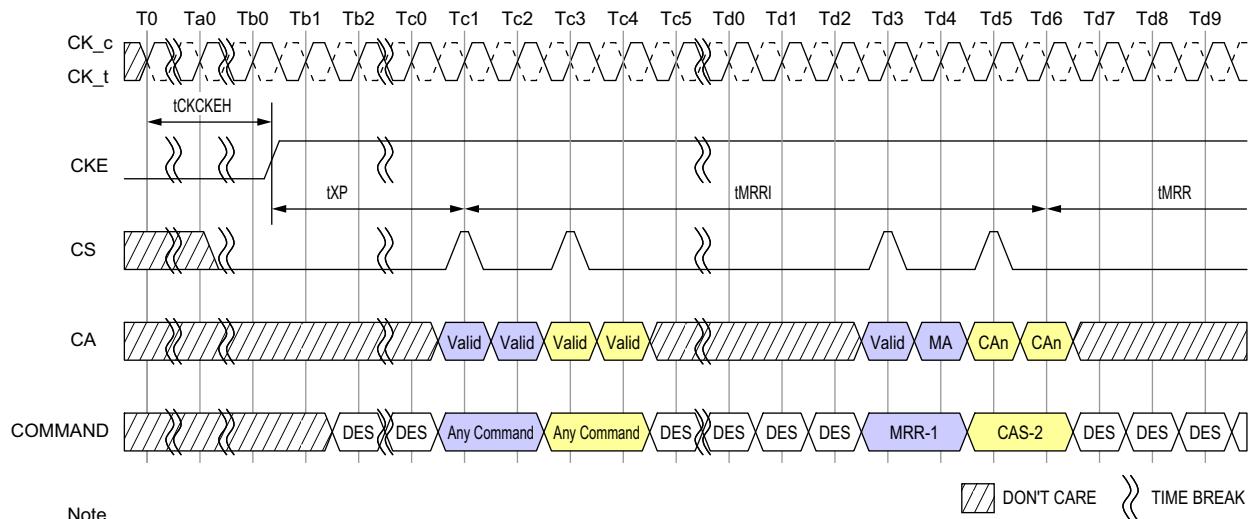
Note

1. Write BL=16, Write Postamble = 0.5nCK, DQ/DQS: VSSQ termination.
2. Only DES is allowed during tMRR period.
3. Din n = data-in to column n.
4. The minimum number of clock cycles from the burst write command to MRR command is WL + BL/2 + 1 + RU(tWTR/tCK).
5. DES commands except tMRR period are shown for ease of illustration; other commands may be valid at these times.

Figure 80 — Write to MRR Timing

4.24.2 MRR after Power-Down Exit

Following the power-down state, an additional time, tMRRI, is required prior to issuing the mode register read (MRR) command. This additional time (equivalent to tRCD) is required in order to be able to maximize power-down current savings by allowing more power-up time for the MRR data path after exit from power-down mode.



Note

1. Only DES is allowed during tMRR period.
2. DES commands except tMRR period are shown for ease of illustration; other commands may be valid at these times.

Figure 81 — MRR Following Power-Down

Table 48 — Mode Register Read/Write AC timing

| Parameter | Symbol | Min/ Max | Data Rate | Unit | Note |
|---|--------|-------------|---------------------|------|------|
| Mode Register Read/Write Timing | | | | | |
| Additional time after tXP has expired until MRR command may be issued | tMRRI | Min | tRCD + 3nCK | - | |
| MODE REGISTER READ command period | tMRR | Min | 8 | nCK | |
| MODE REGISTER WRITE command period | tMRW | Min | MAX(10ns, 10nCK) | - | |
| Mode register set command delay | tMRD | Min | max(14ns, 10nCK) | - | |

4.25 Mode Register Write (MRW) Operation

The Mode Register Write (MRW) command is used to write configuration data to the mode registers. The MRW command is initiated by setting CKE, CS, and CA[5:0] to valid levels at a rising edge of the clock (see Command Truth Table). The mode register address and the data written to the mode registers is contained in CA[5:0] according to the Command Truth Table. The MRW command period is defined by tMRW. Mode register Writes to read-only registers have no impact on the functionality of the device.

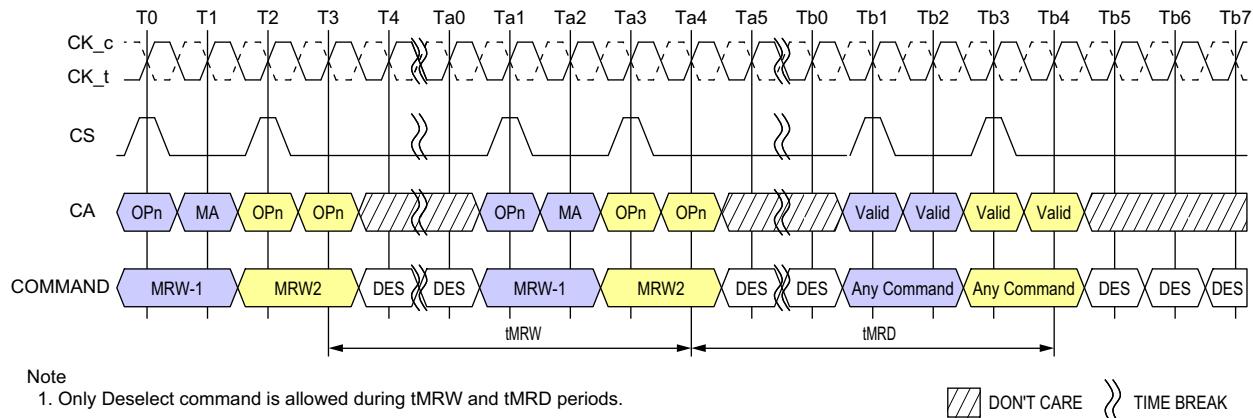


Figure 82 — Mode Register Write Timing

4.25.1 Mode Register Write

MRW can be issued from either a Bank-Idle or Bank-Active state. Certain restrictions may apply for MRW from an Active state.

Table 49 — Truth Table for Mode Register Read (MRR) and Mode Register Write (MRW)

| Current State SDRAM | Command | Intermediate State | Next State |
|-------------------------------|---------|---|----------------|
| | | SDRAM | SDRAM |
| All Banks Idle | MRR | Mode Register Reading (All Banks Idle) | All Banks Idle |
| | MRW | Mode Register Writing (All Banks Idle) | All Banks Idle |
| Bank(s) Active | MRR | Mode Register Reading | Bank(s) Active |
| | MRW | Mode Register Writing | Bank(s) Active |

Table 50 — MRR/MRW Timing Constraints: DQ ODT is Disable

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|-------------------------------|-------------------------|---|------|-------|
| MRR | MRR | tMRR | - | |
| | RD/RDA | tMRR | - | |
| | WR/WRA/ MWR/ MWRA | RL+RU(tDQSCK(max)/tCK)+BL/2- WL+tWPRE+RD(tRPST) | nCK | |
| | MRW | RL+RU(tDQSCK(max)/tCK)+BL/2+ 3 | nCK | |
| RD/RDA | MRR | BL/2 | nCK | |
| WR/WRA/ MWR/MWRA | | WL+1+BL/2+RU(tWTR/tCK) | nCK | |
| MRW | | tMRD | - | |
| Power Down Exit | | tXP+tMRRI | - | |
| MRW | RD/RDA | tMRD | - | |
| | WR/WRA/ MWR/ MWRA | tMRD | - | |
| | MRW | tMRW | - | |
| RD/ RD FIFO/ RD DQ CAL | MRW | RL+BL/2+RU(tDQSCKmax/tCK) +RD(tRPST) +max(RU(7.5ns/tCK),8nCK) | nCK | |
| RD with Auto-Precharge | | RL+BL/2+RU(tDQSCKmax/tCK) +RD(tRPST) +max(RU(7.5ns/tCK),8nCK)+nRTP-8 | nCK | |
| WR/ MWR/ WR FIFO | | WL+1+BL/2+max(RU(7.5ns/tCK),8nCK) | nCK | |
| WR/MWR with Auto-Precharge | | WL+1+BL/2+max(RU(7.5ns/tCK),8nCK)+nWR | nCK | |

Table 51 — MRR/MRW Timing Constraints: DQ ODT is Enable

| From Command | To Command | Minimum Delay between "From Command" and "To Command" | Unit | Notes |
|-------------------------------|-------------------------|--|------|-------|
| MRR | MRR | Same as ODT Disable Case | - | |
| | RD/RDA | | | |
| | WR/WRA/ MWR/ MWRA | RL+RU(tDQSCK(max)/tCK)+BL/2-ODTLon- RD(tODTon(min)/tCK)+RD(tRPST)+1 | | nCK |
| | MRW | Same as ODT Disable Case | | |
| RD/RDA | MRR | Same as ODT Disable Case | - | |
| WR/WRA/ MWR/MWRA | | | | |
| MRW | | | | |
| Power Down Exit | | | | |
| MRW | RD/RDA | Same as ODT Disable Case | - | |
| | WR/WRA/ MWR/ MWRA | | | |
| | MRW | | | |
| RD/ RD FIFO/ RD DQ CAL | MRW | Same as ODT Disable Case | - | |
| RD with Auto-Precharge | | | | |
| WR/ MWR/ WR FIFO | | | | |
| WR/MWR with Auto-Precharge | | | | |

4.26 V_{REF} Current Generator (VRCG)

LPDDR4 SDRAM V_{REF} current generators (VRCG) incorporate a high current mode to reduce the settling time of the internal $V_{REF}(DQ)$ and $V_{REF}(CA)$ levels during training and when changing frequency set points during operation. The high current mode is enabled by setting MR13[OP3] = 1. Only Deselect commands may be issued until tVRCG_ENABLE is satisfied. tVRCG_ENABLE timing is shown in Figure 83.

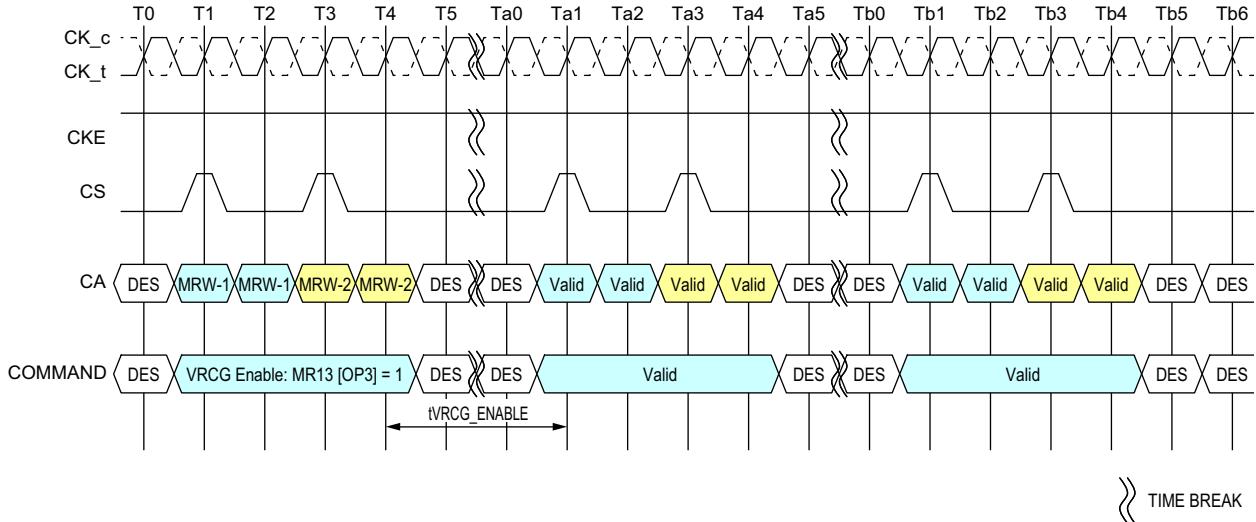


Figure 83 — VRCG Enable timing

VRCG high current mode is disabled by setting MR13[OP3] = 0. Only Deselect commands may be issued until tVRCG_DISABLE is satisfied. tVRCG_DISABLE timing is shown in Figure 84.

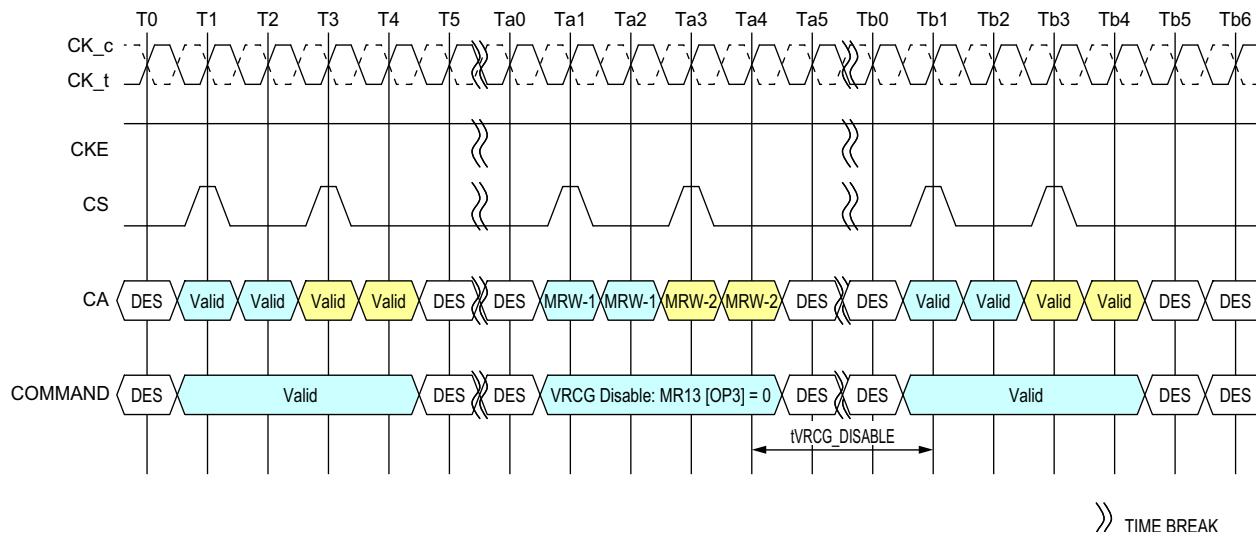


Figure 84 — VRCG Disable timing

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

Table 52 — VRCG Enable/Disable Timing

| Speed | | 533, 1066, 1600, 2133, 2667, 3200, 3733, 4267Mbps | | Units | NOTE |
|---|---------------|---|-----|-------|------|
| Parameter | Symbol | MIN | MAX | | |
| V _{REF} high current mode enable time | tVRCG_ENABLE | - | 200 | ns | |
| V _{REF} high current mode disable time | tVRCG_DISABLE | - | 100 | ns | |

4.27 CA V_{REF} Training

The DRAM internal CA V_{REF} specification parameters are voltage operating range, step size, V_{REF} set tolerance, V_{REF} step time and V_{REF} valid level.

The voltage operating range specifies the minimum required V_{REF} setting range for LPDDR4 DRAM devices. The minimum range is defined by $V_{REF\max}$ and $V_{REF\min}$ as depicted in Figure 85.

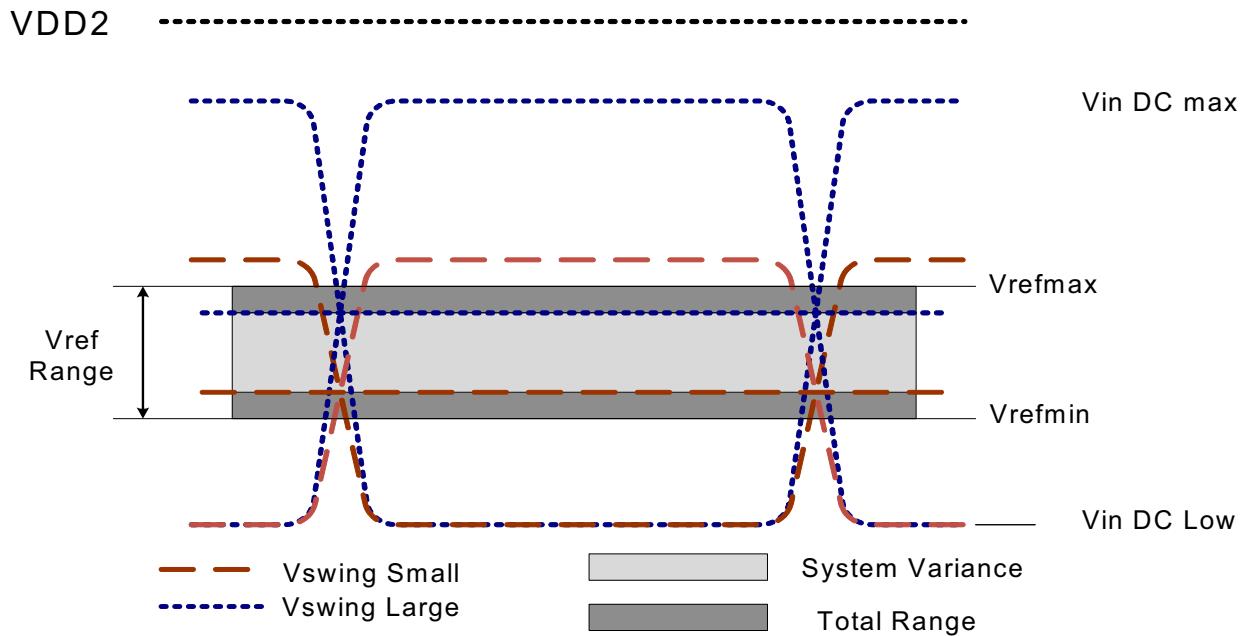


Figure 85 — V_{REF} operating range($V_{REF\min}$, $V_{REF\max}$)

The V_{REF} step size is defined as the step size between adjacent steps. However, for a given design, DRAM has one value for V_{REF} step size that falls within the range.

The V_{REF} set tolerance is the variation in the V_{REF} voltage from the ideal setting. This accounts for accumulated error over multiple steps. There are two ranges for V_{REF} set tolerance uncertainty. The range of V_{REF} set tolerance uncertainty is a function of number of steps n .

The V_{REF} set tolerance is measured with respect to the ideal line which is based on the two endpoints. Where the endpoints are at the min and max V_{REF} values for a specified range. An example of the step size and V_{REF} set tolerance is shown in Figure 86.

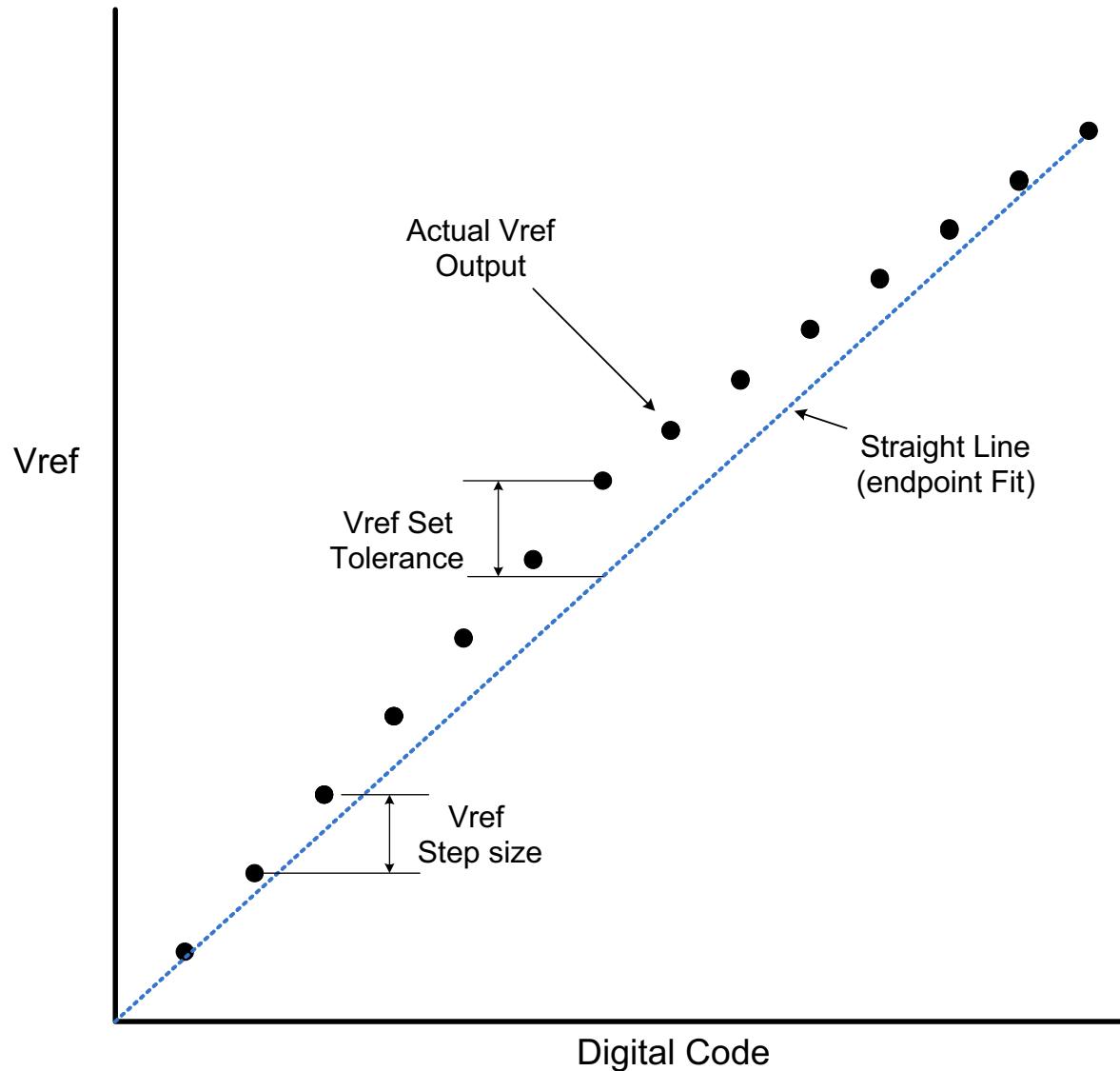


Figure 86 — Example of V_{REF} set tolerance(max case only shown) and step size

The V_{REF} increment/decrement step times are defined by $V_{REF_time-short}$, $V_{REF_time-Middle}$ and $V_{REF_time-long}$. The $V_{REF_time-short}$, $V_{REF_time-Middle}$ and $V_{REF_time-long}$ is defined from TS to TE as shown in Figure 75 where TE is referenced to when the V_{REF} voltage is at the final DC level within the V_{REF} valid tolerance($V_{REF_val_tol}$).

The V_{REF} valid level is defined by V_{REF_val} tolerance to qualify the step time TE as shown in Figure 87. This parameter is used to insure an adequate RC time constant behavior of the voltage level change after any V_{REF} increment/decrement adjustment. This parameter is only applicable for DRAM component level validation/characterization.

$V_{REF_time-Short}$ is for a single step size increment/decrement change in V_{REF} voltage.

$V_{REF_time-Middle}$ is at least 2 step sizes increment/decrement change within the same $V_{REF}CA$ range in V_{REF} voltage.

$V_{REF_time-Long}$ is the time including up to V_{REFmin} to V_{REFmax} or V_{REFmax} to V_{REFmin} change across the $V_{REF}CA$ Range in V_{REF} voltage.

TS - is referenced to MRS command clock

TE - is referenced to the $V_{REF_val_tol}$

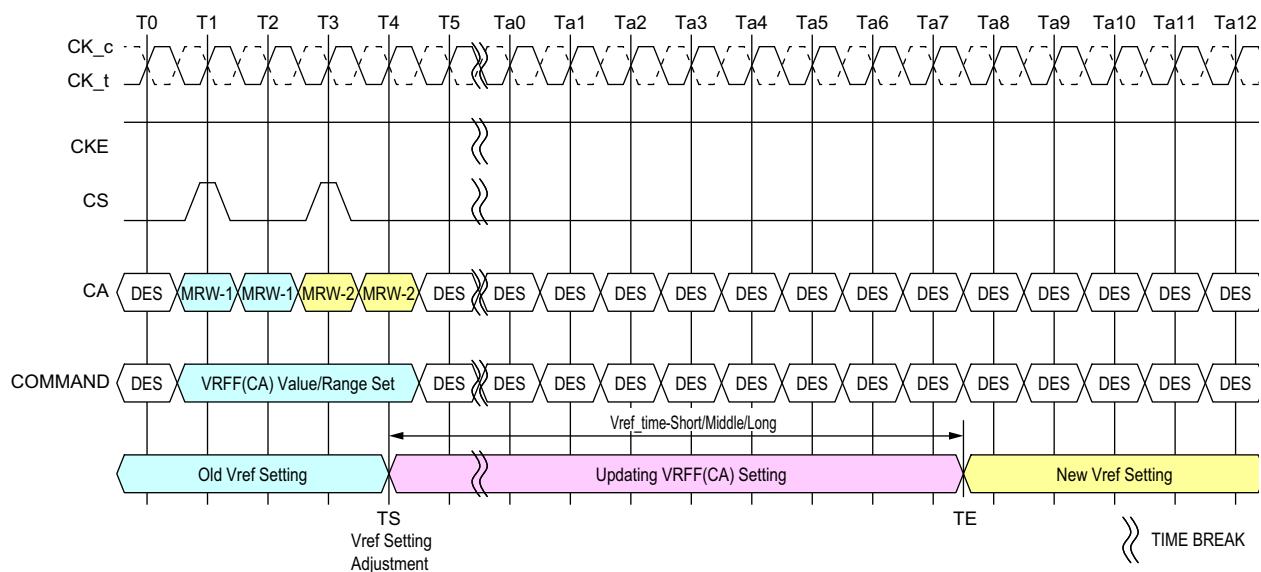


Figure 87 — V_{REF_time} for Short, Middle and Long Timing Diagram

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

MR12 OP[5:0] : $V_{REF}(CA)$ Setting

MR12 OP[6] : $V_{REF}(CA)$ Range

The minimum time required between two V_{REF} MRS commands is $V_{REF_time_short}$ for single step and $V_{REF_time_Middle}$ for a full voltage range step.

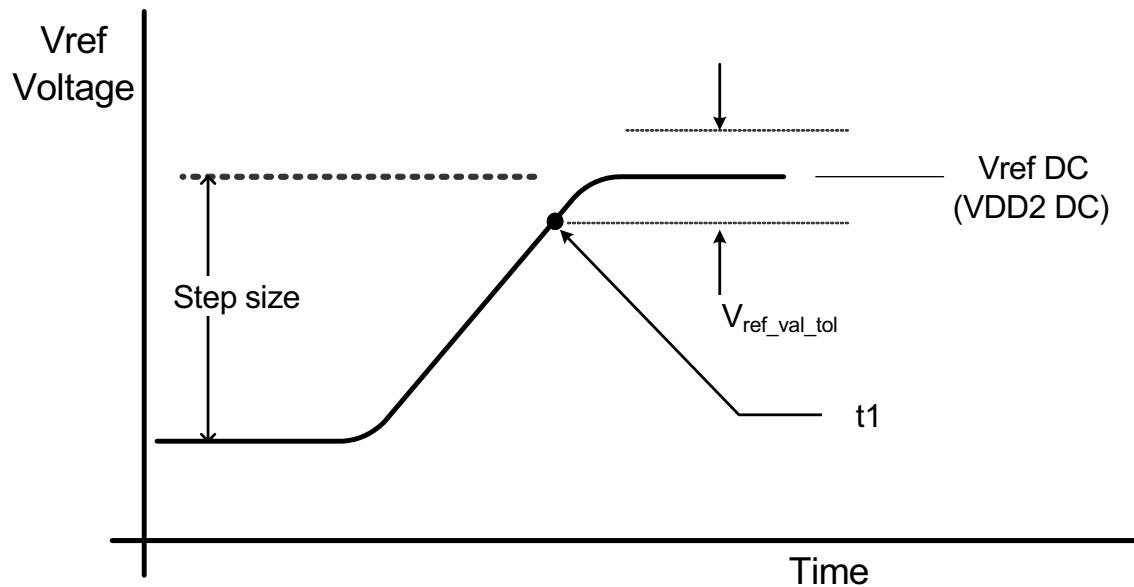


Figure 88 — V_{REF} step single step size increment case

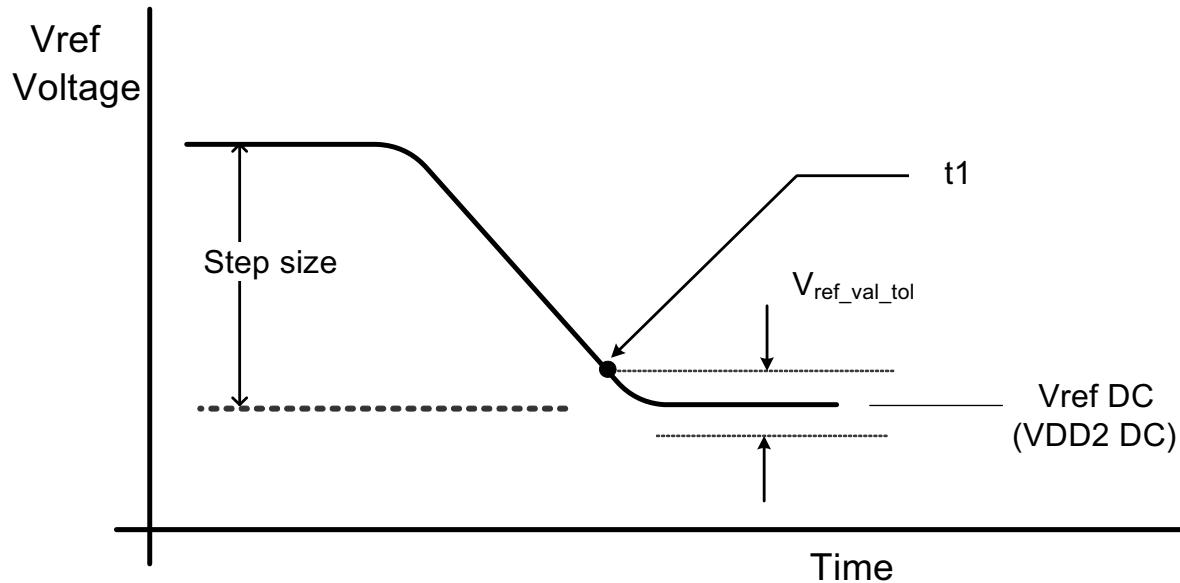


Figure 89 — V_{REF} step single step size decrement case

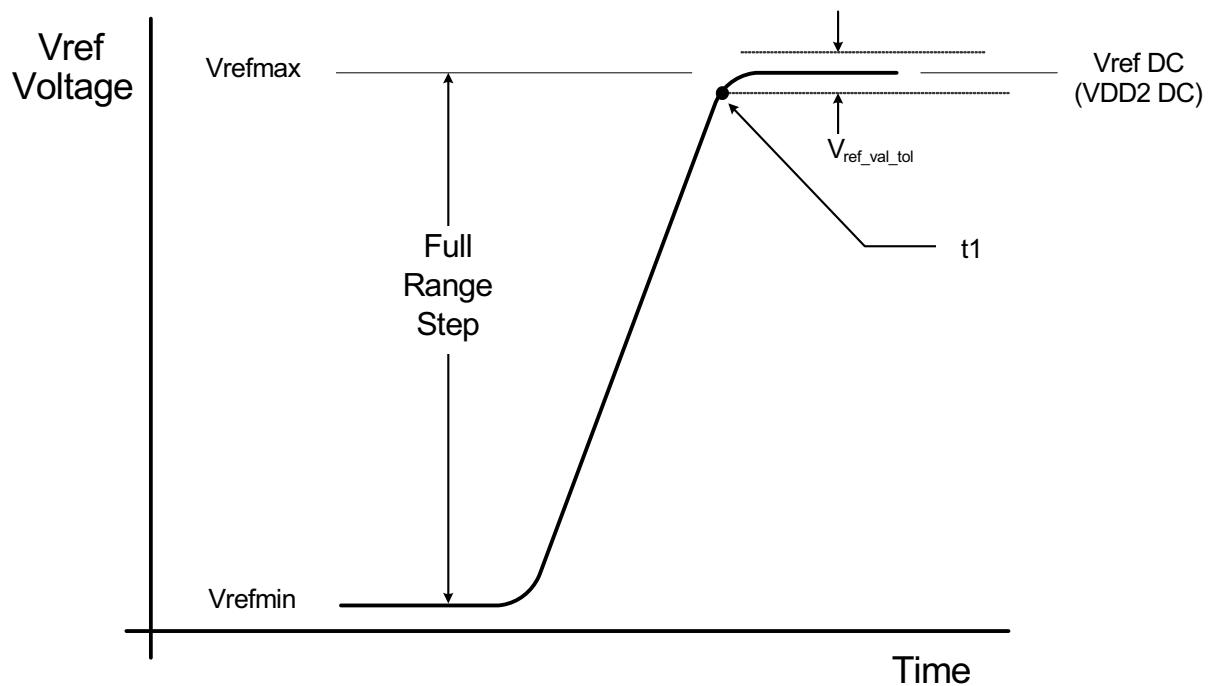


Figure 90 — V_{REF} full step from $V_{REF\min}$ to $V_{REF\max}$ case

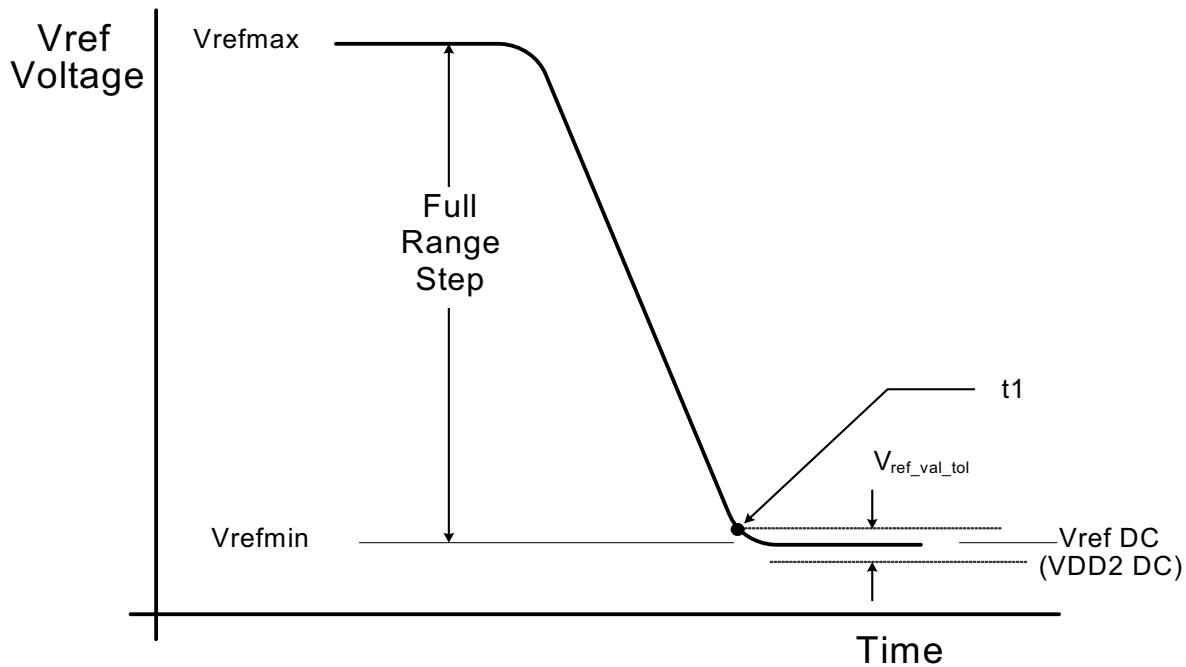


Figure 91 — V_{REF} full step from $V_{REF\max}$ to $V_{REF\min}$ case

Table 53 contains the CA internal V_{REF} specifications that will be characterized at the component level for compliance. The component level characterization method is tbd.

Table 53 — CA Internal V_{REF} Specifications

| Parameter | Symbol | Min | Typ | Max | Unit | Notes |
|---|------------------------------|--------|-------|-------|------------------|-------|
| V _{REF} Max operating point Range0 | V _{REF_max_R0} | - | - | 30% | V _{DD2} | 1,11 |
| V _{REF} Min operating point Range0 | V _{REF_min_R0} | 10% | - | - | V _{DD2} | 1,11 |
| V _{REF} Max operating point Range1 | V _{REF_max_R1} | - | - | 42% | V _{DD2} | 1,11 |
| V _{REF} Min operating point Range1 | V _{REF_min_R1} | 22% | - | - | V _{DD2} | 1,11 |
| V _{REF} Step size | V _{REF_step} | 0.30% | 0.40% | 0.50% | V _{DD2} | 2 |
| V _{REF} Set Tolerance | V _{REF_set_tol} | -1.00% | 0.00% | 1.00% | V _{DD2} | 3,4,6 |
| | | -0.10% | 0.00% | 0.10% | V _{DD2} | 3,5,7 |
| V _{REF} Step Time | V _{REF_time_Short} | - | - | 100 | ns | 8 |
| | V _{REF_time_Middle} | - | - | 200 | ns | 12 |
| | V _{REF_time_Long} | - | - | 250 | ns | 9 |
| | V _{REF_time_weak} | - | - | 1 | ms | 13,14 |
| V _{REF} Valid tolerance | V _{REF_val_tol} | -0.10% | 0.00% | 0.10% | V _{DD2} | 10 |

NOTE 1 V_{REF} DC voltage referenced to V_{DD2_DC}.

NOTE 2 V_{REF} step size increment/decrement range. V_{REF} at DC level.

NOTE 3 V_{REF_new} = V_{REF_old} + n*V_{REF_step}; n= number of steps; if increment use "+"; If decrement use "-".

NOTE 4 The minimum value of V_{REF} setting tolerance = V_{REF_new} - 1.0%*V_{DD2}. The maximum value of V_{REF} setting tolerance = V_{REF_new} + 1.0%*V_{DD2}. For n>4.

NOTE 5 The minimum value of V_{REF} setting tolerance = V_{REF_new} - 0.10%*V_{DD2}. The maximum value of V_{REF} setting tolerance = V_{REF_new} + 0.10%*V_{DD2}. For n≤ 4.

NOTE 6 Measured by recording the min and max values of the V_{REF} output over the range, drawing a straight line between those points and comparing all other V_{REF} output settings to that line.

NOTE 7 Measured by recording the min and max values of the V_{REF} output across 4 consecutive steps(n=4), drawing a straight line between those points and comparing all other V_{REF} output settings to that line.

NOTE 8 Time from MRS command to increment or decrement one step size for V_{REF}.

NOTE 9 Time from MRS command to increment or decrement V_{REFmin} to V_{REFmax} or V_{REFmax} to V_{REFmin} change across the V_{REF}CA Range in V_{REF} voltage.

NOTE 10 Only applicable for DRAM component level test/characterization purpose. Not applicable for normal mode of operation. V_{REF} valid is to qualify the step times which will be characterized at the component level.

NOTE 11 DRAM range 0 or 1 set by MR12 OP[6].

NOTE 12 Time from MRS command to increment or decrement more than one step size up to a full range of V_{REF} voltage within the same V_{REF}CA range.

NOTE 13 Applies when VRCG high current mode is not enabled, specified by MR13[OP3] = 0.

NOTE 14 V_{REF_time_weak} covers all V_{REF}(CA) Range and Value change conditions are applied to V_{REF_time_Short/Middle/Long}.

4.28 DQ V_{REF} Training

The DRAM internal DQ V_{REF} specification parameters are voltage operating range, step size, V_{REF} set tolerance, V_{REF} step time and V_{REF} valid level.

The voltage operating range specifies the minimum required V_{REF} setting range for LPDDR4 DRAM devices. The minimum range is defined by $V_{REF\max}$ and $V_{REF\min}$ as depicted in Figure 92.

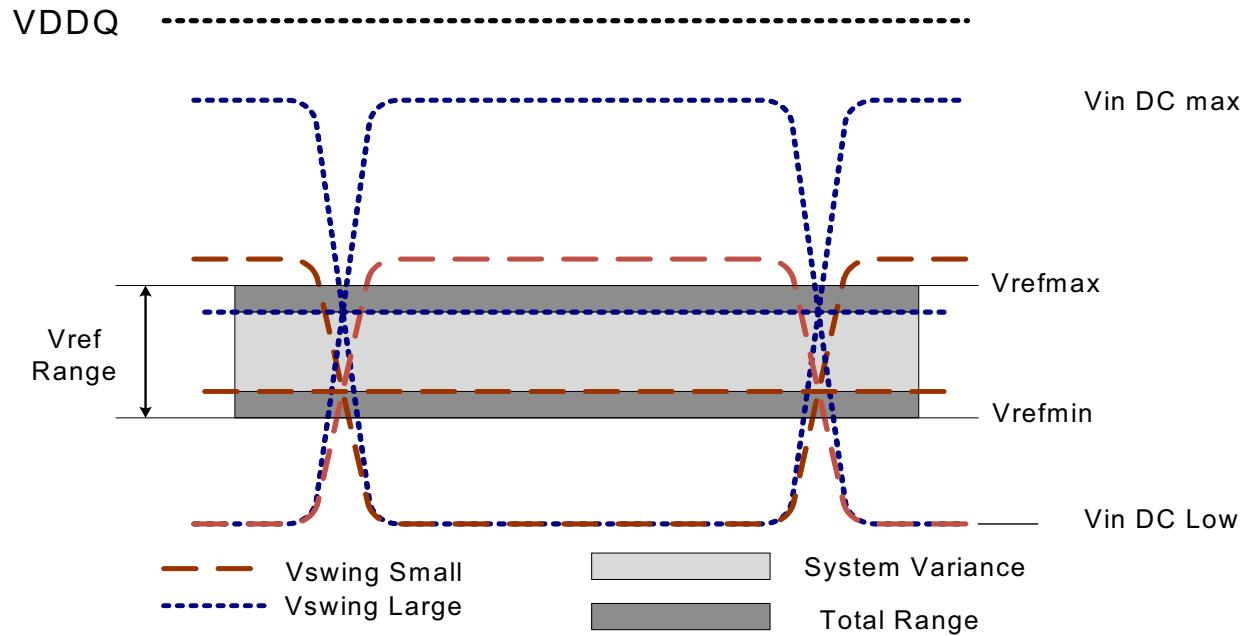


Figure 92 — V_{REF} operating range($V_{REF\min}$, $V_{REF\max}$)

The V_{REF} step size is defined as the step size between adjacent steps. However, for a given design, DRAM has one value for V_{REF} step size that falls within the range.

The V_{REF} set tolerance is the variation in the V_{REF} voltage from the ideal setting. This accounts for accumulated error over multiple steps. There are two ranges for V_{REF} set tolerance

uncertainty. The range of V_{REF} set tolerance uncertainty is a function of number of steps n .

The V_{REF} set tolerance is measured with respect to the ideal line which is based on the two endpoints. Where the endpoints are at the min and max V_{REF} values for a specified range. An example of the step size and V_{REF} set tolerance is shown in Figure 93.

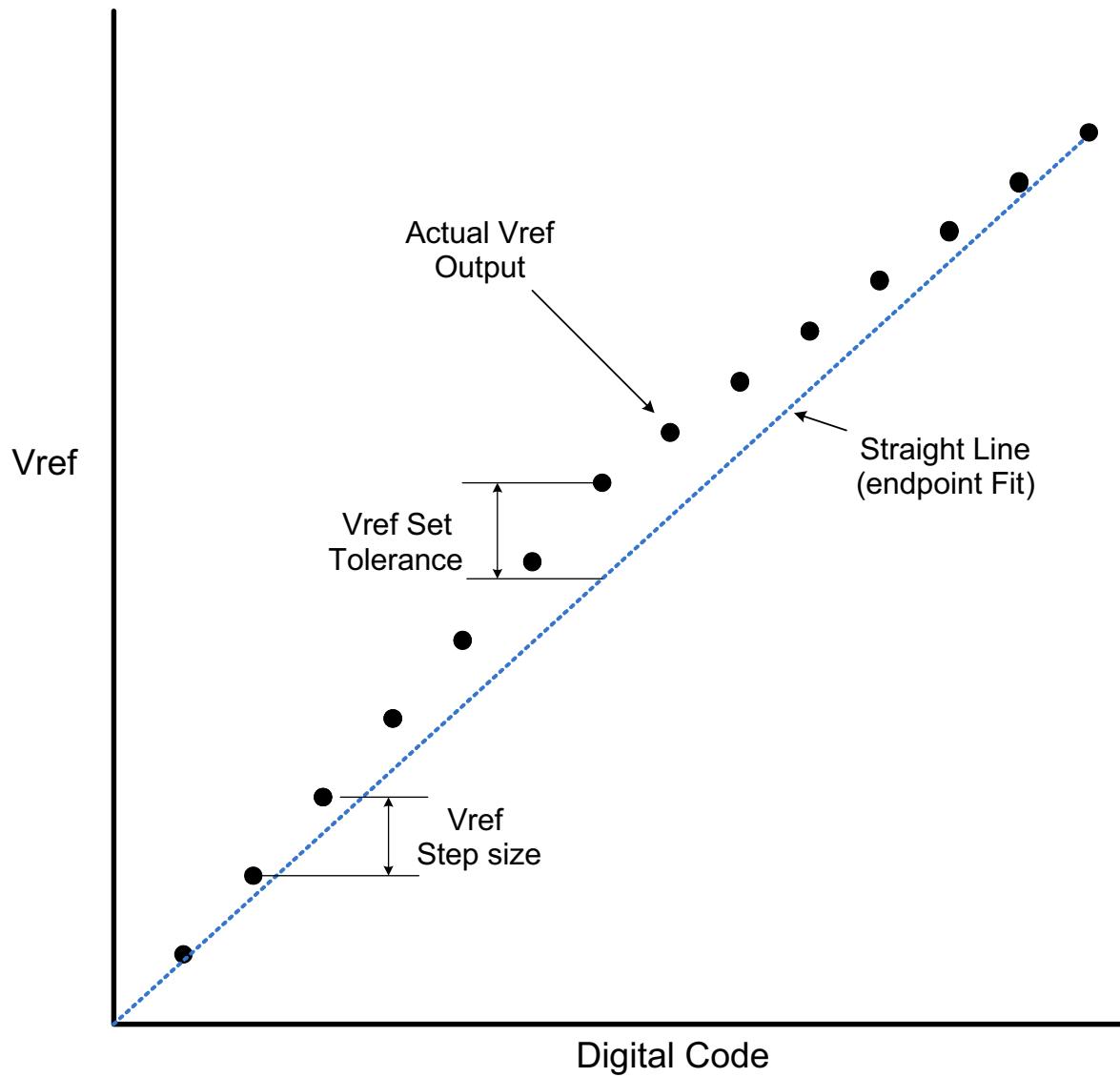


Figure 93 — Example of V_{REF} set tolerance(max case only shown) and step size

The V_{REF} increment/decrement step times are defined by $V_{REF_time_short}$, $V_{REF_time_middle}$ and $V_{REF_time_long}$. The $V_{REF_time_short}$, $V_{REF_time_Middle}$ and $V_{REF_time_long}$ is defined from TS to TE as shown in Figure 94 where TE is referenced to when the V_{REF} voltage is at the final DC level within the V_{REF} valid tolerance($V_{REF_val_tol}$).

The V_{REF} valid level is defined by V_{REF_val} tolerance to qualify the step time TE as shown in Figure 94. This parameter is used to insure an adequate RC time constant behavior of the voltage level change after any V_{REF} increment/decrement adjustment. This parameter is only applicable for DRAM component level validation/characterization.

$V_{REF_time_Short}$ is for a single step size increment/decrement change in V_{REF} voltage.

$V_{REF_time_Middle}$ is at least 2 step sizes increment/decrement change within the same V_{REF} DQ range in V_{REF} voltage.

$V_{REF_time_Long}$ is the time including up to V_{REFmin} to V_{REFmax} or V_{REFmax} to V_{REFmin} change across the V_{REF} DQ Range in V_{REF} voltage.

TS - is referenced to MRS command clock

TE - is referenced to the $V_{REF_val_tol}$

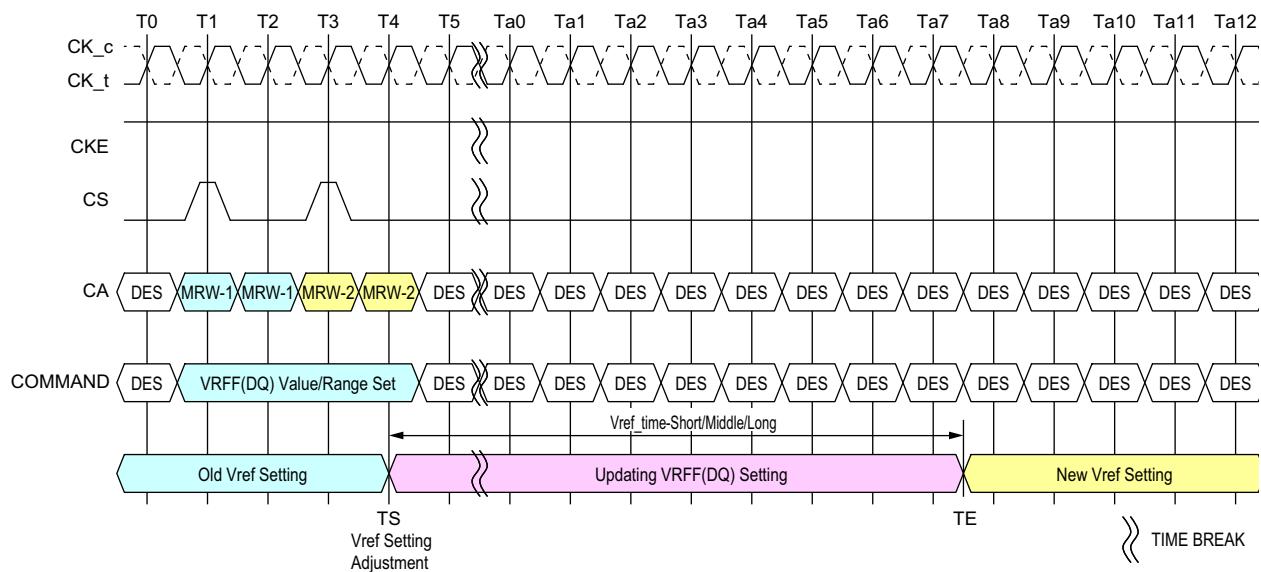


Figure 94 — V_{REF_time} for Short, Middle and Long Timing Diagram

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

MR14 OP[5:0] : $V_{REF}(DQ)$ Setting

MR14 OP[6] : $V_{REF}(DQ)$ Range

The minimum time required between two V_{REF} MRS commands is $V_{REF_time-short}$ for single step and $V_{REF_time-Middle}$ for a full voltage range step.

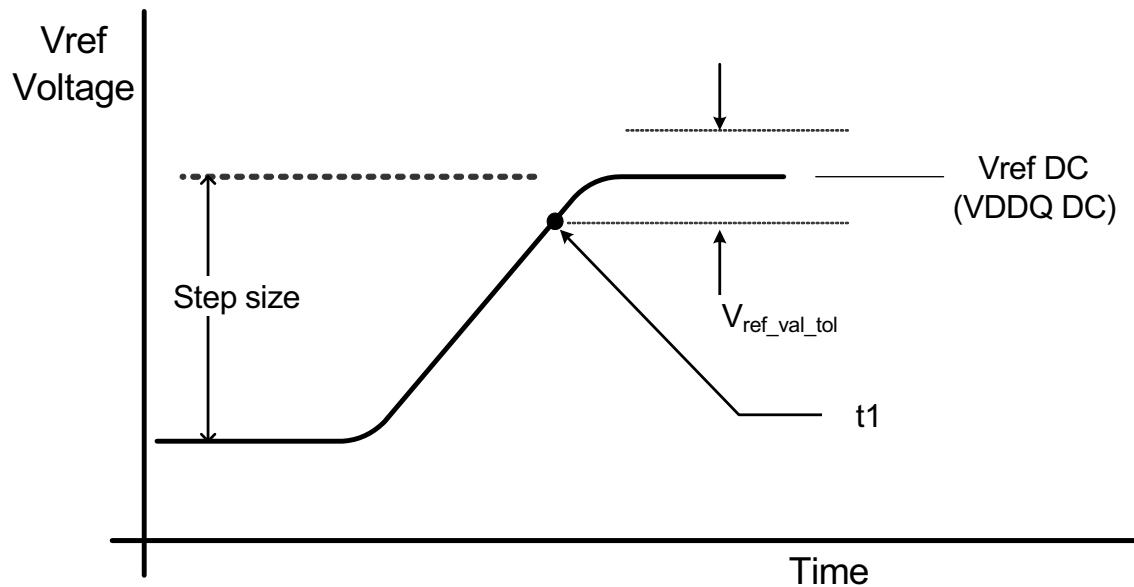


Figure 95 — V_{REF} step single step size increment case

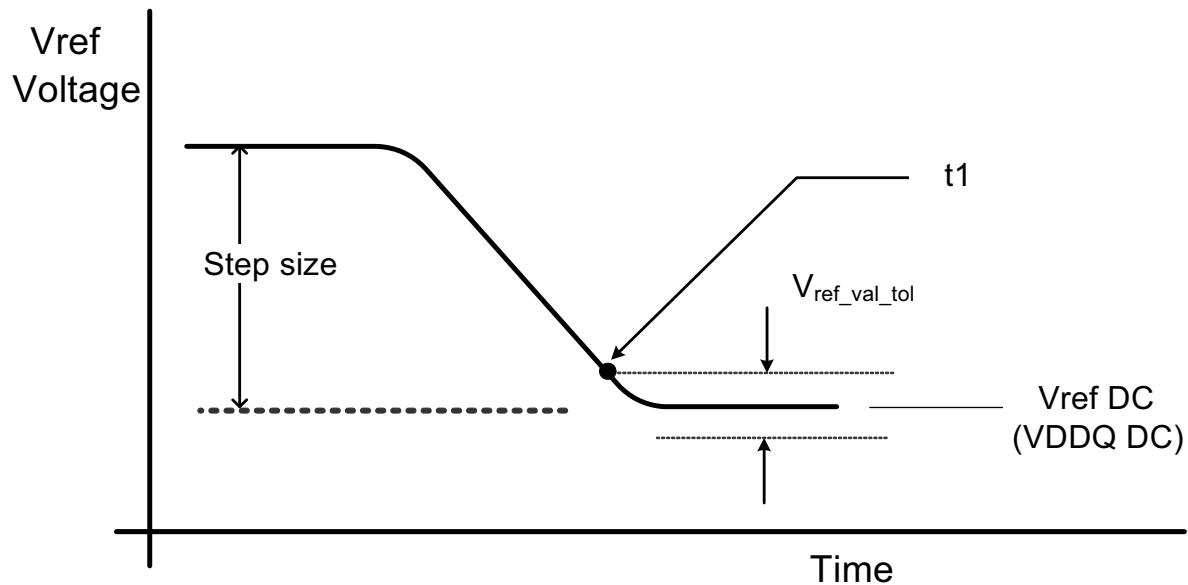


Figure 96 — V_{REF} step single step size decrement case

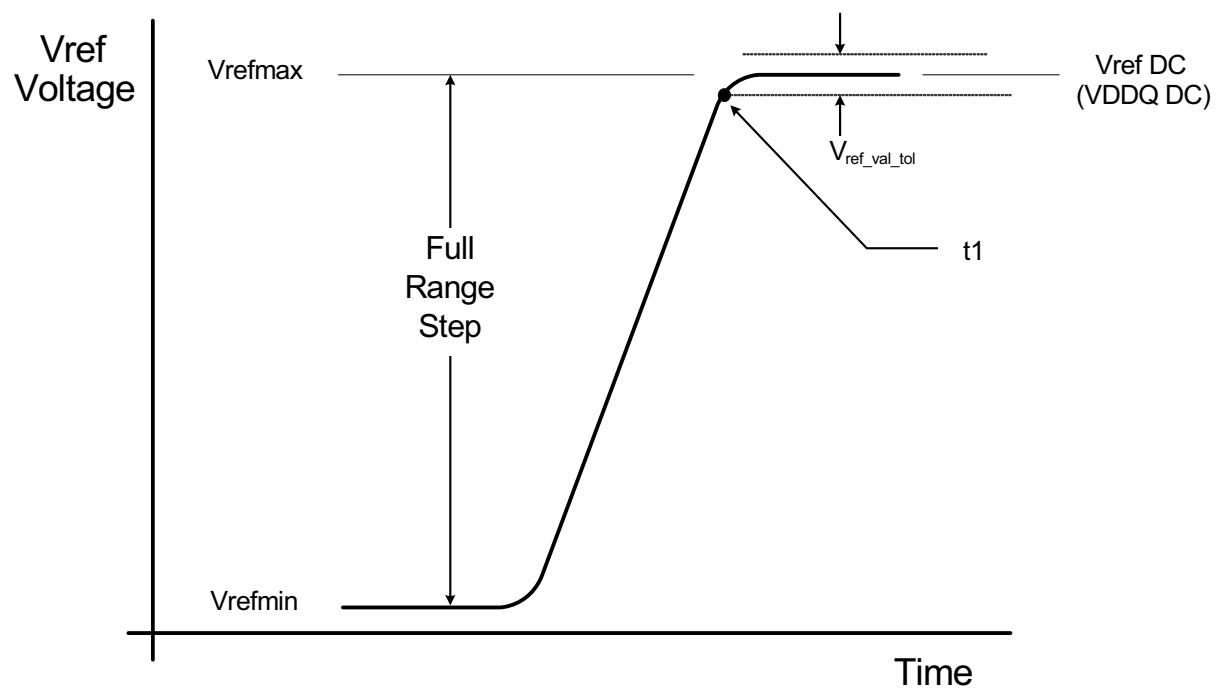


Figure 97 — V_{REF} full step from $V_{REF\min}$ to $V_{REF\max}$ case

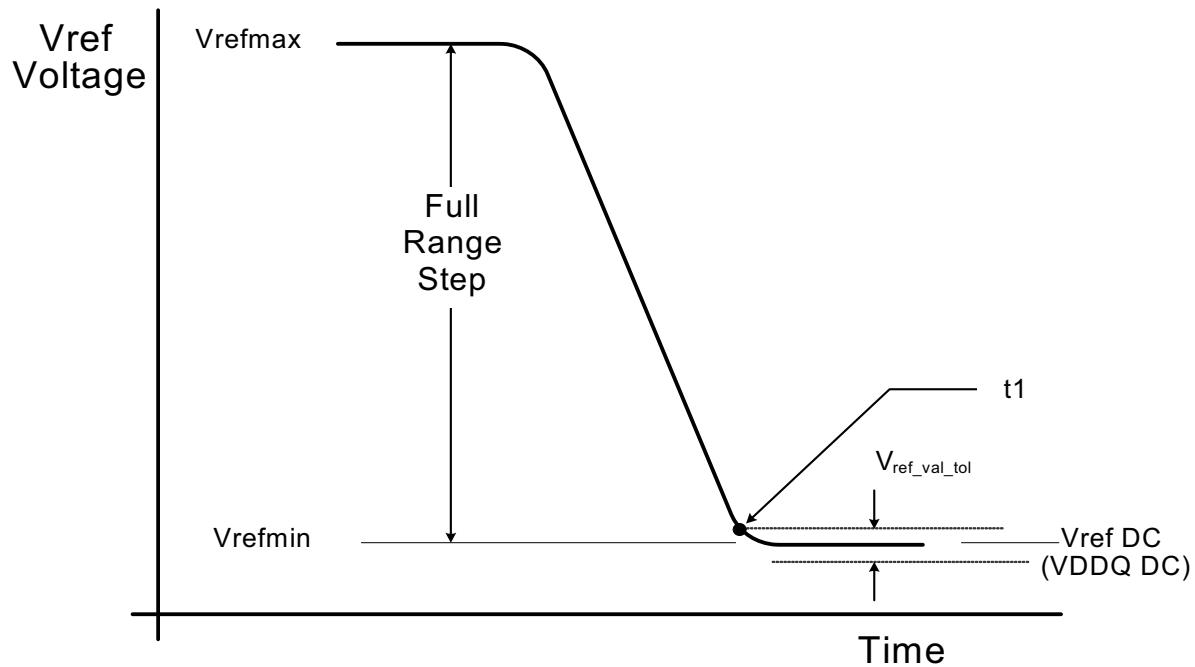


Figure 98 — V_{REF} full step from $V_{REF\max}$ to $V_{REF\min}$ case

Table 54 contains the DQ internal V_{REF} specifications that will be characterized at the component level for compliance. The component level characterization method is TBD^A.

Table 54 — DQ Internal V_{REF} Specifications

| Parameter | Symbol | Min | Typ | Max | Unit | Notes |
|--------------------------------------|-------------------------|--------|-------|-------|-----------|-------|
| V_{REF} Max operating point Range0 | $V_{REF_max_R0}$ | - | - | 30% | V_{DDQ} | 1,11 |
| V_{REF} Min operating point Range0 | $V_{REF_min_R0}$ | 10% | - | - | V_{DDQ} | 1,11 |
| V_{REF} Max operating point Range1 | $V_{REF_max_R1}$ | - | - | 42% | V_{DDQ} | 1,11 |
| V_{REF} Min operating point Range1 | $V_{REF_min_R1}$ | 22% | - | - | V_{DDQ} | 1,11 |
| V_{REF} Step size | V_{REF_step} | 0.30% | 0.40% | 0.50% | V_{DDQ} | 2 |
| V_{REF} Set Tolerance | $V_{REF_set_tol}$ | -1.00% | 0.00% | 1.00% | V_{DDQ} | 3,4,6 |
| | | -0.10% | 0.00% | 0.10% | V_{DDQ} | 3,5,7 |
| V_{REF} Step Time | $V_{REF_time_Short}$ | - | - | 100 | ns | 8 |
| | $V_{REF_time_Middle}$ | - | - | 200 | ns | 12 |
| | $V_{REF_time_Long}$ | - | - | 250 | ns | 9 |
| | $V_{REF_time_weak}$ | - | - | 1 | ms | 13,14 |
| V_{REF} Valid tolerance | $V_{REF_val_tol}$ | -0.10% | 0.00% | 0.10% | V_{DDQ} | 10 |

NOTE 1 V_{REF} DC voltage referenced to V_{DDQ_DC} .

NOTE 2 V_{REF} step size increment/decrement range. V_{REF} at DC level.

NOTE 3 $V_{REF_new} = V_{REF_old} + n * V_{REF_step}$; n= number of steps; if increment use "+"; If decrement use "-".

NOTE 4 The minimum value of V_{REF} setting tolerance = $V_{REF_new} - 1.0\% * V_{DDQ}$. The maximum value of V_{REF} setting tolerance = $V_{REF_new} + 1.0\% * V_{DDQ}$. For n>4.

NOTE 5 The minimum value of V_{REF} setting tolerance = $V_{REF_new} - 0.10\% * V_{DDQ}$. The maximum value of V_{REF} setting tolerance = $V_{REF_new} + 0.10\% * V_{DDQ}$. For n≤ 4.

NOTE 6 Measured by recording the min and max values of the V_{REF} output over the range, drawing a straight line between those points and comparing all other V_{REF} output settings to that line.

NOTE 7 Measured by recording the min and max values of the V_{REF} output across 4 consecutive steps(n=4), drawing a straight line between those points and comparing all other V_{REF} output settings to that line.

NOTE 8 Time from MRS command to increment or decrement one step size for V_{REF} .

NOTE 9 Time from MRS command to increment or decrement V_{REFmin} to V_{REFmax} or $V_{REFfmax}$ to V_{REFmin} change across the V_{REFDQ} Range in V_{REF} voltage.

NOTE 10 Only applicable for DRAM component level test/characterization purpose. Not applicable for normal mode of operation. V_{REF} valid is to qualify the step times which will be characterized at the component level.

NOTE 11 DRAM range 0 or 1 set by MR14 OP[6].

NOTE 12 Time from MRS command to increment or decrement more than one step size up to a full range of V_{REF} voltage within the same V_{REFDQ} range.

NOTE 13 Applies when VRCG high current mode is not enabled, specified by MR13[OP3] = 0.

NOTE 14 $V_{REF_time_weak}$ covers all $V_{REF}(DQ)$ Range and Value change conditions are applied to $V_{REF_time_Short/Middle/Long}$.

^A As of publication of this document, under discussion by the formulating committee.

4.29 Command Bus Training

The LPDDR4-SDRAM command bus must be trained before enabling termination for high-frequency operation. LPDDR4 provides an internal $V_{REF}(CA)$ that defaults to a level suitable for un-terminated, low frequency operation, but the $V_{REF}(CA)$ must be trained to achieve suitable receiver voltage margin for terminated, high-frequency operation. The training mode described here centers the internal $V_{REF}(CA)$ in the CA data eye and at the same time allows for timing adjustments of the CS and CA signals to meet setup/hold requirements. Because it can be difficult to capture commands prior to training the CA inputs, the training mode described here uses a minimum of external commands to enter, train, and exit the Command Bus Training mode.

NOTE It is up to the system designer to determine what constitutes “low-frequency” and “high-frequency” based on the capabilities of the system. Low-frequency should then be defined as an operating frequency in which the system can reliably communicate with the SDRAM before Command Bus Training is executed.

The LPDDR4-SDRAM die has a bond pad (ODT_CA) for multi-rank operation. In a multi-rank system, the terminating rank should be trained first, followed by the non-terminating rank(s). See 4.43.1, ODT section for more information.

The LPDDR4-SDRAM uses Frequency Set-Points to enable multiple operating settings for the die. The LPDDR4-SDRAM defaults to FSP-OP[0] at power-up, which has the default settings to operate in un-terminated, low-frequency environments. Prior to training, the mode register settings should be configured by setting MR13 OP[6]=1B (FSP-WR[1]) and setting all other mode register bits for FSP-OP[1] to the desired settings for high-frequency operation. Prior to entering Command Bus Training, the SDRAM will be operating from FSP-OP[x]. Upon Command Bus Training entry when CKE is driven LOW, the LPDDR4-SDRAM will automatically switch to the alternate FSP register set (FSP-OP[y]) and use the alternate register settings during training (See note 6 in Figure 99 for more information on FSP-OP register sets). Upon training exit when CKE is driven HIGH, the LPDDR4-SDRAM will automatically switch back to the original FSP register set (FSP-OP[x]), returning to the “known-good” state that was operating prior to training. The training values for $V_{REF}(CA)$ are not retained by the DRAM in FSP-OP[y] registers, and must be written to the registers after training exit.

1. To enter Command Bus Training mode, issue a MRW-1 command followed by a MRW-2 command to set MR13 OP[0]=1B (Command Bus Training Mode Enabled).
2. After time tMRD, CKE may be set LOW, causing the LPDDR4-SDRAM to switch from FSP-OP[x] to FSP-OP[y], and completing the entry into Command Bus Training mode.
A status of DQS_t, DQS_c, DQ and DMI are as follows, and DQ ODT state will be followed Frequency Set Point function except output pins.
 - DQS_t[0], DQS_c[0] become input pins for capturing DQ[6:0] levels by its toggling.
 - DQ[5:0] become input pins for setting $V_{REF}(CA)$ Level.
 - DQ[6] becomes a input pin for setting $V_{REF}(CA)$ Range.
 - DQ[7] and DMI[0] become input pins and their input level is Valid level or floating, either way is fine.
 - DQ[13:8] become output pins to feedback its capturing value via command bus by CS signal.
 - DQS_t[1], DQS_c[1], DMI[1] and DQ[15:14] become output pins or disable, it means that SDRAM may drive to a valid level or left floating.
3. At time tCAENT later, LPDDR4 SDRAM can accept to change its $V_{REF}(CA)$ Range and Value using input signals of DQS_t[0], DQS_c[0] and DQ[6:0] from existing value that's setting via MR12 OP[6:0]. The mapping between MR12 OP code and DQs is shown in Table 55. At least one $V_{REF}CA$ setting is required before proceed to next training steps.

Table 55 — Mapping of MR12 OP Code and DQ Numbers

| MR12 OP Code | Mapping | | | | | | |
|--------------|---------|-----|-----|-----|-----|-----|-----|
| | OP6 | OP5 | OP4 | OP3 | OP2 | OP1 | OP0 |
| DQ Number | DQ6 | DQ5 | DQ4 | DQ3 | DQ2 | DQ1 | DQ0 |

4. The new $V_{REF}(CA)$ value must “settle” for time tV_{REF_LONG} before attempting to latch CA information.
5. To verify that the receiver has the correct $V_{REF}(CA)$ setting and to further train the CA eye relative to clock (CK), values latched at the receiver on the CA bus are asynchronously output to the DQ bus.
6. To exit Command Bus Training mode, drive CKE HIGH, and after time tV_{REF_LONG} issue the MRW-1 command followed by the MRW-2 command to set MR13 OP[0]=0B. After time $tMRW$ the LPDDR4-SDRAM is ready for normal operation. After training exit the LPDDR4-SDRAM will automatically switch back to the FSP-OP registers that were in use prior to training.

Command Bus Training may be executed from IDLE or Self Refresh states. When executing CBT within the Self Refresh state, the SDRAM must not be a power down state (i.e., CKE must be HIGH prior to training entry). Command Bus Training entry and exit is the same, regardless of the SDRAM state from which CBT is initiated.

4.29.1 Training Sequence for single-rank systems

Note that the example shown here is assuming an initial low-frequency, no-terminating operating point, training a high-frequency, terminating operating point. **The green text is low-frequency, magenta text is high-frequency.** Any operating point may be trained from any known good operating point.

1. Set MR13 OP[6]=1B to enable writing to Frequency Set Point ‘y’ (FSP-WR[y]) (or FSP-OP[x], See note).
2. Write FSP-WR[y] (or FSP-WR[x]) registers for all channels to set up high-frequency operating parameters.
3. Issue MRW-1 and MRW-2 commands to enter Command Bus Training mode.
4. Drive CKE LOW, and change CK frequency to the high-frequency operating point.
5. Perform Command Bus Training (V_{REFCA} , CS, and CA).
6. Exit training, a change CK frequency to the low-frequency operating point prior to driving CKE HIGH, then issue MRW-1 and MRW-2 commands. When CKE is driven HIGH, the SDRAM will automatically switch back to the FSP-OP registers that were in use prior to training (i.e., trained values are not retained by the SDRAM).
7. Write the trained values to FSP-WR[y] (or FSP-WR[x]) by issuing MRW-1 and MRW-2 commands to the SDRAM and setting all applicable mode register parameters.
8. Issue MRW-1 and MRW-2 commands to switch to FSP-OP[y] (or FSP-OP[x]), to turn on termination, and change CK frequency to the high frequency operating point. At this point the Command Bus is trained and you may proceed to other training or normal operation.

4.29.2 Training Sequence for multi-rank systems

Note that the example shown here assumes an initial low-frequency operating point, training a high-frequency operating point. The green text is low-frequency, magenta text is high-frequency. Any operating point may be trained from any known good operating point.

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

4.29.3 Relation between CA input pin DQ output pin

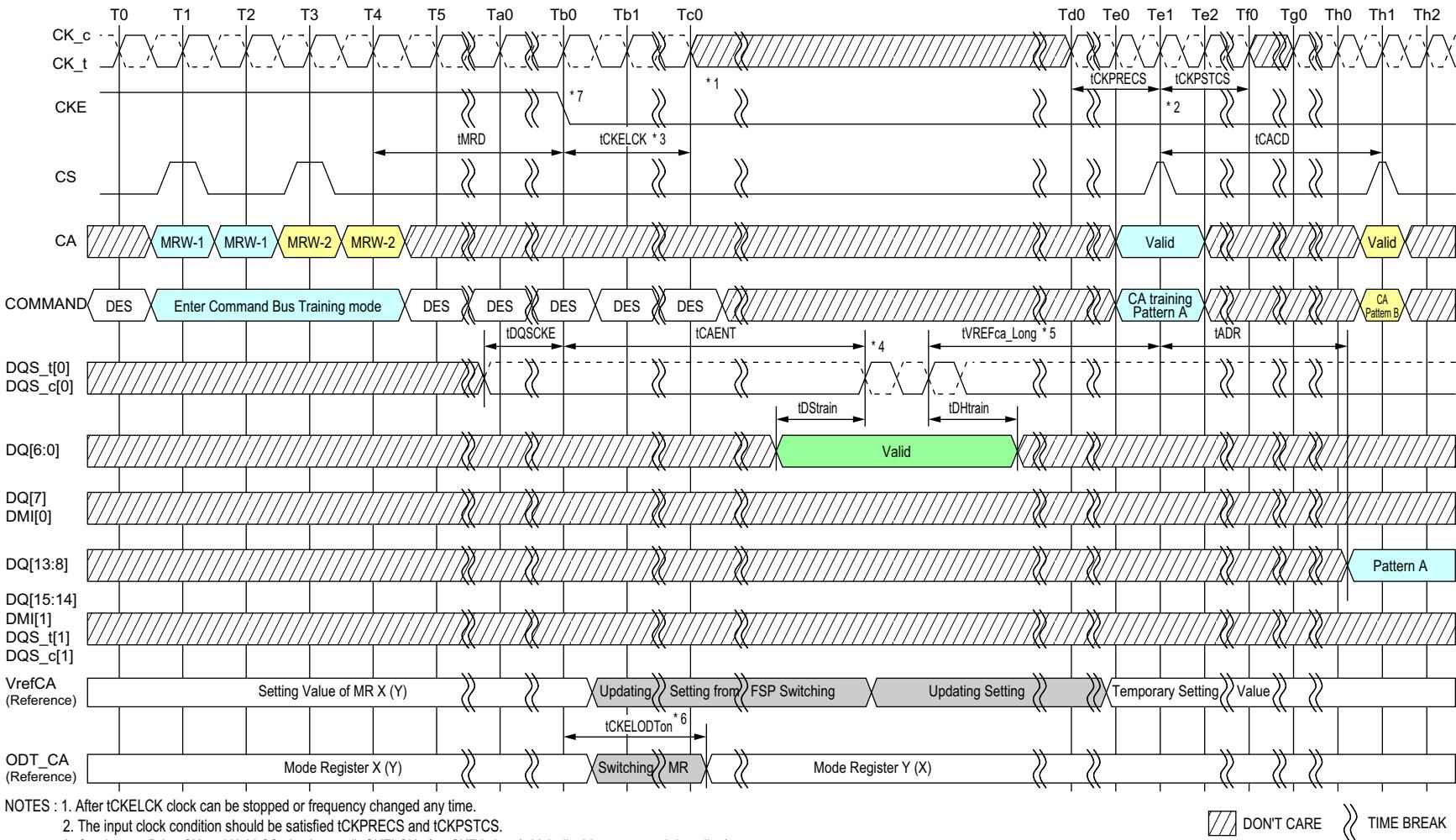
The relation between CA input pin DQ output pin is shown in Table 56.

Table 56 — Mapping of CA Input pin and DQ Output pin

| | Mapping | | | | | |
|-----------|---------|------|------|------|-----|-----|
| CA Number | CA5 | CA4 | CA3 | CA2 | CA1 | CA0 |
| DQ Number | DQ13 | DQ12 | DQ11 | DQ10 | DQ9 | DQ8 |

4.29.4 Timing Diagram

The basic Timing diagrams of Command Bus Training are shown in Figure 99, Figure 100, Figure 101, and Figure 102..



NOTES : 1. After tCKELCK clock can be stopped or frequency changed any time.

2. The input clock condition should be satisfied tCKPRECS and tCKPSTCS.

3. Continue to Drive CK and Hold CS pins low until tCKECLK after CKE is low (which disables command decoding).

4. DRAM may or may not capture first rising/falling edge of DQS t/c due to an unstable first rising edge. Hence provide at least consecutive 2 pulses of DQS signal input is required in every DQS input signal at capturing DQ6:0 signals.

The captured value of DQ6:0 signal level by each DQS edges are overwritten at any time and the DRAM updates its VREFc_a setting of MR12 temporary after time t_{VREFc_a}. Long,

5. tVREF_LONG may be reduced to tVREF_SHORT if the following conditions are met: 1) The new Vref setting is a single step above or below the old Vref setting, and 2) The DOS pulses a single time, or the new Vref setting value on DQ16[0] is static and meets tDSTRAIN/tDHTRAIN for every DOS pulse applied.

6. When CKE is driven LOW, the SDRAM will switch its FSP-OP registers to use the alternate (i.e. non-active) set. Example: If the SDRAM is currently using FSP-OP[0], then it will switch to FSP-OP[1] when CKE is driven LOW. All operating parameters should be written to the alternate mode registers before entering Command Bus Training to ensure that ODT settings, RLWL/NWR setting, etc., are set to the correct values. If the alternate FSP-OP has ODT_CA disabled then termination will not enable in CA Bus Training mode. If the ODT_CA pad is bonded to Vss, ODT_CA termination will never enable for that die.

7. When CKE is driven low in Command Bus Training mode, the LPDDR4-SDRAM will change operation to the alternate ESP, i.e. the inverse of the ESP programmed in the ESP-OP mode register.

Figure 99 — Entering Command Bus Training Mode and CA Training Pattern Input and Output with V_{REFCA} Value Update



NOTES : 1. After tCKELOCK clock can be stopped or frequency changed any time.

2. The input clock condition should be satisfied tCKPRECS.

3. Continue to Drive CK and Hold CS pins low until tCKELOCK after CKE is low (which disables command decoding).

4. DRAM may or may not capture first rising/falling edge of DQS_t/c due to an unstable first rising edge. Hence provide at least consecutive 2 pulses of DQS signal input is required in every DQS input signal at capturing DQ6:0 signals.

The captured value of DQ6:0 signal level by each DQS edges are overwritten at any time and the DRAM updates its VREFca setting of MR12 temporary after time tVREFca_Long.

5. tVREF_LONG may be reduced to tVREF_SHORT if the following conditions are met: 1) The new Vref setting is a single step above or below the old Vref setting,

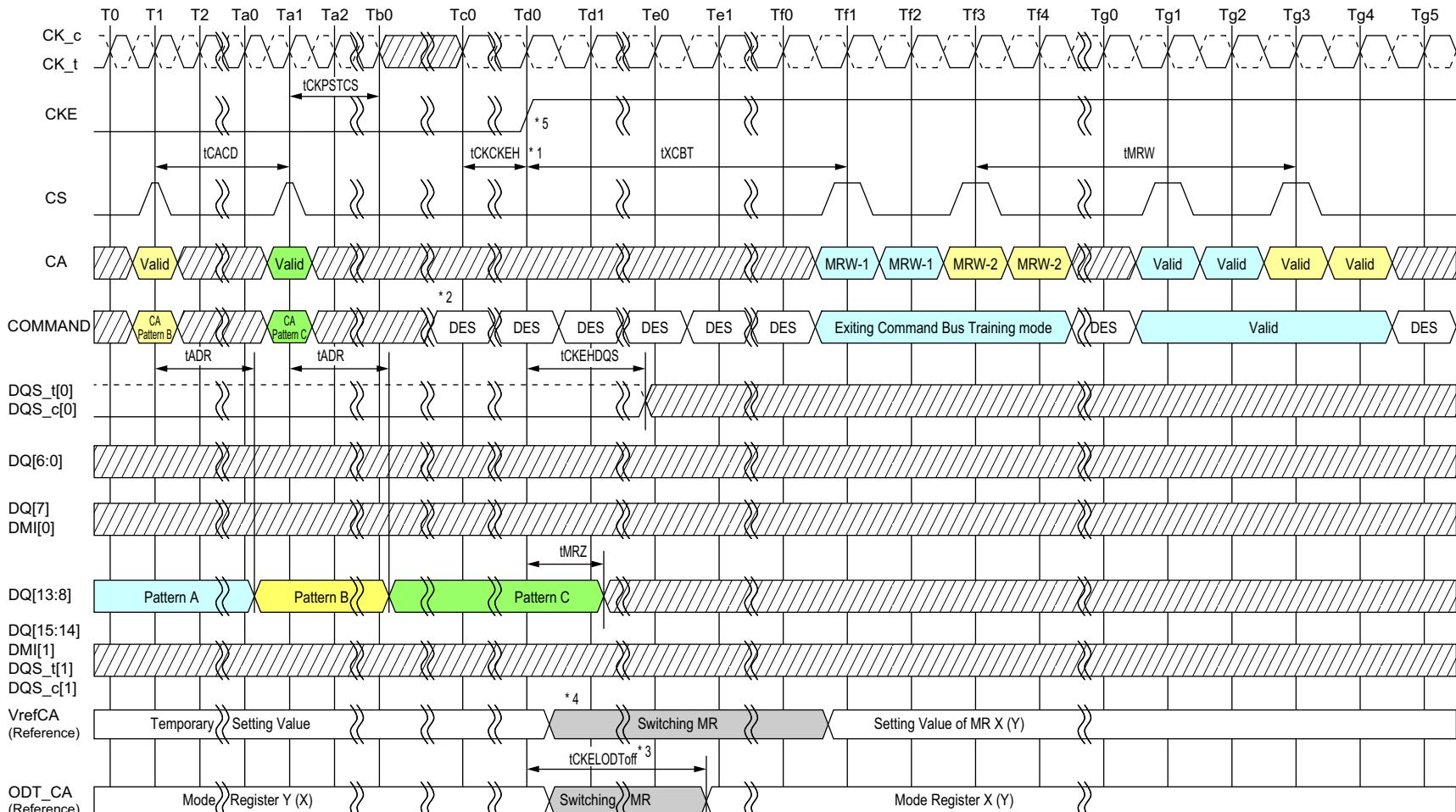
and 2) The DQS pulses a single time, or the new Vref setting value on DQ[6:0] is static and meets tDSTRAIN/tDHTRAIN for every DQS pulse applied.

6. When CKE is driven LOW, the SDRAM will switch its FSP-OP registers to use the alternate (i.e. non-active) set. Example: If the SDRAM is currently using FSP-OP[0],

then it will switch to FSP-OP[1] when CKE is driven LOW. All operating parameters should be written to the alternate mode registers before entering Command Bus Training to ensure that ODT settings, RL/WL/nWR setting, etc., are set to the correct values. If the alternate FSP-OP has ODT_CA disabled then termination will not enable in CA Bus Training mode. If the ODT_CA pad is bonded to Vss, ODT_CA termination will never enable for that die.

7. When CKE is driven low in Command Bus Training mode, the LPDDR4-SDRAM will change operation to the alternate FSP, i.e. the inverse of the FSP programmed in the FSP-OP mode register.

Figure 100 — Consecutive V_{REFCA} Value Update



NOTES : 1. Clock can be stopped or frequency changed any time before tCKCHEH. CK must meet tCKCHEH before CKE is driven high.

When CKE is driven high the clock frequency must be returned to the original frequency (the frequency corresponding to the FSP at which Command Bus Training mode was entered)

2. CS must be Deselect (low) tCKCHEH before CKE is driven high.

3. When CKE is driven high, the SDRAM's ODT_CA will revert to the state/value defined by FSP-OP prior to Command Bus Training mode entry, i.e. the original frequency set point (FSP-OP, MR13-OP[7]).

Example: If the SDRAM was using FSP-OP[1] for training, then it will switch to FSP-OP[0] when CKE is driven HIGH.

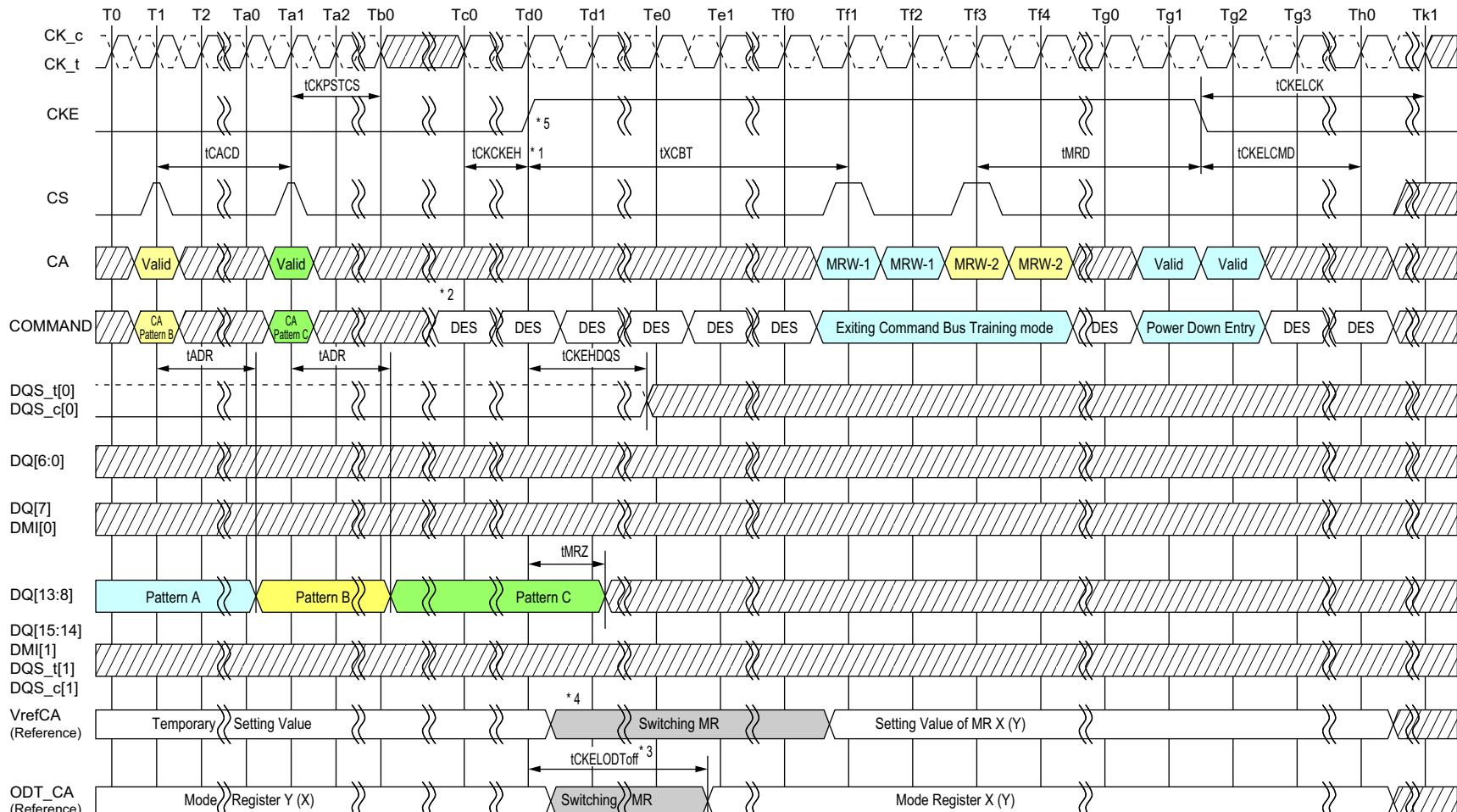
4. Training values are not retained by the SDRAM, and must be written to the FSP-OP register set before returning to operation at the trained frequency.

Example: VREF(ca) will return to the value programmed in the original set point.

5. When CKE is driven high the LPDDR4-SDRAM will revert to the FSP in operation when Command Bus Training mode was entered.

DON'T CARE TIME BREAK

Figure 101 — Exiting Command Bus Training Mode with Valid Command



NOTES : 1. Clock can be stopped or frequency changed any time before tCKCKEH. CK must meet tCKCKEH before CKE is driven high.

When CKE is driven high the clock frequency must be returned to the original frequency (the frequency corresponding to the FSP at which Command Bus Training mode was entered)

2. CS must be Deselect (low) tCKCKEH before CKE is driven high.

3. When CKE is driven high, the SDRAM's ODT_CA will revert to the state/value defined by FSP-OP prior to Command Bus Training mode entry, i.e. the original frequency set point (FSP-OP, MR13-OP[7]).

Example: If the SDRAM was using FSP-OP[1] for training, then it will switch to FSP-OP[0] when CKE is driven HIGH.

4. Training values are not retained by the SDRAM, and must be written to the FSP-OP register set before returning to operation at the trained frequency.

Example: VREF(ca) will return to the value programmed in the original set point.

5. When CKE is driven high the LPDDR4-SDRAM will revert to the FSP in operation when Command Bus Training mode was entered.

DON'T CARE TIME BREAK

Figure 102 — Exiting Command Bus Training Mode with Power Down Entry

4.29.5 Command Bus Training AC Timing Table

Table 57 — Command Bus Training AC Timing

Table 57 — Command Bus Training AC Timing (cont'd)

| Parameter | Symbol | Min/ Max | Data Rate | | | | | | | | Unit | Note |
|--|--------------|-------------|-----------|------|------|------|------|------|------|------|------|------|
| | | | 533 | 1066 | 1600 | 2133 | 2667 | 3200 | 3733 | 4267 | | |
| Command Bus Training Timing | | | | | | | | | | | | |
| Exit Command Bus Training Mode to next valid command delay | tXCBT_Short | Min | | | | | | | | | - | 3 |
| | tXCBT_Middle | Min | | | | | | | | | - | 3 |
| | tXCBT_Long | Min | | | | | | | | | - | 3 |

NOTE 1 DQS_t has to retain a low level during tDQSCKE period, as well as DQS_c has to retain a high level.

NOTE 2 If tCACD is violated, the data for samples which violate tCACD will not be available, except for the last sample (where tCACD after this sample is met). Valid data for the last sample will be available after tADR.

NOTE 3 Exit Command Bus Training Mode to next valid command delay Time depends on value of V_{REF}(CA) setting: MR12 OP[5:0] and V_{REF}(CA) Range: MR12 OP[6] of FSP-OP 0 and 1. The details are shown in Table 61.

Additionally exit Command Bus Training Mode to next valid command delay Time may affect V_{REF}(DQ) setting. Settling time of V_{REF}(DQ) level is same as V_{REF}(CA) level.

4.30 Frequency Set Point

Frequency Set-Points allow the LPDDR4-SDRAM CA Bus to be switched between two differing operating frequencies, with changes in voltage swings and termination values, without ever being in an untrained state which could result in a loss of communication to the DRAM. This is accomplished by duplicating all CA Bus mode register parameters, as well as other mode register parameters commonly changed with operating frequency. These duplicated registers form two sets that use the same mode register addresses, with read/write access controlled by MR bit FSP-WR (Frequency Set-Point Write/Read) and the DRAM operating point controlled by another MR bit FSP-OP (Frequency Set-Point Operation). Changing the FSP-WR bit allows MR parameters to be changed for an alternate Frequency Set-Point without affecting the LPDDR4-SDRAM's current operation. Once all necessary parameters have been written to the alternate Set-Point, changing the FSP-OP bit will switch operation to use all of the new parameters simultaneously (within tFC), eliminating the possibility of a loss of communication that could be caused by a partial configuration change.

Parameters which have two physical registers controlled by FSP-WR and FSP-OP are shown in the following table with the exception as outlined in Note 1.

Table 58 — Mode Register Function with two physical registers

| MR# | Operand | Function | Note |
|------|---------|--|------|
| MR1 | OP[2] | WR-PRE (WR Pre-amble Length) | 1 |
| | OP[3] | RD-PRE (RD Pre-amble Type) | |
| | OP[6:4] | nWR (Write-Recovery for Auto-Precharge commands) | |
| | OP[7] | PST (RD Post-Amble Length) | |
| MR2 | OP[2:0] | RL (Read latency) | |
| | OP[5:3] | WL (Write latency) | |
| | OP[6] | WLS (Write Latency Set) | |
| MR3 | OP[0] | PU-Cal (Pull-up Calibration Point) | 2 |
| | OP[1] | WR PST(WR Post-Amble Length) | |
| | OP[5:3] | PDDS (Pull-Down Drive Strength) | |
| | OP[6] | DBI-RD (DBI-Read Enable) | |
| | OP[7] | DBI-WR (DBI-Write Enable) | |
| MR11 | OP[2:0] | DQ ODT (DQ Bus Receiver On-Die-Termination) | |
| | OP[6:4] | CA ODT (CA Bus Receiver On-Die-Termination) | |
| MR12 | OP[5:0] | VREF(ca) (VREF(ca) Setting) | |
| | OP[6] | VR-CA (VREF(ca) Range) | |
| MR14 | OP[5:0] | VREF(dq) (VREF(dq) Setting) | |
| | OP[6] | VR(dq) (VREF(dq) Range) | |
| MR22 | OP[2:0] | SoC ODT (Controller ODT Value for VOH calibration) | |
| | OP[3] | ODTE-CK (CK ODT enabled for non terminating rank) | |
| | OP[4] | ODTE-CS (CS ODT enable for non-terminating rank) | |
| | OP[5] | ODTD-CA (CA ODT termination disable) | |

NOTE 1 Supporting the two physical registers for Burst Length: MR1 OP[1:0] is optional.
Applications requiring support of both vendor options shall assure that both FSP-OP[0] and FSP-OP[1] are set to the same code. Refer to vendor datasheets for detail.

NOTE 2 For dual channel devices, PU-CAL setting is required as the same value for both Ch.A and Ch.B before issuing ZQ Cal start command.

See Mode Register Definition for more details.

Table 59 shows how the two mode registers for each of the parameters above can be modified by setting the appropriate FSP-WR value, and how device operation can be switched between operating points by setting the appropriate FSP-OP value. The FSP-WR and FSP-OP functions operate completely independently.

Table 59 — Relation between MR Setting and DRAM Operation

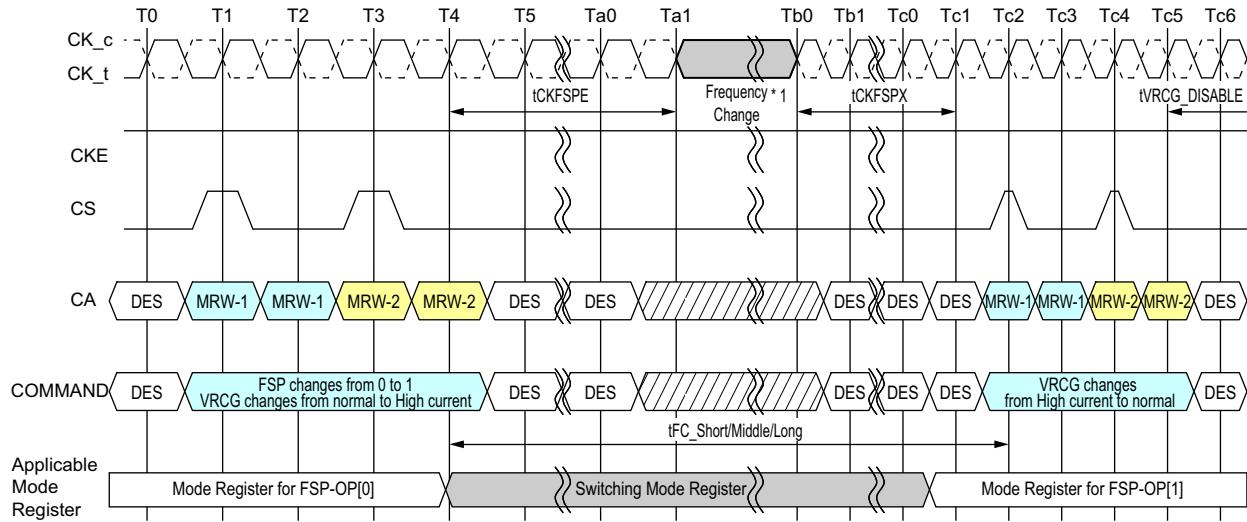
| Function | MR# & Operand | Data | Operation | Note |
|----------|---------------|-------------|---|------|
| FSP-WR | MR13 OP[6] | 0 (Default) | Data write to Mode Register N for FSP-OP[0] by MRW Command. Data read from Mode Register N for FSP-OP[0] by MRR Command. | 1 |
| | | 1 | Data write to Mode Register N for FSP-OP[1] by MRW Command. Data read from Mode Register N for FSP-OP[1] by MRR Command. | |
| FSP-OP | MR13 OP[7] | 0 (Default) | DRAM operates with Mode Register N for FSP-OP[0] setting. | 2 |
| | | 1 | DRAM operates with Mode Register N for FSP-OP[1] setting. | |

NOTE 1 FSP-WR stands for Frequency Set Point Write/Read.

NOTE 2 FSP-OP stands for Frequency Set Point Operating Point.

4.30.1 Frequency set point update Timing

The Frequency set point update timing is shown in Figure 103. When changing the frequency set point via MR13 OP[7], the VRCG setting: MR13 OP[3] have to be changed into V_{REF} Fast Response (high current) mode at the same time. After Frequency change time(tFC) is satisfied. VRCG can be changed into Normal Operation mode via MR13 OP[3].



NOTES : 1. The definition that is Clock frequency change during CKE HIGH should be followed at the frequency change operation.

For more information, refer to Section 4.49 Input Clock Stop and Frequency Change.

□ DON'T CARE }} TIME BREAK

Figure 103 — Frequency Set Point Switching Timing

Table 60 — AC Timing Table

| Parameter | Symbol | Min/ Max | Data Rate | | | | | | | | Unit | Note |
|---|------------|-------------|-----------|------|------|------|------|------|------|------------------|------|------|
| | | | 533 | 1066 | 1600 | 2133 | 2667 | 3200 | 3733 | 4267 | | |
| Frequency Set Point parameters | | | | | | | | | | | | |
| Frequency Set Point Switching Time | tFC_Short | MIN | | | | | | | | 200 | ns | 1 |
| | tFC_Middle | MIN | | | | | | | | 200 | ns | 1 |
| | tFC_Long | MIN | | | | | | | | 250 | ns | 1 |
| Valid Clock Requirement after Entering FSP Change | tCKFSPE | MIN | | | | | | | | max(7.5ns, 4nCK) | - | |
| Valid Clock Requirement before 1st Valid Command after FSP change | tCKFSPX | MIN | | | | | | | | max(7.5ns, 4nCK) | - | |

NOTE 1 Frequency Set Point Switching Time depends on value of $V_{REF}(CA)$ setting: MR12 OP[5:0] and $V_{REF}(CA)$ Range: MR12 OP[6] of FSP-OP 0 and 1. The details are shown in Table 61.
Additionally change of Frequency Set Point may affect $V_{REF}(DQ)$ setting. Settling time of $V_{REF}(DQ)$ level is same as $V_{REF}(CA)$ level.

Table 61 — tFC value mapping

| Application | Step Size | | | Range | |
|-------------|------------------|---|--|------------------|---------------|
| | From FSP -OP0 | To FSP-OP1 | | From FSP -OP0 | To FSP-OP1 |
| tFC_Short | Base | A single step size increment/decrement | | Base | No Change |
| tFC_Middle | Base | Two or more step size increment/decrement | | Base | No Change |
| tFC_Long | - | - | | Base | Change |

NOTE 1 As well as change from FSP-OP1 to FSP-OP0.

Table 62 provides an example of tFC value mapping when FSP-OP moves from OP0 to OP1.

Table 62 — tFC value mapping example

| Case | From/To | FSP-OP: MR13 OP[7] | $V_{REF}(CA)$ Setting: MR12: OP[5:0] | $V_{REF}(CA)$ Range: MR12 OP[6] | Application | Note |
|------|---------|-----------------------|---|------------------------------------|-------------|------|
| 1 | From | 0 | 001100 | 0 | tFC_Short | 1 |
| | To | 1 | 001101 | 0 | | |
| 2 | From | 0 | 001100 | 0 | tFC_Middle | 2 |
| | To | 1 | 001110 | 0 | | |
| 3 | From | 0 | Don't Care | 0 | tFC_Long | 3 |
| | To | 1 | Don't Care | 1 | | |

NOTE 1 A single step size increment/decrement for $V_{REF}(CA)$ Setting Value.

NOTE 2 Two or more step size increment/decrement for $V_{REF}(CA)$ Setting Value.

NOTE 3 $V_{REF}(CA)$ Range is changed. In this case changing $V_{REF}(CA)$ Setting doesn't affect tFC value.

The LPDDR4-SDRAM defaults to FSP-OP[0] at power-up. Both Set-Points default to settings needed to operate in un-terminated, low-frequency environments. To enable the LPDDR4-SDRAM to operate at higher frequencies, Command Bus Training mode should be utilized to train the alternate Frequency Set-Point (Figure 104). See the section Command Bus Training for more details on this training mode.

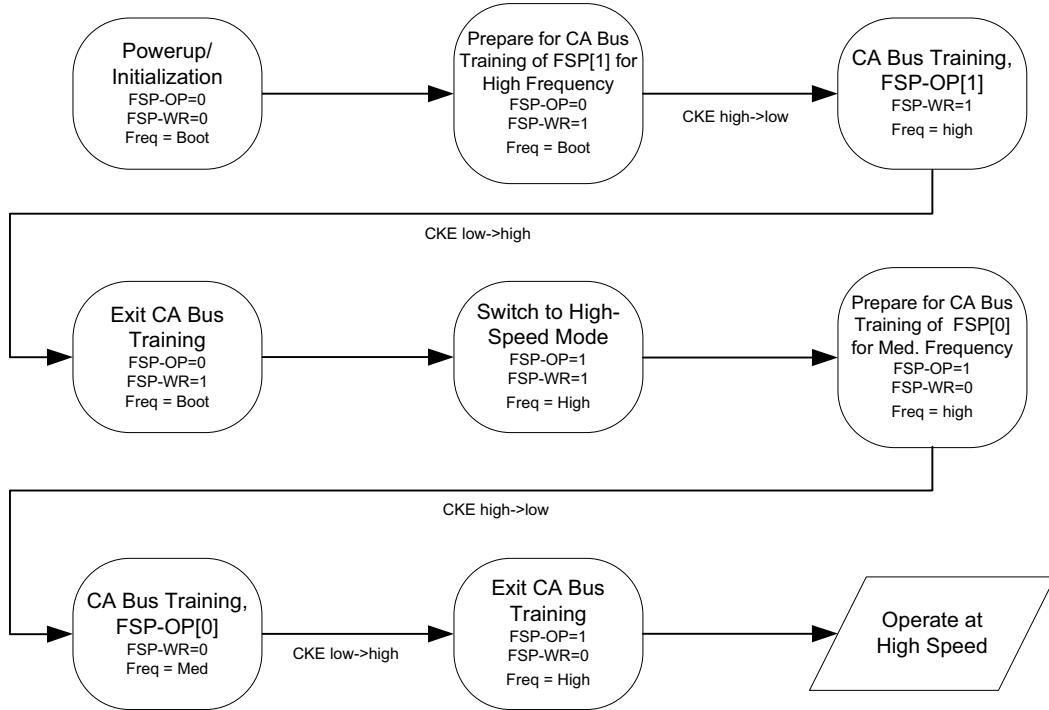


Figure 104 — Training Two Frequency Set-Points

Once both Frequency Set-Points have been trained, switching between points can be performed by a single MRW followed by waiting for tFC (Figure 105).

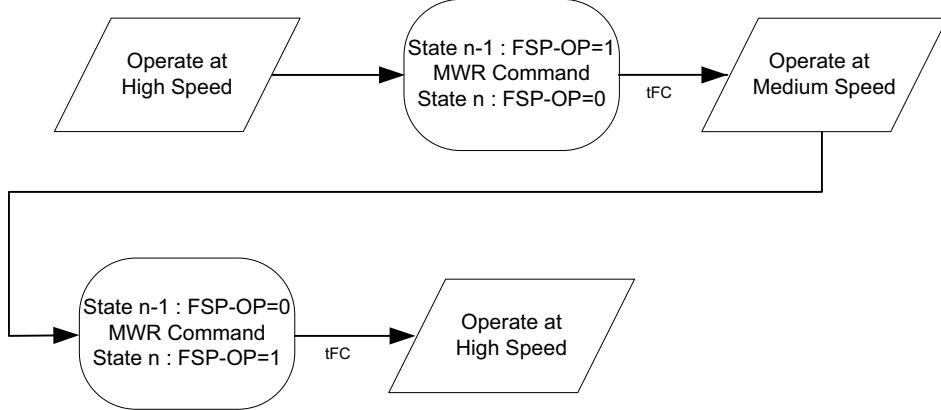


Figure 105 — Switching Between Two Trained Frequency Set-Points

Switching to a third (or more) Set-Point can be accomplished if the memory controller has stored the previously-trained values (in particular the V_{REF} -CA calibration value) and re-writes these to the alternate Set-Point before switching FSP-OP (Figure 106).

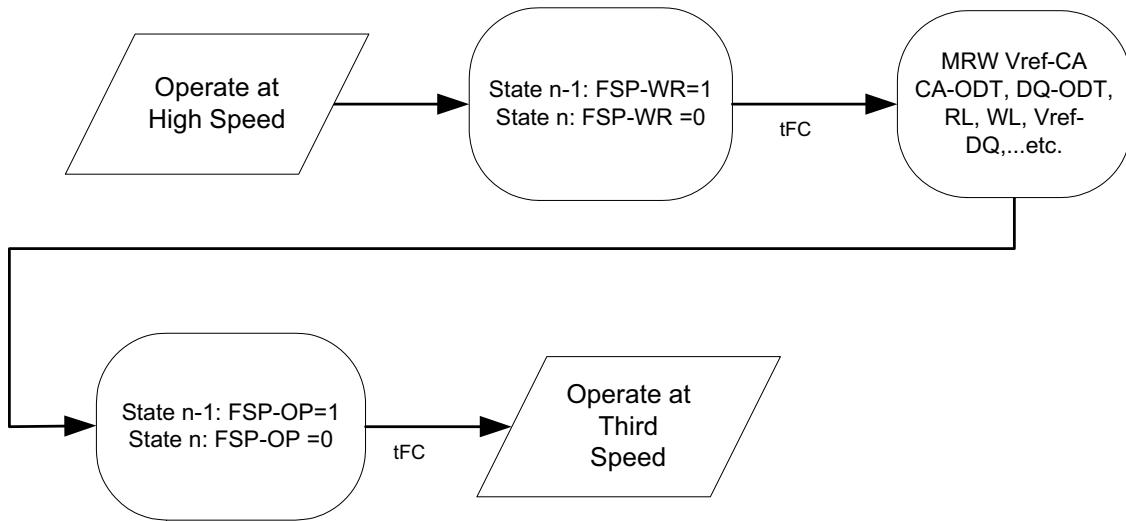


Figure 106 — Switching to a Third Trained Frequency Set-Point

4.31 Mode Register Write-WR Leveling Mode

To improve signal-integrity performance, the LPDDR4 SDRAM provides a write-leveling feature to compensate CK-to-DQS timing skew affecting timing parameters such as tDQSS, tDSS, and tDSH. The DRAM samples the clock state with the rising edge of DQS signals, and asynchronously feeds back to the memory controller. The memory controller references this feedback to adjust the clock-to-data strobe signal relationship for each DQS_t/DQS_c signal pair.

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

The LPDDR4 SDRAM enters into write-leveling mode when mode register MR2-OP[7] is set HIGH. When entering write-leveling mode, the state of the DQ pins is undefined. During write-leveling mode, only DESELECT commands are allowed, or a MRW command to exit the write-leveling operation. Depending on the absolute values of tDQSL and tDQSH in the application, the value of tDQSS may have to be better than the limits provided in the Write AC Timing Table¹ in order to satisfy the tDSS and tDSH specifications. Upon completion of the write-leveling operation, the DRAM exits from write-leveling mode when MR2-OP[7] is reset LOW.

Write Leveling should be performed before Write Training (DQS2DQ Training).

NOTE 1 As of publication of this document, under discussion by the formulating committee.

4.31.1 Write Leveling Procedure

1. Enter into Write-leveling mode by setting MR2-OP[7]=1.
2. Once entered into Write-leveling mode, DQS_t must be driven LOW and DQS_c HIGH after a delay of tWLDQSEN.
3. Wait for a time tWLMDR before providing the first DQS signal input. The delay time tWLMDR(MAX) is controller dependent.
4. DRAM may or may not capture first rising edge of DQS_t due to an unstable first rising edge. Hence provide at least consecutive 2 pulses of DQS signal input is required in every DQS input signal during Write Training Mode.
The captured clock level by each DQS edges are overwritten at any time and the DRAM provides asynchronous feedback on all the DQ bits after time tWLO.
5. The feedback provided by the DRAM is referenced by the controller to increment or decrement the DQS_t and/or DQS_c delay settings.
6. Repeat step 4 through step 5 until the proper DQS_t/DQS_c delay is established.
7. Exit from Write-leveling mode by setting MR2-OP[7]=0.

A Write Leveling timing example is shown in Figure 107, and Figure 108.

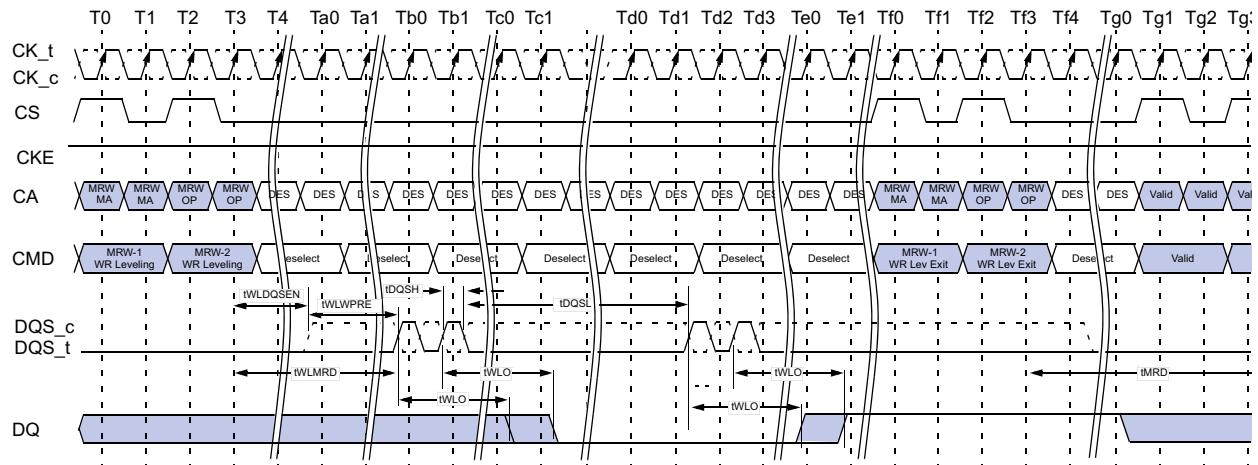


Figure 107 — Write Leveling Timing, tDQSL(max)

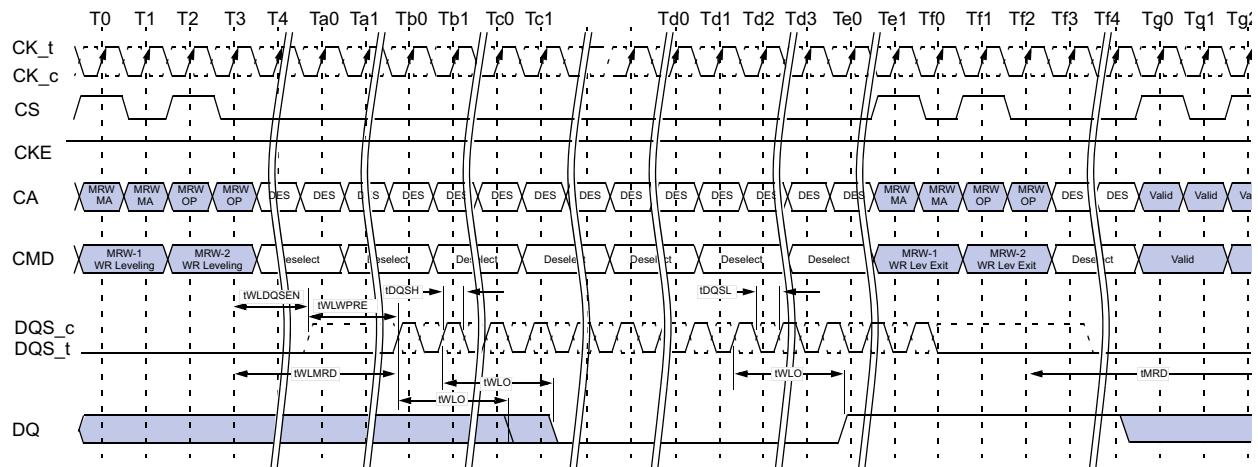
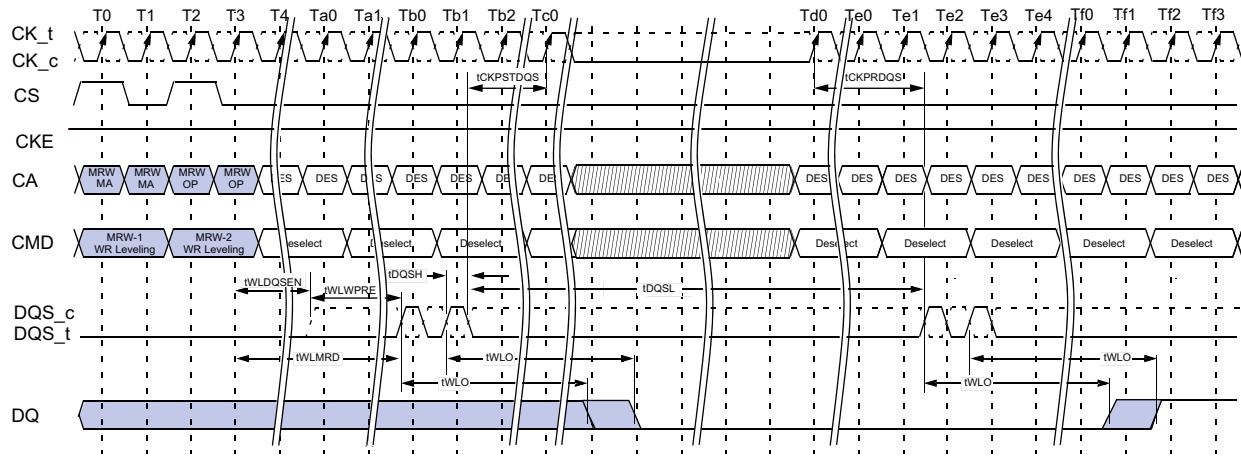


Figure 108 — Write Leveling Timing, tDQSL(min)

4.32.2 Input Clock Frequency Stop and Change

The input clock frequency can be stopped or changed from one stable clock rate to another stable clock rate during Write Leveling mode.

The Frequency stop or change timing is shown in Figure 109.



NOTES :
 1. CK_t is held LOW and CK_c is held HIGH during clock stop.
 2. CS shall be held LOW during clock clock stop

Figure 109 — Clock Stop and Timing during Write Leveling

Table 63 — Write Leveling Timing Parameters

| Parameter | Symbol | Min/Max | Value | Units | Notes |
|--|-----------|---------|------------------|-------|-------|
| DQS_t/DQS_c delay after write leveling mode is programmed | tWLQSEN | Min | 20 | tCK | |
| | | Max | - | | |
| Write preamble for Write Leveling | tWLWPRE | Min | 20 | tCK | |
| | | Max | - | | |
| First DQS_t/DQS_c edge after write leveling mode is programmed | tWLMD | Min | 40 | tCK | |
| | | Max | - | | |
| Write leveling output delay | tWLO | Min | 0 | ns | |
| | | Max | 20 | | |
| Mode register set command delay | tMRD | Min | max(14ns, 10nCK) | ns | |
| | | Max | - | | |
| Valid Clock Requirement before DQS Toggle | tCKPRDQS | Min | max(7.5ns, 4nCK) | - | |
| | | Max | - | | |
| Valid Clock Requirement after DQS Toggle | tCKPSTDQS | Min | max(7.5ns, 4nCK) | - | |
| | | Max | - | | |

4.33.3 Write Leveling Setup and Hold Time

Table 64 — Write Leveling Setup and Hold Time

| Parameter | Symbol | Min/Max | Data Rate | | | | Unit |
|-----------------------------------|--------|---------|-----------|------|------|------|------|
| | | | 1600 | 2400 | 3200 | 4266 | |
| Write Leveling Parameters | | | | | | | |
| Write leveling hold time | tWLH | MIN | 150 | 100 | 75 | 50 | ps |
| Write leveling setup time | tWLS | MIN | 150 | 100 | 75 | 50 | ps |
| Write leveling input valid window | tWLIVW | MIN | 240 | 160 | 120 | 90 | ps |

NOTE 1 In addition to the traditional setup and hold time specifications above, there is value in a input valid window based specification for write-leveling training. As the training is based on each device, worst case process skews for setup and hold do not make sense to close timing between CK and DQS.

NOTE 2 tWLIVW is defined in a similar manner to tDIVW_Total, except that here it is a DQS input valid window with respect to CK. This would need to account for all VT (voltage and temperature) drift terms between CK and DQS within the DRAM that affect the write-leveling input valid window.

The DQS input mask for timing with respect to CK is shown in Figure 110. The "total" mask (tWLIVW) defines the time the input signal must not encroach in order for the DQS input to be successfully captured by CK with a BER of lower than tbd. The mask is a receiver property and it is not the valid data-eye.

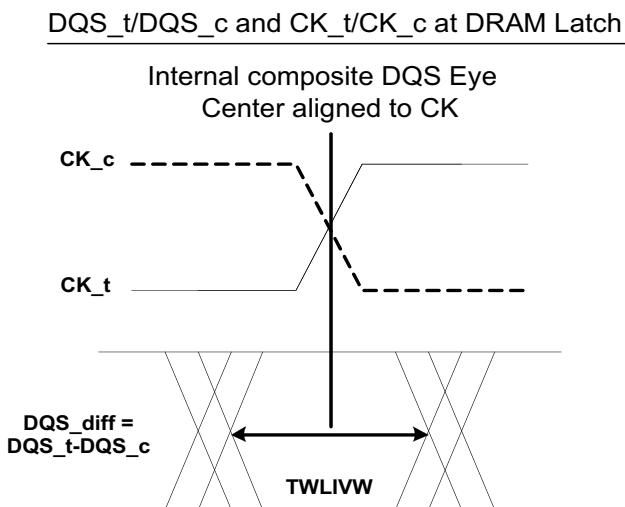


Figure 110 — DQS_t/DQS_c to CK_t/CK_c timings at the DRAM pins referenced from the internal latch

4.34 RD DQ Calibration

LPDDR4 devices feature a RD DQ Calibration training function that outputs a 16-bit user-defined pattern on the DQ pins. RD DQ Calibration is initiated by issuing a MPC-1 [RD DQ Calibration] command followed by a CAS-2 command, cause the LPDDR4-SDRAM to drive the contents of MR32 followed by the contents of MR40 on each of DQ[15:0] and DMI[1:0]. The pattern can be inverted on selected DQ pins according to user-defined invert masks written to MR15 and MR20.

4.34.1 RD DQ Calibration Training Procedure

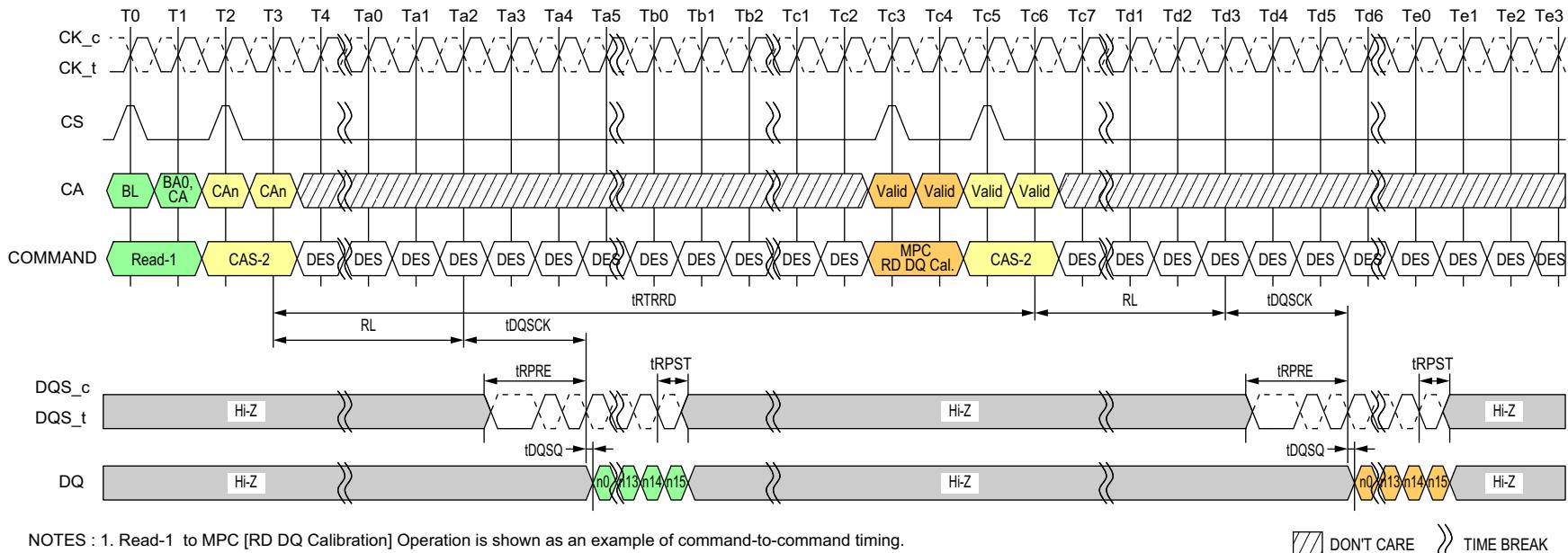
The procedure for executing RD DQ Calibration is:

- Issue MRW commands to write MR32 (first eight bits), MR40 (second eight bits), MR15 (eight-bit invert mask for byte 0), and MR20 (eight-bit invert mask for byte 1).
 - Optionally this step could be skipped to use the default patterns
 - MR32 default = 5Ah
 - MR40 default = 3Ch
 - MR15 default = 55h
 - MR20 default = 55h
- Issue an MPC-1 [RD DQ Calibration] command followed immediately by a CAS-2 command.
 - Each time an MPC-1 [RD DQ Calibration] command followed by a CAS-2 is received by the LPDDR4 SDRAM, a 16-bit data burst will, after the currently set RL, drive the eight bits programmed in MR32 followed by the eight bits programmed in MR40 on all I/O pins.
 - The data pattern will be inverted for I/O pins with a '1' programmed in the corresponding invert mask mode register bit (see Table 65).
 - Note that the pattern is driven on the DMI pins, but no data bus inversion function is enabled, even if Read DBI is enabled in the DRAM mode register.
 - The MPC-1 [RD DQ Calibration] command can be issued every tCCD seamlessly, and tRTRRD delay is required between Array Read command and the MPC-1 [RD DQ Calibration] command as well the delay required between the MPC-1 [RD DQ Calibration] command and an array read.
 - The operands received with the CAS-2 command must be driven LOW.
- DQ Read Training can be performed with any or no banks active, during Refresh, or during SREF with CKE high.

Table 65 — Invert Mask Assignments

| DQ Pin | 0 | 1 | 2 | 3 | DMI0 | 4 | 5 | 6 | 7 |
|----------|---|---|---|---|------|---|---|---|---|
| MR15 bit | 0 | 1 | 2 | 3 | N/A | 4 | 5 | 6 | 7 |

| DQ Pin | 8 | 9 | 10 | 11 | DMI1 | 12 | 13 | 14 | 15 |
|----------|---|---|----|----|------|----|----|----|----|
| MR20 bit | 0 | 1 | 2 | 3 | N/A | 4 | 5 | 6 | 7 |



NOTES : 1. Read-1 to MPC [RD DQ Calibration] Operation is shown as an example of command-to-command timing.

Timing from Read-1 to MPC [RD DQ Calibration] command is tRTRRD.

2. MPC [RD DQ Calibration] uses the same command-to-data timing relationship (RL, tDQSCK, tDQSQ) as a Read-1 command.

3. BL = 16, Read Preamble: Toggle, Read Postamble: 0.5nCK.

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

[/\] DON'T CARE { } TIME BREAK

Figure 111 — DQ Read Training Timing: Read to Read DQ Calibration

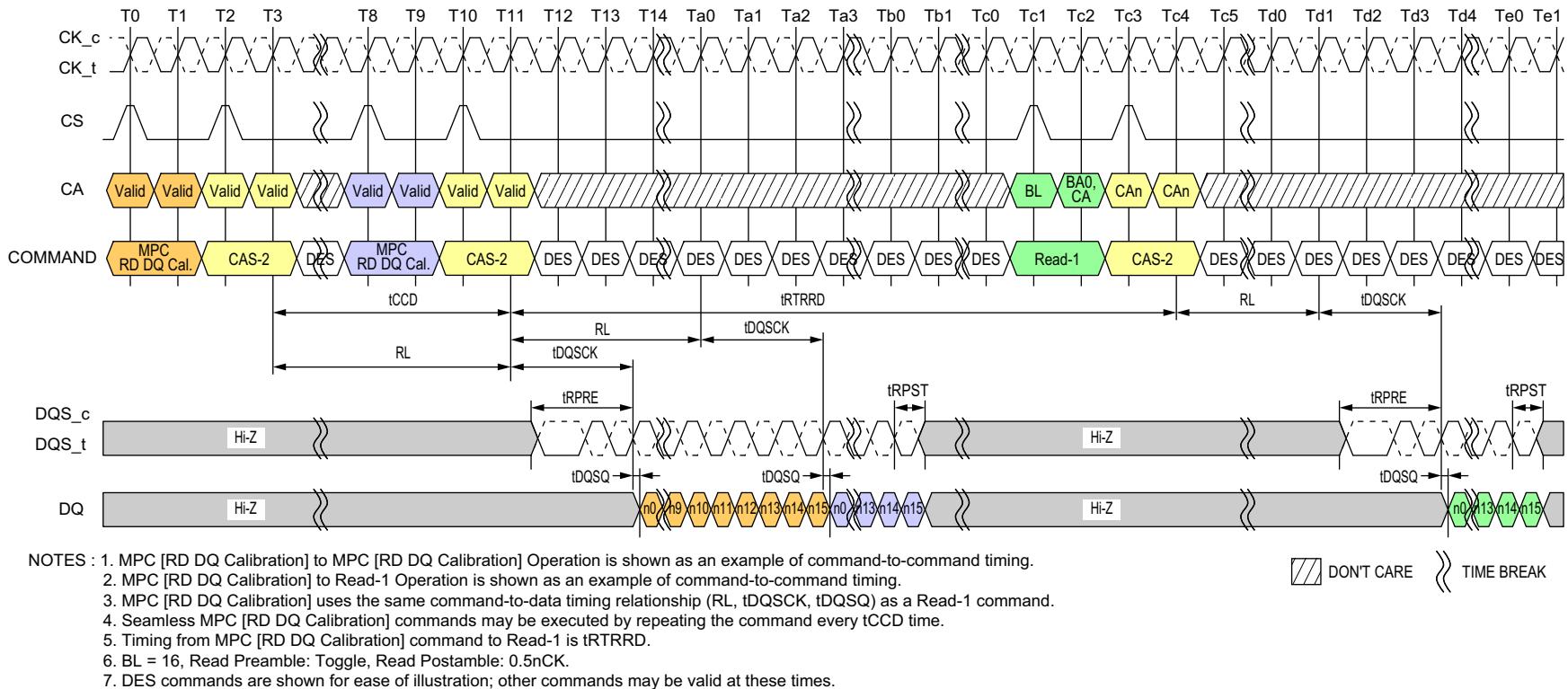


Figure 112 — DQ Read Training Timing: Read DQ Cal. to Read DQ Cal. / Read

4.34.2 DQ Read Training Example

An example of DQ Read Training output is shown in Table 66. This shows the 16-bit data pattern that will be driven on each DQ in byte 0 when one DQ Read Training command is executed. This output assumes the following mode register values are used:

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

Table 66 — DQ Read Calibration Bit Ordering and Inversion Example

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

NOTE 1 The patterns contained in MR32 and MR40 are transmitted on DQ[15:0] and DMI[1:0] when RD DQ Calibration is initiated via a MPC-1 [RD DQ Calibration] command. The pattern transmitted serially on each data lane, organized "little endian" such that the low-order bit in a byte is transmitted first. If the data pattern is 27H, then the first bit transmitted will be a '1', followed by '1', '1', '0', '0', '1', '0', and '0'. The bit stream will be 00100111 →.

NOTE 2 MR15 and MR20 may be used to invert the MR32/MR40 data pattern on the DQ pins. See MR15 and MR20 for more information. Data is never inverted on the DMI[1:0] pins.

NOTE 3 DMI [1:0] outputs status follows Table 67.

Table 67 — MR Setting vs. DMI Status

| DM Function MR13 OP[5] | Write DBIdc Function MR3 OP[7] | Read DBIdc Function MR3 OP[6] | DMI Status |
|---------------------------|-----------------------------------|----------------------------------|---------------------------------|
| 1: Disable | 0: Disable | 0: Disable | Hi-Z |
| 1: Disable | 1: Enable | 0: Disable | The data pattern is transmitted |
| 1: Disable | 0: Disable | 1: Enable | The data pattern is transmitted |
| 1: Disable | 1: Enable | 1: Enable | The data pattern is transmitted |
| 0: Enable | 0: Disable | 0: Disable | The data pattern is transmitted |
| 0: Enable | 1: Enable | 0: Disable | The data pattern is transmitted |
| 0: Enable | 0: Disable | 1: Enable | The data pattern is transmitted |
| 0: Enable | 1: Enable | 1: Enable | The data pattern is transmitted |

NOTE 4 No Data Bus Inversion (DBI) function is enacted during RD DQ Calibration, even if DBI is enabled in MR3-OP[6].

4.34.3 MPC of Read DQ Calibration after Power-Down Exit

Following the power-down state, an additional time, tMRRI, is required prior to issuing the MPC of Read DQ Calibration command. This additional time (equivalent to tRCD) is required in order to be able to maximize power-down current savings by allowing more power-up time for the Read DQ data in MR32 and MR40 data path after exit from standby, power-down mode.

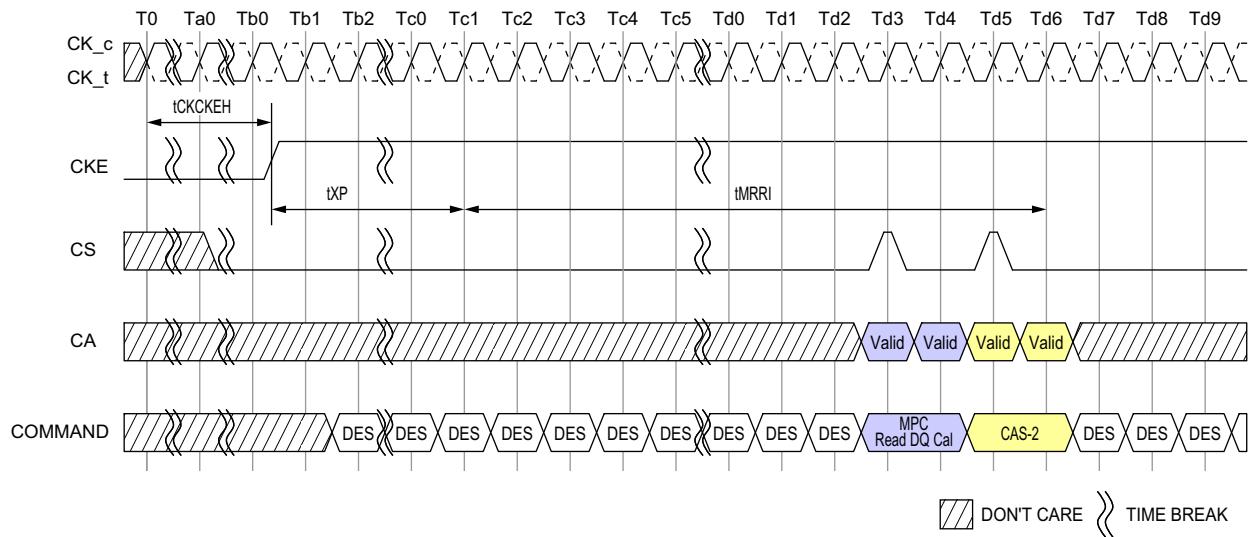


Figure 113 — MPC Read DQ Calibration Following Power-Down State

4.35 DQS-DQ Training

The LPDDR4-SDRAM uses an un-matched DQS-DQ path to enable high speed performance and save power in the DRAM. As a result, the DQS strobe must be trained to arrive at the DQ latch center-aligned with the Data eye. The SDRAM DQ receiver is located at the DQ pad, and has a shorter internal delay in the SDRAM than does the DQS signal. The SDRAM DQ receiver will latch the data present on the DQ bus when DQS reaches the latch, and training is accomplished by delaying the DQ signals relative to DQS such that the Data eye arrives at the receiver latch centered on the DQS transition.

Two modes of training are available in LPDDR4:

- Command-based FIFO WR/RD with user patterns
- A internal DQS clock-tree oscillator, to determine the need for, and the magnitude of required training.

The command-based FIFO WR/RD uses the MPC command with operands to enable this special mode of operation. When issuing the MPC command, if OP6 is set LOW then the DRAM will perform a NOP command. When OP6 is set HIGH, then OP5:0 enable training functions or are reserved for future use (RFU). MPC commands that initiate a Read FIFO, READ DQ Calibration or Write FIFO to the SDRAM must be followed immediately by a CAS-2 command. See 4.38, "Multi-Purpose Command (MPC) Definition" for more information.

To perform Write Training, the controller can issue a MPC [Write DQ FIFO] command with OP[6:0] set as described in the MPC Definition section, followed immediately by a CAS-2 command (CAS-2 operands should be driven LOW) to initiate a Write DQ FIFO. Timings for MPC [Write DQ FIFO] are identical to a Write command, with WL (Write Latency) timed from the 2nd rising clock edge of the CAS-2 command. Up to 5 consecutive MPC [Write DQ FIFO] commands with user defined patterns may be issued to the SDRAM to store up to 80 values (BL16 x5) per pin that can be read back via the MPC [Read DQ FIFO] command. Write/Read FIFO Pointer operation is described later in this section.

After writing data to the SDRAM with the MPC [Write DQ FIFO] command, the data can be read back with the MPC [Read DQ FIFO] command and results compared with "expect" data to see if further training (DQ delay) is needed. MPC [Read DQ FIFO] is initiated by issuing a MPC command with OP[6:0] set as described in the MPC Definition section, followed immediately by a CAS-2 command (CAS-2 operands must be driven LOW). Timings for the MPC [Read DQ FIFO] command are identical to a Read command, with RL (Read Latency) timed from the 2nd rising clock edge of the CAS-2 command.

Read DQ FIFO is non-destructive to the data captured in the FIFO, so data may be read continuously until it is either overwritten by a Write DQ FIFO command or disturbed by CKE LOW or any of the following commands; Write, Masked Write, Read, Read DQ Calibration and a MRR. If fewer than 5 Write DQ FIFO commands were executed, then unwritten registers will have un-defined (but valid) data when read back.

The following command about MRW is only allowed from MPC [Write DQ FIFO] command to MPC [Read DQ FIFO].

Allowing MRW command is for OP[7]:FSP-OP, OP[6]:FSP-WR and OP[3]:VRCG of MR13 and MR14. And the rest of MRW command is prohibited.

For example: If 5 Write DQ FIFO commands are executed sequentially, then a series of Read DQ FIFO commands will read valid data from FIFO[0], FIFO[1]....FIFO[4], and will then wrap back to FIFO[0] on the next Read DQ FIFO.

On the other hand, if fewer than 5 Write DQ FIFO commands are executed sequentially (example=3), then a series of Read DQ FIFO commands will return valid data for FIFO[0], FIFO[1], and FIFO[2], but the next two Read DQ FIFO commands will return un-defined data for FIFO[3] and FIFO[4] before wrapping back to the valid data in FIFO[0].

4.35.1 FIFO Pointer Reset and Synchronism

The Read and Write DQ FIFO pointers are reset under the following conditions:

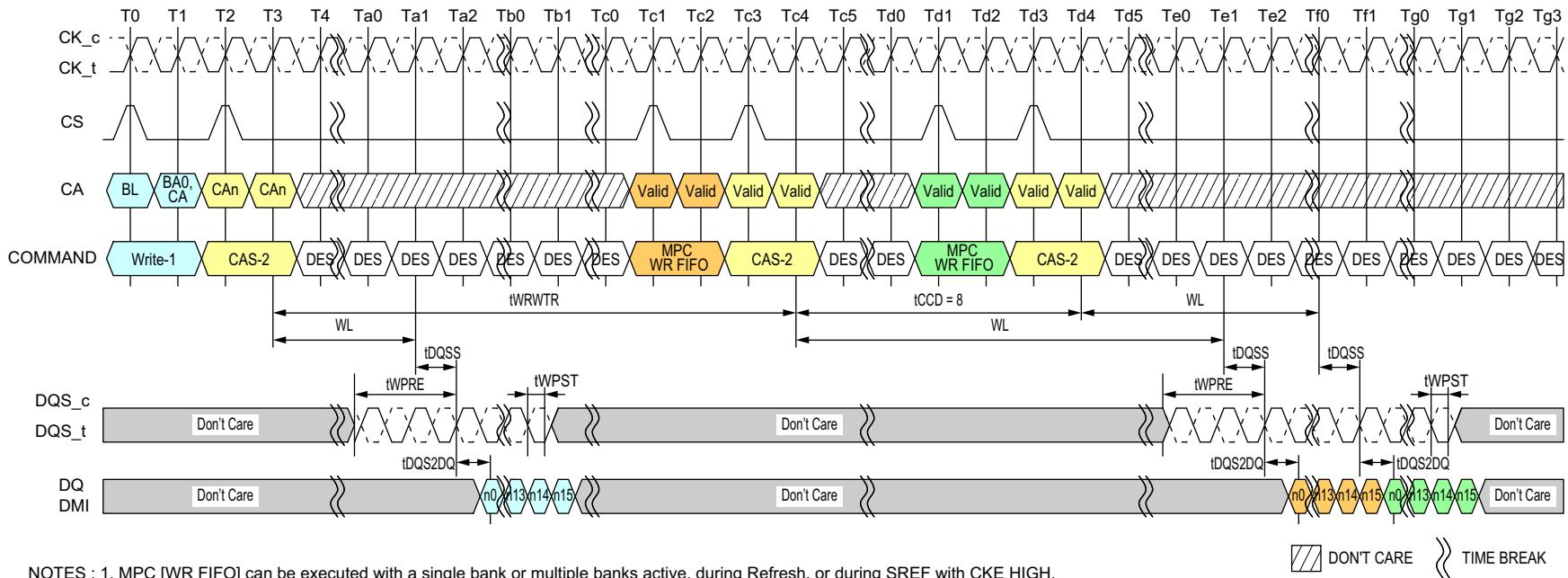
- Power-up initialization
- RESET_n asserted
- Power-down entry
- Self Refresh Power-Down entry

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

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

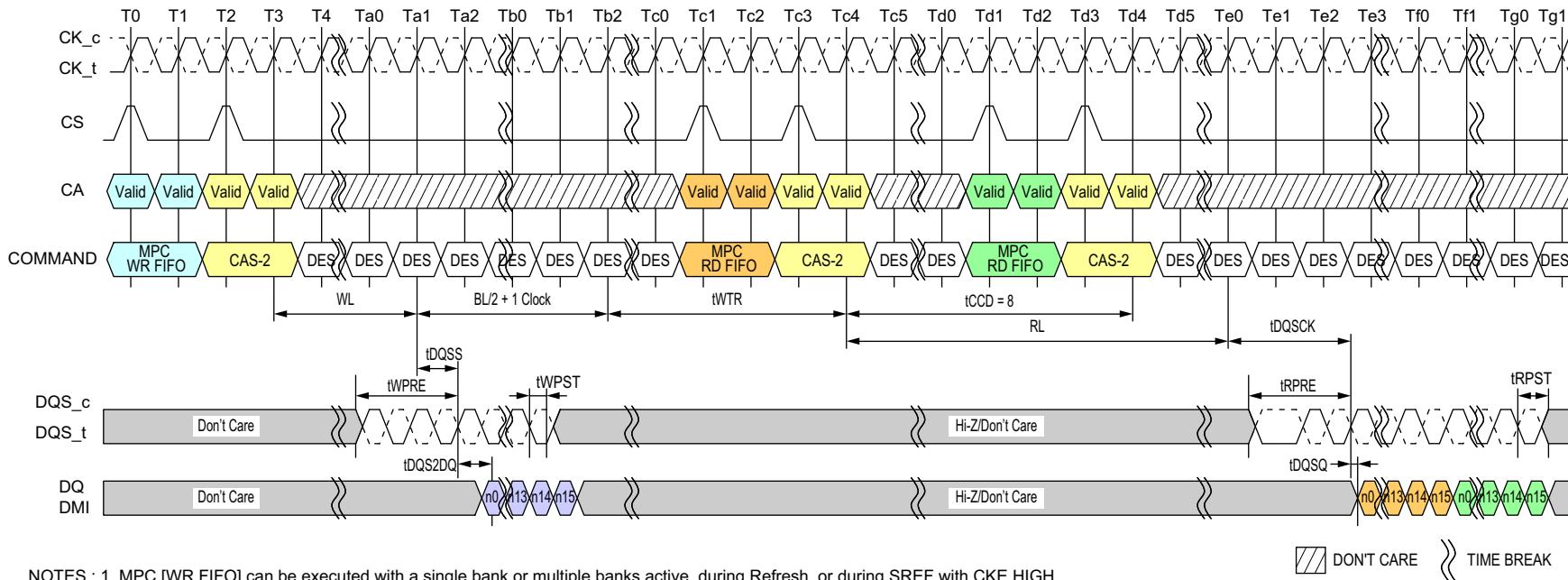
Where:

- 'a' is the number of MPC [Write DQ FIFO] commands
- 'b' is the number of MPC [Read DQ FIFO] commands
- 'c' is the FIFO depth (=5 for LPDDR4)
- 'n' is a positive integer, ≥ 0



- NOTES :
1. MPC [WR FIFO] can be executed with a single bank or multiple banks active, during Refresh, or during SREF with CKE HIGH.
 2. Write-1 to MPC is shown as an example of command-to-command timing for MPC. Timing from Write-1 to MPC [WR-FIFO] is tWRWTR.
 3. Seamless MPC [WR-FIFO] commands may be executed by repeating the command every tCCD time.
 4. MPC [WR-FIFO] uses the same command-to-data timing relationship (WL, tDQSS, tDQS2DQ) as a Write-1 command.
 5. A maximum of 5 MPC [WR-FIFO] commands may be executed consecutively without corrupting FIFO data.
The 6th MPC [WR-FIFO] command will overwrite the FIFO data from the first command. If fewer than 5 MPC [WR-FIFO] commands are executed, then the remaining FIFO locations will contain undefined data.
 6. For the CAS-2 command following a MPC command, the CAS-2 operands must be driven "LOW."
 7. To avoid corrupting the FIFO contents, MPC [RD-FIFO] must immediately follow MPC [WR-FIFO]/CAS-2 without any other command disturbing FIFO pointers in-between. FIFO pointers are disturbed by CKE Low, Write, Masked Write, Read, Read DQ Calibration and MRR.
 8. BL = 16, Write Postamble = 0.5nCK
 9. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 114 — Write to MPC [Write FIFO] Operation Timing



NOTES : 1. MPC [WR FIFO] can be executed with a single bank or multiple banks active, during Refresh, or during SREF with CKE HIGH.

2. MPC [WR-FIFO] to MPC [RD-FIFO] is shown as an example of command-to-command timing for MPC.

Timing from MPC [WR-FIFO] to MPC [RD-FIFO] is specified in the command-to-command timing table.

3. Seamless MPC [RD-FIFO] commands may be executed by repeating the command every tCCD time.

4. MPC [RD-FIFO] uses the same command-to-data timing relationship (RL, tDQSQCK, tDQSQ) as a Read-1 command.

5. Data may be continuously read from the FIFO without any data corruption. After 5 MPC [RD-FIFO] commands the FIFO pointer will wrap back to the 1st FIFO and continue advancing. If fewer than 5 MPC [WR-FIFO] commands were executed, then the MPC [RD-FIFO] commands to those

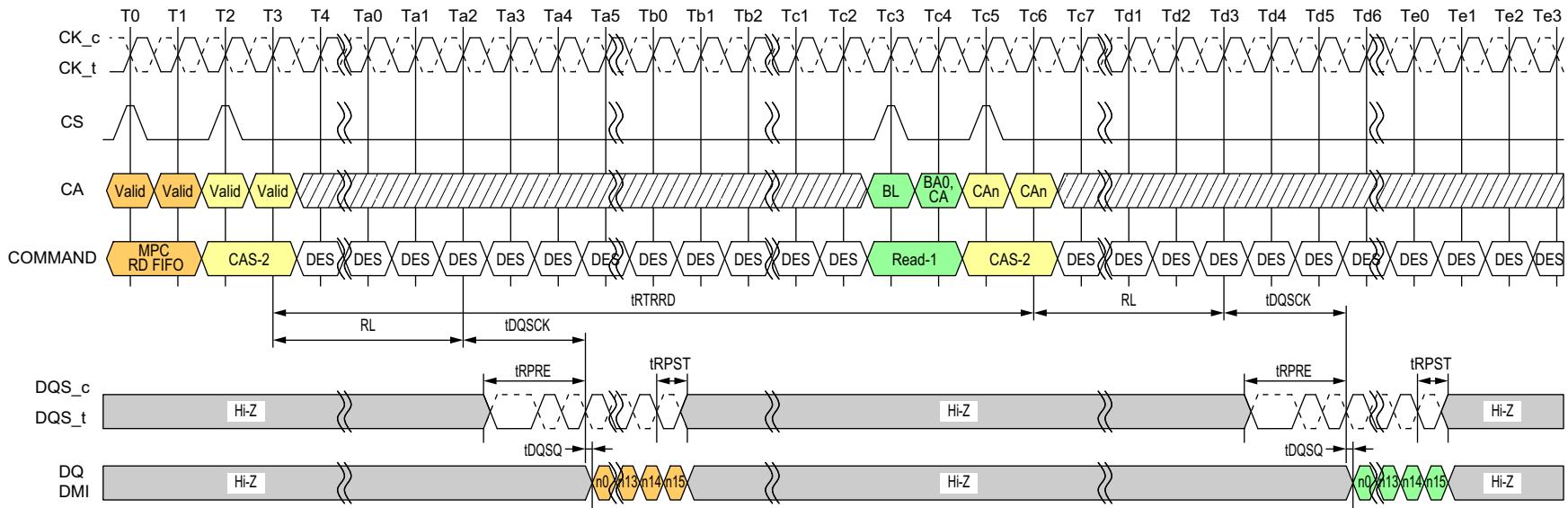
FIFO locations will return undefined data. See the Write Training section for more information on the FIFO point.

6. For the CAS-2 command immediately following a MPC command, the CAS-2 operands must be driven "LOW."

7. DMI[1:0] signals will be driven if any of WR-DBI, RD-DBI, or DM is enabled in the mode register.

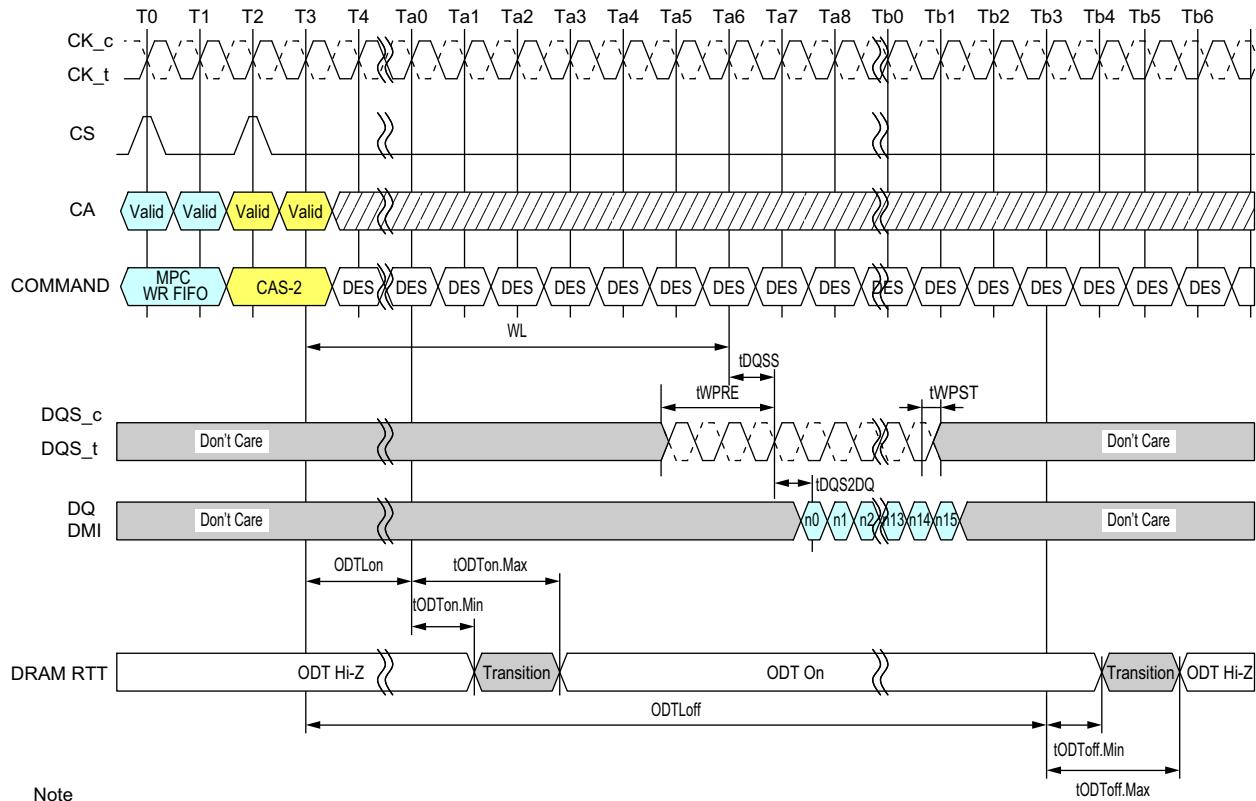
8. BL = 16. Write Postamble = 0.5nCk. Read Preamble: Toggle. Read Postamble: 0.5nCk

Figure 115 — MPC [Write FIFO] to MPC [Read FIFO] Timing



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

Figure 116 — MPC [Read FIFO] to Read Timing

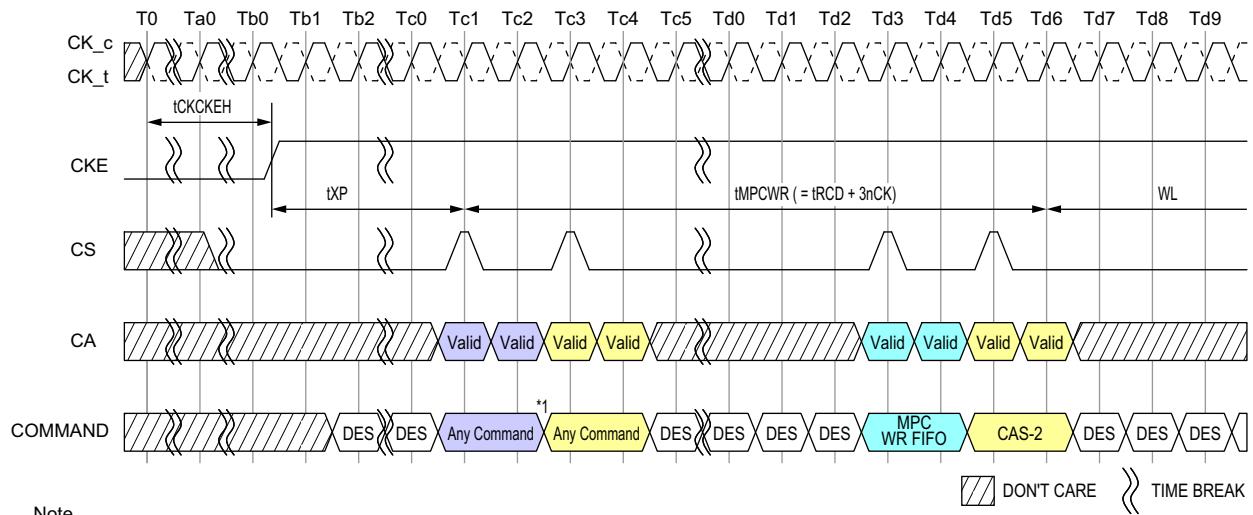


Note

1. MPC [WR FIFO] can be executed with a single bank or multiple banks active, during Refresh, or during SREF with CKE HIGH.
2. MPC [WR-FIFO] uses the same command-to-data/ODT timing relationship (WL, tDQSS, tDQS2DQ, ODTLon, ODTloff, tODTon, tODTOff) as a Write-1 command.
3. For the CAS-2 command immediately following a MPC command, the CAS-2 operands must be driven "LOW."
4. BL = 16, Write Postamble = 0.5nCK
5. DES commands are shown for ease of illustration; other commands may be valid at these times.

|||| DON'T CARE |||| TIME BREAK

Figure 117 — MPC [Write FIFO] with DQ ODT Timing



Note

1. Any commands except MPC WR FIFO and other exception commands defined other section in this document (i.e. MPC Read DQ Cal).
2. DES commands are shown for ease of illustration; other commands may be valid at these times.

Figure 118 — Power Down Exit to MPC [Write FIFO] Timing

Table 68 — MPC [Write FIFO] AC Timing

| Parameter | Symbol | Min/ Max | Data Rate | Unit | Note |
|---|-----------|-------------|------------------|------|------|
| MPC Write FIFO Timing | | | | | |
| Additional time after t_{XP} has expired until MPC [Write FIFO] command may be issued | t_{MPW} | Min | $t_{RCD} + 3nCK$ | | |

4.36 DQS Interval Oscillator

As voltage and temperature change on the SDRAM die, the DQS clock tree delay will shift and may require re-training. The LPDDR4-SDRAM includes an internal DQS clock-tree oscillator to measure the amount of delay over a given time interval (determined by the controller), allowing the controller to compare the trained delay value to the delay value seen at a later time. The DQS Oscillator will provide the controller with important information regarding the need to re-train, and the magnitude of potential error.

The DQS Interval Oscillator is started by issuing a MPC [Start DQS Osc] command with OP[6:0] set as described in the MPC Operation section, which will start an internal ring oscillator that counts the number of time a signal propagates through a copy of the DQS clock tree.

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

The controller may adjust the accuracy of the result by running the DQS Interval Oscillator for shorter (less accurate) or longer (more accurate) duration. The accuracy of the result for a given temperature and voltage is determined by the following equation:

$$\text{DQS Oscillator Granularity Error} = \frac{2 * (\text{DQS delay})}{\text{Run Time}}$$

Where:

Run Time = total time between start and stop commands

DQS delay = the value of the DQS clock tree delay (tDQS2DQ min/max)

Additional matching error must be included, which is the difference between DQS training circuit and the actual DQS clock tree across voltage and temperature. The matching error is vendor specific.

Therefore, the total accuracy of the DQS Oscillator counter is given by:

$$\text{DQS Oscillator Accuracy} = 1 - \text{Granularity Error} - \text{Matching Error}$$

Example: If the total time between start and stop commands is 100ns, and the maximum DQS clock tree delay is 800ps (tDQS2DQ max), then the DQS Oscillator Granularity Error is:

$$\text{DQS Oscillator Granularity Error} = \frac{2 * (0.8\text{ns})}{100\text{ns}} = 1.6\%$$

This equates to a granularity timing error of 12.8ps.

Assuming a circuit Matching Error of 5.5ps across voltage and temperature, then the accuracy is:

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

Example: Running the DQS Oscillator for a longer period improves the accuracy. If the total time between start and stop commands is 500ns, and the maximum DQS clock tree delay is 800ps (tDQS2DQ max), then the DQS Oscillator Granularity Error is:

$$\text{DQS Oscillator Granularity Error} = \frac{2 * (0.8\text{ns})}{500\text{ns}} = 0.32\%$$

This equates to a granularity timing error or 2.56ps.

Assuming a circuit Matching Error of 5.5ps across voltage and temperature, then the accuracy is:

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

The result of the DQS Interval Oscillator is defined as the number of DQS Clock Tree Delays that can be counted within the “run time,” determined by the controller. The result is stored in MR18-OP[7:0] and MR19-OP[7:0]. MR18 contains the least significant bits (LSB) of the result, and MR19 contains the most significant bits (MSB) of the result. MR18 and MR19 are overwritten by the SDRAM when a MPC-1 [Stop DQS Osc] command is received. The SDRAM counter will count to its maximum value ($=2^{16}$) and stop. If the maximum value is read from the mode registers, then the memory controller must assume that the counter overflowed the register and discard the result. The longest “run time” for the oscillator that will not overflow the counter registers can be calculated as follows:

$$\text{Longest Run Time Interval} = 2^{16} * t_{DQS2DQ(\min)} = 2^{16} * 0.2\text{ns} = 13.1\mu\text{s}$$

4.36.1 Interval Oscillator matching error

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

- Parameters:
 - tDQS2DQ: Actual DQS clock tree delay
 - tDQSOSC: Training ckt(interval oscillator) delay
 - OSCOffset: Average delay difference over voltage and temp (shown in Figure119)
 - OSCMatch: DQS oscillator matching error

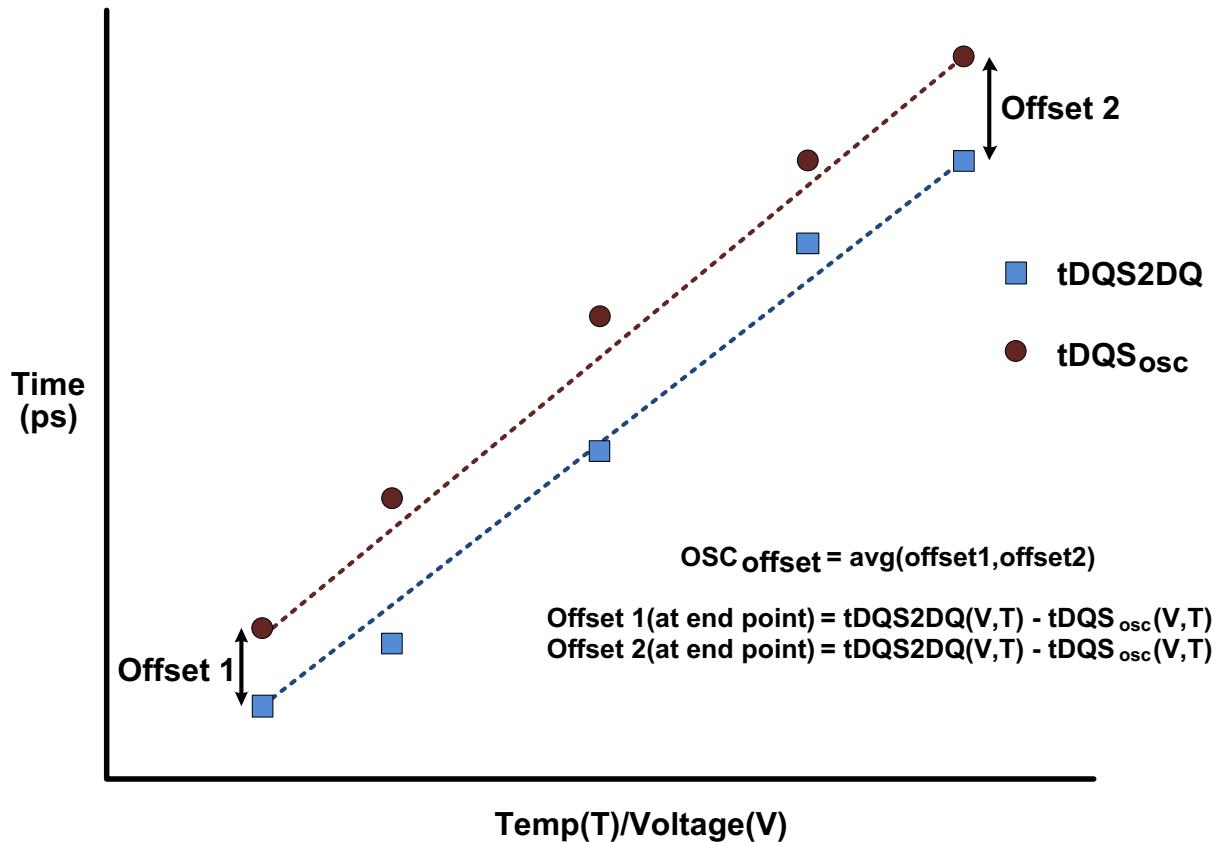


Figure 119 — Interval oscillator offset OSCoffset

- OSC_{Match} :

$$OSC_{Match} = [tDQS_{2DQ}(V,T) - tDQS_{osc}(V,T) - OSC_{offset}]$$

- $tDQS_{osc}$:

$$tDQS_{osc}(V,T) = \frac{Runtime}{2 * Count}$$

Table 69 — DQS Oscillator Matching Error Specification

| Parameter | Symbol | Min | Max | Units | Notes |
|-------------------------------|----------------|------|-----|-------|---------------|
| DQS Oscillator Matching Error | OSC_{Match} | -20 | 20 | ps | 1,2,3,4,5,6,7 |
| DQS Oscillator Offset | OSC_{offset} | -100 | 100 | ps | 2,4,7 |

NOTE 1 The OSC_{Match} is the matching error per between the actual DQS and DQS interval oscillator over voltage and temp.

NOTE 2 This parameter will be characterized or guaranteed by design.

NOTE 3 The OSC_{Match} is defined as the following:

$$OSC_{Match} = [tDQS2DQ_{(V,T)} - tDQS_{OSC(V,T)} - OSC_{offset}]$$

Where $tDQS2DQ_{(V,T)}$ and $tDQS_{OSC(V,T)}$ are determined over the same voltage and temp conditions.

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

$$tDQS_{OSC(V,T)} = \frac{\text{Runtime}}{2 * \text{Count}}$$

NOTE 5 The input stimulus for $tDQS2DQ$ will be consistent over voltage and temp conditions.

NOTE 3 The OSC_{offset} is the average difference of the endpoints across voltage and temp.

NOTE 7 These parameters are defined per channel.

NOTE 8 $tDQS2DQ(V,T)$ delay will be the average of DQS to DQ delay over the runtime period.

4.36.2 DQS Interval Oscillator Readout Timing

OSC Stop to its counting value readout timing is shown in Figure 120 and Figure 121.

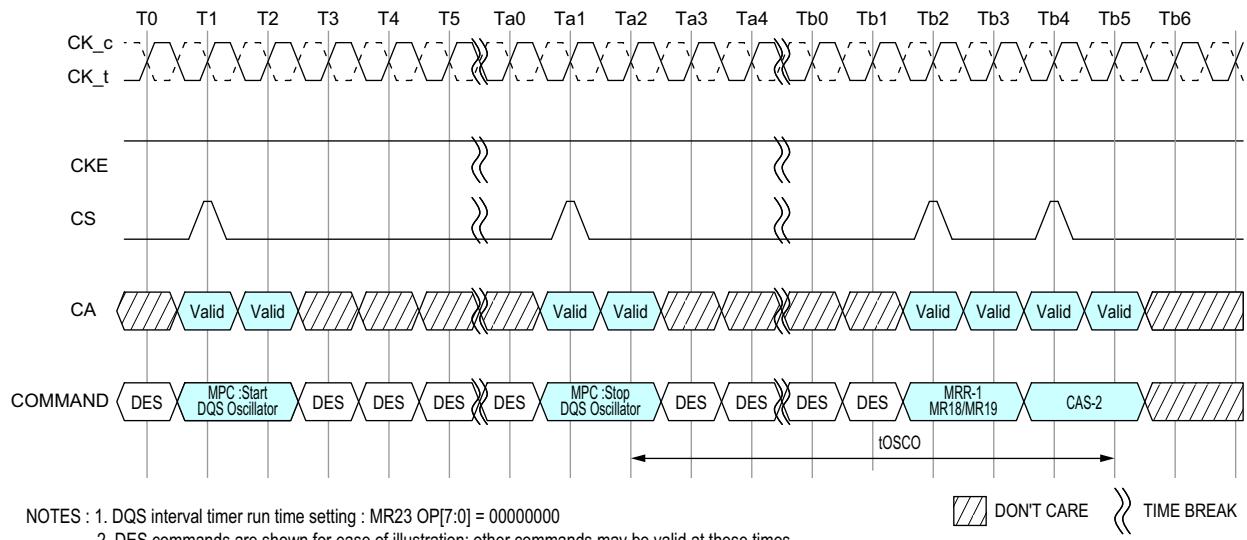


Figure 120 — In case of DQS Interval Oscillator is stopped by MPC Command

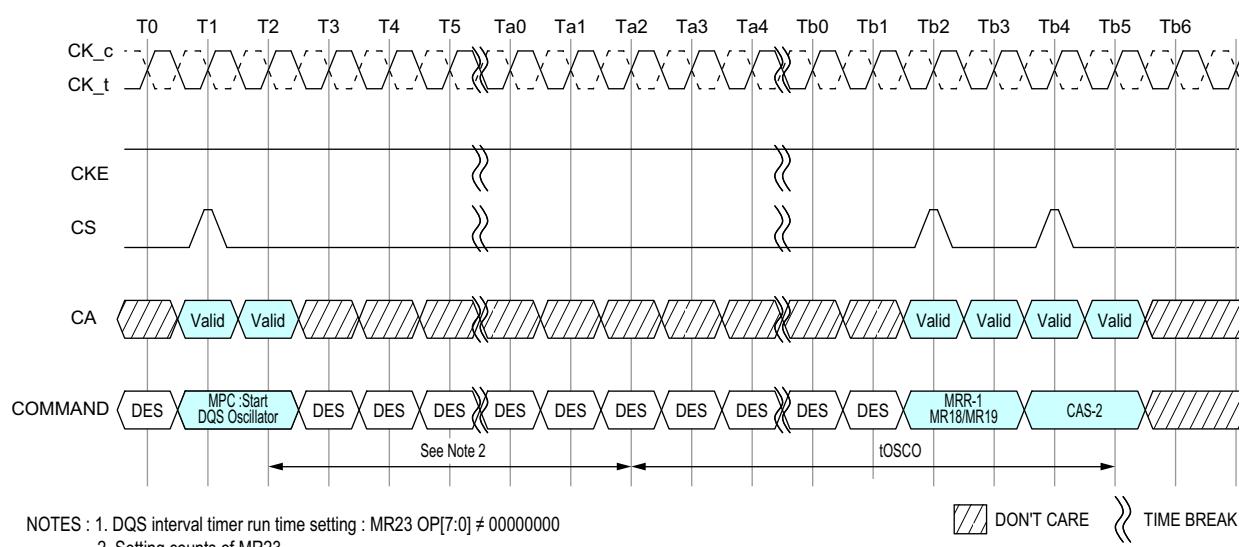


Figure 121 — In case of DQS Interval Oscillator is stopped by DQS interval timer

Table 70 — DQS Interval Oscillator AC Timing

| Parameter | Symbol | Min/Max | Value | Units | Notes |
|---|--------|---------|----------------|-------|-------|
| Delay time from OSC stop to Mode Register Readout | tOSCO | Min | Max(40ns,8nCK) | ns | |

NOTE 1 Start DQS OSC command is prohibited until tOSCO(Min) is satisfied.

4.37 READ Preamble Training

LPDDR4 READ Preamble Training is supported through the MPC function.

This mode can be used to train or read level the DQS receivers. Once READ Preamble Training is enabled by MR13[OP1] = 1, the LPDDR4 DRAM will drive DQS_t LOW, DQS_c HIGH within tSDO and remain at these levels until an MPC DQ READ Calibration command is issued.

During READ Preamble Training the DQS preamble provided during normal operation will not be driven by the DRAM. Once the MPC DQ READ Calibration command is issued, the DRAM will drive DQS_t/DQS_c and DQ like a normal READ burst after RL and tDQSCK. Prior to the MPC DQ READ Calibration command, the DRAM may or may not drive DQ[15:0] in this mode.

While in READ Preamble Training Mode, only READ DQ Calibration commands may be issued.

- Issue an MPC [RD DQ Calibration] command followed immediately by a CAS-2 command.
 - Each time an MPC [RD DQ Calibration] command followed by a CAS-2 is received by the LPDDR4 SDRAM, a 16-bit data burst will, after the currently set RL, drive the eight bits programmed in MR32 followed by the eight bits programmed in MR40 on all I/O pins.
 - The data pattern will be inverted for I/O pins with a '1' programmed in the corresponding invert mask mode register bit.
 - Note that the pattern is driven on the DMI pins, but no data bus inversion function is enabled, even if Read DBI is enabled in the DRAM mode register.
 - This command can be issued every tCCD seamlessly.
 - The operands received with the CAS-2 command must be driven LOW.

READ Preamble Training is exited within tSDO after setting MR13[OP1] = 0.

LPDDR4 supports the READ Preamble Training as optional feature. Refer to vendor specific datasheets.

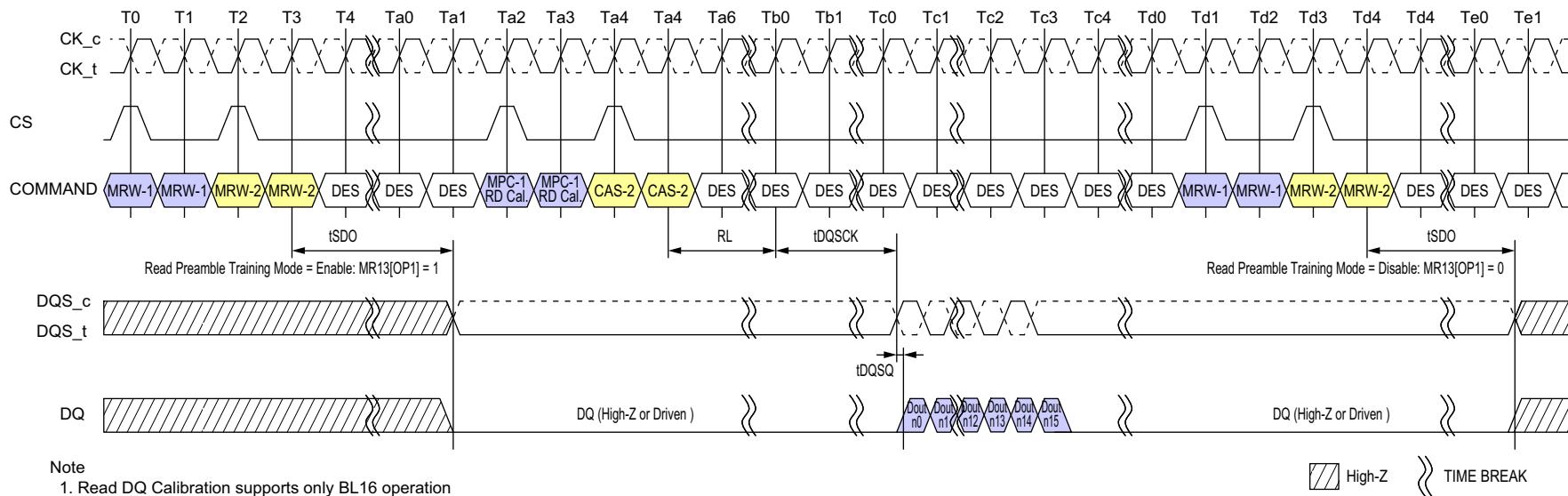


Figure 122 — Read Preamble Training

Table 71 — Timing Parameters

| Parameter | Symbol | Min | Max | Unit | Notes |
|--------------------------------------|--------|-----|------------------|------|-------|
| Delay from MRW command to DQS Driven | tSDO | - | Max(12nCK, 20ns) | - | |

4.38 Multi-Purpose Command (MPC)

LPDDR4-SDRAMs use the MPC command to issue a NOP and to access various training modes. The MPC command is initiated with CS, and CA[5:0] asserted to the proper state at the rising edge of CK, as defined by the Command Truth Table. The MPC command has seven operands (OP[6:0]) that are decoded to execute specific commands in the SDRAM. OP[6] is a special bit that is decoded on the first rising CK edge of the MPC command. When OP[6]=0 then the SDRAM executes a NOP (no operation) command, and when OP[6]=1 then the SDRAM further decodes one of several training commands.

When OP[6]=1 and when the training command includes a Read or Write operation, the MPC command must be followed immediately by a CAS-2 command. For training commands that Read or Write the SDRAM, read latency (RL) and write latency (WL) are counted from the second rising CK edge of the CAS-2 command with the same timing relationship as any normal Read or Write command. The operands of the CAS-2 command following a MPC Read/Write command must be driven LOW.

The following MPC commands must be followed by a CAS-2 command:

- Write FIFO
- Read FIFO
- Read DQ Calibration

All other MPC-1 commands do not require a CAS-2 command, including:

- NOP
- Start DQS Interval Oscillator
- Stop DQS Interval Oscillator
- Start ZQ Calibration
- Latch ZQ Calibration

Table 72 — MPC Command Definition

| SDRAM Command | SDR Command Pins | | SDR CA Pins | | | | | | | CK_t EDGE | Notes | | |
|---------------------|------------------|---------|-------------|-----|-----|-----|-----|-----|-----|-----------|-------|--|--|
| | CKE | | CS | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 | | | | |
| | CK_t(n-1) | CK_t(n) | | | | | | | | | | | |
| MPC (Train, NOP) | H | H | H | L | L | L | L | L | OP6 | R1 | 1, 2 | | |
| | | | L | OP0 | OP1 | OP2 | OP3 | OP4 | OP5 | R2 | | | |

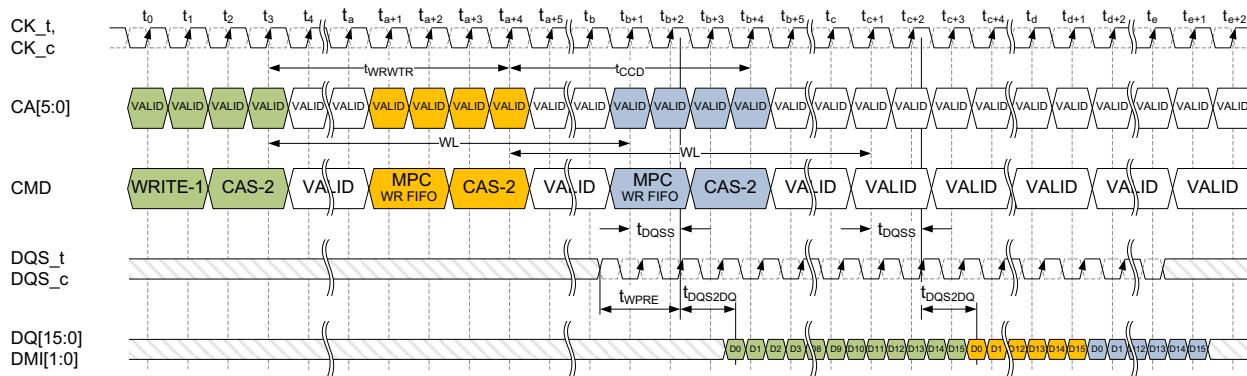
Table 73 — MPC Command Definition for OP[6:0]

| Function | Operand | Data | Notes |
|----------------|---------|---|---------|
| Training Modes | OP[6:0] | 0XXXXXX _B : NOP 1000001 _B : RD FIFO: RD FIFO supports only BL16 operation 1000011 _B : RD DQ Calibration (MR32/MR40) 1000101 _B : RFU 1000111 _B : WR FIFO: WR FIFO supports only BL16 operation 1001001 _B : RFU 1001011 _B : Start DQS Osc 1001101 _B : Stop DQS Osc 1001111 _B : ZQCal Start 1010001 _B : ZQCal Latch All Others: Reserved | 1, 2, 3 |

NOTE 1 See command truth table for more information.

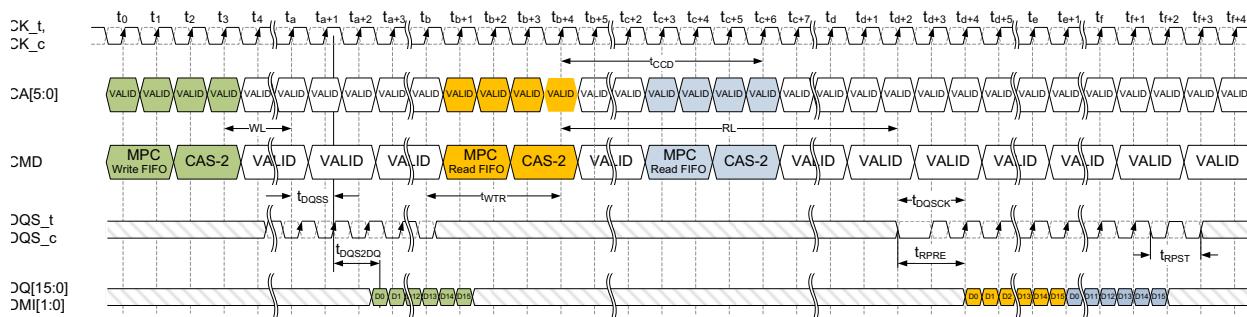
NOTE 2 MPC commands for Read or Write training operations must be immediately followed by CAS-2 command consecutively without any other commands in-between. MPC command must be issued first before issuing the CAS-2 command.

NOTE 3 Write FIFO and Read FIFO commands will only operate as BL16, ignoring the burst length selected by MR1 OP[1:0].



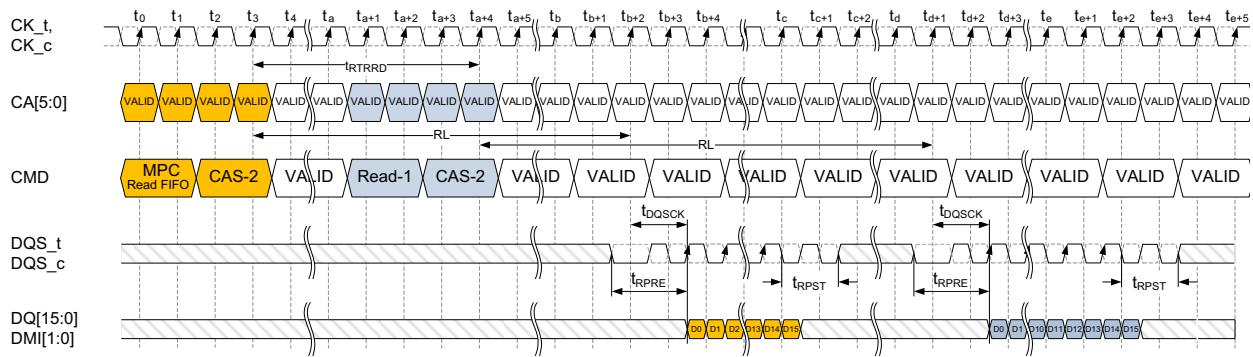
- NOTES :
1. MPC [WR FIFO] can be executed with a single bank or multiple banks active, during Refresh, or during SREF with CKE HIGH.
 2. Write-1 to MPC is shown as an example of command-to-command timing for MPC. Timing from Write-1 to MPC [WR-FIFO] is tWRWTR.
 3. Seamless MPC [WR-FIFO] commands may be executed by repeating the command every tCCD time.
 4. MPC [WR-FIFO] uses the same command-to-data timing relationship (WL, tDQSS, tDQS2DQ) as a Write-1 command.
 5. A maximum of 5 MPC [WR-FIFO] commands may be executed consecutively without corrupting FIFO data.
 6. For the CAS-2 command following a MPC command, the CAS-2 operands must be driven "LOW".
 7. To avoid corrupting the FIFO contents, MPC-1 [RD-FIFO] must immediately follow MPC-1 [WR-FIFO]/CAS-2 without any other command disturbing FIFO pointers in-between. FIFO pointers are disturbed by CKE Low, Write, Masked Write, Read, Read DQ Calibration and MRR.
- See Write Training session for more information on FIFO pointer behavior.

Figure 123 — MPC [WRITE FIFO] Operation : tWPRE=2nCK, tWPST=0.5nCK



- NOTES :
1. MPC [WR FIFO] can be executed with a single bank or multiple banks active, during Refresh, or during SREF with CKE HIGH.
 2. Write-1 to MPC is shown as an example of command-to-command timing for MPC. Timing from Write-1 to MPC-1 [WR-FIFO] is tWRWTR.
 3. Seamless MPC [RD-FIFO] commands may be executed by repeating the command every tCCD time.
 4. MPC [RD-FIFO] uses the same command-to-data timing relationship (RL, tDQSCK) as a Read-1 command.
 5. Data may be continuously read from the FIFO without any data corruption. After 5 MPC [RD-FIFO] commands the FIFO pointer will wrap back to the 1st FIFO and continue advancing. If fewer than 5 MPC [RD-FIFO] commands were executed, then the MPC [RD-FIFO] commands to those FIFO locations will return undefined data. See the Write Training section for more information on the FIFO pointer behavior.
 6. For the CAS-2 command immediately following a MPC command, the CAS-2 operands must be driven "LOW."
 7. DMI[1:0] signals will be driven if any of WR-DBI, RD-DBI, or DM is enabled in the mode registers. See Write Training section for more information on DMI behavior.

**Figure 124 — MPC [RD FIFO] Read Operation :
tWPRE=2nCK, tWPST=0.5nCK, tRPRE=toggling, tRPST=1.5nCK**



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

Figure 125 — MPC [RD FIFO] Operation : t_{RPRE}=toggling, t_{RPST}=1.5nCK

Table 74 — Timing Constraints for Training Commands

| Previous Command | Next Command | Minimum Delay | Unit | Notes |
|-------------------------|-------------------------|--|------|-------|
| WR/MWR | MPC [WR FIFO] | tWRWTR | nCK | 1 |
| | MPC [RD FIFO] | Not Allowed | - | 2 |
| | MPC [RD DQ Calibration] | WL+RU(tDQSS(max)/tCK) +BL/2+RU(tWTR/tCK) | nCK | |
| RD/MRR | MPC [WR FIFO] | tRTRRD | nCK | 3 |
| | MPC [RD FIFO] | Not Allowed | - | 2 |
| | MPC [RD DQ Calibration] | tRTRRD | nCK | 3 |
| MPC [WR FIFO] | WR/MWR | Not Allowed | - | 2 |
| | MPC [WR FIFO] | tCCD | nCK | |
| | RD/MRR | Not Allowed | - | 2 |
| | MPC [RD FIFO] | WL+RU(tDQSS(max)/tCK) +BL/2+RU(tWTR/tCK) | nCK | |
| | MPC [RD DQ Calibration] | Not Allowed | - | 2 |
| MPC [RD FIFO] | WR/MWR | tRTRRD | nCK | 3 |
| | MPC [WR FIFO] | tRTW | nCK | 4 |
| | RD/MRR | tRTRRD | nCK | 3 |
| | MPC [RD FIFO] | tCCD | nCK | |
| | MPC [RD DQ Calibration] | tRTRRD | nCK | 3 |
| MPC [RD DQ Calibration] | WR/MWR | tRTRRD | nCK | 3 |
| | MPC [WR FIFO] | tRTRRD | nCK | 3 |
| | RD/MRR | tRTRRD | nCK | 3 |
| | MPC [RD FIFO] | Not Allowed | - | 2 |
| | MPC [RD DQ Calibration] | tCCD | nCK | |

NOTE 1 tWRWTR = WL + BL/2 + RU(tDQSS(max)/tCK) + max(RU(7.5ns/tCK),8nCK)

NOTE 2 No commands are allowed between MPC [WR FIFO] and MPC-1 [RD FIFO] except MRW commands related to training parameters.

NOTE 3 tRTRRD = RL + RU(tDQSCK(max)/tCK) + BL/2 + RD(tRPST) + max(RU(7.5ns/tCK),8nCK)

NOTE 4 tRTW :

In Case of DQ ODT Disable MR11 OP[2:0] = 000_B:

RL+RU(tDQSCK(max)/ tCK) +BL/2- WL+tWPRE+RD(tRPST)

In Case of DQ ODT Enable MR11 OP[2:0] ≠ 000_B:

RL + RU(tDQSCK(max)/tCK) + BL/2 + RD(tRPST) - ODTLon - RD(tODTon,min/tCK) + 1

4.39 Thermal Offset

Because of their tight thermal coupling with the LPDDR4 device, hot spots on an SOC can induce thermal gradients across the LPDDR4 device. As these hot spots may not be located near the device thermal sensor, the devices' temperature compensated Self Refresh circuit may not generate enough refresh cycles to guarantee memory retention. To address this shortcoming, the controller can provide a thermal offset that the memory uses to adjust its TCSR circuit to ensure reliable operation.

This offset is provided through MR4(6:5) to either or to both the channels (dual-channel devices). This temperature offset may modify refresh behavior for the channel to which the offset is provided. It will take a max of 200us to have the change reflected in MR4(2:0) for the channel to which the offset is provided. If the induced thermal gradient from the device temperature sensor location to the hot spot location of the controller is larger than 15 degrees C, then Self Refresh mode will not reliably maintain memory contents.

To accurately determine the temperature gradient between the memory thermal sensor and the induced hot spot, the memory thermal sensor location must be provided to the LPDDR4 memory controller.

Support of thermal offset function is optional. Please refer to vendor datasheet determine if the function is supported or not.

4.40 Temperature Sensor

LPDDR4 devices feature a temperature sensor whose status can be read from MR4. This sensor can be used to determine an appropriate refresh rate, determine whether AC timing de-rating is required in the elevated temperature range, and/or monitor the operating temperature. Either the temperature sensor or the device TOPER may be used to determine whether operating temperature requirements are being met.

LPDDR4 devices shall monitor device temperature and update MR4 according to tTSI. Upon assertion of CKE (Low to High transition), the device temperature status bits shall be no older than tTSI. MR4 will be updated even when device is in Self Refresh state with CKE HIGH.

When using the temperature sensor, the actual device case temperature may be higher than the TOPER specification that applies for the standard or elevated temperature ranges. For example, TCASE may be above 85°C when MR4[2:0] equals 'b011. LPDDR4 devices shall allow for 2°C temperature margin between the point at which the device updates the MR4 value and the point at which the controller reconfigures the system accordingly. In the case of tight thermal coupling of the memory device to external hot spots, the maximum device temperature might be higher than what is indicated by MR4.

To assure proper operation using the temperature sensor, applications should consider the following factors:

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

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

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

Table 75 — Temperature Sensor

| Parameter | Symbol | Max/Min | Value | Unit | Notes |
|-----------------------------|--------------|---------|------------------|------|-------|
| System Temperature Gradient | TempGradient | Max | System Dependent | °C/s | |
| MR4 Read Interval | ReadInterval | Max | System Dependent | ms | |
| Temperature Sensor Interval | tTSI | Max | 32 | ms | |
| System Response Delay | SysRespDelay | Max | System Dependent | ms | |
| Device Temperature Margin | TempMargin | Max | 2 | °C | |

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

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

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

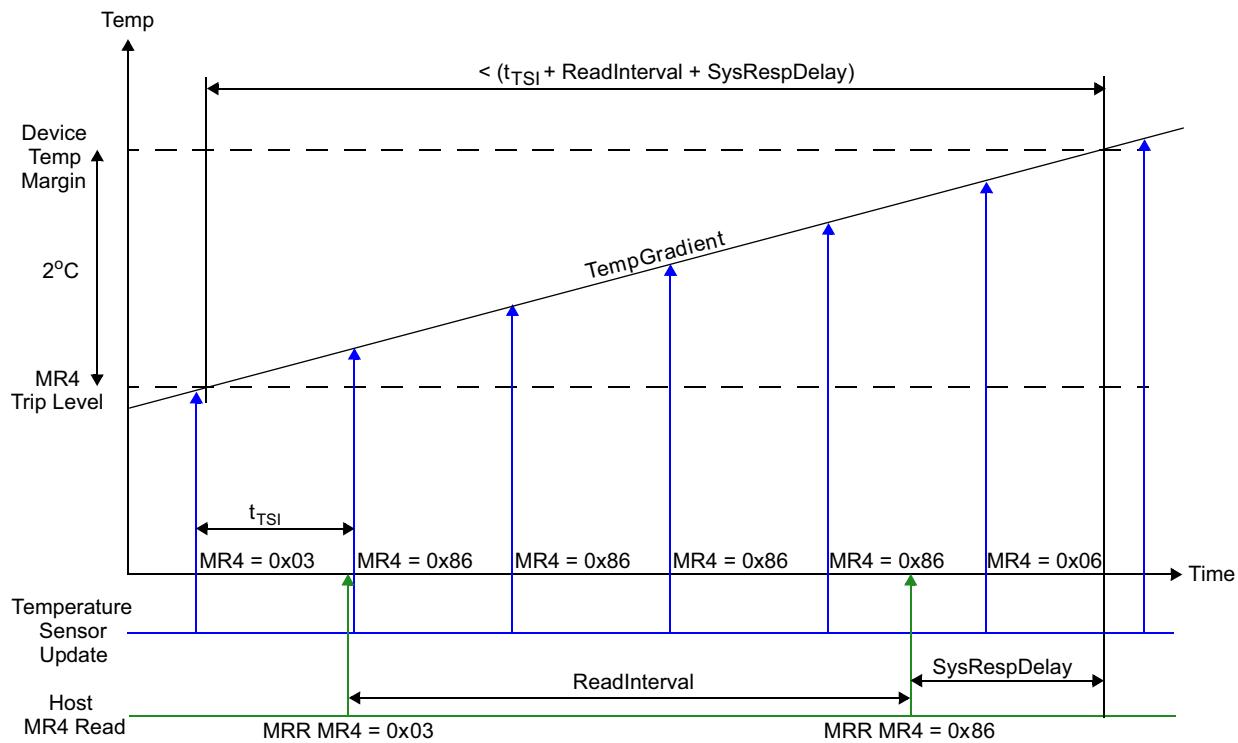


Figure 126 — Temp Sensor Timing

4.41 ZQ Calibration

The MPC command is used to initiate ZQ Calibration, which calibrates the output driver impedance across process, temperature, and voltage. ZQ Calibration occurs in the background of device operation. Dual channel devices share common ZQ circuitry between channels which follow a protocol (See Section 4.41.2) to allow for channel independence.

There are two ZQ Calibration modes initiated with the MPC command: ZQCal Start, and ZQCal Latch. ZQCal Start initiates the SDRAM's calibration procedure, and ZQCal Latch captures the result and loads it into the SDRAM's drivers.

A ZQCal Start command may be issued anytime the LPDDR4-SDRAM is not in a power-down state. A ZQCal Latch Command may be issued anytime outside of power-down after tZQCAL has expired and all DQ bus operations have completed. The CA Bus must maintain a Deselect state during tZQLAT to allow CA ODT calibration settings to be updated. The following mode register fields that modify I/O parameters cannot be changed following a ZQCal Start command and before tZQCAL has expired:

- PU-Cal (Pull-up Calibration VOH Point)
- PDDS (Pull Down Drive Strength and Rx Termination)
- DQ-ODT (DQ ODT Value)
- CA-ODT (CA ODT Value)

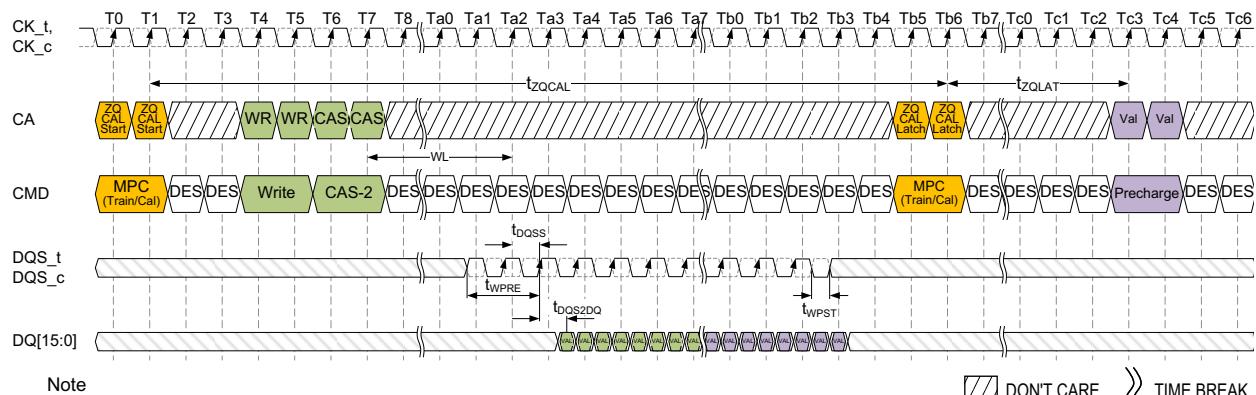
4.41.1 ZQCal Reset

The ZQCal Reset command resets the output impedance calibration to a default accuracy of +/- 30% across process, voltage, and temperature. This command is used to ensure output impedance accuracy to +/- 30% when ZQCal Start and ZQCal Latch commands are not used.

The ZQCal Reset command is executed by writing MR10 OP[0]=1B.

Table 76 — ZQCal Timing Parameters

| Parameter | Symbol | Min/Max | Value | Unit |
|---------------------------|----------|---------|----------------|------|
| ZQ Calibration Time | tZQCAL | MIN | 1 | us |
| ZQ Calibration Latch Time | tZQLAT | MIN | max(30ns,8nCK) | ns |
| ZQ Calibration Reset Time | tZQRESET | MIN | max(50ns,3nCK) | ns |



Note

1. Write and Precharge operations shown for illustrative purposes.
Any single or multiple valid commands may be executed within the tZQCAL time and prior to latching the results.
2. Before the ZQ-Latch command can be executed, any prior commands utilizing the DQ bus must have completed.
Write commands with DQ Termination must be given enough time to turn off the DQ-ODT before issuing the ZQ-Latch command.
See the ODT section for ODT timing.

Figure 127 — ZQCal Timing

4.41.2 Multi-Channel Considerations for Dual Channel Devices

The LPDDR4-SDRAM includes a single ZQ pin and associated ZQ Calibration circuitry. Calibration values from this circuit will be used by both channels according to the following protocol:

1. ZQCAL Start commands may be issued to either or both channels.
2. ZQCAL Start commands may be issued when either or both channels are executing other commands and other commands may be issued during tZQCAL.
3. ZQCAL Start commands may be issued to both channels simultaneously.
4. The ZQCAL Start command will begin the calibration unless a previously requested ZQ calibration is in progress.
5. If a ZQCAL Start command is received while a ZQ calibration is in progress on the SDRAM, the ZQCAL Start command will be ignored and the in-progress calibration will not be interrupted.
6. ZQCAL Latch commands are required for each channel.
7. ZQCAL Latch commands may be issued to both channels simultaneously.
8. ZQCAL Latch commands will latch results of the most recent ZQCAL Start command provided tZQCAL has been met.
9. ZQCAL Latch commands which do not meet tZQCAL will latch the results of the most recently completed ZQ calibration.
10. ZQ Reset MRW commands will only reset the calibration values for the channel issuing the command.

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

4.31.3 ZQ External Resistor, Tolerance, and Capacitive Loading

To use the ZQ calibration function, a 240 ohm +/- 1% tolerance external resistor must be connected between the ZQ pin and V_{DDQ}.

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

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

The total capacitive loading on the ZQ pin must be limited to 25pF.

Example: If a system configuration shares a CA bus between 'n' channels to form a n * 16 wide bus, and no means are available to control the ZQCAL separately for each channel (i.e., separate CS, CKE, or CK), then each x16 channel must have a separate ZQCAL resistor.

Example: For a x32, two rank system, each x16 channel must have its own ZQCAL resistor, but the ZQCAL resistor can be shared between ranks on each x16 channel. In this configuration, the CS signal can be used to ensure that the ZQCAL commands for Rank[0] and Rank[1] don't overlap.

4.42 Pull Up/Pull Down Driver Characteristics and Calibration

Table 77 — Pull-down Driver Characteristics, with ZQ Calibration

| $R_{ONPD,nom}$ | Resistor | Min | Nom | Max | Unit |
|----------------|---------------|-----|-----|-----|-------|
| 40 Ohm | R_{ON40PD} | 0.9 | 1 | 1.1 | RZQ/6 |
| 48 Ohm | R_{ON48PD} | 0.9 | 1 | 1.1 | RZQ/5 |
| 60 Ohm | R_{ON60PD} | 0.9 | 1 | 1.1 | RZQ/4 |
| 80 Ohm | R_{ON80PD} | 0.9 | 1 | 1.1 | RZQ/3 |
| 120 Ohm | $R_{ON120PD}$ | 0.9 | 1 | 1.1 | RZQ/2 |
| 240 Ohm | $R_{ON240PD}$ | 0.9 | 1 | 1.1 | RZQ/1 |

NOTE 1 All value are after ZQ Calibration. Without ZQ Calibration R_{ONPD} values are $\pm 30\%$.

Table 78 — Pull-Up Characteristics, with ZQ Calibration

| $VOH_{PU,nom}$ | $VOH,nom(mV)$ | Min | Nom | Max | Unit |
|----------------|---------------|-----|-----|-----|---------|
| $V_{DDQ}/2.5$ | 440 | 0.9 | 1 | 1.1 | VOH,nom |
| $V_{DDQ}/3$ | 367 | 0.9 | 1 | 1.1 | VOH,nom |

NOTE 1 All values are after ZQ Calibration. Without ZQ Calibration $VOH(nom)$ values are $\pm 30\%$.

NOTE 2 VOH,nom (mV) values are based on a nominal $V_{DDQ} = 1.1V$.

Table 79 — Valid Calibration Points

| $VOH_{PU,nom}$ | ODT Value | | | | | |
|----------------|-----------|-------|-------|-------|-------|-------|
| | 240 | 120 | 80 | 60 | 48 | 40 |
| $V_{DDQ}/2.5$ | VALID | VALID | VALID | DNU | DNU | DNU |
| $V_{DDQ}/3$ | VALID | VALID | VALID | VALID | VALID | VALID |

NOTE 1 Once the output is calibrated for a given $VOH(nom)$ calibration point, the ODT value may be changed without recalibration.

NOTE 2 If the $VOH(nom)$ calibration point is changed, then re-calibration is required.

NOTE 3 DNU = Do Not Use

4.43 On Die Termination for Command/Address Bus

ODT (On-Die Termination) is a feature of the LPDDR4 SDRAM that allows the SDRAM to turn on/off termination resistance for CK_t, CK_c, CS and CA[5:0] signals without the ODT control pin.

The ODT feature is designed to improve signal integrity of the memory channel by allowing the DRAM controller to turn on and off termination resistance for any target DRAM devices via Mode Register setting. A simple functional representation of the DRAM ODT feature is shown in Figure 128.

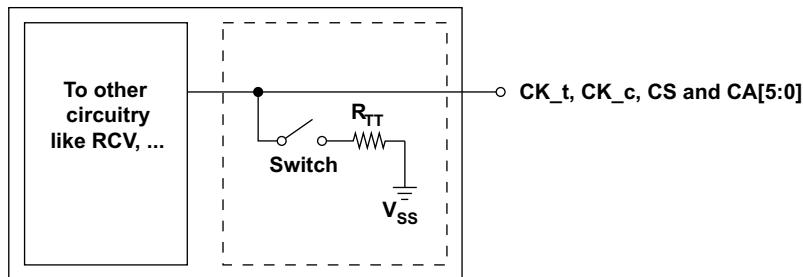


Figure 128 — Functional Representation of CA ODT

4.43.1 ODT Mode Register and ODT State Table

ODT termination values are set and enabled via MR11. The CA bus (CK_t, CK_C, CS, CA[5:0]) ODT resistance values are set by MR11 OP[6:4]. The default state for the CA is ODT disabled.

ODT is applied on the CA bus to the CK_t, CK_c, CS and CA[5:0] signals. The CA ODT of the device is designed to enable one rank to terminate the entire command bus in a multi-rank system, so only one termination load will be present even if multiple devices are sharing the command signals. For this reason, CA ODT remains on even when the device is in the power-down or Self Refresh power-down states.

The die has a bond pad (ODT_CA) for multi-rank operations. When the ODT_CA pad is LOW, the die will not terminate the CA bus regardless of the state of the mode register CA ODT bits (MR11 OP[6:4]). If, however, the ODT_CA bond pad is HIGH, and the mode register CA ODT bits are enabled, the die will terminate the CA bus with the ODT values found in MR11 OP[6:4]. In a multi-rank system, the terminating rank should be trained first, followed by the non-terminating rank(s).

Table 80 — Command Bus ODT State

| ODTE-CA MR11[6:4] | ODT_CA bond pad | ODTD-CA MR22[5] | ODTF-CK MR22[3] | ODTF-CS MR22[4] | ODT State for CA | ODT State for CK_t/CK_c | ODT State for CS |
|-----------------------|--------------------|--------------------|--------------------|--------------------|---------------------|----------------------------|---------------------|
| Disabled ¹ | Valid ² | Valid ³ | Valid ³ | Valid ³ | Off | Off | Off |
| Valid ³ | 0 | Valid ³ | 0 | 0 | Off | Off | Off |
| Valid ³ | 0 | Valid ³ | 0 | 1 | Off | Off | On |
| Valid ³ | 0 | Valid ³ | 1 | 0 | Off | On | Off |
| Valid ³ | 0 | Valid ³ | 1 | 1 | Off | On | On |
| Valid ³ | 1 | 0 | Valid ³ | Valid ³ | On | On | On |
| Valid ³ | 1 | 1 | Valid ³ | Valid ³ | Off | On | On |

NOTE 1 Default Value.

NOTE 2 “Valid” means “H or L (but a defined logic level)”.

NOTE 3 “Valid” means “0 or 1”.

NOTE 4 The state of ODT_CA is not changed when the DRAM enters power-down mode. This maintains termination for alternate ranks in multi-rank systems.

4.43.2 ODT Mode Register and ODT Characteristics

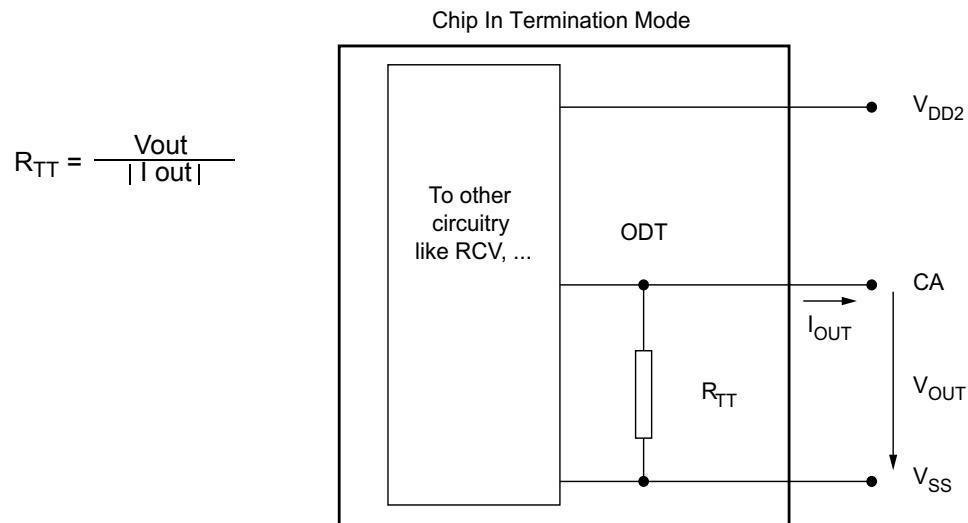


Figure 129 — On Die Termination for CA

Table 81 — ODT DC Electrical Characteristics, assuming RZQ = 240 Ω +/-1% over the entire operating temperature range after a proper ZQ calibration up to 3200 Mbps

| MR11[6:4] | R _{TT} | V _{out} | Min | Nom | Max | Unit | Note |
|---------------------------------|-----------------|--------------------------------|-----|-----|------------------|-------|-------|
| 001 | 240 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.2 | RZQ | 1,2,3 |
| 010 | 120 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.2 | RZQ/2 | 1,2,3 |
| 011 | 80 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.2 | RZQ/3 | 1,2,3 |
| 100 | 60 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.2 | RZQ/4 | 1,2,3 |
| 101 | 48 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.2 | RZQ/5 | 1,2,3 |
| 110 | 40 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.2 | RZQ/6 | 1,2,3 |
| Mismatch CA-CA within clk group | | 0.33* V _{DD2} | - | | TBD ¹ | % | 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 sensitivity¹.

NOTE 2 Pull-dn ODT resistors are recommended to be calibrated at 0.33*V_{DD2}. Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at 0.5*V_{DD2} and 0.1*V_{DD2}.

NOTE 3 Measurement definition for R_{TT}: TBD¹.

NOTE 4 CA to CA mismatch within clock group (CA,CS) variation for a given component including CK_t and CK_c (characterized).

$$\text{CA - CA Mismatch} = \frac{\text{RODT(max)} - \text{RODT(min)}}{\text{RODT(avg)}}$$

1. As of publication of this document, under discussion by the formulating committee.

Table 82 — ODT DC Electrical Characteristics, assuming RZQ = 240 Ω +/-1% over the entire operating temperature range after a proper ZQ calibration for beyond 3200Mbps

| MR11[6:4] | R _{TT} | V _{out} | Min | Nom | Max | Unit | Note |
|---------------------------------|-----------------|--------------------------------|-----|-----|------------------|-------|-------|
| 001 | 240 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.3 | RZQ | 1,2,3 |
| 010 | 120 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.3 | RZQ/2 | 1,2,3 |
| 011 | 80 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.3 | RZQ/3 | 1,2,3 |
| 100 | 60 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.3 | RZQ/4 | 1,2,3 |
| 101 | 48 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.3 | RZQ/5 | 1,2,3 |
| 110 | 40 Ω | VOLdc= 0.1 * V _{DD2} | 0.8 | 1.0 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOMdc= 0.33 * V _{DD2} | 0.9 | 1.0 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOHdc= 0.5 * V _{DD2} | 0.9 | 1.0 | 1.3 | RZQ/6 | 1,2,3 |
| Mismatch CA-CA within clk group | | 0.33* V _{DD2} | - | | TBD ¹ | % | 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 sensitivity¹.

NOTE 2 Pull-dn ODT resistors are recommended to be calibrated at 0.33*V_{DD2}. Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at 0.5*V_{DD2} and 0.1*V_{DD2}.

NOTE 3 Measurement definition for R_{TT}: TBD¹

NOTE 4 CA to CA mismatch within clock group (CA,CS) variation for a given component including CK_t and CK_c (characterized).

$$\text{CA - CA Mismatch} = \frac{\text{RODT(max)} - \text{RODT(min)}}{\text{RODT(avg)}}$$

1. As of publication of this document, under discussion by the formulating committee.

4.43.3 ODT for Command/Address update time

ODT for Command/Address update time after Mode Register set are shown in Figure 130.

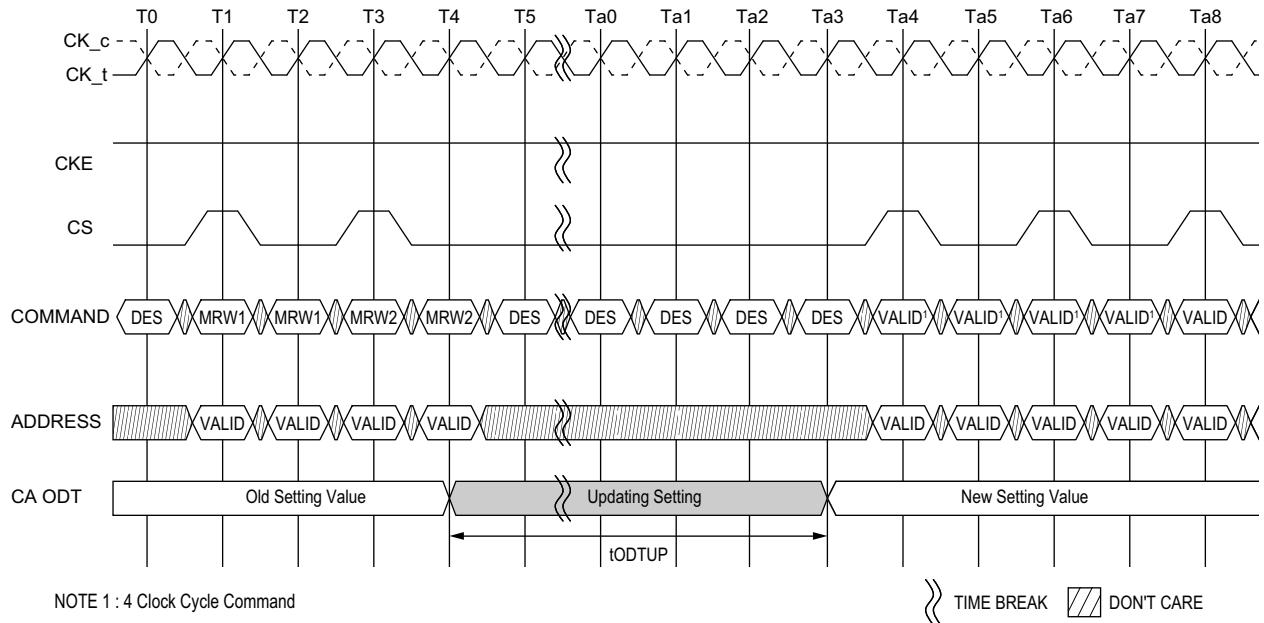


Figure 130 — ODT for Command/Address setting update timing in 4 Clock Cycle Command

Table 83 — ODT CA AC Timing

| Speed | | LPDDR4-1600/1866/2133/2400/3200/4266 | | Units | NOTE |
|--------------------------|--------|--------------------------------------|-----|-------|------|
| Parameter | Symbol | MIN | MAX | | |
| ODT CA Value Update Time | tODTUP | RU(TBDns/tCK(avg)) | - | | |

4.44 On-Die Termination

ODT (On-Die Termination) is a feature of the LPDDR4 SDRAM that allows the DRAM to turn on/off termination resistance for each DQ, DQS_t, DQS_c and DMI signals without the ODT control pin. The ODT feature is designed to improve signal integrity of the memory channel by allowing the DRAM controller to turn on and off termination resistance for any target DRAM devices during Write or Mask Write operation.

The ODT feature is off and cannot be supported in Power Down and Self Refresh modes.

A simple functional representation of the DRAM ODT feature is shown in Figure 131.

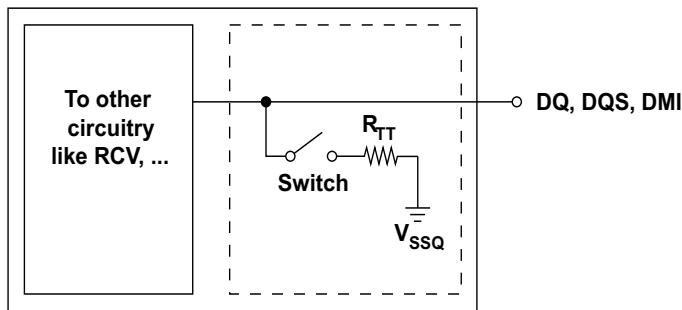


Figure 131 — Functional Representation of ODT

The switch is enabled by the internal ODT control logic, which uses the Write-1 or Mask Write-1 command and other mode register control information. The value of R_{TT} is determined by the settings of Mode Register bits.

4.44.1 ODT Mode Register

The ODT Mode is enabled if MR11 OP[3:0] are non-zero. In this case, the value of R_{TT} is determined by the settings of those bits. The ODT Mode is disabled if MR11 OP[3] = 0.

4.44.2 Asynchronous ODT

When ODT Mode is enabled in MR11 OP[3:0], DRAM ODT is always Hi-Z. DRAM ODT feature is automatically turned ON asynchronously based on the Write-1 or Mask Write-1 command that DRAM samples. After the write burst is complete, DRAM ODT feature is automatically turned OFF asynchronously.

Following timing parameters apply when DRAM ODT mode is enabled:

- ODTLon, tODTon,min, tODTon,max
- ODTLoff, tODToff,min, tODToff,max

ODTLon is a synchronous parameter and it is the latency from CAS-2 command to tODTon reference. ODTlon latency is a fixed latency value for each speed bin. Each speed bin has a different ODTlon latency.

Minimum R_{TT} turn-on time (tODTon,min) is the point in time when the device termination circuit leaves high impedance state and ODT resistance begins to turn on.

Maximum R_{TT} turn on time (tODTon,max) is the point in time when the ODT resistance is fully on.

tODTon,min and tODTon,max are measured once ODTlon latency is satisfied from CAS-2 command.

ODTloff is a synchronous parameter and it is the latency from CAS-2 command to tODToff reference. ODTloff latency is a fixed latency value for each speed bin. Each speed bin has a different ODTloff latency.

Minimum R_{TT} turn-off time (tODToff,min) is the point in time when the device termination circuit starts to turn off the ODT resistance.

Maximum ODT turn off time ($t_{ODT\text{off},\text{max}}$) is the point in time when the on-die termination has reached high impedance.

$t_{ODT\text{off,min}}$ and $t_{ODT\text{off,max}}$ are measured once ODTloff latency is satisfied from CAS-2 command.

Table 84 — ODTLon and ODTLoff Latency Values

| ODTLon Latency ¹ | | ODTLoff Latency ² | | Lower Clock Frequency Limit (>) | Upper Clock Frequency Limit (≤) |
|-----------------------------|------------|------------------------------|------------|---------------------------------|---------------------------------|
| tWPRE = 2 tCK | | WL Set "A" | | | |
| WL Set "A" | WL Set "B" | WL Set "A" | WL Set "B" | | |
| N/A | N/A | N/A | N/A | 10 | 266 |
| N/A | N/A | N/A | N/A | 266 | 533 |
| N/A | 6 | N/A | 22 | 533 | 800 |
| 4 | 12 | 20 | 28 | 800 | 1066 |
| 4 | 14 | 22 | 32 | 1066 | 1333 |
| 6 | 18 | 24 | 36 | 1333 | 1600 |
| 6 | 20 | 26 | 40 | 1600 | 1866 |
| 8 | 24 | 28 | 44 | 1866 | 2133 |
| nCK | nCK | nCK | nCK | MHz | MHz |

NOTE 1 ODTLon is referenced from CAS-2 command. See Figure 132.

NOTE 2 ODTLoff as shown in table assumes BL=16. For BL32, 8 tCK should be added.

Table 85 — Asynchronous ODT Turn On and Turn Off Timing

| Parameter | 800 - 2133 MHz | Unit |
|---------------------------------|----------------|------|
| $t_{ODT\text{on}, \text{min}}$ | 1.5 | ns |
| $t_{ODT\text{on}, \text{max}}$ | 3.5 | ns |
| $t_{ODT\text{off}, \text{min}}$ | 1.5 | ns |
| $t_{ODT\text{off}, \text{max}}$ | 3.5 | ns |

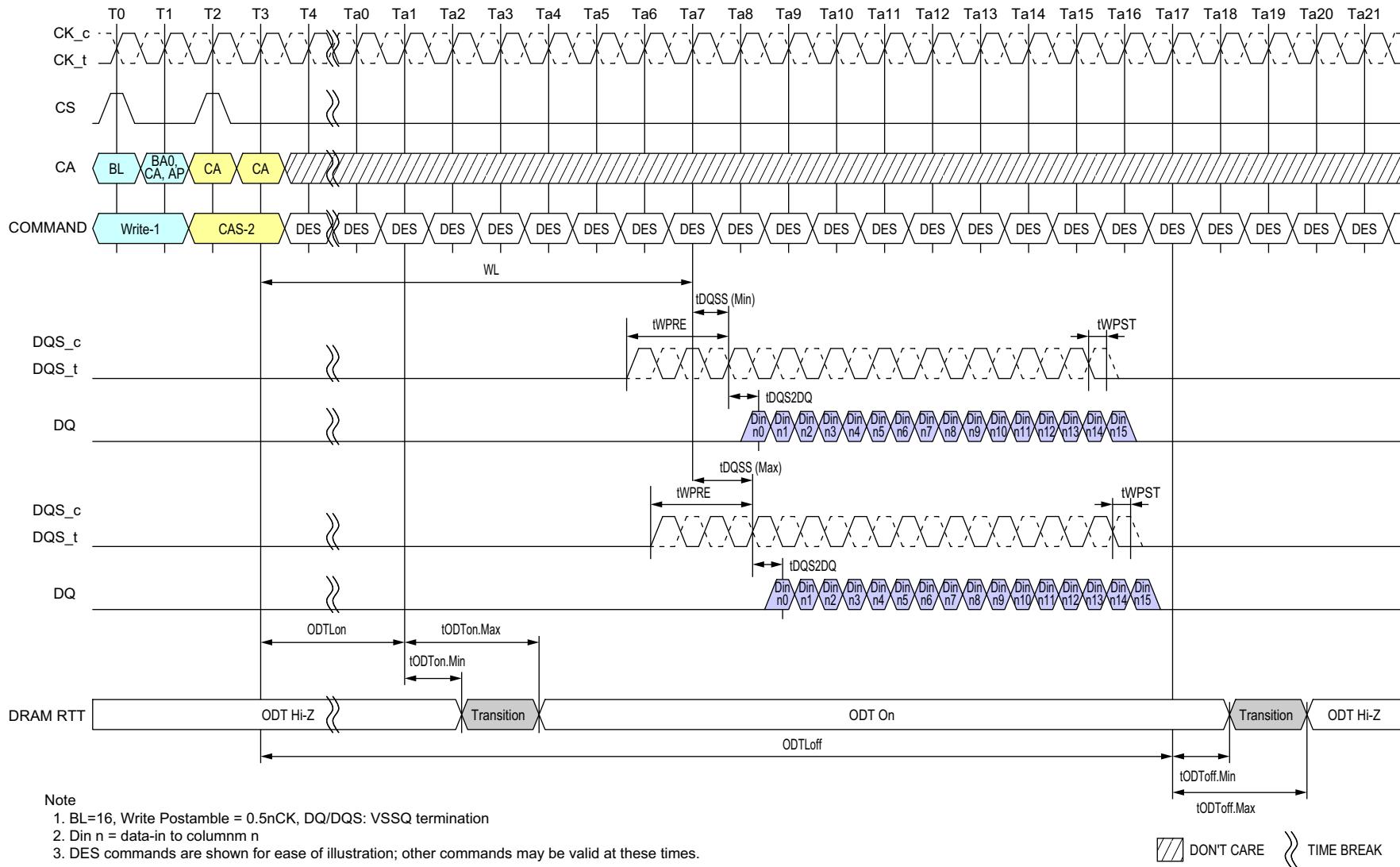


Figure 132 — Asynchronous ODTon/ODToff Timing

4.44.3 ODT during Write Leveling

If ODT is enabled in MR11 OP[3:0], in Write Leveling mode, DRAM always provides the termination on DQS_t/DQS_c signals. DQ termination is always off in Write Leveling mode regardless.

Table 86 — DRAM Termination Function in Write Leveling Mode

| ODT Enabled in MR11 | DQS_t/DQS_c termination | DQ termination |
|---------------------|-------------------------|----------------|
| Disabled | OFF | OFF |
| Enabled | ON | OFF |

4.45 On Die Termination for DQ, DQS and DMI

On-Die Termination effective resistance R_{TT} is defined by MR11 OP[2:0].

ODT is applied to the DQ, DMI, DQS_t and DQS_c pins.

A functional representation of the on-die termination is shown in Figure 133.

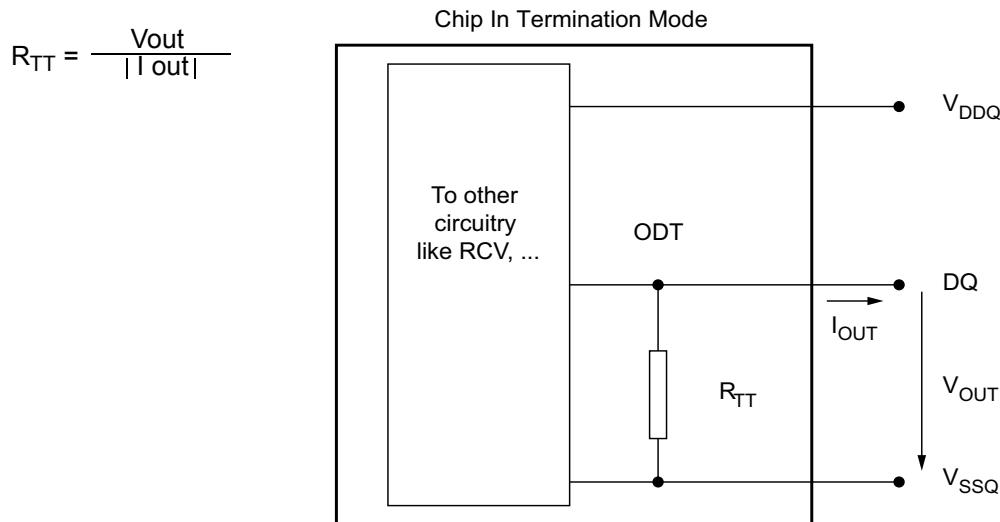


Figure 133 — On Die Termination

Table 87 — ODT DC Electrical Characteristics, assuming RZQ = 240 Ω +/-1% over the entire operating temperature range after a proper ZQ calibration for up to 3200Mbps.

| MR11 OP[2:0] | R _{TT} | V _{out} | Min | Nom | Max | Unit | Notes |
|----------------------------|-----------------|-------------------------------|-----|-----|-----|-------|-------|
| 001 | 240 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.2 | RZQ | 1,2,3 |
| 010 | 120 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.2 | RZQ/2 | 1,2,3 |
| 011 | 80 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.2 | RZQ/3 | 1,2,3 |
| 100 | 60 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.2 | RZQ/4 | 1,2,3 |
| 101 | 48 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.2 | RZQ/5 | 1,2,3 |
| 110 | 40 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.2 | RZQ/6 | 1,2,3 |
| Mismatch DQ-DQ within byte | | 0.33* V _{DDQ} | - | | 2 | % | 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 sensitivity¹.

NOTE 2 Pull-down ODT resistors are recommended to be calibrated at 0.33*V_{DDQ}. Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at 0.5*V_{DDQ} and 0.1*V_{DDQ}.

NOTE 3 Measurement definition for R_{TT}: TBD.

NOTE 4 DQ to DQ mismatch within byte variation for a given component including DQS_t and DQS_c (characterized).

$$\text{DQ - DQ Mismatch} = \frac{\text{RODT(max)} - \text{RODT(min)}}{\text{RODT(avg)}}$$

1. As of publication of this document, under discussion by the formulating committee.

Table 88 — ODT DC Electrical Characteristics, assuming RZQ = 240 Ω +/-1% over the entire operating temperature range after a proper ZQ calibration for beyond 3200Mbps.

| MR11 OP[2:0] | R _{TT} | V _{out} | Min | Nom | Max | Unit | Notes |
|----------------------------|-----------------|-------------------------------|-----|-----|-----|-------|-------|
| 001 | 240 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.3 | RZQ | 1,2,3 |
| 010 | 120 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/2 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.3 | RZQ/2 | 1,2,3 |
| 011 | 80 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/3 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.3 | RZQ/3 | 1,2,3 |
| 100 | 60 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/4 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.3 | RZQ/4 | 1,2,3 |
| 101 | 48 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/5 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.3 | RZQ/5 | 1,2,3 |
| 110 | 40 Ω | VOLdc= 0.1* V _{DDQ} | 0.8 | 1 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOMdc= 0.33* V _{DDQ} | 0.9 | 1 | 1.1 | RZQ/6 | 1,2,3 |
| | | VOHdc= 0.5* V _{DDQ} | 0.9 | 1 | 1.3 | RZQ/6 | 1,2,3 |
| Mismatch DQ-DQ within byte | | 0.33* V _{DDQ} | - | | 2 | % | 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 sensitivity¹.

NOTE 2 Pull-dn ODT resistors are recommended to be calibrated at 0.33*V_{DDQ}. Other calibration schemes may be used to achieve the linearity spec shown above, e.g., calibration at 0.5*V_{DDQ} and 0.1*V_{DDQ}.

NOTE 3 Measurement definition for R_{TT}: TBD.

NOTE 4 DQ to DQ mismatch within byte variation for a given component including DQS_t and DQS_c (characterized).

$$\text{DQ - DQ Mismatch} = \frac{\text{RODT(max)} - \text{RODT(min)}}{\text{RODT(avg)}}$$

1. As of publication of this document, under discussion by the formulating committee.

4.46 Non-target DRAM

Support for the optional Non-target DRAM ODT control feature described in this section as well as other sections of this document is expected to be removed in future revision of this standard.

LPDDR4 SDRAM supports the function of Non-target DRAM ODT control for DQ,DQS and DMI pins to improve signal integrity of the two or more rank system.

The Non-target DRAM ODT control function is an optional feature. Refer to vendor datasheets.

The Non-Target DRAM ODT control function is applied to the following commands.

- Write-1
- Mask Write-1
- Read-1
- Mode Register Read-1
- MPC Write FIFO
- MPC Read FIFO
- MPC Read DQ calibration

DRAM receives above-mentioned commands followed by consecutive CAS-2 Non-target ODT command instead of CAS-2 command.

For the purpose of illustration, “Non-target Write” includes Write-1, Mask Write-1 and MPC Write FIFO, as well as “Non-target Read” case.

The ODT Mode for Non-target DRAM ODT control is enabled if MR11 OP[7,3] is set to a non-zero value. The ODT Mode for non-target DRAM is disabled if MR11 OP[7,3] = 00_B.

The Non-target DRAM ODT control command can be issued at any state except the following conditions.

- During Power-up and Initialization Procedure.
- MR11 OP[7,3] = 00_B
- Executing Mode Register Write command: tMRW period.
- Executing Frequency set point update: tFC period
- DRAM on the Command Bus Training mode.
- DRAM on the Write Leveling Mode.
- When data or ODT conflict on DQ bus happens by executing the Non-target DRAM ODT control command. See constraints table for Non-target DRAM ODT control Command in this section for detail.
- During Power Down (Idle, Active and Self Refresh) and before or after Power Down.
 - The timing of Non-target Read to Power Down entry is the same as Read and Read with Auto-Precharge to Power-Down Entry.
 - The timing of Non-target Write to Power Down entry is the same as Write and Mask Write to Power-Down Entry.
 - Issuing Non-target DRAM ODT control command has to satisfy tXP timing.
- Read Preamble Training Mode is Enable: MR13[OP1] = 1.

The burst length in other words ODT turn on period when issuing Write-1 and Read-1 for Non-target ODT control follows MR1 OP[1:0] :Burst Length setting. Also the burst length follows the burst length control bit: CA5 in these commands if Burst Length on-the-fly is enabled. The burst length of other commands such as Mask Write-1, Mode Register Read-1, MPC Write FIFO, MPC Read FIFO and MPC Read DQ calibration is always BL=16.

4.46.1 Write-1, Mask Write-1, MPC(Write FIFO) Case

CAS-2 command is replaced by CAS-2 Non-target ODT command for the Non-target DRAM ODT control command. ODT timings (ODTLon and ODTLoff) are referenced to the CAS-2 Non-target ODT command (See Figure 134). ODT latency values remain the same as for a normal DQ ODT control as shown in Tables 74 and 75.

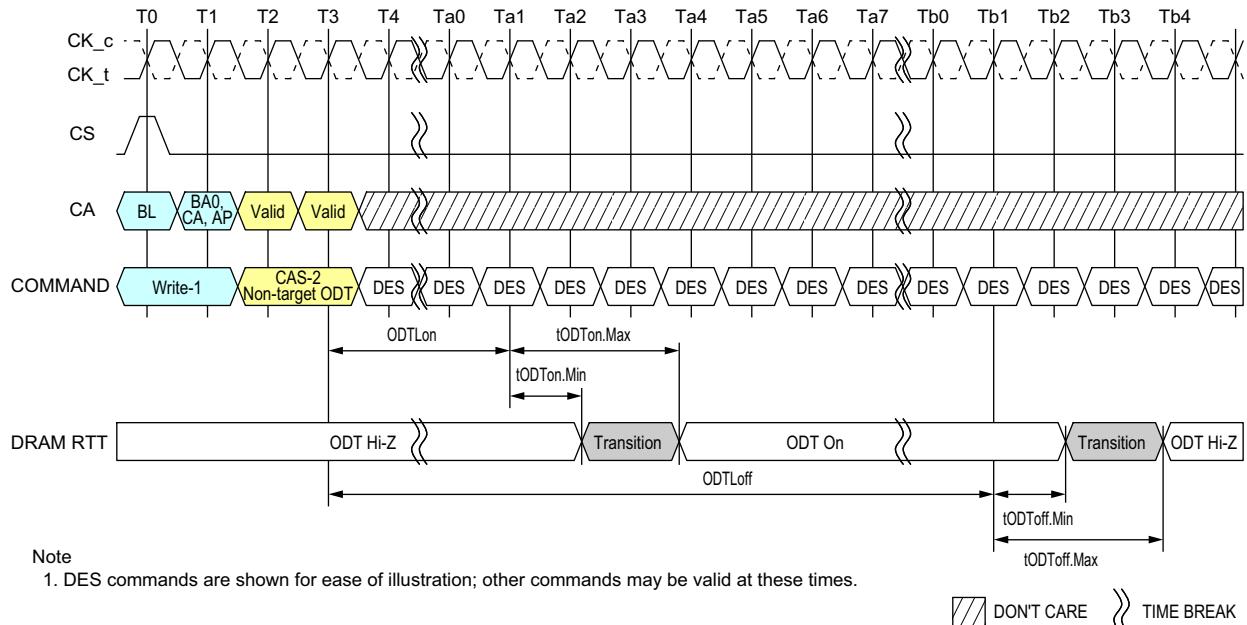


Figure 134 — ODT Control on Non-target DRAM for Writes

4.46.2 Read-1, Mode Register Read-1 and MPC (Read FIFO and Read DQ Calibration) Case

CAS-2 command is replaced by CAS-2 Non-target ODT command for the Non-target DRAM ODT control command. ODT timings (ODTLon_rd and ODTLoff_rd) for Non-target DRAM are referenced to the CAS-2 Non-target ODT command.

Read Latency(RL) complies with MR0 OP[1].

Final values for ODTLon_rd are rounded down to an even number and final values for ODTLoff_rd are rounded up to an even number.

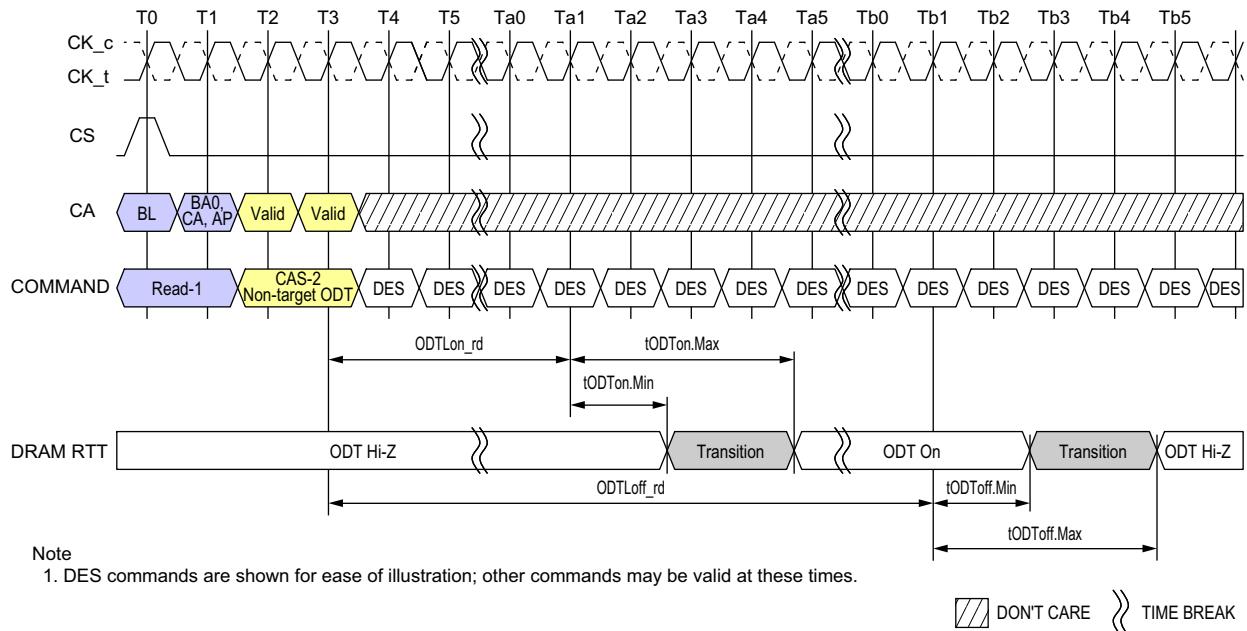


Figure 135 — ODT Control on Non-target DRAM for Read

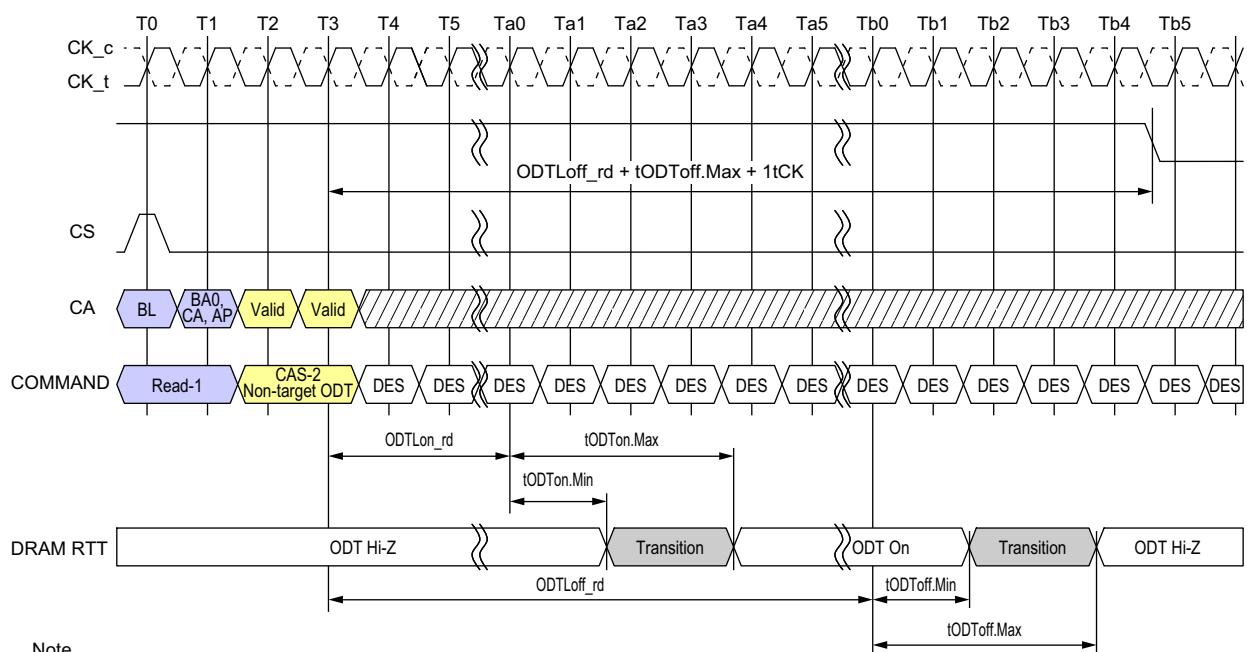


Figure 136 — Non-target DRAM for Read to Power-Down Entry

Table 89 — ODTLon_rd and ODTLoff_rd Latency Values: MR0 [OP1=0] Normal Latency Support

| ODTLon_rd Latency | | ODTLooff_rd Latency ^(1,2) | | Lower Clock Frequency Limit (>) | Upper Clock Frequency Limit (≤) |
|-------------------|--------|--------------------------------------|--------|---------------------------------|---------------------------------|
| No DBI | w/ DBI | No DBI | w/ DBI | | |
| N/A | N/A | N/A | N/A | 10 | 266 |
| N/A | N/A | N/A | N/A | 266 | 533 |
| N/A | N/A | N/A | N/A | 533 | 800 |
| 14 | 16 | 32 | 34 | 800 | 1066 |
| 18 | 22 | 36 | 40 | 1066 | 1333 |
| 22 | 26 | 42 | 46 | 1333 | 1600 |
| 26 | 30 | 46 | 50 | 1600 | 1866 |
| 28 | 32 | 50 | 54 | 1866 | 2133 |
| nCK | nCK | nCK | nCK | MHz | MHz |

NOTE 1 ODTLooff_rd assumes BL=16, For BL32, 8tCK should be added.

NOTE 2 ODTLooff_rd assumes a fixed tRPST of 1.5tCK (DRAM will assume 1.5 tCK independent MR setting).

Table 90 — ODTLon_rd and ODTLooff_rd Latency Values: MR0 [OP1=1] Byte Mode Latency Support

| ODTLon_rd Latency | | ODTLooff_rd Latency ^(1,2) | | Lower Clock Frequency Limit (>) | Upper Clock Frequency Limit (≤) |
|-------------------|--------|--------------------------------------|--------|---------------------------------|---------------------------------|
| No DBI | w/ DBI | No DBI | w/ DBI | | |
| N/A | N/A | N/A | N/A | 10 | 266 |
| N/A | N/A | N/A | N/A | 266 | 533 |
| N/A | N/A | N/A | N/A | 533 | 800 |
| 16 | 18 | 34 | 36 | 800 | 1066 |
| 20 | 24 | 38 | 42 | 1066 | 1333 |
| 26 | 30 | 46 | 50 | 1333 | 1600 |
| 30 | 34 | 50 | 54 | 1600 | 1866 |
| 32 | 36 | 54 | 58 | 1866 | 2133 |
| nCK | nCK | nCK | nCK | MHz | MHz |

NOTE 1 ODTLooff_rd assumes BL=16, For BL32, 8tCK should be added.

NOTE 2 ODTLooff_rd assumes a fixed tRPST of 1.5tCK (DRAM will assume 1.5 tCK independent MR setting).

Table 91 — Constraints table for Non-target DRAM ODT control Command

| Next CMD Current CMD | Write ^{*1,5} (BL=16 or 32) | NT Write ^{*2,5} (BL=16 or 32) | Read ^{*3,6} (BL=16 or 32) | NT Read ^{*4,6} (BL=16 or 32) |
|---|---|---|--|--|
| Write ^{*1,5} (BL=16 or 32) | tCCD | ODTloff+RU(tODToff.Max/tCK) -ODTLon-RD(tODTon.Min/tCK) | WL+1+BL/2 +RU(tWTR/tCK) | ODTloff+RU(tODToff.Max/tCK) -ODTLon_rd-RD(tODTon.Min/tCK) |
| NT Write ^{*2,5} (BL=16 or 32) | ODTloff+RU(tODToff.Max/tCK) -ODTLon-RD(tODTon.Min/tCK) | tCCD | ODTloff+RU(tODToff.Max/tCK) +tRPRE-RL-RD(tDQSCK.Min/tCK) | ODTloff+RU(tODToff.Max/tCK) -ODTLon_rd-RD(tODTon.Min/tCK) |
| Read ^{*3,6} (BL=16 or 32) | RL+RU(tDQSCK(max)/tCK) +BL/2+RD(tRPST)-ODTLon -RD(tODTon,min/tCK) | RL+RU(tDQSCK(max)/tCK) +BL/2+RD(tRPST)-ODTLon- RD(tODTon,min/tCK) | tCCD | RL+RU(tDQSCK(max)/tCK) +BL/2+RD(tRPST)-ODTLon_rd -RD(tODTon.Min/tCK) |
| NT Read ^{*4,6} (BL=16 or 32) | ODTloff_rd+RU(tODToff.Max/tCK) -ODTLon -RD(tODTon.Min/tCK) | ODTloff_rd+RU(tODToff.Max/tCK) -ODTLon -RD(tODTon.Min/tCK) | ODTloff_rd+RU(tODToff.Max/tCK) +tRPRE-RL-RD(tDQSCK.Min/tCK) | tCCD |

NOTE 1 Write includes Mask Write command.

NOTE 2 NT Write includes Mask Write and MPC Write FIFO for Non Target ODT command.

NOTE 3 Read includes Mode Register Read, MPC Read FIFO and MPC Read DQ calibration command.

NOTE 4 NT Read includes Mode Register Read, MPC Read FIFO and MPC Read DQ calibration for command Non Target ODT command.

NOTE 5 Burst length 32 only applies Write and NT Write.

NOTE 6 Burst length 32 only applies Read and NT Read.

4.47 Output Driver and Termination Register Temperature and Voltage Sensitivity

If temperature and/or voltage change after calibration, the tolerance limits widen according to Table 92 and Table 93.

Table 92 — Output Driver and Termination Register Sensitivity Definition

| Resistor | Definition Point | Min | Max | Unit | Notes |
|---------------|--------------------|--|---|------|-------|
| R_{ONPD} | $0.33 \times VDDQ$ | $90 - (dR_{on}dT \times \Delta T) - (dR_{on}dV \times \Delta V)$ | $110 + (dR_{on}dT \times \Delta T) + (dR_{on}dV \times \Delta V)$ | % | 1,2 |
| VOH_{PU} | $0.33 \times VDDQ$ | $90 - (dVOHdT \times \Delta T) - (dVOHdV \times \Delta V)$ | $110 + (dVOHdT \times \Delta T) + (dVOHdV \times \Delta V)$ | % | 1,2,5 |
| $R_{TT(I/O)}$ | $0.33 \times VDDQ$ | $90 - (dR_{on}dT \times \Delta T) - (dR_{on}dV \times \Delta V)$ | $110 + (dR_{on}dT \times \Delta T) + (dR_{on}dV \times \Delta V)$ | % | 1,2,3 |
| $R_{TT(In)}$ | $0.33 \times VDD2$ | $90 - (dR_{on}dT \times \Delta T) - (dR_{on}dV \times \Delta V)$ | $110 + (dR_{on}dT \times \Delta T) + (dR_{on}dV \times \Delta V)$ | % | 1,2,4 |

NOTE 1 $\Delta T = T - T(@ \text{Calibration})$, $\Delta V = V - V(@ \text{Calibration})$.

NOTE 2 $dR_{ON}dT$, $dR_{ON}dV$, $dVOHdT$, $dVOHdV$, $dR_{TT}dV$, and $dR_{TT}dT$ are not subject to production test but are verified by design and characterization.

NOTE 3 This parameter applies to Input/Output pin such as DQS, DQ and DMI.

NOTE 4 This parameter applies to Input pin such as CK, CA and CS.

NOTE 5 Refer to 4.42 Pull Up/Pull Down Driver Characteristics for VOH_{PU} .

Table 93 — Output Driver and Termination Register Temperature and Voltage Sensitivity

| Symbol | Parameter | Min | Max | Unit |
|-------------|----------------------------------|------|------|-----------------------|
| $dR_{ON}dT$ | R_{ON} Temperature Sensitivity | 0.00 | 0.75 | %/ $^{\circ}\text{C}$ |
| $dR_{ON}dV$ | R_{ON} Voltage Sensitivity | 0.00 | 0.20 | %/mV |
| $dVOHdT$ | VOH Temperature Sensitivity | 0.00 | 0.75 | %/ $^{\circ}\text{C}$ |
| $dVOHdV$ | VOH Voltage Sensitivity | 0.00 | 0.35 | %/mV |
| $dR_{TT}dT$ | R_{TT} Temperature Sensitivity | 0.00 | 0.75 | %/ $^{\circ}\text{C}$ |
| $dR_{TT}dV$ | R_{TT} Voltage Sensitivity | 0.00 | 0.20 | %/mV |

4.48 Power-Down Mode

4.48.1 Power-Down Entry and Exit

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

- Mode Register Read
- Mode Register Write
- Read
- Write
- $V_{REF}(CA)$ Range and Value setting via MRW
- $V_{REF}(DQ)$ Range and Value setting via MRW
- Command Bus Training mode Entering/Exiting via MRW
- VRCG High Current mode Entering/Exiting via MRW

And the LPDDR4 DRAM cannot be placed in power-down state during “Start DQS Interval Oscillator” operation.

CKE can go LOW while any other operations such as row activation, Precharge, Auto-Precharge, or Refresh are in progress. The power-down IDD specification will not be applied until such operations are complete. Power-down entry and exit are shown in Figure 137.

Entering power-down deactivates the input and output buffers, excluding CKE and Reset_n. To ensure that there is enough time to account for internal delay on the CKE signal path, CS input is required stable Low level and CA input level is don't care after CKE is driven LOW, this timing period is defined as tCKELCS. Clock input is required after CKE is driven LOW, this timing period is defined as tCKELCK. CKE LOW will result in deactivation of all input receivers except Reset_n after tCKELCK has expired. In power-down mode, CKE must be held LOW; all other input signals except Reset_n are "Don't Care". CKE LOW must be maintained until tCKE,min is satisfied.

No refresh operations are performed in power-down mode except Self Refresh power-down. The maximum duration in non-Self Refresh power-down mode is only limited by the refresh requirements outlined in the Refresh command section.

The power-down state is asynchronously exited when CKE is driven HIGH. CKE HIGH must be maintained until tCKE,min is satisfied. A valid, executable command can be applied with power-down exit latency tXP after CKE goes HIGH. Power-down exit latency is defined in the AC timing parameter table.

Clock frequency change or Clock Stop is inhibited during tCMDCKE, tCKELCK, tCKCCKEH, tXP, tMRWCCKE and tZQCKE periods.

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

V_{DDQ} may be turned off during power-down after tCKELCK(Max(5ns,5nCK)) is satisfied(Refer to Figure 137 about tCKELCK). Prior to exiting power-down, V_{DDQ} must be within its minimum/maximum operating range.

When CA, CK and/or CS ODT is enabled via MR11 OP[6:4] and also via MR22 or CA-ODT pad setting, the rank providing ODT will continue to terminate the command bus in all DRAM states including power-down when V_{DDQ} is stable and within its minimum/maximum operating range.

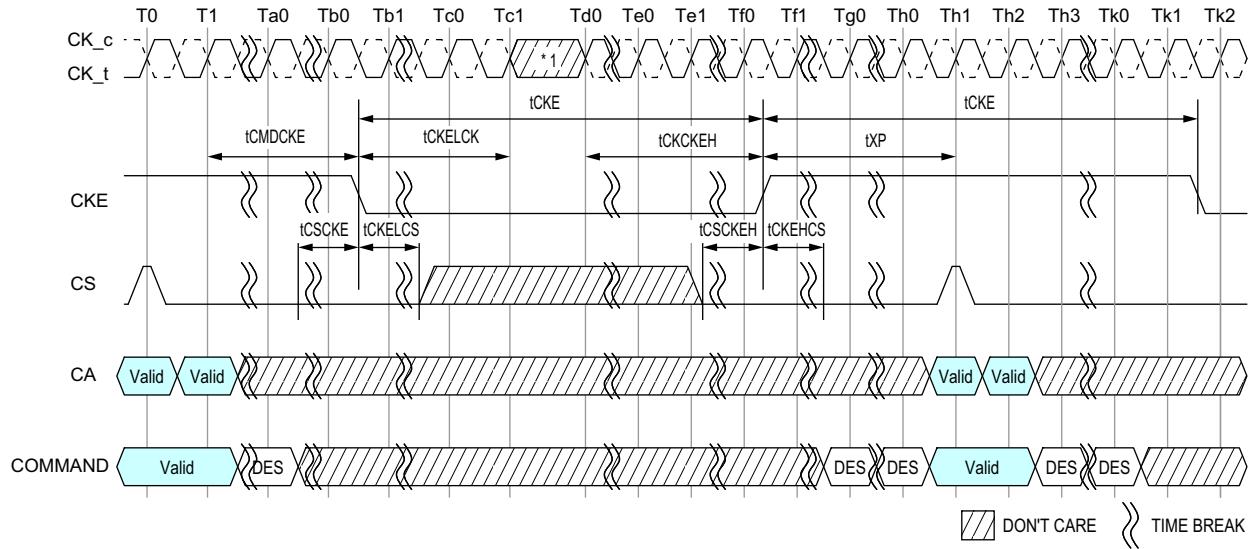


Figure 137 — Basic Power-Down Entry and Exit Timing

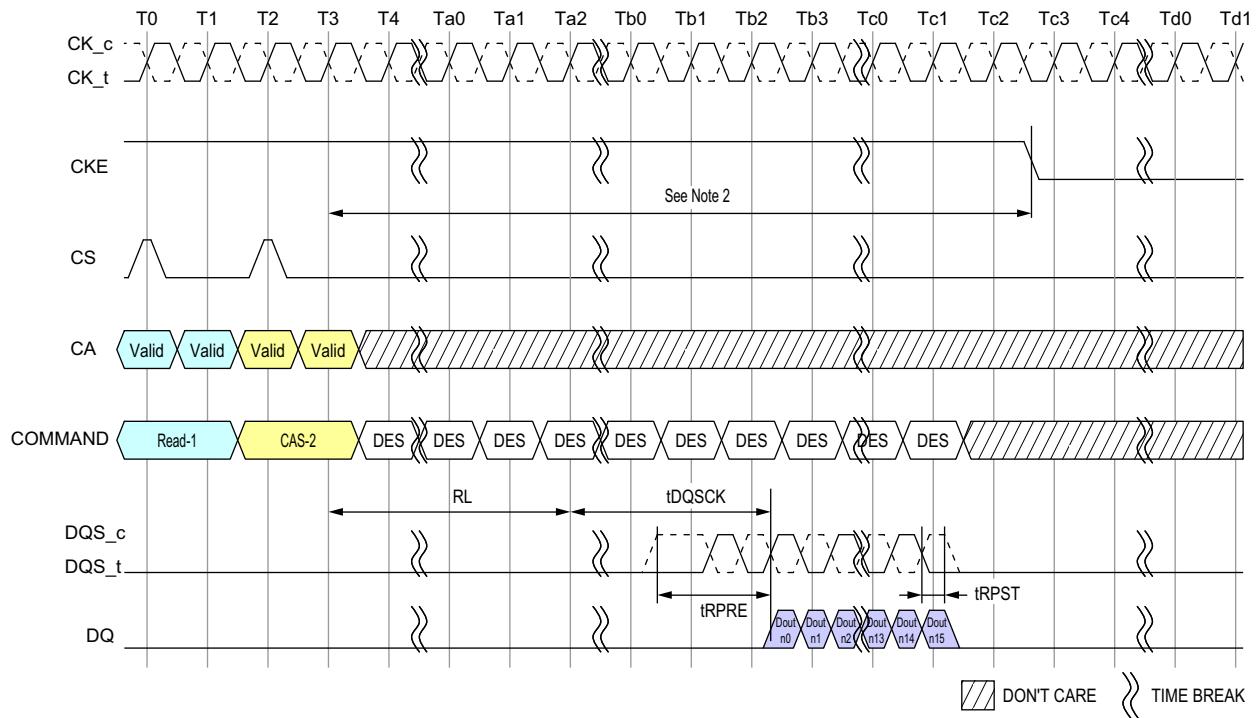
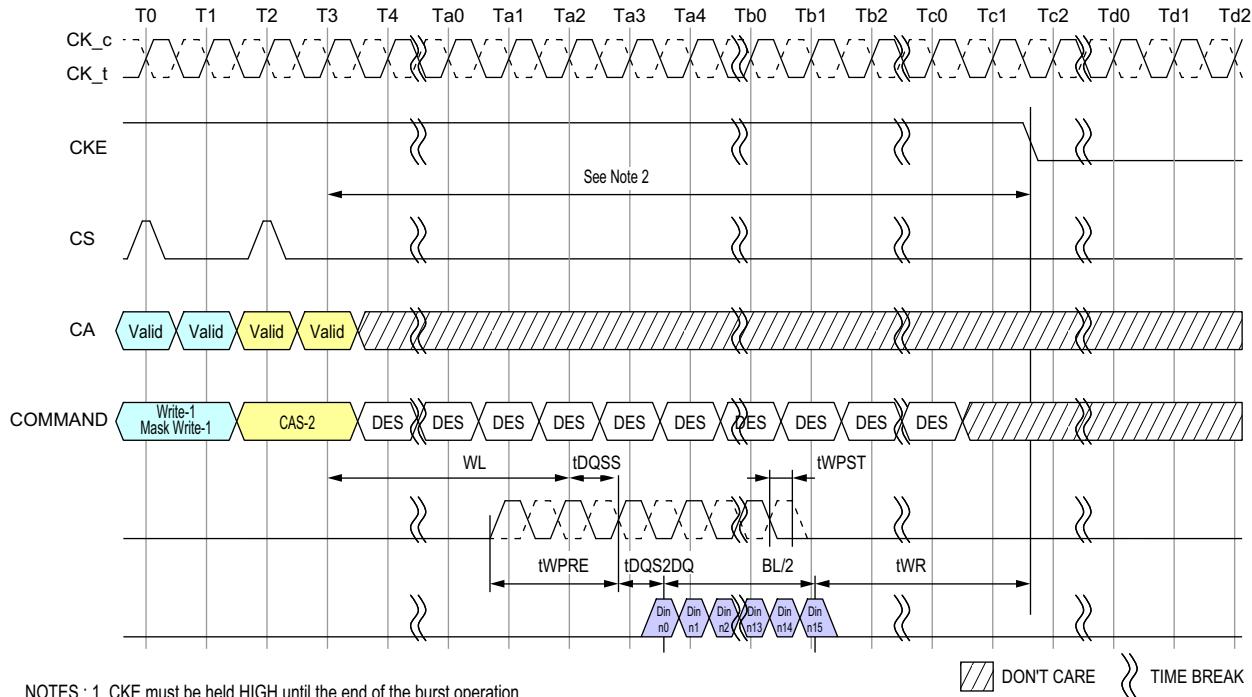


Figure 138 — Read and Read with Auto-Precharge to Power-Down Entry



NOTES : 1. CKE must be held HIGH until the end of the burst operation.

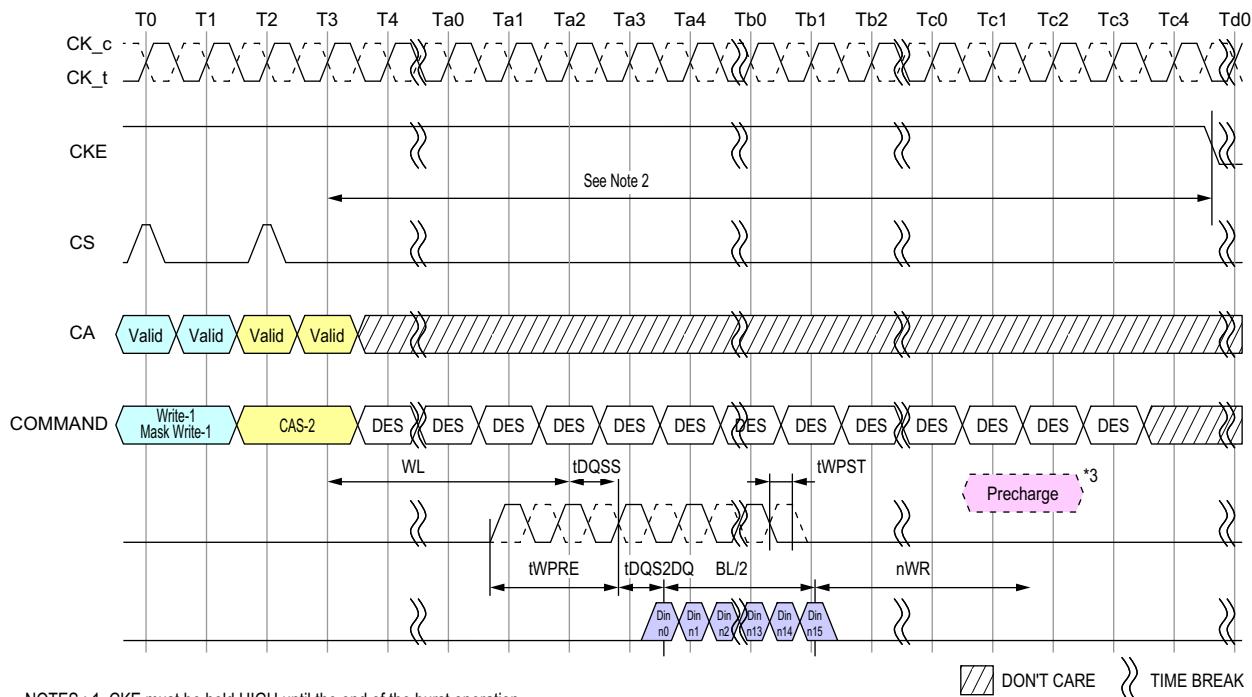
2. Minimum Delay time from Write Command or Mask Write Command to falling edge of CKE signal is as follows.

$$(WL \times tCK) + tDQSS(\text{Max}) + tDQS2DQ(\text{Max}) + ((BL/2) \times tCK) + tWR$$

3. This timing is applied regardless of DQ ODT Disable/Enable setting: MR11[OP2:0].

4. This timing diagram only applies to the Write and Mask Write Commands without Auto-Precharge.

Figure 139 — Write and Mask Write to Power-Down Entry



NOTES : 1. CKE must be held HIGH until the end of the burst operation.

2. Delay time from Write with Auto-Precharge Command or Mask Write with Auto-Precharge Command to falling edge of CKE signal is more than $(WL \times tCK) + tDQSS(\text{Max}) + tDQS2DQ(\text{Max}) + ((BL/2) \times tCK) + (nWR \times tCK) + (2 \times tCK)$

3. Internal Precharge Command

4. This timing is applied regardless of DQ ODT Disable/Enable setting: MR11[OP2:0].

Figure 140 — Write with Auto-Precharge and Mask Write with Auto-Precharge to Power-Down

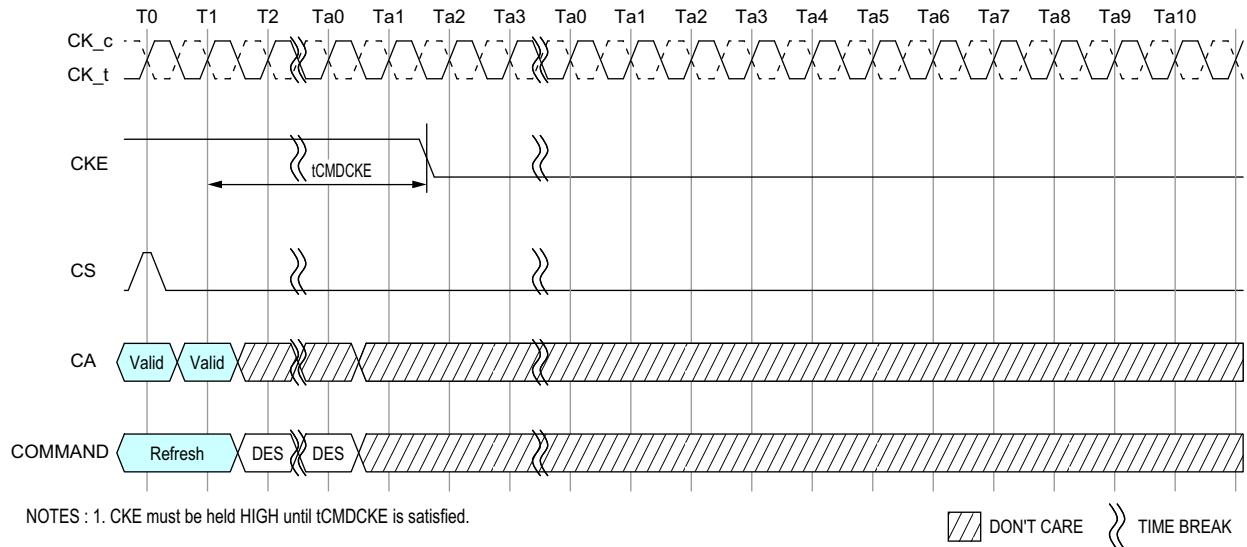


Figure 141 — Refresh entry to Power-Down Entry

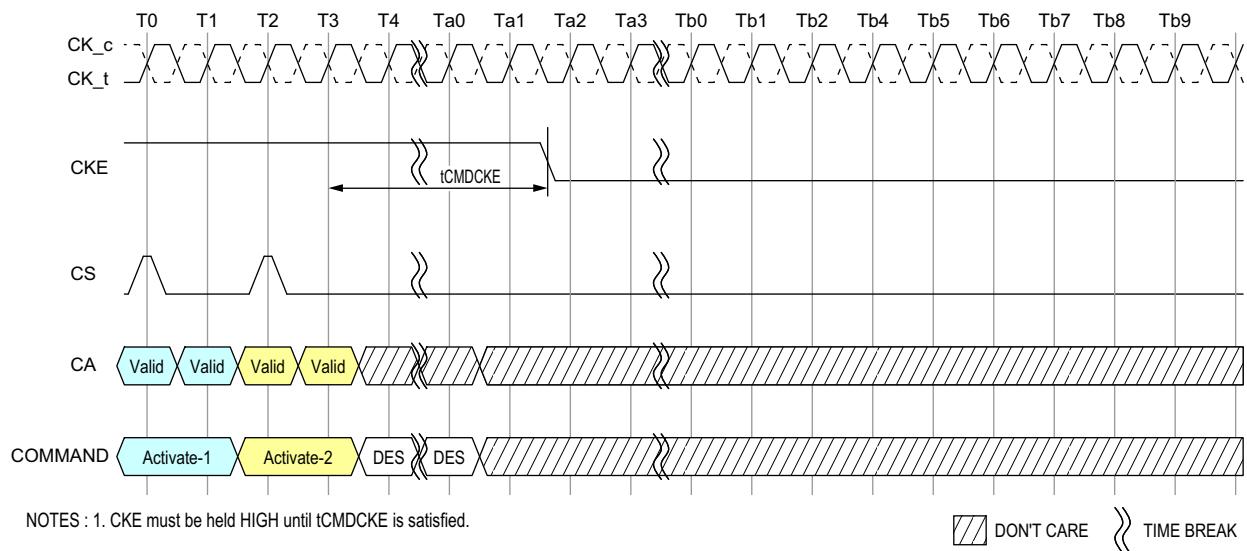


Figure 142 — Activate Command to Power-Down Entry

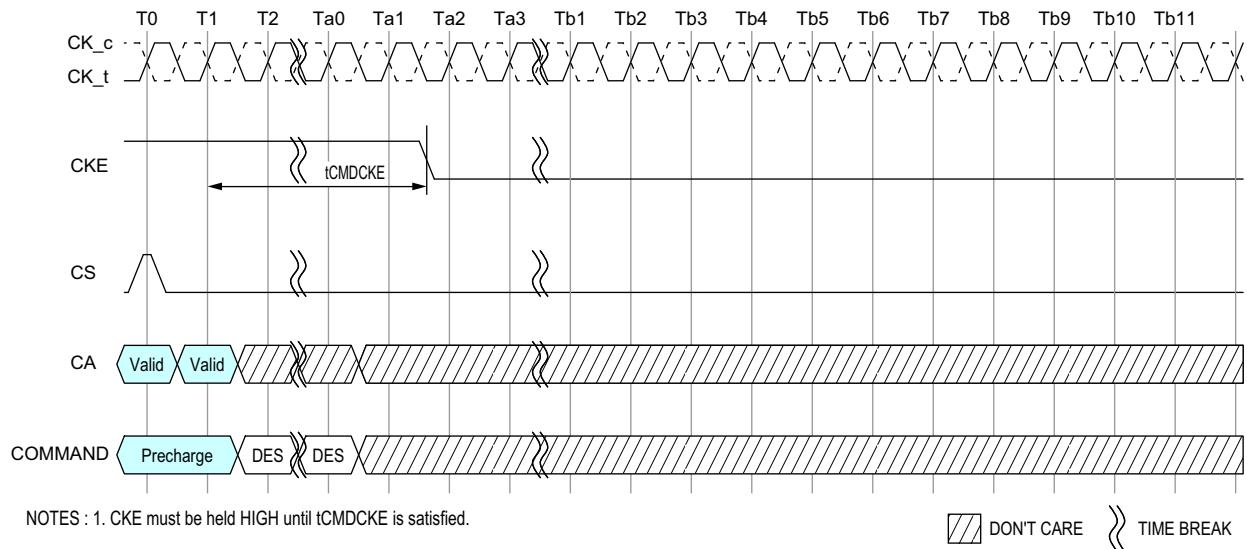


Figure 143 — Precharge Command to Power-Down Entry

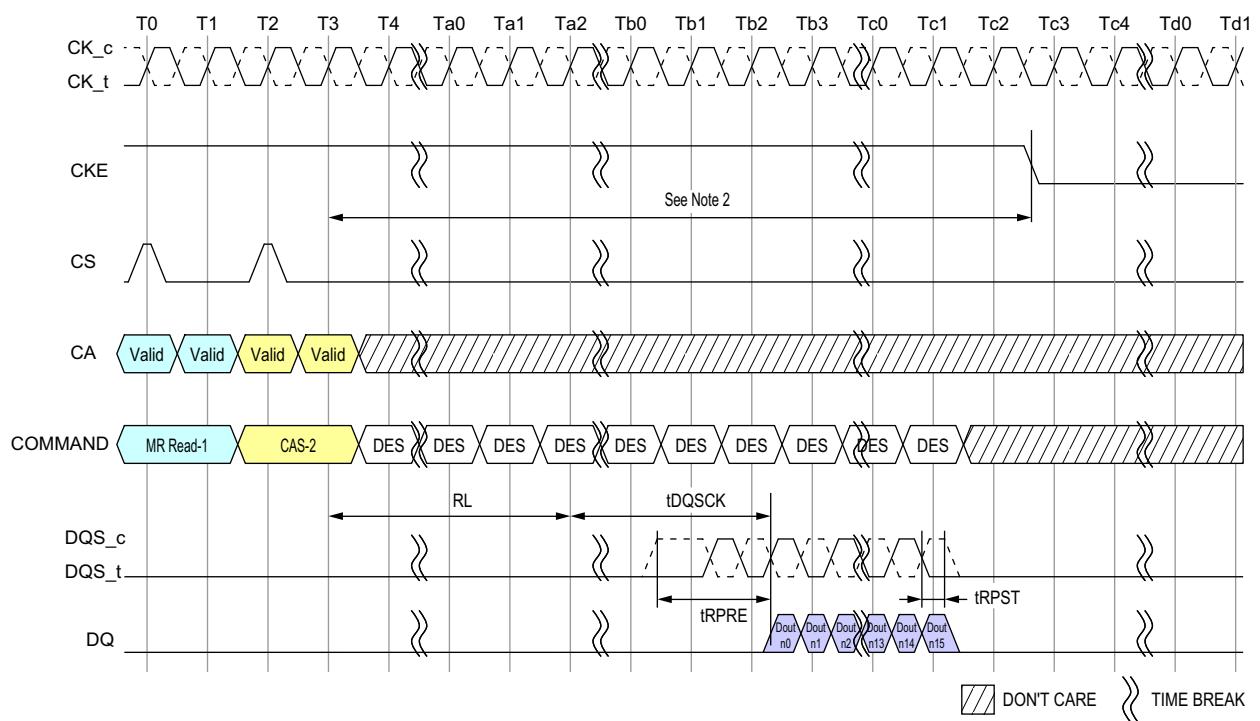


Figure 144 — Mode Register Read to Power-Down Entry

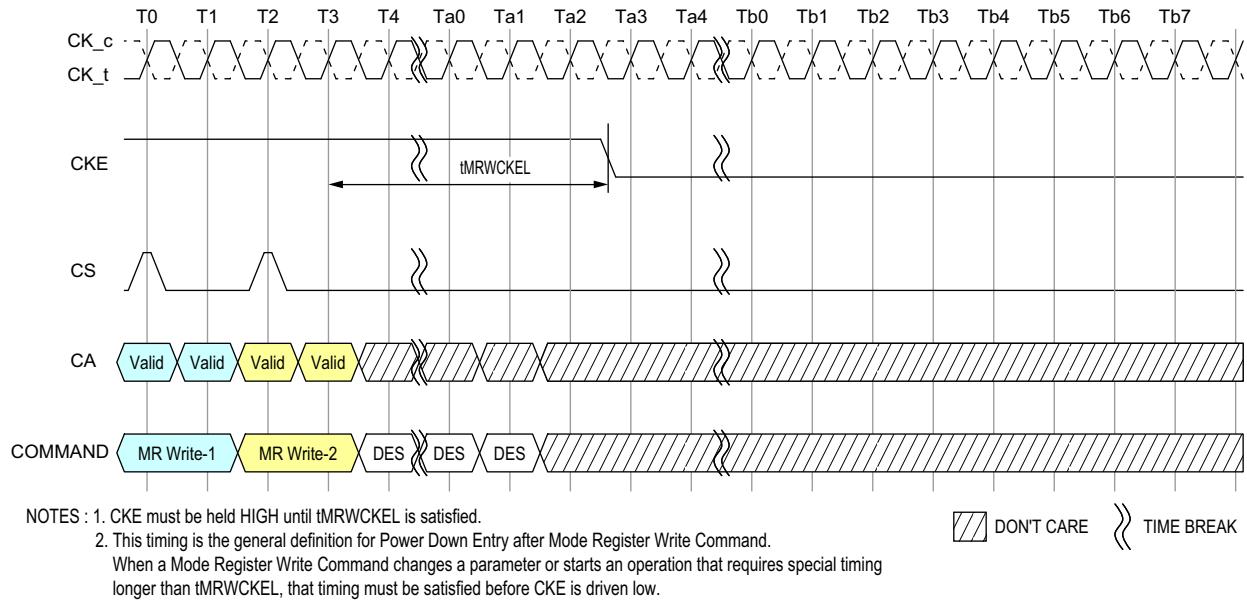


Figure 145 — Mode Register Write to Power-Down Entry

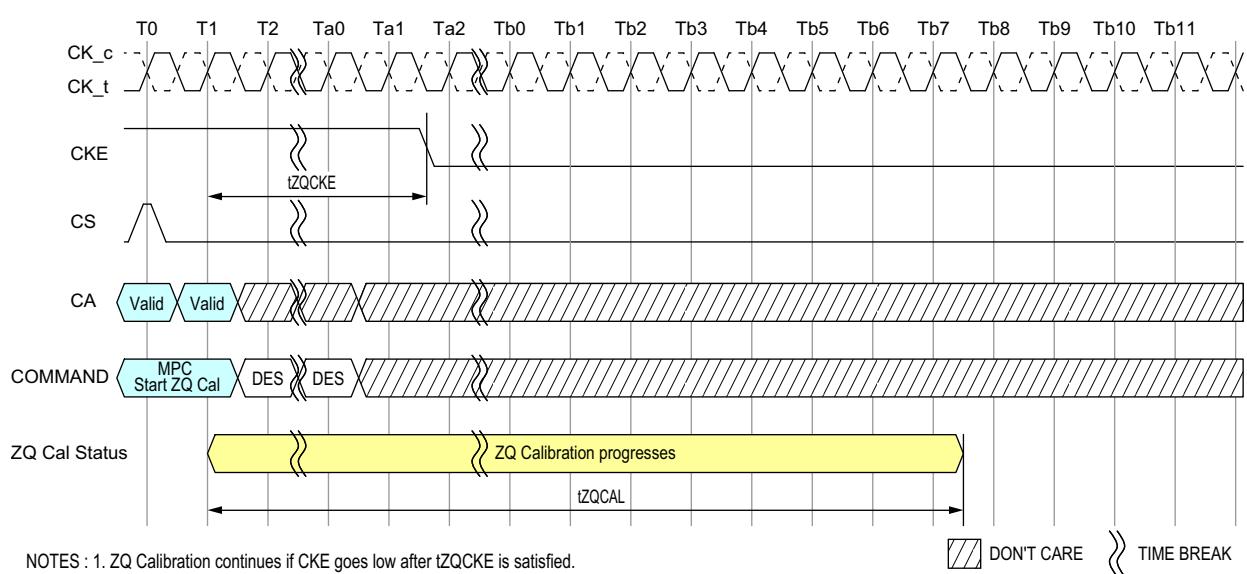


Figure 146 — Multi-Purpose Command for Start ZQ Calibration to Power-Down Entry

Table 94 — Power-Down AC Timing

| Parameter | Symbol | Min/ Max | Data Rate | Unit | Note |
|--|----------|-------------|----------------------|------|------|
| Power Down Timing | | | | | |
| CKE minimum pulse width (HIGH and LOW pulse width) | tCKE | Min | Max(7.5ns, 4nCK) | - | |
| Delay from valid command to CKE input LOW | tCMDCKE | Min | Max(1.75ns, 3nCK) | ns | 1 |
| Valid Clock Requirement after CKE Input low | tCKELCK | Min | Max(5ns, 5nCK) | ns | 1 |
| Valid CS Requirement before CKE Input Low | tCSCKE | Min | 1.75 | ns | |
| Valid CS Requirement after CKE Input low | tCKELCS | Min | Max(5ns, 5nCK) | ns | |
| Valid Clock Requirement before CKE Input High | tCKCKEH | Min | Max(1.75ns, 3nCK) | ns | 1 |
| Exit power- down to next valid command delay | tXP | Min | Max(7.5ns, 5nCK) | ns | 1 |
| Valid CS Requirement before CKE Input High | tCSCKEH | Min | 1.75 | ns | |
| Valid CS Requirement after CKE Input High | tCKEHCS | Min | Max(7.5ns, 5nCK) | ns | |
| Valid Clock and CS Requirement after CKE Input low after MRW Command | tMRWCKEL | Min | Max(14ns, 10nCK) | ns | 1 |
| Valid Clock and CS Requirement after CKE Input low after ZQ Calibration Start Command | tZQCKE | Min | Max(1.75ns, 3nCK) | ns | 1 |

NOTE 1 Delay time has to satisfy both analog time(ns) and clock count(nCK).

For example, tCMDCKE will not expire until CK has toggled through at least 3 full cycles (3 *tCK) and 1.75ns has transpired. The case which 3nCK is applied to is shown In Figure 147.

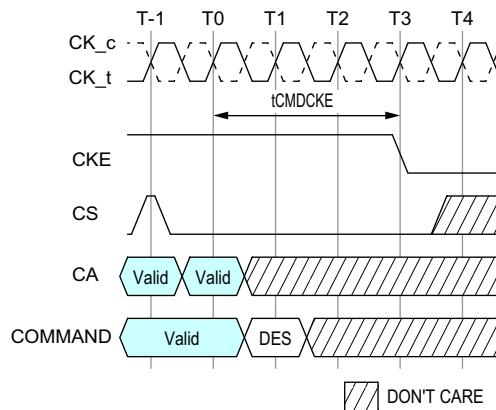


Figure 147 — tCMDCKE Timing

4.49 Input Clock Stop and Frequency Change

LPDDR4 SDRAMs support input clock frequency change during CKE LOW under the following conditions:

- tCK(abs)min is met for each clock cycle;
- Refresh requirements apply during clock frequency change;
- During clock frequency change, only REFab or REFpb commands may be executing;
- Any Activate or Precharge commands have executed to completion prior to changing the frequency;
- The related timing conditions (tRCD, tRP) have been met prior to changing the frequency;
- The initial clock frequency shall be maintained for a minimum of tCKELCK after CKE goes LOW;
- The clock satisfies tCH(abs) and tCL(abs) for a minimum of tCKCKEH prior to CKE going HIGH

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

LPDDR4 devices support clock stop during CKE LOW under the following conditions:

- CK_t and CK_c are don't care during clock stop;
- Refresh requirements apply during clock stop;
- During clock stop, only REFab or REFpb commands may be executing;
- Any Activate or Precharge commands have executed to completion prior to stopping the clock;
- The related timing conditions (tRCD, tRP) have been met prior to stopping the clock;
- The initial clock frequency shall be maintained for a minimum of tCKELCK after CKE goes LOW;
- The clock satisfies tCH(abs) and tCL(abs) for a minimum of tCKCKEH prior to CKE going HIGH

LPDDR4 devices support input clock frequency change during CKE HIGH under the following conditions:

- tCK(abs)min is met for each clock cycle;
- Refresh requirements apply during clock frequency change;
- Any Activate, Read, Write, Precharge, Mode Register Write, or Mode Register Read commands must have executed to completion, including any associated data bursts prior to changing the frequency;
- The related timing conditions (tRCD, tWR, tWRA, tRP, tMRW, tMRR, etc.) have been met prior to changing the frequency;
- Non Target ODT function is completed which means that ODTLoff or ODTLoff_rd must be satisfied before clock frequency change.
- CS shall be held LOW during clock frequency change;
- During clock frequency change, only REFab or REFpb commands may be executing;
- The LPDDR4 SDRAM is ready for normal operation after the clock satisfies tCH(abs) and tCL(abs) for a minimum of 2*tCK+tXP.

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

LPDDR4 devices support clock stop during CKE HIGH under the following conditions:

- CK_t is held LOW and CK_c is held HIGH during clock stop;
- CS shall be held LOW during clock clock stop;
- Refresh requirements apply during clock stop;
- During clock stop, only REFab or REFpb commands may be executing;
- Any Activate, Read, Write, MPC(WRFIFO,RDFIFO,RDDQCAL), Precharge, Mode Register Write or Mode Register Read commands must have executed to completion, including any associated data bursts and extra 4 clock cycles must be provided prior to stopping the clock;
- The related timing conditions (tRCD, tWR, tRP, tMRW, tMRR, tZQLAT, etc.) have been met prior to stopping the clock;
- Read with auto precharge and write with auto precharge commands need extra 4 clock cycles in addition to the related timing constraints, nWR and nRTP, to complete the operations.
- Non Target ODT function is completed which means that ODTloff or ODTloff_rd must be satisfied before clock stop.
- REFab, REFpb, SRE, SRX and MPC(Zqcal Start)commands are required to have 4 additional clocks prior to stopping the clock same as CKE=L case.
- The LPDDR4 SDRAM is ready for normal operation after the clock is restarted and satisfies tCH(abs) and tCL(abs) for a minimum of $2*tCK+tXP$.

4.50 Truth Tables

Operation or timing that is not specified is illegal, and after such an event, in order to guarantee proper operation, the LPDDR4 device must be reset or power-cycled and then restarted through the specified initialization sequence before normal operation can continue.

CKE signal has to be held High when the commands listed in Table 95 input.

4.50.1 Command Truth Table**Table 95 — Command Truth Table**

| | SDR Command Pins | SDR CA Pins (6) | | | | | | | | |
|--|---------------------------------|------------------------|------------|------------|------------|------------|------------|----------------------|--------------------|-----|
| SDRAM Command | CS | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 | CK_t edge | Notes | |
| Deselect (DES) | L | X | | | | | | | R1 | 1,2 |
| Multi-Purpose Command (MPC) | H | L | L | L | L | L | OP6 | R1 | 1,9,13 | |
| | L | OP0 | OP1 | OP2 | OP3 | OP4 | OP5 | R2 | | |
| Precharge (PRE) (Per Bank, All Bank) | H | L | L | L | L | H | AB | R1 | 1,2,3,4 | |
| | L | BA0 | BA1 | BA2 | V | V | V | R2 | | |
| Refresh (REF) (Per Bank, All Bank) | H | L | L | L | H | L | AB | R1 | 1,2,3,4 | |
| | L | BA0 | BA1 | BA2 | V | V | V | R2 | | |
| Self Refresh Entry (SRE) | H | L | L | L | H | H | V | R1 | 1,2 | |
| | L | V | | | | | | | | |
| Write -1 (WR-1) | H | L | L | H | L | L | BL | R1 | 1,2,3,6,7, 9,13 | |
| | L | BA0 | BA1 | BA2 | V | C9 | AP | R2 | | |
| Self Refresh Exit (SRX) | H | L | L | H | L | H | V | R1 | 1,2 | |
| | L | V | | | | | | | | |
| Mask Write -1 (MWR-1) | H | L | L | H | H | L | L | R1 | 1,2,3,5,6, 9,13 | |
| | L | BA0 | BA1 | BA2 | V | C9 | AP | R2 | | |
| RFU | H | L | L | H | H | H | V | R1 | 1,2 | |
| | L | V | | | | | | | | |
| Read -1 (RD-1) | H | L | H | L | L | L | BL | R1 | 1,2,3,6,7, 9,13 | |
| | L | BA0 | BA1 | BA2 | V | C9 | AP | R2 | | |
| CAS-2 (Write-2, Mask Write -2, Read-2, MRR-2, MPC) | H | L | H | L | L | H | C8 | R1 | 1,8,9 | |
| | L | C2 | C3 | C4 | C5 | C6 | C7 | R2 | | |
| CAS-2 Non-target ODT | L | L | H | L | L | H | V | R1 | 1,2,3,14 | |
| | L | V | | | | | | | | |
| RFU | H | L | H | L | H | L | V | R1 | 1,2 | |
| | L | V | | | | | | | | |
| RFU | H | L | H | L | H | H | V | R1 | 1,2 | |
| | L | V | | | | | | | | |
| Mode Register Write - 1 (MRW-1) | H | L | H | H | L | L | OP7 | R1 | 1,11 | |
| | L | MA0 | MA1 | MA2 | MA3 | MA4 | MA5 | R2 | | |
| Mode Register Write- 2 (MRW-2) | H | L | H | H | L | H | OP6 | R1 | 1,11 | |
| | L | OP0 | OP1 | OP2 | OP3 | OP4 | OP5 | R2 | | |
| Mode Register Read- 1 (MRR-1) | H | L | H | H | H | L | V | R1 | 1,2,12,13 | |
| | L | MA0 | MA1 | MA2 | MA3 | MA4 | MA5 | R2 | | |
| RFU | H | L | H | H | H | H | V | R1 | 1,2 | |
| | L | V | | | | | | | | |
| Activate -1 (ACT-1) | H | H | L | R12 | R13 | R14 | R15 | R1 | 1,2,3,10 | |
| | L | BA0 | BA1 | BA2 | R16 | R10 | R11 | R2 | | |
| Activate -2 (ACT-2) | H | H | H | R6 | R7 | R8 | R9 | R1 | 1,10 | |
| | L | R0 | R1 | R2 | R3 | R4 | R5 | R2 | | |

4.50.1 Command Truth Table (cont'd)

Table 95 — Command Truth Table Notes

NOTE 1 All LPDDR4 commands except for Deselect are 2 clock cycle long and defined by states of CS and CA[5:0] at the first rising edge of clock. Deselect command is 1 clock cycle long.

NOTE 2 "V" means "H" or "L" (a defined logic level). "X" means don't care in which case CA[5:0] can be floated.

NOTE 3 Bank addresses BA[2:0] determine which bank is to be operated upon.

NOTE 4 AB "HIGH" during Precharge or Refresh command indicates that command must be applied to all banks and bank address is a don't care.

NOTE 5 Mask Write-1 command supports only BL 16. For Mark Write-1 command, CA5 must be driven LOW on first rising clock cycle (R1).

NOTE 6 AP "HIGH" during Write-1, Mask Write-1 or Read-1 commands indicates that an Auto-Precharge will occur to the bank associated with the Write, Mask Write or Read command.

NOTE 7 If Burst Length on-the-fly is enabled, BL "HIGH" during Write-1 or Read-1 command indicates that Burst Length should be set on-the-Fly to BL=32. BL "LOW" during Write-1 or Read-1 command indicates that Burst Length should be set on-the-fly to BL=16. If Burst Length on-the-fly is disabled, then BL must be driven to defined logic level "H" or "L".

NOTE 8 For CAS-2 commands (Write-2 or Mask Write-2 or Read-2 or MRR-2 or MPC (Only Write FIFO, Read FIFO & Read DQ Calibration), C[1:0] are not transmitted on the CA[5:0] bus and are assumed to be zero. Note that for CAS-2 Write-2 or CAS-2 Mask Write-2 command, C[3:2] must be driven LOW.

NOTE 9 Write-1 or Mask Write-1 or Read-1 or Mode Register Read-1 or MPC (Only Write FIFO, Read FIFO & Read DQ Calibration) command must be immediately followed by CAS-2 command consecutively without any other command in between. Write-1 or Mask Write-1 or Read-1 or Mode Register Read-1 or MPC (Only Write FIFO, Read FIFO & Read DQ Calibration) command must be issued first before issuing CAS-2 command. MPC (Only Start & Stop DQS Oscillator, Start & Latch ZQ Calibration) commands do not require CAS-2 command; they require two additional DES or NOP commands consecutively before issuing any other commands.

NOTE 10 Activate-1 command must be immediately followed by Activate-2 command consecutively without any other command in between. Activate-1 command must be issued first before issuing Activate-2 command. Once Activate-1 command is issued, Activate-2 command must be issued before issuing another Activate-1 command.

NOTE 11 MRW-1 command must be immediately followed by MRW-2 command consecutively without any other command in between. MRW-1 command must be issued first before issuing MRW-2 command.

NOTE 12 MRR-1 command must be immediately followed by CAS-2 command consecutively without any other command in between. MRR-1 command must be issued first before issuing CAS-2 command.

NOTE 13 The Non-Target DRAM function is supported for Write-1, Mask Write-1, Read-1, Mode Register Read-1, MPC (only Write FIFO, Read FIFO and Read DQ calibration) command. And CAS-2 is not needed for Non-Target DRAM and CAS-2 Non-target ODT is used instead. The Non-Target DRAM function as optional feature. Refer to vendor specific datasheets.

NOTE 14 Write-1, Mask Write-1, Read-1, Mode Register Read-1, MPC (only Write FIFO, Read FIFO and Read DQ calibration) command must be immediately followed by CAS-2 Non-target ODT command consecutively without any other command in between. Write-1, Mask Write-1, Read-1, Mode Register Read-1, MPC (only Write FIFO, Read FIFO and Read DQ calibration) command must be issued first before issuing CAS-2 Non-target ODT command.

4.51 TRR Mode - Target Row Refresh

A LPDDR4 SDRAM's row has a limited number of times a given row can be accessed within a refresh period ($t_{REFW} * 2$) prior to requiring adjacent rows to be refreshed. The Maximum Activate Count (MAC) is the maximum number of activates that a single row can sustain within a refresh period before the adjacent rows need to be refreshed. The row receiving the excessive actives is the Target Row (TRn), the adjacent rows to be refreshed are the victim rows. When the MAC limit is reached on TRn, either the LPDDR4 SDRAM receive all ($R * 2$) Refresh Commands before another row activate is issued, or the LPDDR4 SDRAM should be placed into Targeted Row Refresh (TRR) mode. The TRR Mode will re-fresh the rows adjacent to the TRn that encountered tMAC limit.

If LPDDR4 SDRAM supports Unlimited MAC value: MR24 [OP2:0=000] and MR24 [OP3=1], Target Row Refresh operation is not required. Even though LPDDR4 SDRAM allows to set MR24 [OP7=1]: TRR mode enable, in this case LPDDR4 SDRAM's behavior is vendor specific. For example, a certain LPDDR4 SDRAM may ignore MRW command for entering/exiting TRR mode or a certain SDRAM may support commands related TRR mode. See vendor device datasheets for details about TRR mode definition at supporting Unlimited MAC value case.

There could be a maximum of two target rows to a victim row in a bank. The cumulative value of the activates from the two target rows on a victim row in a bank should not exceed MAC value as well.

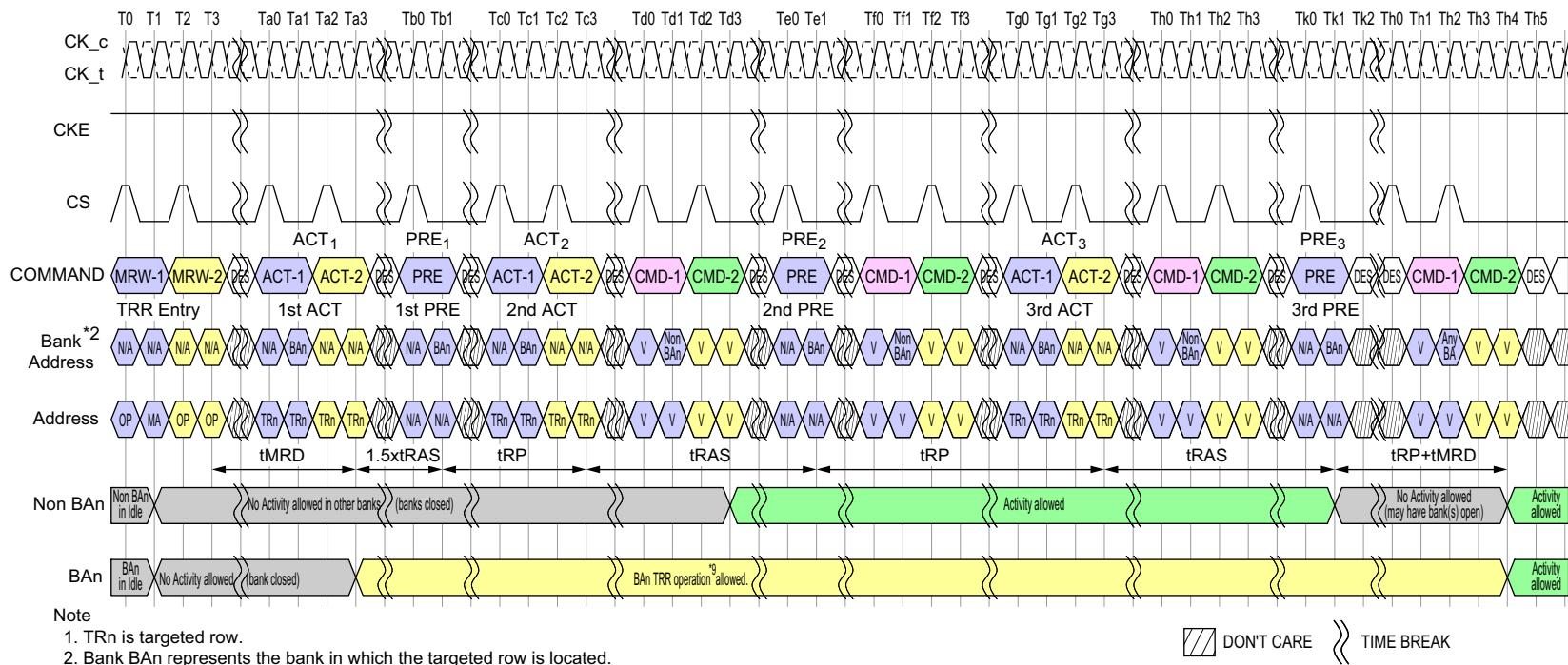
MR24 fields required to support the new TRR settings. Setting MR24 [OP7=1] enables TRR Mode and setting MR24 [OP7=0] disables TRR Mode. MR24 [OP6:OP4] defines which bank (BAn) the target row is located in (See MR24 table for details).

The TRR mode must be disabled during initialization as well as any other LPDDR4 SDRAM calibration modes. The TRR mode is entered from a DRAM Idle State, once TRR mode has been entered, no other Mode Register commands are allowed until TRR mode is completed, except setting MR24 [OP7=0] to interrupt and reissue the TRR mode is allowed.

When enabled; TRR Mode is self-clearing; the mode will be disabled automatically after the completion of defined TRR flow; after the 3rd BAn precharge has completed plus tMRD. Optionally the TRR mode can also be exited via another MRS command at the completion of TRR by setting MR24 [OP7=0]; if the TRR is exited via another MRS command, the value written to MR24 [OP6:OP4] are don't cares.

4.51.1 TRR Mode Operation

1. The timing diagram in Figure 148 depicts TRR mode. The following steps must be performed when TRR mode is enabled. This mode requires all three ACT (ACT1, ACT2 and ACT3) and three corresponding PRE commands (PRE1, PRE2 and PRE3) to complete TRR mode. A Precharge All (PREA) command issued while LPDDR4 SDRAM is in TRR mode will also perform precharge to BAn and counts towards a PREn command.
2. Prior to issuing the MRW command to enter TRR mode, the SDRAM should be in the idle state. A MRW command must be issued with MR24 [OP7=1] and MR24 [OP6:4] defining the bank in which the targeted row is located. All other MR24 bits should remain unchanged.
3. No activity is to occur in the DRAM until tMRD has been satisfied. Once tMRD has been satisfied, the only commands to BAn allowed are ACT and PRE until the TRR mode has been completed.
4. The first ACT to the BAn with the TRn address can now be applied, no other command is allowed at this point. All other banks must remain inactive from when the first BAn ACT command is issued until [(1.5 * tRAS) + tRP] is satisfied.
5. After the first ACT to the BAn with the TRn address is issued, a PRE to BAn is to be issued (1.5 * tRAS) later; and then followed tRP later by the second ACT to the BAn with the TRn address. Once the 2nd activate to the BAn is issued, nonBAn banks are allowed to have activity.
6. After the second ACT to the BAn with the TRn address is issued, a PRE to BAn is to be issued tRAS later and then followed tRP later by the third ACT to the BAn with the TRn address.
7. After the third ACT to the BAn with the TRn address is issued, a PRE to BAn would be issued tRAS later; and once the third PRE has been issued, nonBAn banks are not allowed to have activity until TRR mode is exited. The TRR mode is completed once tRP plus tMRD is satisfied.
8. TRR mode must be completed as specified to guarantee that adjacent rows are refreshed. Any-time the TRR mode is interrupted and not completed, the interrupted TRR Mode must be cleared and then subsequently performed again. To clear an interrupted TRR mode, an MR24 change is required with setting MR24 [OP7=0], MR24 [OP6:4] are don't care, followed by three PRE to BAn, tRP time in between each PRE command. The complete TRR sequence (Steps 2-7) must be then re-issued and completed to guarantee that the adjacent rows are refreshed.
9. Refresh command to the LPDDR4 SDRAM or entering Self Refresh mode is not allowed while the DRAM is in TRR mode.



1. TRn is targeted row.
 2. Bank BAn represents the bank in which the targeted row is located.
 3. TRR mode self-clears after tMRD + tRP measured from 3rd BAn precharge PRE3 at clock edge Th4.
 4. TRR mode or any other activity can be re-engaged after tRP + tMRD from 3rd BAn precharge PRE3.
PRE_ALL also counts if issued instead of PREn. TRR mode is cleared by DRAM after PRE3 to the BAn bank.
 5. Activate commands to BAn during TRR mode do not provide refreshing support, i.e. the Refresh counter is unaffected.
 6. The DRAM must restore the degraded row(s) caused by excessive activation of the targeted row (TRn) necessary to meet refresh requirements.
 7. A new TRR mode must wait tMRD+tRP time after the third precharge.
 8. BAn may not be used with any other command.
 9. ACT and PRE are the only allowed commands to BAn during TRR Mode.
 10. Refresh commands are not allowed during TRR mode.
 11. All DRAM timings are to be met by DRAM during TRR mode such as tFAW. Issuing of ACT1, ACT2 and ACT3 counts towards tFAW budget.

Figure 148 — TRR Mode

4.52 Post Package Repair (PPR)

LPDDR4 supports Fail Row address repair as optional feature and it is readable through MR25 OP[7:0] PPR provides simple and easy repair method in the system and Fail Row address can be repaired by the electrical programming of Electrical-fuse scheme.

With PPR, LPDDR4 can correct 1Row per Bank.

Electrical-fuse cannot be switched back to un-fused states once it is programmed. The controller should prevent unintended the PPR mode entry and repair.

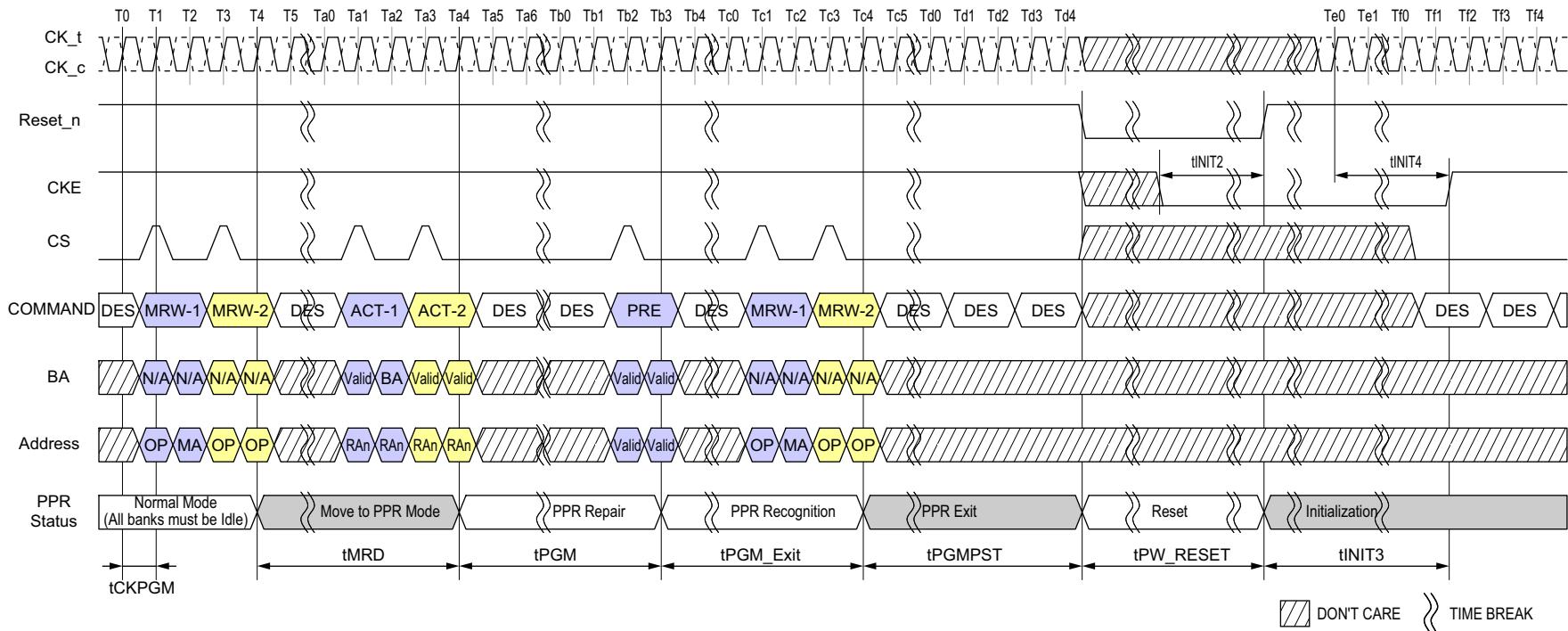
4.52.1 Fail Row Address Repair

The following is procedure of PPR.

1. Before entering 'PPR' mode, All banks must be Precharged
2. Enable PPR using MR4 bit "OP4=1" and wait tMRD
3. Issue ACT command with Fail Row address
4. Wait tPGM to allow DRAM repair target Row Address internally then issue PRE
5. Wait tPGM_Exit after PRE which allow DRAM to recognize repaired Row address RAn
6. Exit PPR with setting MR4 bit "OP4=0"
7. Issue RESET command after tPGMPST
8. Repeat steps in '3.3.2 Reset Initialization with Stable Power' section
9. In More than one fail address repair case, Repeat Step 2 to 8

Once PPR mode is exited, to confirm if target row is repaired correctly, host can verify by writing data into the target row and reading it back after PPR exit with MR4 [OP4=0] and tPGMPST.

Figure 149 shows PPR operation.



- NOTE 1 During tPGM, any other commands (including refresh) are not allowed on each die.
- NOTE 2 With one PPR command, only one row can be repaired at one time per die.
- NOTE 3 RESET command is required at the end of every PPR procedure.
- NOTE 4 During PPR, memory contents is not refreshed and may be lost.
- NOTE 5 Assert Reset_n below 0.2 X V_{DD2}. Reset_n needs to be maintained LOW for minimum tPW_RESET. CKE must be pulled LOW at least 10ns before deasserting Reset_n.
- NOTE 6 After RESET command, follow steps 4 to 10 in 'Voltage Ramp and Device Initialization' section.

Figure 149 — PPR Timing

Table 96 — PPR Timing Parameters

| Parameter | Symbol | min | max | Unit | Note |
|--------------------------|-----------|------|-----|------|------|
| PPR Programming Time | tPGM | 1000 | - | ms | |
| PPR Exit Time | tPGM_Exit | 15 | - | ns | |
| New Address Setting time | tPGMPST | 50 | - | us | |
| PPR Programming Clock | tCKPGM | 1.25 | - | ns | |

5 Absolute Maximum DC Ratings

Stresses greater than those listed 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.

Table 97 — Absolute Maximum DC Ratings

| Parameter | Symbol | Min | Max | Units | Notes |
|---|-------------------|------|-----|-------|-------|
| V_{DD1} supply voltage relative to V_{SS} | V_{DD1} | -0.4 | 2.1 | V | 1 |
| V_{DD2} supply voltage relative to V_{SS} | V_{DD2} | -0.4 | 1.5 | V | 1 |
| V_{DDQ} supply voltage relative to V_{SSQ} | V_{DDQ} | -0.4 | 1.5 | V | 1 |
| Voltage on any ball except V_{DD1} relative to V_{SS} | V_{IN}, V_{OUT} | -0.4 | 1.5 | V | |
| Storage Temperature | TSTG | -55 | 125 | °C | 2 |

NOTE 1 See "Power-Ramp" in 3.3 for relationships between power supplies.

NOTE 2 Storage Temperature is the case surface temperature on the center/top side of the LPDDR4 device. For the measurement conditions, please refer to JESD51-2.

6 AC and DC Operating Conditions

6.1 Recommended DC Operating Conditions

Table 98 — Recommended DC Operating Conditions

| DRAM | Symbol | Min | Typ | Max | Unit | Notes |
|---------------------------------|------------------|------|------|------|------|-------|
| Core 1 Power | V _{DD1} | 1.70 | 1.80 | 1.95 | V | 1,2 |
| Core 2 Power/Input Buffer Power | V _{DD2} | 1.06 | 1.10 | 1.17 | V | 1,2,3 |
| I/O Buffer Power | V _{DDQ} | 1.06 | 1.10 | 1.17 | V | 2,3 |

NOTE 1 V_{DD1} uses significantly less current than V_{DD2}.

NOTE 2 The voltage range is for DC voltage only. DC is defined as the voltage supplied at the DRAM and is inclusive of all noise up to 20MHz at the DRAM package ball.

NOTE 3 VdIVW and TdIVW limits described elsewhere in this document apply for voltage noise on supply voltages of up to 45 mV (peak-to-peak) from DC to 20MHz.

6.2 Input Leakage Current

Table 99 — Input Leakage Current

| Parameter/Condition | Symbol | Min | Max | Unit | Notes |
|-----------------------|----------------|-----|-----|------|-------|
| Input Leakage current | I _L | -4 | 4 | uA | 1,2 |

NOTE 1 For CK_t, CK_c, CKE, CS, CA, ODT_CA and RESET_n. Any input 0V ≤ V_{IN} ≤ V_{DD2} (All other pins not under test = 0V).

NOTE 2 CA ODT is disabled for CK_t, CK_c, CS, and CA.

6.3 Input/Output Leakage Current

Table 100 — Input/Output Leakage Current

| Parameter/Condition | Symbol | Min | Max | Unit | Notes |
|------------------------------|-----------------|-----|-----|------|-------|
| Input/Output Leakage current | I _{OZ} | -5 | 5 | uA | 1,2 |

NOTE 1 For DQ, DQS_t, DQS_c and DMI. Any I/O 0V ≤ V_{OUT} ≤ V_{DDQ}.

NOTE 2 I/Os status are disabled: High Impedance and ODT Off.

6.4 Operating Temperature Range

Table 101 — Operating Temperature Range

| Parameter/Condition | Symbol | Min | Max | Unit |
|---------------------|-------------------|-----|-----|------|
| Standard | T _{OPER} | -25 | 85 | C° |
| Elevated | | 85 | 105 | C° |

NOTE 1 Operating Temperature is the case surface temperature on the center-top side of the LPDDR4 device. For the measurement conditions, please refer to JESD51-2.

NOTE 2 Some applications require operation of LPDDR4 in the maximum temperature conditions in the Elevated Temperature Range between 85 °C and 105 °C case temperature. For LPDDR4 devices, derating may be necessary to operate in this range. See MR4.

NOTE 3 Either the device case temperature rating or the temperature sensor (see 4.40) may be used to set an appropriate refresh rate, determine the need for AC timing de-rating and/or monitor the operating temperature. When using the temperature sensor, the actual device case temperature may be higher than the T_{OPER} rating that applies for the Standard or Elevated Temperature Ranges. For example, T_{CASE} may be above 85 °C when the temperature sensor indicates a temperature of less than 85 °C.

7 AC and DC Input/Output Measurement levels

7.1 1.1 V High speed LVC MOS (HS_LLVC MOS)

7.1.1 Standard specifications

All voltages are referenced to ground except where noted.

7.1.2 DC electrical characteristics

7.1.2.1 LPDDR4 Input Level for CKE

This definition applies to CKE_A/B.

Table 102 — LPDDR4 Input Level for CKE

| Parameter | Symbol | Min | Max | Unit | Note |
|-----------------------|---------|-----------------------------|-----------------------------|------|------|
| Input high level (AC) | VIH(AC) | 0.75*V _{DD2} 0.825 | V _{DD2} +0.2 | V | 1 |
| Input low level (AC) | VIL(AC) | -0.2 | 0.25*V _{DD2} 0.275 | V | 1 |
| Input high level (DC) | VIH(DC) | 0.65*V _{DD2} 0.715 | V _{DD2} +0.2 | V | |
| Input low level (DC) | VIL(DC) | -0.2 | 0.35*V _{DD2} 0.385 | V | |

NOTE 1 Refer LPDDR4 AC Over/U n dershoot section.

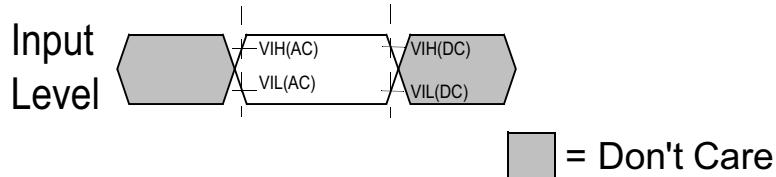


Figure 150 — LPDDR4 Input AC timing definition for CKE

7.1.2.2 LPDDR4 Input Level for Reset_n and ODT_CA

This definition applies to Reset_n and ODT_CA.

Table 103 — LPDDR4 Input Level for Reset_n and ODT_CA

| Parameter | Symbol | Min | Max | Unit | Note |
|------------------|--------|----------------------------|----------------------------|------|------|
| Input high level | VIH | 0.80*V _{DD2} 0.88 | V _{DD2} +0.2 | V | 1 |
| Input low level | VIL | -0.2 | 0.20*V _{DD2} 0.22 | V | 1 |

NOTE 1 Refer LPDDR4 AC Over/U n dershoot section.

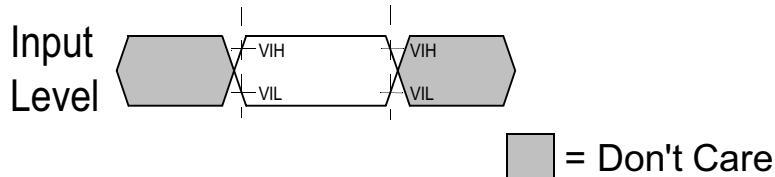


Figure 151 — LPDDR4 Input AC timing definition for Reset_n and ODT_CA

7.1.3 AC Over/Ubershoot

7.1.3.1 LPDDR4 AC Over/Ubershoot

Table 104 — LPDDR4 AC Over/Ubershoot

| Parameter | Specification |
|--|---------------|
| Maximum peak Amplitude allowed for overshoot area | 0.35 V |
| Maximum peak Amplitude allowed for undershoot area | 0.35 V |
| Maximum overshoot area above V_{DD}/V_{DDQ} | 0.8 V·ns |
| Maximum undershoot area below V_{SS}/V_{SSQ} | 0.8 V·ns |

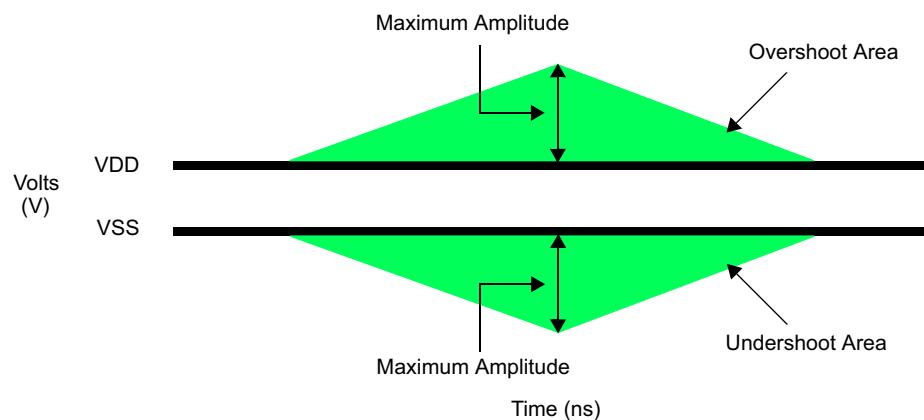


Figure 152 — AC Overshoot and Undershoot Definition for Address and Control Pins

7.2 Differential Input Voltage

7.2.1 Differential Input Voltage for CK

The minimum input voltage need to satisfy both Vindiff_CK and Vindiff_CK /2 specification at input receiver and their measurement period is 1tCK. Vindiff_CK is the peak to peak voltage centered on 0 volts differential and Vindiff_CK /2 is max and min peak voltage from 0V.

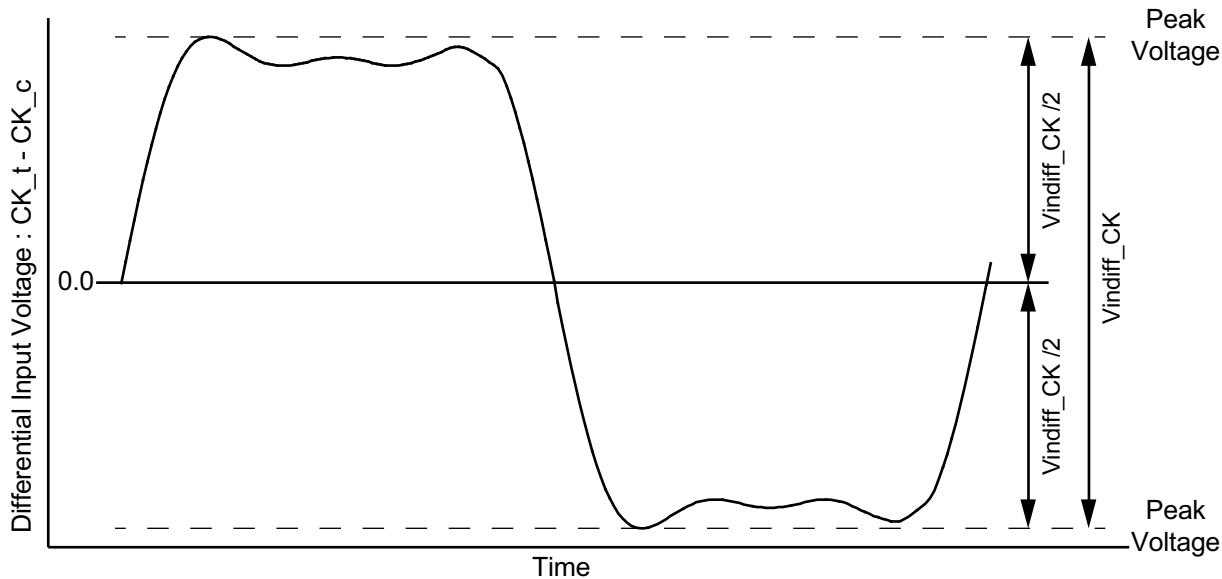


Figure 153 — CK Differential Input Voltage

Table 105 — CK differential input voltage

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|-------------------------------|------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| CK differential input voltage | Vindiff_CK | 420 | - | 380 | - | 360 | - | mV | 1 | | |

a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867.

NOTE 1 The peak voltage of Differential CK signals is calculated in a following equation.

$$\text{Vindiff}_\text{CK} = (\text{Max Peak Voltage}) - (\text{Min Peak Voltage})$$

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

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

$$f(t) = VCK_t - VCK_c$$

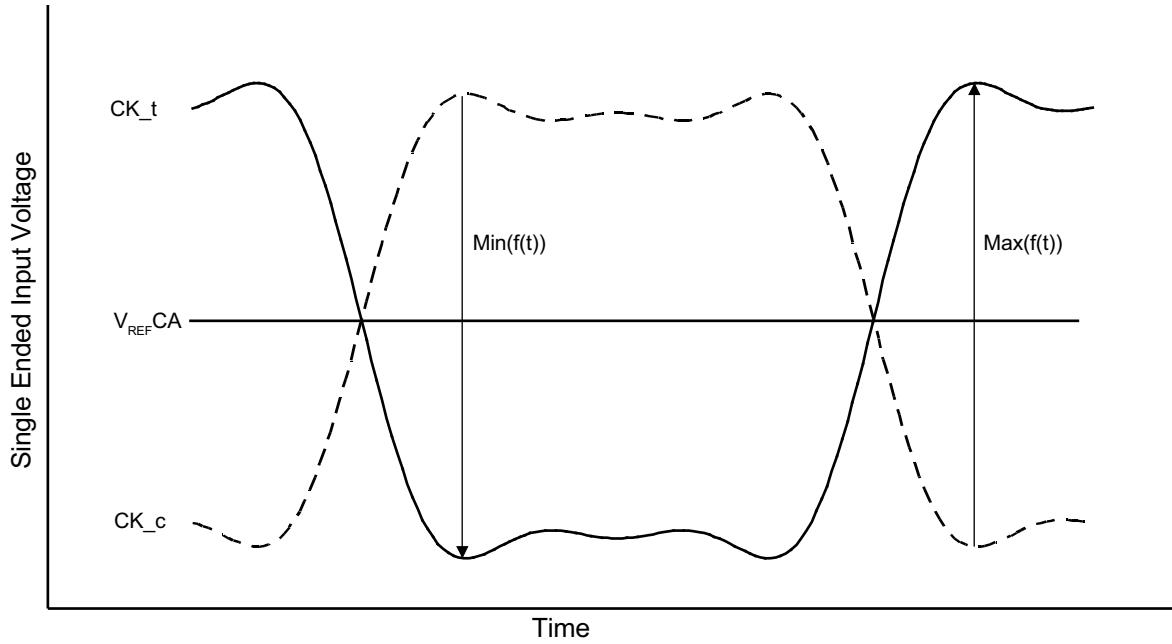
7.2.2 Peak voltage calculation method

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

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

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

$$f(t) = VCK_t - VCK_c$$

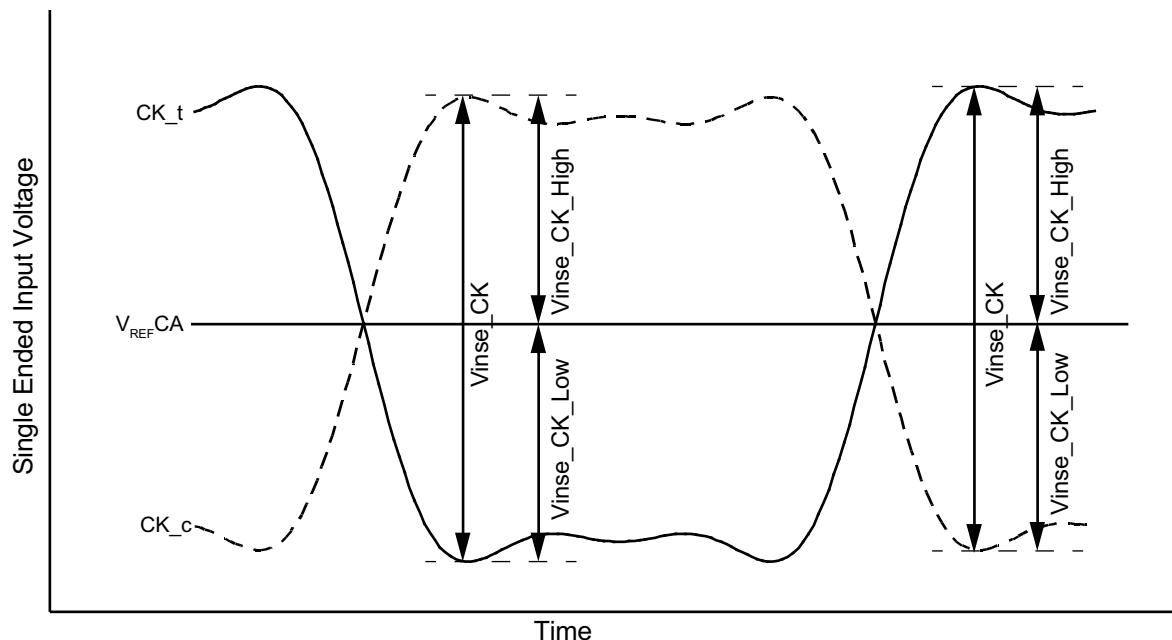


NOTES : 1. $V_{\text{REF CA}}$ is LPDDR4 SDRAM internal setting value by V_{REF} Training.

Figure 154 — Definition of differential Clock Peak Voltage

7.2.3 Single-Ended Input Voltage for Clock

The minimum input voltage need to satisfy both Vinse_CK, Vinse_CK_High/Low specification at input receiver.



NOTES : 1. $V_{REF\ CA}$ is LPDDR4 SDRAM internal setting value by V_{REF} Training.

Figure 155 — Clock Single-Ended Input Voltage

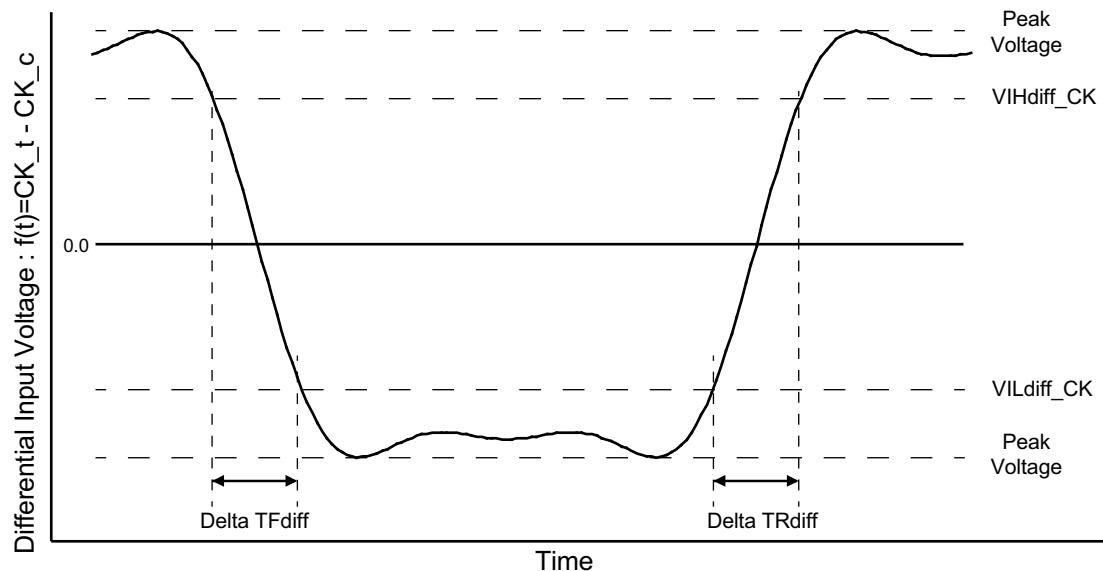
Table 106 — Clock Single-Ended input voltage

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|--|---------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| Clock Single-Ended input voltage | Vinse_CK | 210 | - | 190 | - | 180 | - | mV | | | |
| Clock Single-Ended input voltage High from $V_{REF\ DQ}$ | Vinse_CK_High | 105 | - | 95 | - | 90 | - | mV | | | |
| Clock Single-Ended input voltage Low from $V_{REF\ DQ}$ | Vinse_CK_Low | 105 | - | 95 | - | 90 | - | mV | | | |

a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867.

7.2.4 Differential Input Slew Rate Definition for Clock

Input slew rate for differential signals (CK_t , CK_c) are defined and measured as shown in Figure 156 and the following Tables.



NOTES : 1. Differential signal rising edge from VIL_{diff_CK} to VIH_{diff_CK} must be monotonic slope.
2. Differential signal falling edge from VIH_{diff_CK} to VIL_{diff_CK} must be monotonic slope.

Figure 156 — Differential Input Slew Rate Definition for CK_t , CK_c

Table 107 — Differential Input Slew Rate Definition for CK_t , CK_c

| Description | From | To | Defined by |
|--|------------------|------------------|--|
| | | | |
| Differential input slew rate for rising edge($CK_t - CK_c$) | VIL_{diff_CK} | VIH_{diff_CK} | $ VIL_{diff_CK} - VIH_{diff_CK} /\Delta T_{Rdiff}$ |
| Differential input slew rate for falling edge($CK_t - CK_c$) | VIH_{diff_CK} | VIL_{diff_CK} | $ VIL_{diff_CK} - VIH_{diff_CK} /\Delta T_{Fdiff}$ |

Table 108 — Differential Input Level for CK_t , CK_c

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|-------------------------|------------------|------------------------|------|----------------|------|-----------|------|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| Differential Input High | VIH_{diff_CK} | 175 | - | 155 | - | 145 | - | mV | | | |
| Differential Input Low | VIL_{diff_CK} | - | -175 | - | -155 | - | -145 | mV | | | |

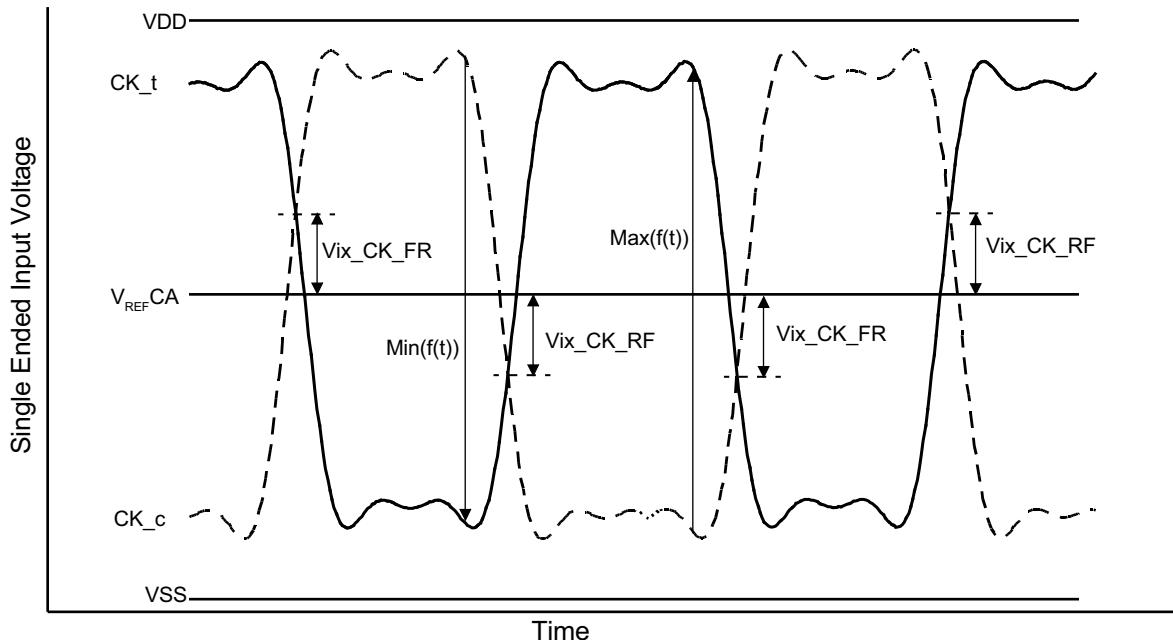
a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867.a

Table 109 — Differential Input Slew Rate for CK_t , CK_c

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|--|------------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| Differential Input Slew Rate for Clock | SRI_{diff_CK} | 2 | 14 | 2 | 14 | 2 | 14 | V/ns | | | |

7.2.5 Differential Input Cross Point Voltage

The cross point voltage of differential input signals (CK_t , CK_c) must meet the requirements in Table 110. The differential input cross point voltage V_{IX} is measured from the actual cross point of true and complement signals to the mid level that is V_{REFCA} .



NOTES : 1. The base level of $V_{IX_CK_FR/RF}$ is V_{REFCA} that is LPDDR4 SDRAM internal setting value by V_{REF} Training.

Figure 157 — Vix Definition (Clock)

Table 110 — Cross point voltage for differential input signals (Clock)

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|--|---------------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| Clock Differential input cross point voltage ratio | $V_{IX_CK_ratio}$ | - | 25 | - | 25 | - | 25 | % | 1,2 | | |
| a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867. | | | | | | | | | | | |

NOTE 1 $V_{IX_CK_Ratio}$ is defined by this equation: $V_{IX_CK_Ratio} = V_{IX_CK_FR}/|Min(f(t))|$

NOTE 2 $V_{IX_CK_Ratio}$ is defined by this equation: $V_{IX_CK_Ratio} = V_{IX_CK_RF}/Max(f(t))$

7.2.6 Differential Input Voltage for DQS

The minimum input voltage need to satisfy both Vindiff_DQS and Vindiff_DQS /2 specification at input receiver and their measurement period is 1UI(tCK/2). Vindiff_DQS is the peak to peak voltage centered on 0 volts differential and Vindiff_DQS /2 is max and min peak voltage from 0V.

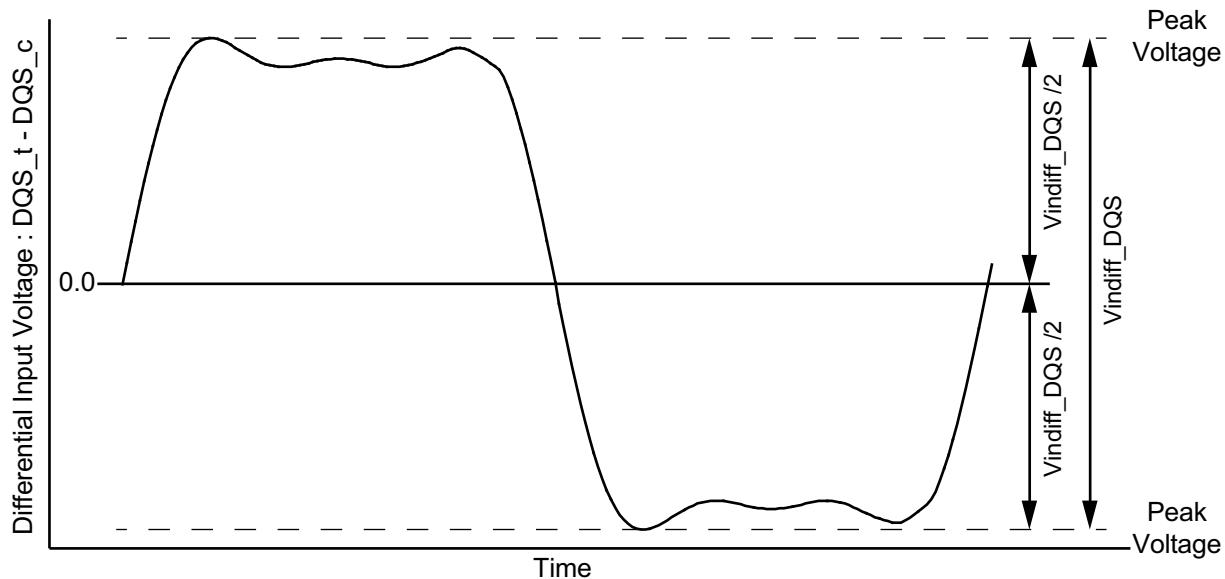


Figure 158 — DQS Differential Input Voltage

Table 111 — DQS differential input voltage

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|------------------------|-------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| DQS differential input | Vindiff_DQS | 360 | - | 360 | - | 340 | - | mV | 1 | | |

a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867

NOTE 1 The peak voltage of Differential DQS signals is calculated in a following equation.

$$\text{Vindiff_DQS} = (\text{Max Peak Voltage}) - (\text{Min Peak Voltage})$$

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

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

$$f(t) = \text{VDQS}_t - \text{VDQS}_c$$

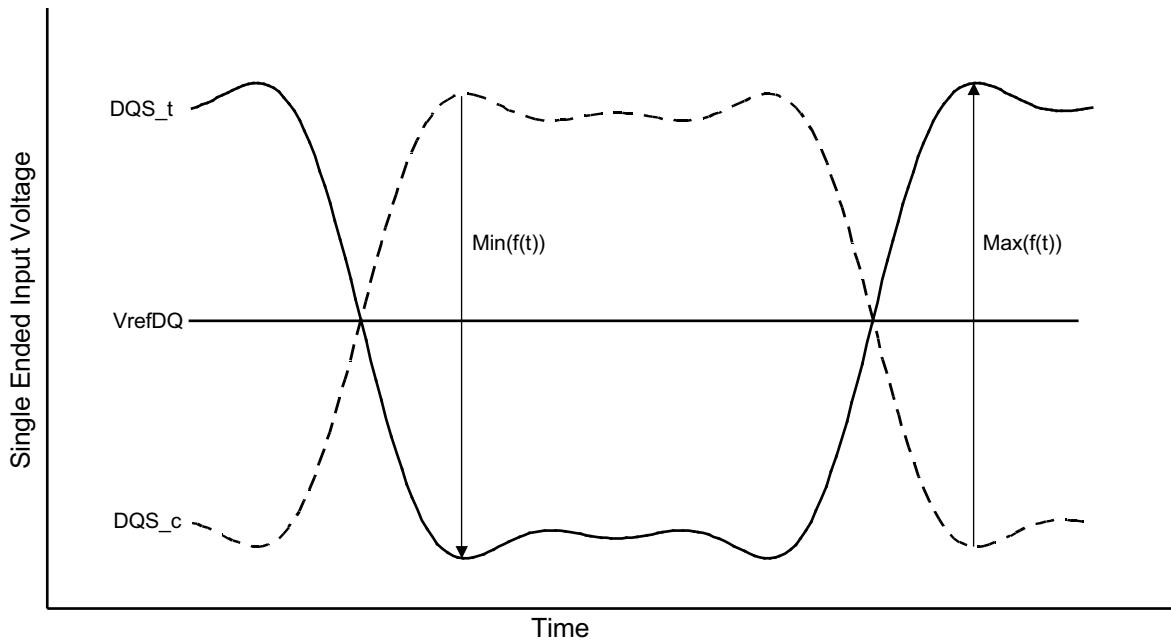
7.2.7 Peak voltage calculation method

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

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

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

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

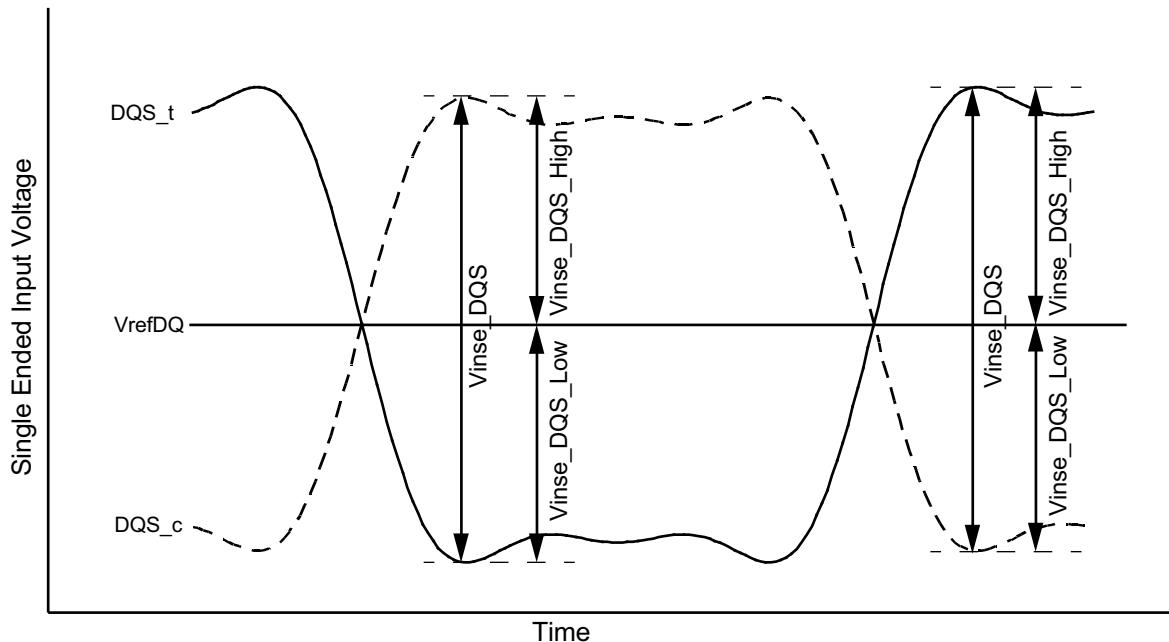


NOTES : 1. VrefDQ is LPDDR4 SDRAM internal setting value by Vref Training.

Figure 159 — Definition of differential DQS Peak Voltage

7.2.8 Single-Ended Input Voltage for DQS

The minimum input voltage need to satisfy both Vinse_DQS, Vinse_DQS_High/Low specification at input receiver.



NOTES : 1. VrefDQ is LPDDR4 SDRAM internal setting value by Vref Training.

Figure 160 — DQS Single-Ended Input Voltage

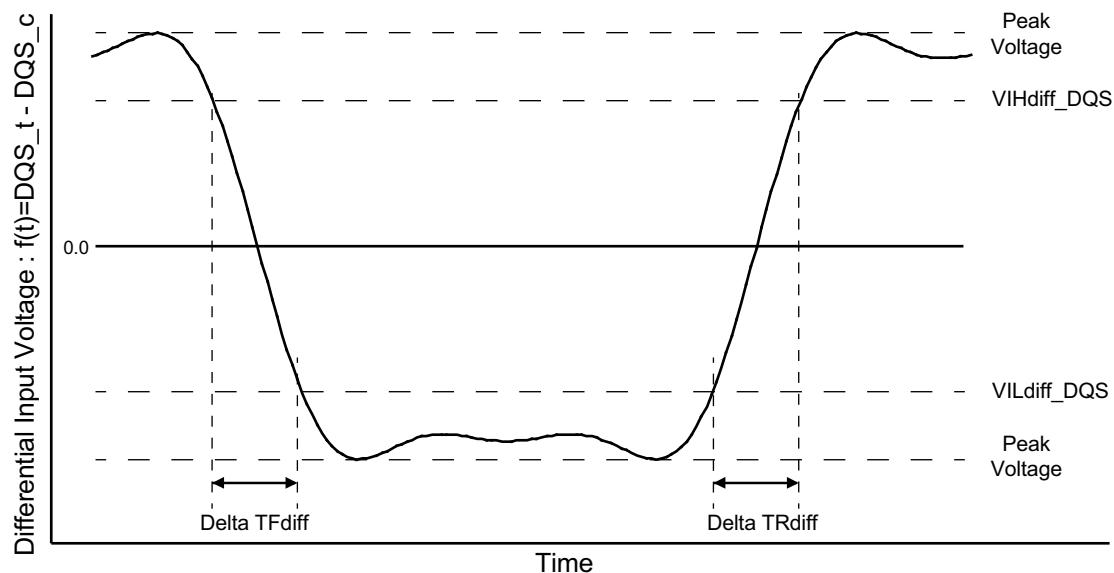
Table 112 — DQS Single-Ended input voltage

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|--|----------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| DQS Single-Ended input voltage | Vinse_DQS | 180 | - | 180 | - | 170 | - | mV | | | |
| DQS Single-Ended input voltage High from V _{REF} DQ | Vinse_DQS_High | 90 | - | 90 | - | 85 | - | mV | | | |
| DQS Single-Ended input voltage Low from V _{REF} DQ | Vinse_DQS_Low | 90 | - | 90 | - | 85 | - | mV | | | |

a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867.

7.2.9 Differential Input Slew Rate Definition for DQS

Input slew rate for differential signals (DQS_t , DQS_c) are defined and measured as shown in Figure 161 and Table 113.



NOTES : 1. Differential signal rising edge from VIL_{diff_DQS} to VIH_{diff_DQS} must be monotonic slope.
2. Differential signal falling edge from VIH_{diff_DQS} to VIL_{diff_DQS} must be monotonic slope.

Figure 161 — Differential Input Slew Rate Definition for DQS_t , DQS_c

Table 113 — Differential Input Slew Rate Definition for DQS_t , DQS_c

| Description | From | To | Defined by | | | |
|--|-------------------|-------------------|--|--|--|--|
| | | | | | | |
| Differential input slew rate for rising edge($DQS_t - DQS_c$) | VIL_{diff_DQS} | VIH_{diff_DQS} | $ VIL_{diff_DQS} - VIH_{diff_DQS} /\Delta TR_{diff}$ | | | |
| Differential input slew rate for falling edge($DQS_t - DQS_c$) | VIH_{diff_DQS} | VIL_{diff_DQS} | $ VIL_{diff_DQS} - VIH_{diff_DQS} /\Delta TF_{diff}$ | | | |

Table 114 — Differential Input Level for DQS_t , DQS_c

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|-------------------------|-------------------|------------------------|------|----------------|------|-----------|------|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| Differential Input High | VIH_{diff_DQS} | 140 | - | 140 | - | 120 | - | mV | | | |
| Differential Input Low | VIL_{diff_DQS} | - | -140 | - | -140 | - | -120 | mV | | | |

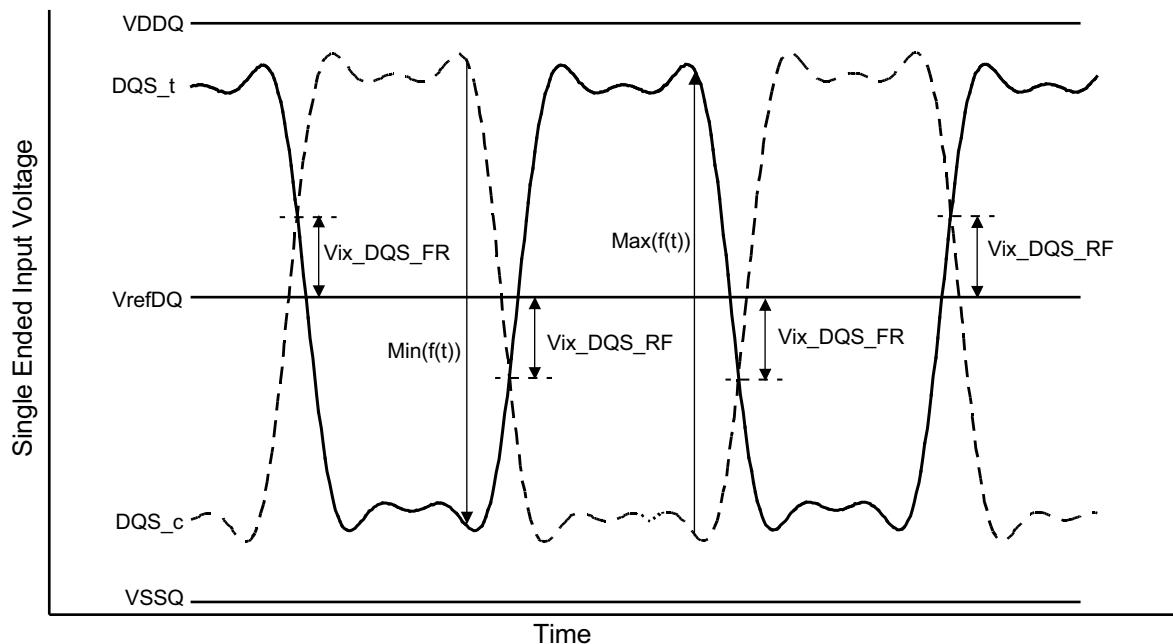
a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867.a

Table 115 — Differential Input Slew Rate for DQS_t , DQS_c

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|------------------------------|--------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| Differential Input Slew Rate | SR_{Idiff} | 2 | 14 | 2 | 14 | 2 | 14 | V/ns | | | |

7.2.10 Differential Input Cross Point Voltage

The cross point voltage of differential input signals (DQS_t, DQS_c) must meet the requirements in Table 116. The differential input cross point voltage VIX is measured from the actual cross point of true and complement signals to the mid level that is V_{REFDQ} .



NOTES : 1. The base level of Vix_DQS_RF/RF is VrefDQ that is LPDDR4 SDRAM internal setting value by Vref Training.

Figure 162 — Vix Definition (DQS)

Table 116 — Cross point voltage for differential input signals (DQS)

| Parameter | Symbol | Data Rate | | | | | | Unit | Note | | |
|--|---------------|------------------------|-----|----------------|-----|-----------|-----|------|------|--|--|
| | | 1600/1867 ^a | | 2133/2400/3200 | | 3733/4266 | | | | | |
| | | Min | Max | Min | Max | Min | Max | | | | |
| DQS Differential input cross point voltage ratio | Vix_DQS_ratio | - | 20 | - | 20 | - | 20 | % | 1,2 | | |

a. The following requirements apply for DQ operating frequencies at or below 1333Gbps for all speed bins for the first column 1600/1867.

NOTE 1 Vix_DQS_Ratio is defined by this equation: $Vix_DQS_Ratio = Vix_DQS_FR / |Min(f(t))|$.

NOTE 2 Vix_DQS_Ratio is defined by this equation: $Vix_DQS_Ratio = Vix_DQS_RF / Max(f(t))$

7.3 AC/DC Input level for ODT input

Table 117 — LPDDR4 Input Level for ODT

| Symbol | | Min | Max | Unit | Note |
|------------|---------------------------|---------------|---------------|------|------|
| VIHODT(AC) | ODT Input High Level (AC) | $0.75*V_{DD}$ | $V_{DD}+0.2$ | V | 1 |
| VILODT(AC) | ODT Input Low Level (AC) | -0.2 | $0.25*V_{DD}$ | V | 1 |
| VIHODT(DC) | ODT Input High Level (DC) | $0.65*V_{DD}$ | $V_{DD}+0.2$ | V | |
| VILODT(DC) | ODT Input Low Level (DC) | -0.2 | $0.35*V_{DD}$ | V | |

NOTE 1 See Overshoot and Undershoot Specifications.

7.4 Single Ended Output Slew Rate

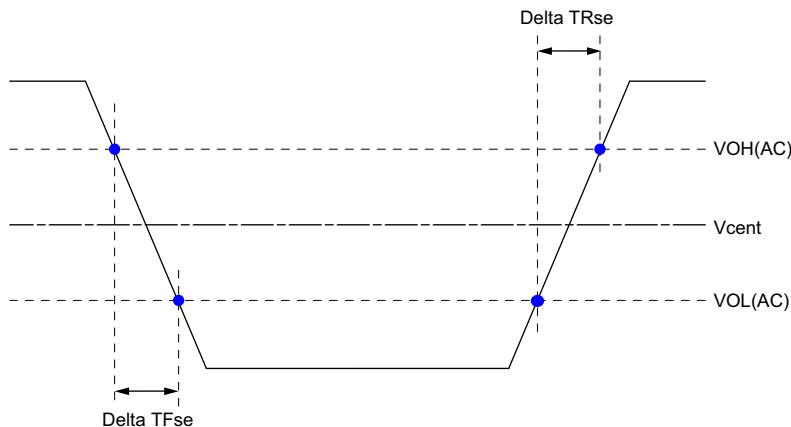


Figure 163 — Single Ended Output Slew Rate Definition

Table 118 — Output Slew Rate (single-ended)

| Parameter | Symbol | Value | | Units |
|---|--------|------------------|------------------|-------|
| | | Min ¹ | Max ² | |
| Single-ended Output Slew Rate ($VOH = V_{DDQ}/3$) | SRQse | 3.5 | 9 | V/ns |
| Output slew-rate matching Ratio (Rise to Fall) | - | 0.8 | 1.2 | - |

Description: SR: Slew Rate

Q: Query Output (like in DQ, which stands for Data-in, Query-Output)

se: Single-ended Signals

Notes: 1. Measured with output reference load.

2. The ratio of pull-up to pull-down slew rate is specified for the same temperature and voltage, over the entire temperature and voltage range. For a given output, it represents the maximum difference between pull-up and pull-down drivers due to process variation.
3. The output slew rate for falling and rising edges is defined and measured between $VOL(AC)=0.2*VOH(DC)$ and $VOH(AC)=0.8*VOH(DC)$.
4. Slew rates are measured under average SSO conditions, with 50% of DQ signals per data byte switching.

7.5 Differential Output Slew Rate

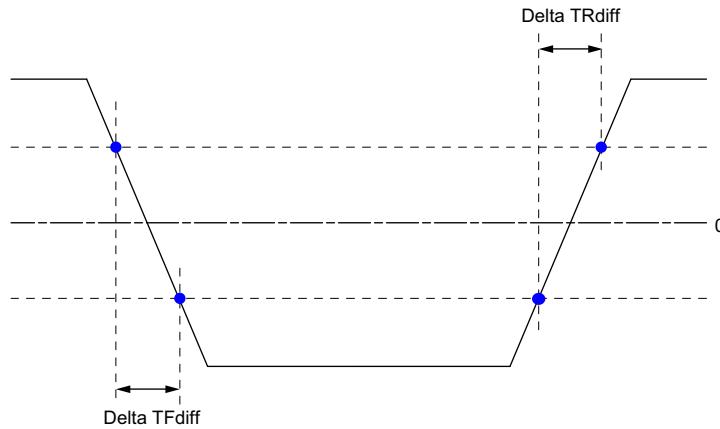


Figure 164 — Differential Output Slew Rate Definition

Table 119 — Differential Output Slew Rate

| Parameter | Symbol | Value | | Units |
|--|---------|-------|-----|-------|
| | | Min | Max | |
| Differential Output Slew Rate ($V_{OH}=V_{DDQ}/3$) | SRQdiff | 7 | 18 | V/ns |

Description:

SR: Slew Rate

Q: Query Output (like in DQ, which stands for Data-in, Query-Output)

diff: Differential Signals

NOTE 1 Measured with output reference load.

NOTE 2 The output slew rate for falling and rising edges is defined and measured between $V_{OL}(AC) = -0.8 \cdot V_{OH}(DC)$ and $V_{OH}(AC) = 0.8 \cdot V_{OH}(DC)$.

NOTE 3 Slew rates are measured under average SSO conditions, with 50% of DQ signals per data byte switching.

7.6 Overshoot and Undershoot for LVSTL

Table 120 — AC Overshoot/Undershoot Specification

| Parameter | | Data Rate | | | | Units |
|---|-----|-----------|------|------|------|-------|
| | | 1600 | 1866 | 3200 | 4266 | |
| Maximum peak amplitude allowed for overshoot area. (See Figure 165) | Max | 0.3 | 0.3 | 0.3 | TBD | V |
| Maximum peak amplitude allowed for undershoot area. (See Figure 165) | Max | 0.3 | 0.3 | 0.3 | TBD | V |
| Maximum area above V _{DD} . (See Figure 165) | Max | 0.1 | 0.1 | 0.1 | TBD | V-ns |
| Maximum area below V _{SS} . (See Figure 165) | Max | 0.1 | 0.1 | 0.1 | TBD | V-ns |

NOTE 1 V_{DD2} stands for V_{DD} for CA[5:0], CK_t, CK_c, CS_n, CKE and ODT. V_{DD} stands for V_{DDQ} for DQ, DMI, DQS_t and DQS_c.

NOTE 2 V_{SS} stands for V_{SS} for CA[5:0], CK_t, CK_c, CS_n, CKE and ODT. V_{SS} stands for V_{SSQ} for DQ, DMI, DQS_t and DQS_c.

NOTE 3 Maximum peak amplitude values are referenced from actual V_{DD} and V_{SS} values.

NOTE 4 Maximum area values are referenced from maximum operating V_{DD} and V_{SS} values.

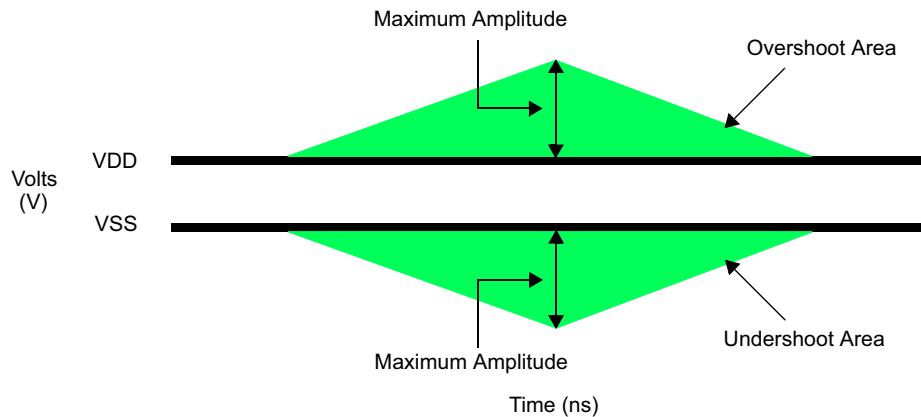
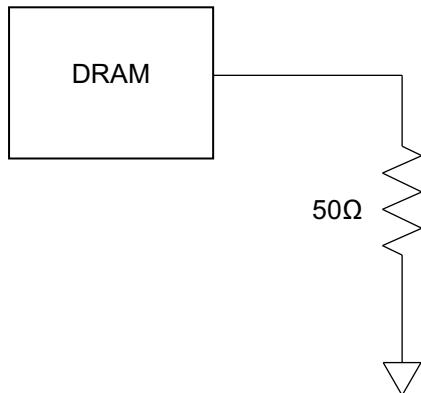


Figure 165 — Overshoot and Undershoot Definition

7.7 LPDDR4 Driver Output Timing Reference load

These 'Timing Reference Loads' are 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.



Note

1. All output timing parameter values are reported with respect to this reference load.
This reference load is also used to report slew rate.

Figure 166 — Driver Output Reference Load for Timing and Slew Rate

7.8 LVSTL(Low Voltage Swing Terminated Logic) IO System

LVSTL I/O cell is comprised of pull-up, pull-down driver and a terminator. The basic cell is shown in Figure 167.

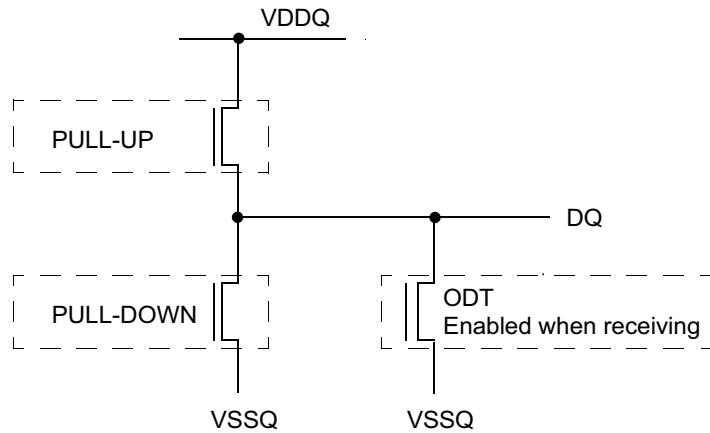


Figure 167 — LVSTL I/O Cell

To ensure that the target impedance is achieved the LVSTL I/O cell is designed to calibrated as below procedure.

1. First calibrate the pull-down device against a $240\ \Omega$ resistor to V_{DDQ} via the ZQ pin.
 - Set Strength Control to minimum setting.
 - Increase drive strength until comparator detects data bit is less than $V_{DDQ}/2$.
 - NMOS pull-down device is calibrated to $240\ \Omega$.

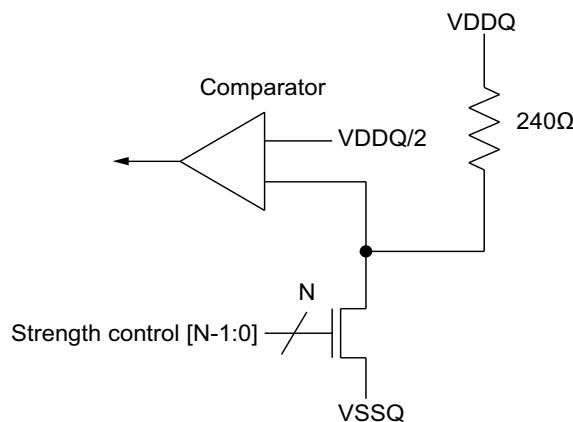


Figure 168 — Pull-down calibration

2. Then calibrate the pull-up device against the calibrated pull-down device.

- Set VOH target and NMOS controller ODT replica via MRS (VOH can be automatically controlled by ODT MRS).
- Set Strength Control to minimum setting.
- Increase drive strength until comparator detects data bit is greater than VOH target.
- NMOS pull-up device is now calibrated to VOH target.

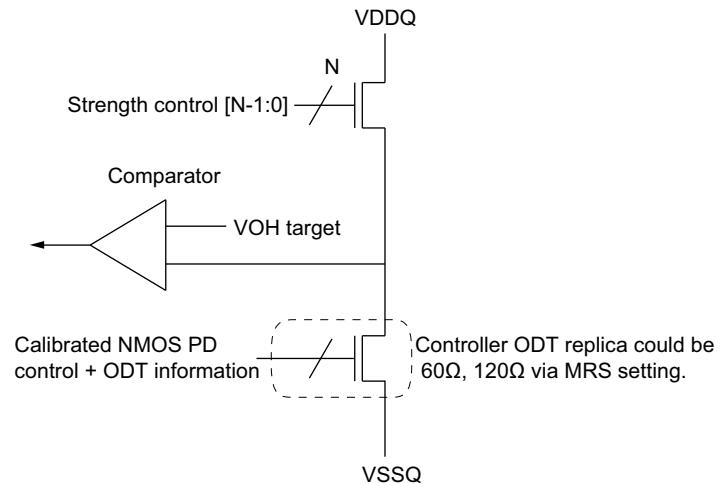


Figure 169 — Pull-up calibration

8 Input/Output Capacitance

Table 121 — Input/output capacitance

| Parameter | Symbol | | LPDDR4 3200-533 | LPDDR4 4266-3733 | Units | Notes |
|--|--------|-----|--------------------|---------------------|-------|-------|
| Input capacitance, CK_t and CK_c | CCK | Min | 0.5 | TBD | pF | 1,2 |
| | | Max | 0.9 | TBD | pF | 1,2 |
| Input capacitance delta, CK_t and CK_c | CDCK | Min | 0.0 | TBD | pF | 1,2,3 |
| | | Max | 0.09 | TBD | pF | 1,2,3 |
| Input capacitance, All other input-only pins | CI | Min | 0.5 | TBD | pF | 1,2,4 |
| | | Max | 0.9 | TBD | pF | 1,2,4 |
| Input capacitance delta, All other input-only pins | CDI | Min | -0.1 | TBD | pF | 1,2,5 |
| | | Max | 0.1 | TBD | pF | 1,2,5 |
| Input/output capacitance, DQ, DMI, DQS_t, DQS_c | CIO | Min | 0.7 | TBD | pF | 1,2,6 |
| | | Max | 1.3 | TBD | pF | 1,2,6 |
| Input/output capacitance delta, DQS_t, DQS_c | CDDQS | Min | 0.0 | TBD | pF | 1,2,7 |
| | | Max | 0.1 | TBD | pF | 1,2,7 |
| Input/output capacitance delta, DQ, DMI | CDIO | Min | -0.1 | TBD | pF | 1,2,8 |
| | | Max | 0.1 | TBD | pF | 1,2,8 |
| Input/output capacitance, ZQ pin | CZQ | Min | 0.0 | TBD | pF | 1,2 |
| | | Max | 5.0 | TBD | pF | 1,2 |

NOTE 1 This parameter applies to die device only (does not include package capacitance).

NOTE 2 This parameter is not subject to production test. It is verified by design and characterization. The capacitance is measured according to JEP147 (Procedure for measuring input capacitance using a vector network analyzer (VNA) with V_{DD1}, V_{DD2}, V_{DDQ}, V_{SS}, V_{SSQ} applied and all other pins floating.

NOTE 3 Absolute value of CCK_t . CCK_c.

NOTE 4 CI applies to CS_n, CKE, CA0~CA5.

NOTE 5 CDI = CI . 0.5 * (CCK_t + CCK_c)

NOTE 6 DMI loading matches DQ and DQS.

NOTE 7 Absolute value of CDQS_t and CDQS_c.

NOTE 8 CDIO = CIO . 0.5 * (CDQS_t + CDQS_c) in byte-lane.

9 I_{DD} Specification Parameters and Test Conditions

9.1 I_{DD} Measurement Conditions

The following definitions are used within the I_{DD} measurement tables unless stated otherwise:

LOW: $VIN \leq VIL(DC)$ MAX

HIGH: $VIN \geq VIH(DC)$ MIN

STABLE: Inputs are stable at a HIGH or LOW level

SWITCHING: See Table 122 and Table 123.

Table 122 — Definition of Switching for CA Input Signals

| Switching for CA | | | | | | | | |
|------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| CK_t edge | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 |
| CKE | HIGH |
| CS | LOW |
| CA0 | HIGH | LOW | LOW | LOW | LOW | HIGH | HIGH | HIGH |
| CA1 | HIGH | HIGH | HIGH | LOW | LOW | LOW | LOW | HIGH |
| CA2 | HIGH | LOW | LOW | LOW | LOW | HIGH | HIGH | HIGH |
| CA3 | HIGH | HIGH | HIGH | LOW | LOW | LOW | LOW | HIGH |
| CA4 | HIGH | LOW | LOW | LOW | LOW | HIGH | HIGH | HIGH |
| CA5 | HIGH | HIGH | HIGH | LOW | LOW | LOW | LOW | HIGH |

NOTE 1 CS must always be driven LOW.

NOTE 2 50% of CA bus is changing between HIGH and LOW once per clock for the CA bus.

NOTE 3 The pattern is used continuously during I_{DD} measurement for I_{DD} values that require switching on the CA bus.

Table 123 — CA pattern for $I_{DD}4R$

| Clock Cycle Number | CKE | CS | Command | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |
|---------------------------|------------|-----------|----------------|------------|------------|------------|------------|------------|------------|
| N | HIGH | HIGH | Read-1 | L | H | L | L | L | L |
| N+1 | HIGH | LOW | | L | H | L | L | L | L |
| N+2 | HIGH | HIGH | CAS-2 | L | H | L | L | H | L |
| N+3 | HIGH | LOW | | L | L | L | L | L | L |
| N+4 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+5 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+6 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+7 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+8 | HIGH | HIGH | Read-1 | L | H | L | L | L | L |
| N+9 | HIGH | LOW | | L | H | L | L | H | L |
| N+10 | HIGH | HIGH | CAS-2 | L | H | L | L | H | H |
| N+11 | HIGH | LOW | | H | H | H | H | H | H |
| N+12 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+13 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+14 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+15 | HIGH | LOW | DES | L | L | L | L | L | L |

NOTE 1 BA[2:0] = 010, CA[9:4] = 000000 or 111111, Burst Order CA[3:2] = 00 or 11 (Same as LPDDR3 $I_{DD}4R$).

NOTE 2 Difference from LPDDR3 (JESD209-3): CA pins are kept low with DES CMD to reduce ODT current.

Table 124 — CA pattern for I_{DD}4W

| Clock Cycle Number | CKE | CS | Command | CA0 | CA1 | CA2 | CA3 | CA4 | CA5 |
|--------------------|------|------|---------|-----|-----|-----|-----|-----|-----|
| N | HIGH | HIGH | Write-1 | L | L | H | L | L | L |
| N+1 | HIGH | LOW | | L | H | L | L | L | L |
| N+2 | HIGH | HIGH | CAS-2 | L | H | L | L | H | L |
| N+3 | HIGH | LOW | | L | L | L | L | L | L |
| N+4 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+5 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+6 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+7 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+8 | HIGH | HIGH | Write-1 | L | L | H | L | L | L |
| N+9 | HIGH | LOW | | L | H | L | L | H | L |
| N+10 | HIGH | HIGH | CAS-2 | L | H | L | L | H | H |
| N+11 | HIGH | LOW | | L | L | H | H | H | H |
| N+12 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+13 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+14 | HIGH | LOW | DES | L | L | L | L | L | L |
| N+15 | HIGH | LOW | DES | L | L | L | L | L | L |

NOTE 1 BA[2:0] = 010, CA[9:4] = 000000 or 111111 (Same as LPDDR3 I_{DD}4W).

NOTE 2 Difference from LPDDR3 (JESD209-3): 1)-No burst ordering, and 2) CA pins are kept low with DES CMD to reduce ODT current.

Table 125 — Data Pattern for I_{DD}4W (DBI off)

| | DBI OFF Case | | | | | | | | | No. of 1's |
|-----------------------|--------------|-------|-------|-------|-------|-------|-------|-------|-----|---------------|
| | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI | |
| BL0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL6 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL7 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL9 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL11 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL13 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL14 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL15 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL16 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL17 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL18 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL19 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL21 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL23 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL24 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL25 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL26 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL27 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL28 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL29 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL31 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| No. of 1's | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | | |

NOTE 1 Simplified pattern compared predecessor. Same data pattern was applied to DQ[4], DQ[5], DQ[6], DQ[7] for reducing complexity for I_{DD}4W/R pattern programming.

Table 126 — Data Pattern for I_{DD}4R (DBI off)

| | DBI OFF Case | | | | | | | | | No. of 1's |
|---------------|--------------|-------|-------|-------|-------|-------|-------|-------|-----|---------------|
| | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI | |
| BL0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL6 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL7 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL9 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL11 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL13 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL14 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL15 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL17 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL19 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL20 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL21 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL22 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL23 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL25 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL26 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8 |
| BL27 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL28 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL29 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL30 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| BL31 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| No. of 1's | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | | |

NOTE 1 Same data pattern was applied to DQ[4], DQ[5], DQ[6], DQ[7] for reducing complexity for I_{DD}4W/R pattern programming.

Table 127 — Data Pattern for I_{DD}4W (DBI on)

| | DBI ON Case | | | | | | | | | | No. of 1's |
|---------------|-------------|-------|-------|-------|-------|-------|-------|-------|-----|--|---------------|
| | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI | | |
| BL0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | 1 |
| BL1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| BL3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | | 2 |
| BL5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | 3 |
| BL7 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | 1 |
| BL9 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| BL11 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | | 2 |
| BL13 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL14 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | 3 |
| BL15 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL16 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | 3 |
| BL17 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL18 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | | 2 |
| BL19 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| BL21 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | 1 |
| BL23 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL24 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | | 2 |
| BL25 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| BL26 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | | 3 |
| BL27 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | 1 |
| BL29 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | | 4 |
| BL30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| BL31 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | | 4 |
| No. of 1's | 8 | 8 | 8 | 8 | 8 | 8 | 16 | 16 | 8 | | |

NOTE 1 DBI enabled burst

Table 128 — Data Pattern for I_{DD}4R (DBI on)

| | DBI ON Case | | | | | | | | | No. of 1's |
|---------------|-------------|-------|-------|-------|-------|-------|-------|-------|-----|---------------|
| | DQ[7] | DQ[6] | DQ[5] | DQ[4] | DQ[3] | DQ[2] | DQ[1] | DQ[0] | DBI | |
| BL0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| BL1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 |
| BL7 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| BL9 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL11 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL13 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL14 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 |
| BL15 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| BL17 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL19 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL20 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 |
| BL21 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL22 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL23 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BL25 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| BL27 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| BL28 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| BL29 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| BL30 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 |
| BL31 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| No. of 1's | 8 | 8 | 8 | 8 | 8 | 8 | 16 | 16 | 8 | |

9.2 I_{DD} Specifications

I_{DD} values are for the entire operating voltage range, and all of them are for the entire standard range, with the exception of I_{DD6ET} which is for the entire elevated temperature range.

Table 129 — LPDDR4 I_{DD} Specification Parameters and Operating Conditions

| Parameter/Condition | Symbol | Power Supply | Notes |
|---|---------------|--------------|-------|
| Operating one bank active-precharge current: $tCK = tCKmin$; $tRC = tRCmin$; CKE is HIGH; CS is LOW between valid commands; CA bus inputs are switching; Data bus inputs are stable ODT disabled | I_{DD0_1} | V_{DD1} | |
| | I_{DD0_2} | V_{DD2} | |
| | I_{DD0_Q} | V_{DDQ} | 3 |
| Idle power-down standby current: $tCK = tCKmin$; CKE is LOW; CS is LOW; All banks are idle; CA bus inputs are switching; Data bus inputs are stable ODT disabled | I_{DD2P_1} | V_{DD1} | |
| | I_{DD2P_2} | V_{DD2} | |
| | I_{DD2P_Q} | V_{DDQ} | 3 |
| Idle power-down standby current with clock stop: $CK_t = LOW$, $CK_c = HIGH$; CKE is LOW; CS is LOW; All banks are idle; CA bus inputs are stable; Data bus inputs are stable ODT disabled | I_{DD2PS_1} | V_{DD1} | |
| | I_{DD2PS_2} | V_{DD2} | |
| | I_{DD2PS_Q} | V_{DDQ} | 3 |
| Idle non power-down standby current: $tCK = tCKmin$; CKE is HIGH; CS is LOW; All banks are idle; CA bus inputs are switching; Data bus inputs are stable ODT disabled | I_{DD2N_1} | V_{DD1} | |
| | I_{DD2N_2} | V_{DD2} | |
| | I_{DD2N_Q} | V_{DDQ} | 3 |
| Idle non power-down standby current with clock stopped: $CK_t = LOW$; $CK_c = HIGH$; CKE is HIGH; CS is LOW; All banks are idle; CA bus inputs are stable; Data bus inputs are stable ODT disabled | I_{DD2NS_1} | V_{DD1} | |
| | I_{DD2NS_2} | V_{DD2} | |
| | I_{DD2NS_Q} | V_{DDQ} | 3 |

Table 129 — LPDDR4 I_{DD} Specification Parameters and Operating Conditions (cont'd)

| Parameter/Condition | Symbol | Power Supply | Notes |
|---|---------------------|------------------|-------|
| Active power-down standby current: tCK = tCKmin; CKE is LOW; CS is LOW; One bank is active; CA bus inputs are switching; Data bus inputs are stable ODT disabled | I _{DD3P1} | V _{DD1} | |
| | I _{DD3P2} | V _{DD2} | |
| | I _{DD3PQ} | V _{DDQ} | 3 |
| Active power-down standby current with clock stop: CK_t=LOW, CK_c=HIGH; CKE is LOW; CS is LOW; One bank is active; CA bus inputs are stable; Data bus inputs are stable ODT disabled | I _{DD3PS1} | V _{DD1} | |
| | I _{DD3PS2} | V _{DD2} | |
| | I _{DD3PSQ} | V _{DDQ} | 4 |
| Active non-power-down standby current: tCK = tCKmin; CKE is HIGH; CS is LOW; One bank is active; CA bus inputs are switching; Data bus inputs are stable ODT disabled | I _{DD3N1} | V _{DD1} | |
| | I _{DD3N2} | V _{DD2} | |
| | I _{DD3NQ} | V _{DDQ} | 4 |
| Active non-power-down standby current with clock stopped: CK_t=LOW, CK_c=HIGH; CKE is HIGH; CS is LOW; One bank is active; CA bus inputs are stable; Data bus inputs are stable ODT disabled | I _{DD3NS1} | V _{DD1} | |
| | I _{DD3NS2} | V _{DD2} | |
| | I _{DD3NSQ} | V _{DDQ} | 4 |
| Operating burst READ current: tCK = tCKmin; CS is LOW between valid commands; One bank is active; BL = 16 or 32; RL = RL(MIN); CA bus inputs are switching; 50% data change each burst transfer ODT disabled | I _{DD4R1} | V _{DD1} | |
| | I _{DD4R2} | V _{DD2} | |
| | I _{DD4RQ} | V _{DDQ} | 5 |

Table 129 — LPDDR4 IDD Specification Parameters and Operating Conditions (cont'd)

| Parameter/Condition | Symbol | Power Supply | Notes |
|--|--------------------------------|------------------|------------|
| Operating burst WRITE current: tCK = tCKmin; CS is LOW between valid commands; One bank is active; BL = 16 or 32; WL = WLmin; CA bus inputs are switching; 50% data change each burst transfer ODT disabled | I _{DD4W₁} | V _{DD1} | |
| | I _{DD4W₂} | V _{DD2} | |
| | I _{DD4W_Q} | V _{DDQ} | 4 |
| All bank REFRESH Burst current: tCK = tCKmin; CKE is HIGH between valid commands; tRC = tRFCabmin; Burst refresh; CA bus inputs are switching; Data bus inputs are stable; ODT disabled | I _{DD5₁} | V _{DD1} | |
| | I _{DD5₂} | V _{DD2} | |
| | I _{DD5_Q} | V _{DDQ} | 4 |
| All bank REFRESH Average current: tCK = tCKmin; CKE is HIGH between valid commands; tRC = tREFI; CA bus inputs are switching; Data bus inputs are stable; ODT disabled | I _{DD5AB₁} | V _{DD1} | |
| | I _{DD5AB₂} | V _{DD2} | |
| | I _{DD5AB_Q} | V _{DDQ} | 4 |
| Per bank REFRESH Average current: tCK = tCKmin; CKE is HIGH between valid commands; tRC = tREFI/8; CA bus inputs are switching; Data bus inputs are stable; ODT disabled | I _{DD5PB₁} | V _{DD1} | |
| | I _{DD5PB₂} | V _{DD2} | |
| | I _{DD5PB_Q} | V _{DDQ} | 4 |
| Power Down Self Refresh current (-25 °C to +85 °C): CK_t=LOW, CK_c=HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable; Maximum 1x Self Refresh Rate; ODT disabled | I _{DD6₁} | V _{DD1} | 6,7,8,10 |
| | I _{DD6₂} | V _{DD2} | 6,7,8,10 |
| | I _{DD6_Q} | V _{DDQ} | 4,6,7,8,10 |

Table 129 — LPDDR4 I_{DD} Specification Parameters and Operating Conditions (cont'd)

| Parameter/Condition | Symbol | Power Supply | Notes |
|--|--------------|--------------|----------|
| Power Down Self Refresh current (+85 °C to +105 °C): CK_t=LOW, CK_c=HIGH; CKE is LOW; CA bus inputs are stable; Data bus inputs are stable; Maximum 1x Self Refresh Rate; ODT disabled | I_{DD6ET1} | V_{DD1} | 7,8,11 |
| | I_{DD6ET2} | V_{DD2} | 7,8,11 |
| | I_{DD6ETQ} | V_{DDQ} | 4,7,8,11 |

NOTE 1 Published I_{DD} values are the maximum of the distribution of the arithmetic mean.

NOTE 2 ODT disabled: MR11[2:0] = 000B.

NOTE 3 I_{DD} current specifications are tested after the device is properly initialized.

NOTE 4 Measured currents are the summation of V_{DDQ} and V_{DD2} .

NOTE 5 Guaranteed by design with output load = 5pF and RON = 40 Ω.

NOTE 6 The 1x Self Refresh Rate is the rate at which the LPDDR4 device is refreshed internally during Self Refresh, before going into the elevated Temperature range.

NOTE 7 This is the general definition that applies to full array Self Refresh.

NOTE 8 Supplier datasheets may contain additional Self Refresh I_{DD} values for temperature subranges within the Standard or elevated Temperature Ranges.

NOTE 9 For all I_{DD} measurements, VIHCKE = 0.8 × V_{DD2} , VILCKE = 0.2 × V_{DD2} .

NOTE 10 I_{DD6} 85 °C is guaranteed, I_{DD6} 45 °C is typical of the distribution of the arithmetic mean.

NOTE 11 I_{DD6ET} is a typical value, is sampled only, and is not tested.

NOTE 12 Dual Channel devices are specified in dual channel operation (both channels operating together).

10 Electrical Characteristics and AC Timing

10.1 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 LPDDR4 device.

10.1.1 Definition for tCK(avg) and nCK

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

$$tCK(\text{avg}) = \left(\sum_{j=1}^N tCK_j \right) / N$$

where $N = 200$

Unit ‘tCK(avg)’ represents the actual clock average tCK(avg) of the input clock under operation. Unit ‘nCK’ represents one clock cycle of the input clock, counting the actual clock edges.
tCK(avg) may change by up to +/-1% within a 100 clock cycle window, provided that all jitter and timing specs are met.

10.1.2 Definition for tCK(abs)

tCK(abs) is defined as the absolute clock period, as measured from one rising edge to the next consecutive rising edge.

tCK(abs) is not subject to production test.

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

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

$$tCH(\text{avg}) = \left(\sum_{j=1}^N tCH_j \right) / (N \times tCK(\text{avg}))$$

where $N = 200$

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

$$tCL(\text{avg}) = \left(\sum_{j=1}^N tCL_j \right) / (N \times tCK(\text{avg}))$$

where $N = 200$

10.1.4 Definition for tCH(abs) and tCL(abs)

tCH(abs) is the absolute instantaneous clock high pulse width, as measured from one rising edge to the following falling edge.

tCL(abs) is the absolute instantaneous clock low pulse width, as measured from one falling edge to the following rising edge.

Both tCH(abs) and tCL(abs) are not subject to production test.

10.1.5 Definition for tJIT(per)

tJIT(per) is the single period jitter defined as the largest deviation of any signal tCK from tCK(avg).

tJIT(per) = Min/max of {tCK_i - tCK(avg) where i = 1 to 200}.

tJIT(per),act is the actual clock jitter for a given system.

tJIT(per),allowed is the specified allowed clock period jitter.

tJIT(per) is not subject to production test.

10.1.6 Definition for tJIT(cc)

tJIT(cc) is defined as the absolute difference in clock period between two consecutive clock cycles.

tJIT(cc) = Max of |{tCK(i +1) - tCK(i)}|.

tJIT(cc) defines the cycle to cycle jitter.

tJIT(cc) is not subject to production test.

10.2 Clock Timing

Table 130 — Clock AC Timings

| Parameter | Symbol | LPDDR4-1600 | | LPDDR4-2400 | | LPDDR4-3200 | | LPDDR4-4266 | | Units | Notes |
|---|-----------|---------------------------------------|------|---------------------------------------|------|---------------------------------------|------|---------------------------------------|-----|----------|-------|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Clock Timing | | | | | | | | | | | |
| Average clock period | tCK(avg) | 1.25 | 100 | 0.833 | 100 | 0.625 | 100 | 0.468 | 100 | ns | |
| Average High pulse width | tCH(avg) | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | TBD | TBD | tCK(avg) | |
| Average Low pulse width | tCL(avg) | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | TBD | TBD | tCK(avg) | |
| Absolute clock period | tCK(abs) | tCK(avg) MIN + tJIT(per) MIN | - | tCK(avg) MIN + tJIT(per) MIN | - | tCK(avg) MIN + tJIT(per) MIN | - | tCK(avg) MIN + tJIT(per) MIN | - | ns | |
| Absolute High clock pulse width | tCH(abs) | 0.43 | 0.57 | 0.43 | 0.57 | 0.43 | 0.57 | TBD | TBD | tCK(avg) | |
| Absolute Low clock pulse width | tCL(abs) | 0.43 | 0.57 | 0.43 | 0.57 | 0.43 | 0.57 | TBD | TBD | tCK(avg) | |
| Clock period jitter | tJIT(per) | -70 | 70 | -50 | 50 | -40 | 40 | - | TBD | ps | |
| Maximum Clock Jitter between consecutive cycles | tJIT(cc) | - | 140 | - | 100 | - | 80 | - | TBD | ps | |

10.2 Clock Timing

Table 130 — Clock AC Timings

| Parameter | Symbol | LPDDR4-1600 | | LPDDR4-2400 | | LPDDR4-3200 | | LPDDR4-4266 | | Units | Notes |
|---|-----------|---------------------------------------|------|---------------------------------------|------|---------------------------------------|------|---------------------------------------|-----|----------|-------|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Clock Timing | | | | | | | | | | | |
| Average clock period | tCK(avg) | 1.25 | 100 | 0.833 | 100 | 0.625 | 100 | 0.468 | 100 | ns | |
| Average High pulse width | tCH(avg) | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | TBD | TBD | tCK(avg) | |
| Average Low pulse width | tCL(avg) | 0.46 | 0.54 | 0.46 | 0.54 | 0.46 | 0.54 | TBD | TBD | tCK(avg) | |
| Absolute clock period | tCK(abs) | tCK(avg) MIN + tJIT(per) MIN | - | tCK(avg) MIN + tJIT(per) MIN | - | tCK(avg) MIN + tJIT(per) MIN | - | tCK(avg) MIN + tJIT(per) MIN | - | ns | |
| Absolute High clock pulse width | tCH(abs) | 0.43 | 0.57 | 0.43 | 0.57 | 0.43 | 0.57 | TBD | TBD | tCK(avg) | |
| Absolute Low clock pulse width | tCL(abs) | 0.43 | 0.57 | 0.43 | 0.57 | 0.43 | 0.57 | TBD | TBD | tCK(avg) | |
| Clock period jitter | tJIT(per) | -70 | 70 | -50 | 50 | -40 | 40 | - | TBD | ps | |
| Maximum Clock Jitter between consecutive cycles | tJIT(cc) | - | 140 | - | 100 | - | 80 | - | TBD | ps | |

10.3 Temperature Derating for AC timing

Table 131 — Temperature Derating AC Timing

| Parameter | Symbol | Min/ Max | Data Rate | | | | | | | | Unit | Note |
|--|--------|-------------|-----------|------|------|------|------|------|------|------|------|------|
| | | | 533 | 1066 | 1600 | 2133 | 2667 | 3200 | 3733 | 4267 | | |
| Temperature Derating ¹ | | | | | | | | | | | | |
| DQS output access time from CK_tCK_c (derated) | tDQSCK | MAX | | | | | | | | | ps | |
| RAS-to-CAS delay (derated) | tRCD | MIN | | | | | | | | | ns | |
| ACTIVATE-to- ACTIVATE command period (derated) | tRC | MIN | | | | | | | | | ns | |
| Row active time (derated) | tRAS | MIN | | | | | | | | | ns | |
| Row precharge time (derated) | tRP | MIN | | | | | | | | | ns | |
| Active bank A to active bank B (derated) | tRRD | MIN | | | | | | | | | ns | |

Note.1 : Timing derating applies for operation at 85 °C to 105 °C.

10.4 CA Rx voltage and timing

The command and address(CA) including CS input receiver compliance mask for voltage and timing is shown in Figure 170. All CA, CS signals apply the same compliance mask and operate in single data rate mode.

The CA input receiver mask for voltage and timing is shown in Figure 171 is applied across all CA pins. The receiver mask (Rx Mask) defines the area that the input signal must not encroach in order for the DRAM input receiver to be expected to be able to successfully capture a valid input signal; it is not the valid data-eye.

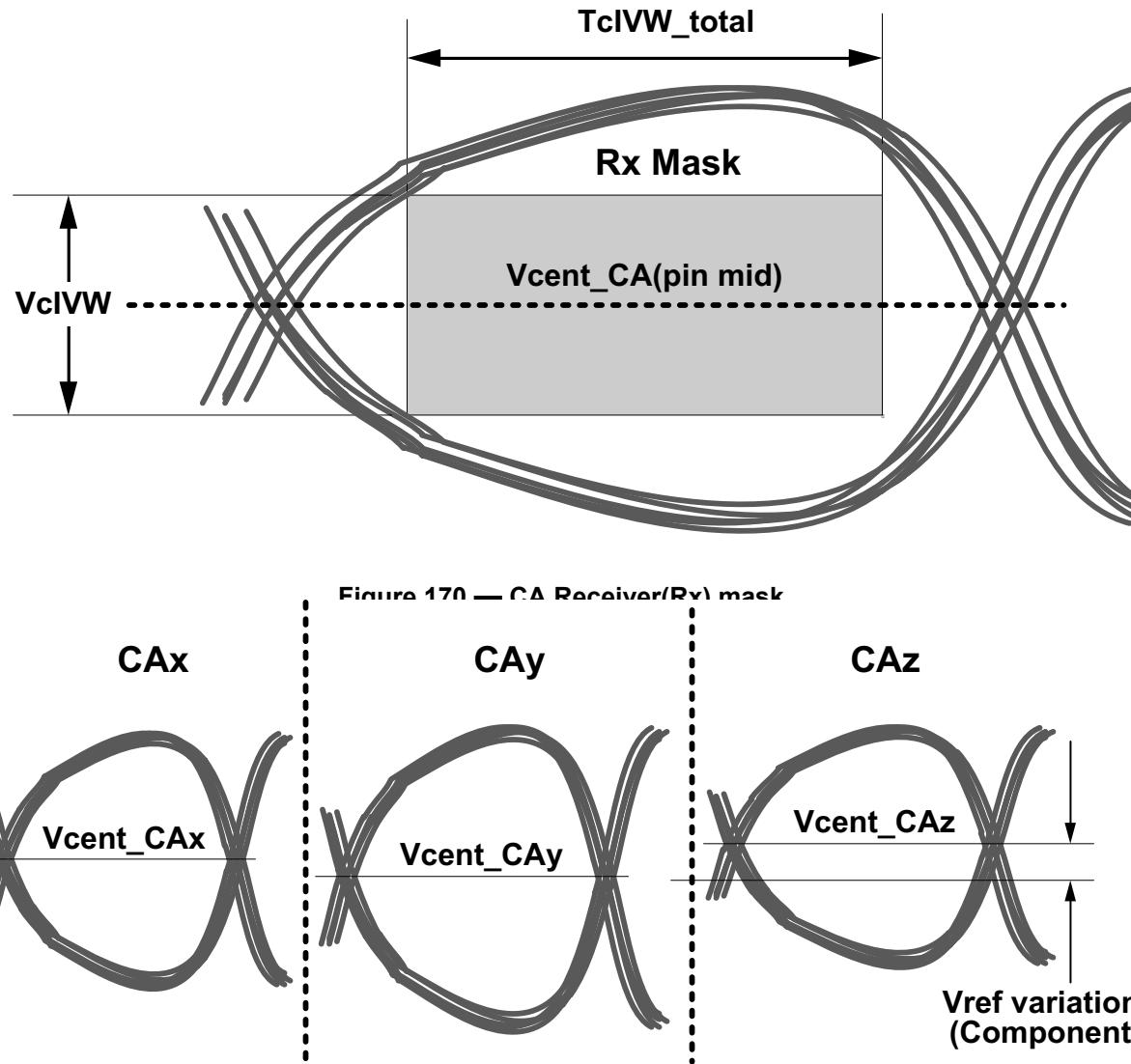
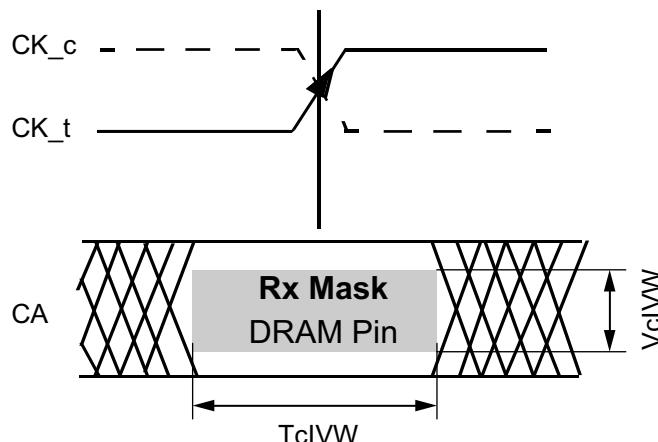


Figure 171 — Across pin V_{REFCA} voltage variation

$V_{cent_CA}(\text{pin mid})$ is defined as the midpoint between the largest V_{cent_CA} voltage level and the smallest V_{cent_CA} voltage level across all CA and CS pins for a given DRAM component. Each CA V_{cent} level is defined by the center, i.e., widest opening, of the cumulative data input eye as depicted in Figure 171. This clarifies that any DRAM component level variation must be accounted for within the DRAM CA Rx mask. The component level V_{REF} will be set by the system to account for R_{on} and ODT settings.

CK_t, CK_c Data-in at DRAM Pin

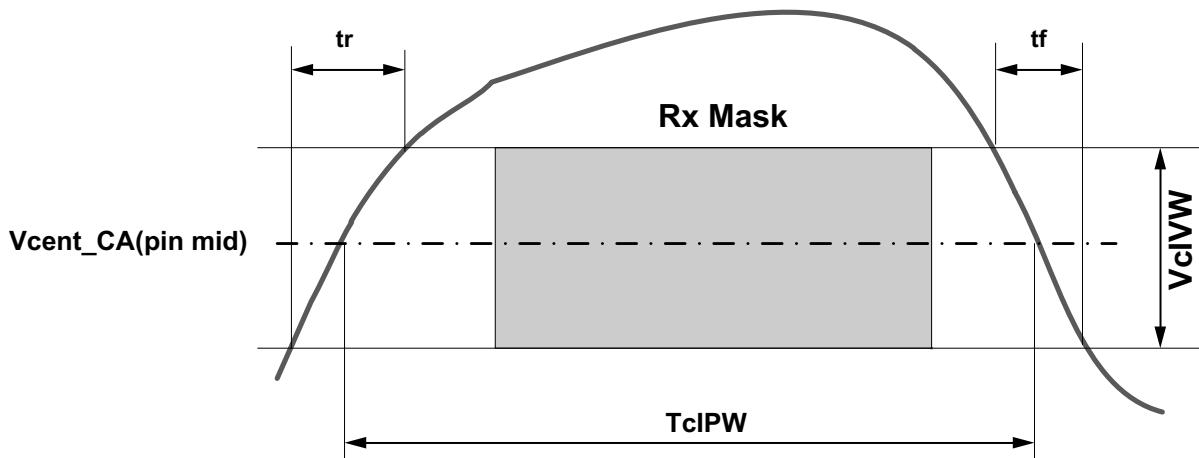
Minimum CA Eye center aligned



T_{ClVW} for all CA signals is defined as centered on the CK_t/CK_c crossing at the DRAM pin.

Figure 172 — CA Timings at the DRAM Pins

All of the timing terms in Figure 172 are measured from the CK_t/CK_c to the center(midpoint) of the T_{ClVW} window taken at the V_{ClVW_total} voltage levels centered around $V_{cent_CA}(\text{pin mid})$.



Note

1. $\text{SRIN}_{\text{ClVW}} = V_{ClVW_Total} / (tr \text{ or } tf)$, signal must be monotonic within tr and tf range.

Figure 173 — CA T_{cIPW} and $\text{SRIN}_{\text{ClVW}}$ definition (for each input pulse)

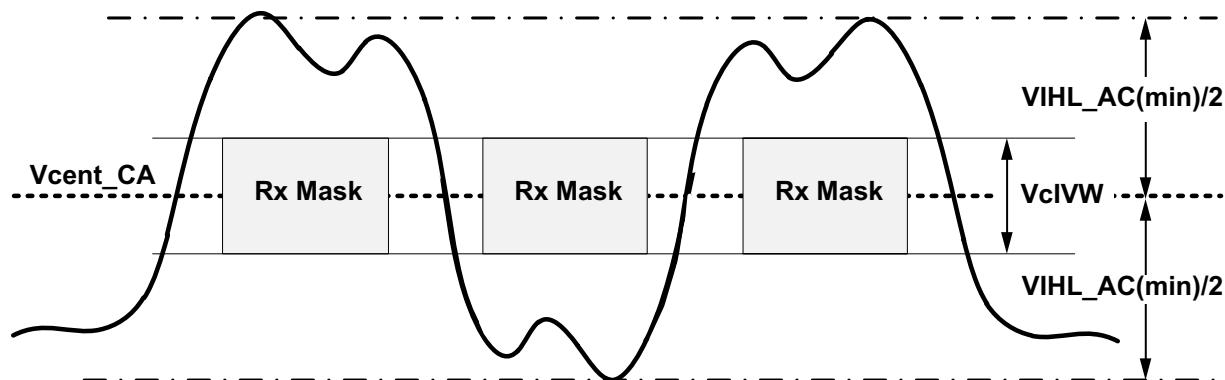


Figure 174 — CA VIHL_AC definition (for each input pulse)

Table 132 — DRAM CMD/ADR, CS

* UI=tck(avg)min

| Symbol | Parameter | DQ-1333 ^A | | DQ-1600/1867 | | DQ-3200 | | DQ-4266 | | Unit | NOTE |
|-----------|-----------------------------------|----------------------|-----|--------------|-----|---------|-----|---------|-----|------|-------|
| | | min | max | min | max | min | max | min | max | | |
| VclVW | Rx Mask voltage - p-p | - | 175 | - | 175 | - | 155 | - | 145 | mV | 1,2,3 |
| TclVW | Rx timing window | - | 0.3 | - | 0.3 | - | 0.3 | - | 0.3 | UI* | 1,2,3 |
| VIHL_AC | CA AC input pulse amplitude pk-pk | 210 | - | 210 | - | 190 | - | 180 | - | mV | 4,7 |
| TclPW | CA input pulse width | 0.55 | | 0.55 | | 0.6 | | 0.6 | | UI* | 5 |
| SRIN_cIVW | Input Slew Rate over VclVW | 1 | 7 | 1 | 7 | 1 | 7 | 1 | 7 | V/ns | 6 |

A. The following Rx voltage and absolute timing requirements apply for DQ operating frequencies at or below 1333 for all speed bins. For example the TclVW(ps) = 450ps at or below 1333 operating frequencies.

NOTE 1 CA Rx mask voltage and timing parameters at the pin including voltage and temperature drift.

NOTE 2 Rx mask voltage VclVW total(max) must be centered around Vcent_CA(pin mid).

NOTE 3 Vcent_CA must be within the adjustment range of the CA internal Vref.

NOTE 4 CA only input pulse signal amplitude into the receiver must meet or exceed VIHL AC at any point over the total UI. No timing requirement above level. VIHL AC is the peak to peak voltage centered around Vcent_CA(pin mid) such that VIHL_AC/2 min must be met both above and below Vcent_CA.

NOTE 5 CA only minimum input pulse width defined at the Vcent_CA(pin mid).

NOTE 6 Input slew rate over VclVW Mask centered at Vcent_CA(pin mid).

NOTE 7 VIHL_AC does not have to be met when no transitions are occurring.

10.5 DRAM Data Timing

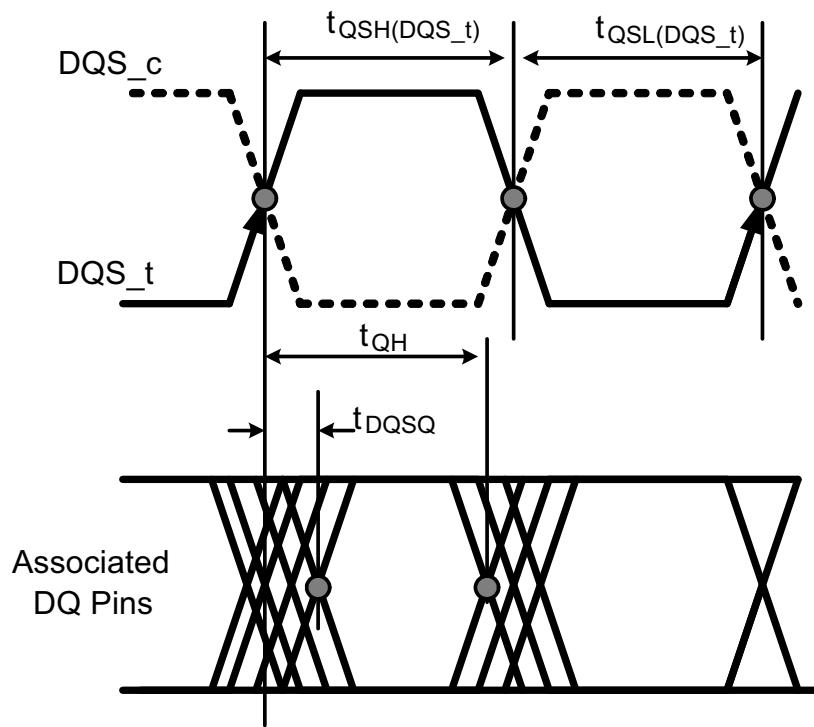


Figure 175 — Read data timing definitions t_{QH} and t_{DQSQ} across all DQ signals per DQS group

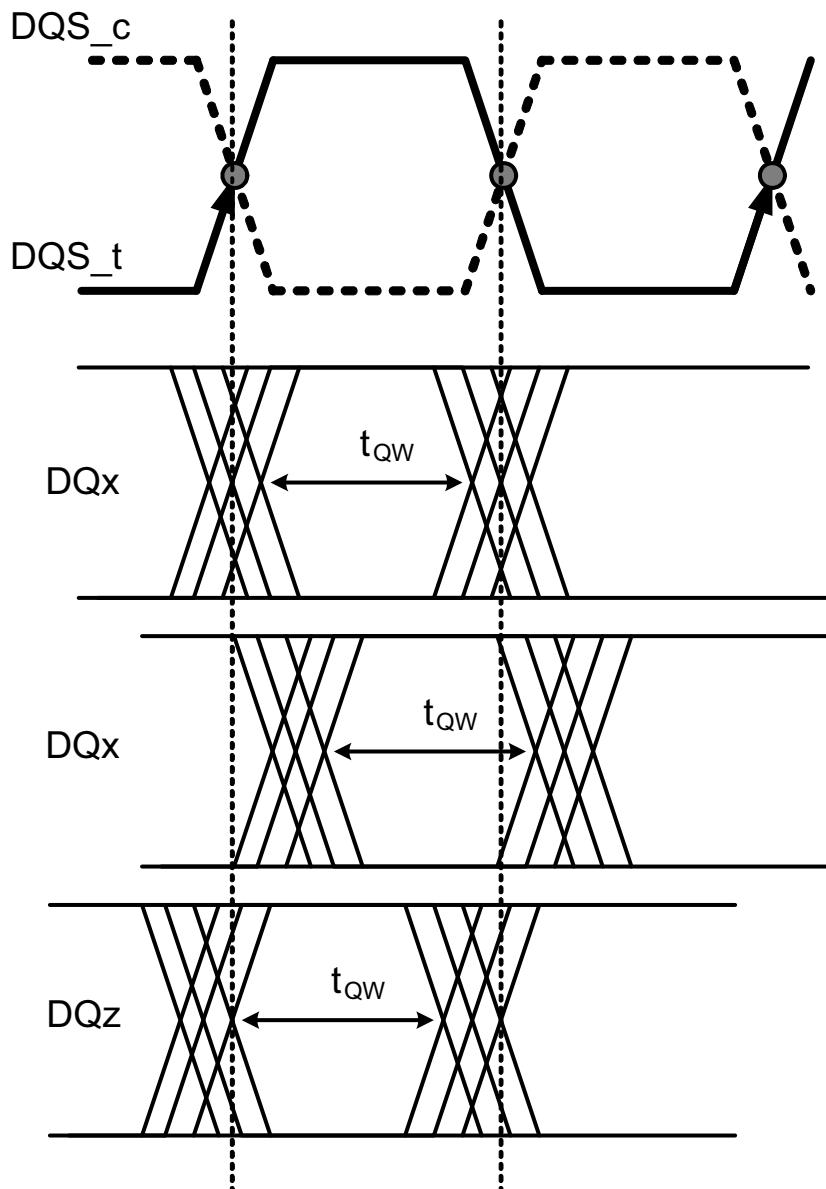


Figure 176 — Read data timing t_{QW} valid window defined per DQ signal

Table 133 — Read output timings

Unit UI = tCK(avg)min/2

| Parameter | Symbol | LPDDR4-1600/1867 | | LPDDR4-2133/2400 | | LPDDR4-3200 | | LPDDR4-4266 | | Units | Notes |
|---|---------------|----------------------------|------|----------------------------|------|----------------------------|------|----------------------------|------|-------|-------|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Data Timing | | | | | | | | | | | |
| DQS_t,DQS_c to DQ Skew total, per group, per access (DBIDisabled) | tDQSQ | - | 0.18 | - | 0.18 | - | 0.18 | - | 0.18 | UI | |
| DQ output hold time total from DQS_t, DQS_c (DBI-Disabled) | tQH | min(tQSH, tQSL) | - | min(tQSH, tQSL) | - | min(tQSH, tQSL) | - | min(tQSH, tQSL) | - | UI | |
| DQ output window time total, per pin (DBI-Disabled) | tQW_total | 0.75 | - | 0.73 | - | 0.7 | - | 0.7 | - | UI | 3 |
| DQ output window time deterministic, per pin (DBIDisabled) | tQW_dj | tbd | - | tbd | - | tbd | - | tbd | - | UI | 2,3 |
| DQS_t,DQS_c to DQ Skew total,per group, per access (DBI-Enabled) | tDQSQ_DB1 | - | 0.18 | - | 0.18 | - | 0.18 | - | 0.18 | UI | |
| DQ output hold time total from DQS_t, DQS_c (DBI-Enabled) | tQH_DB1 | min(tQSH_DB1, tQSL_DB1) | - | min(tQSH_DB1, tQSL_DB1) | - | min(tQSH_DB1, tQSL_DB1) | - | min(tQSH_DB1, tQSL_DB1) | tbd | UI | |
| DQ output window time total, per pin (DBI-Enabled) | tQW_total_DB1 | 0.75 | - | 0.73 | - | 0.70 | - | 0.70 | - | UI | 3 |

Table 133 — Read output timings (cont'd)

Unit UI = tCK(avg)min/2

| Parameter | Symbol | LPDDR4-1600/1867 | | LPDDR4-2133/2400 | | LPDDR4-3200 | | LPDDR4-4266 | | Units | Notes |
|--|----------|--------------------|-----|--------------------|-----|--------------------|-----|--------------------|-----|----------|-------|
| | | Min | Max | Min | Max | Min | Max | Min | Max | | |
| Data Strobe Timing | | | | | | | | | | | |
| DQS, DQS# differential output low time (DBI-Disabled) | tQSL | tCL(abs) -0.05 | - | tCL(abs) -0.05 | - | tCL(abs) -0.05 | - | tCL(abs) -0.05 | - | tCK(avg) | 3,4 |
| DQS, DQS# differential output high time (DBI-Disabled) | tQSH | tCH(abs) -0.05 | - | tCH(abs) -0.05 | - | tCH(abs) -0.05 | - | tCH(abs) -0.05 | - | tCK(avg) | 3,5 |
| DQS, DQS# differential output low time (DBI-Enabled) | tQSL_DB1 | tCL(abs) -0.045 | - | tCL(abs) -0.045 | - | tCL(abs) -0.045 | - | tCL(abs) -0.045 | - | tCK(avg) | 4,6 |
| DQS, DQS# differential output high time (DBI-Enabled) | tQSH_DB1 | tCH(abs) -0.045 | - | tCH(abs) -0.045 | - | tCH(abs) -0.045 | - | tCH(abs) -0.045 | - | tCK(avg) | 5,6 |

NOTE 1 The deterministic component of the total timing. Measurement method tbd.

NOTE 2 This parameter will be characterized and guaranteed by design.

NOTE 3 This parameter is function of input clock jitter. These values assume the min tCH(abs) and tCL(abs). When the input clock jitter min tCH(abs) and tCL(abs) is 0.44 or greater of tck(avg) the min value of tQSL will be tCL(abs)-0.04 and tQSH will be tCH(abs) -0.04.

NOTE 4 tQSL describes the instantaneous differential output low pulse width on DQS_t - DQS_c, as it measured the next rising edge from an arbitrary falling edge.

NOTE 5 tQSH describes the instantaneous differential output high pulse width on DQS_t - DQS_c, as it measured the next rising edge from an arbitrary falling edge.

NOTE 6 This parameter is function of input clock jitter. These values assume the min tCH(abs) and tCL(abs). When the input clock jitter min tCH(abs) and tCL(abs) is 0.44 or greater of tck(avg) the min value of tQSL will be tCL(abs)-0.04 and tQSH will be tCH(abs) -0.04.

10.6 DQ Rx voltage and timing

The DQ input receiver mask for voltage and timing is shown in Figure 177 is applied per pin. The "total" mask ($VdIVW_{total}$, $TdIVW_{total}$) defines the area the input signal must not encroach in order for the DQ input receiver to successfully capture an input signal with a BER of lower than tbd. The mask is a receiver property and it is not the valid data-eye.

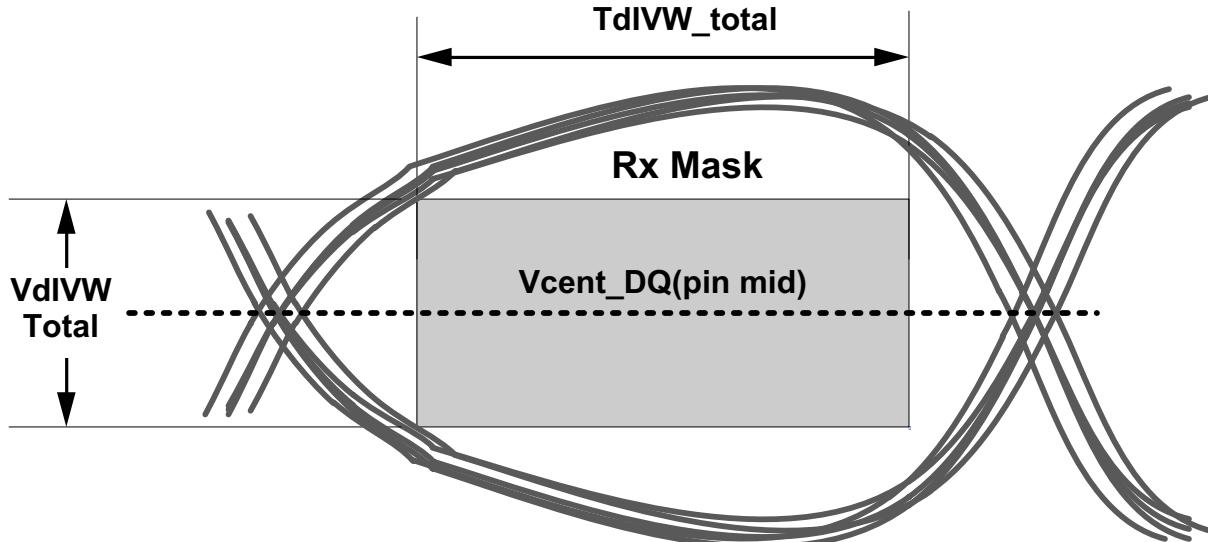


Figure 177 — DQ Receiver(Rx) mask

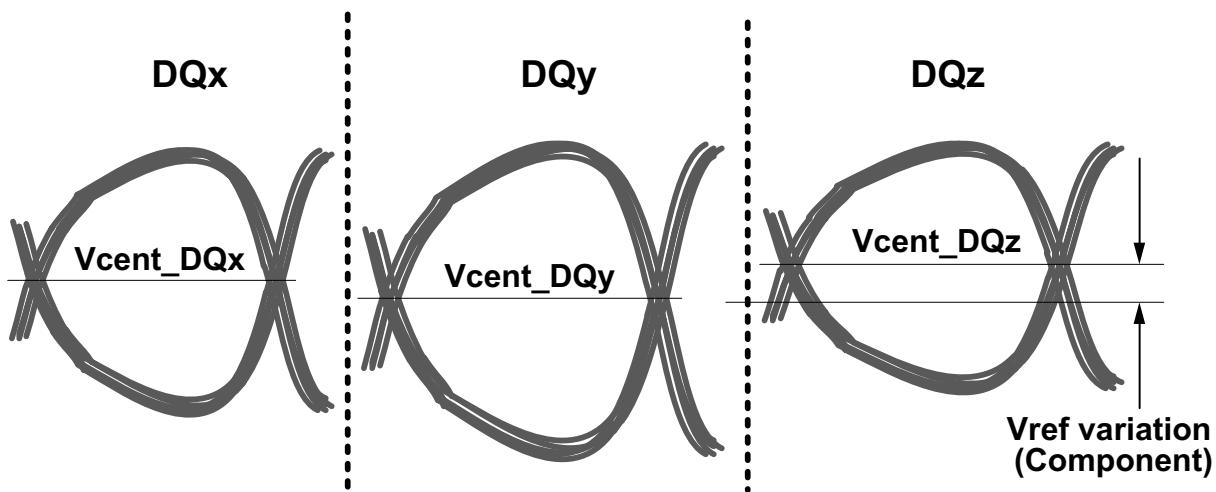
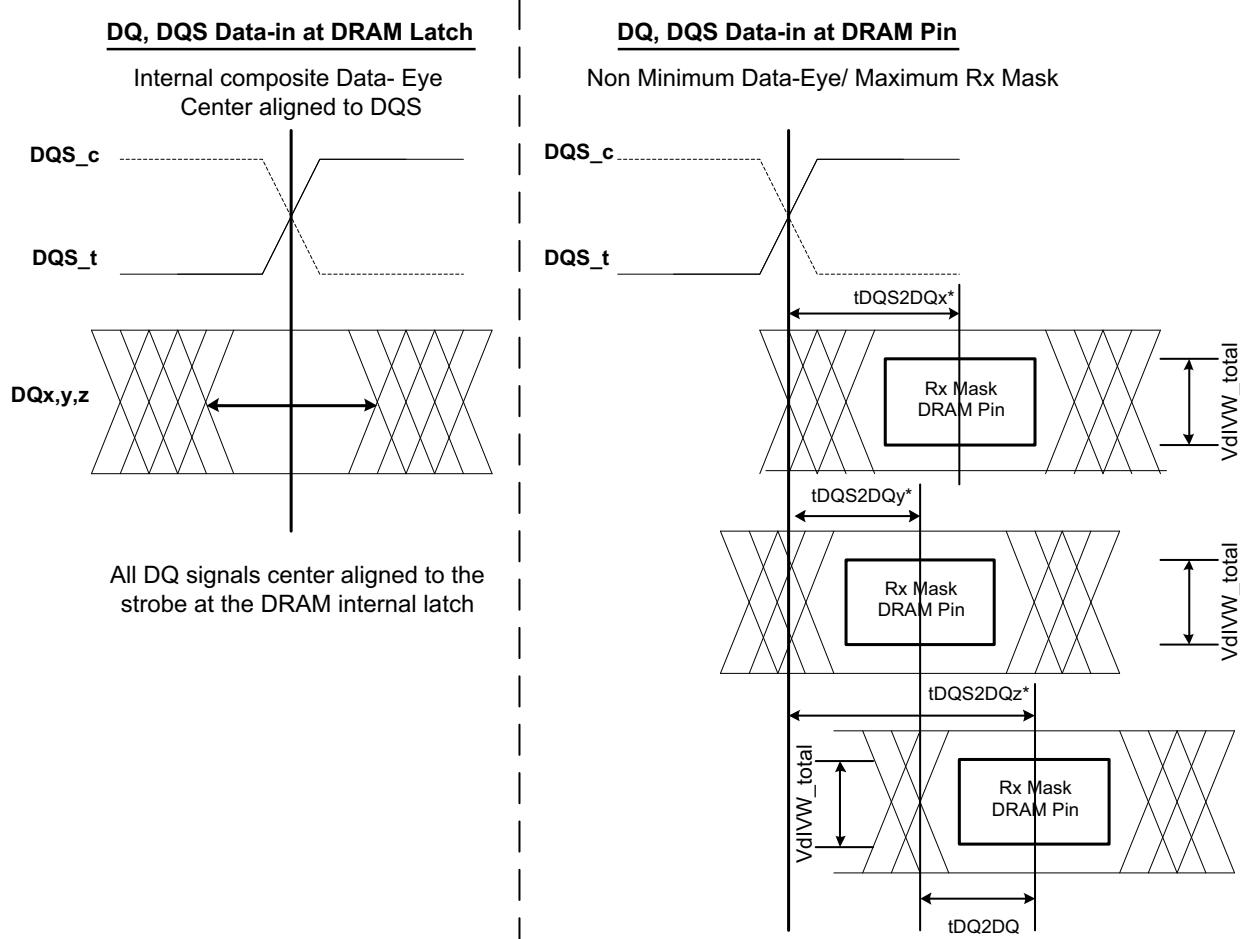


Figure 178 — Across pin Vref DQ voltage variation

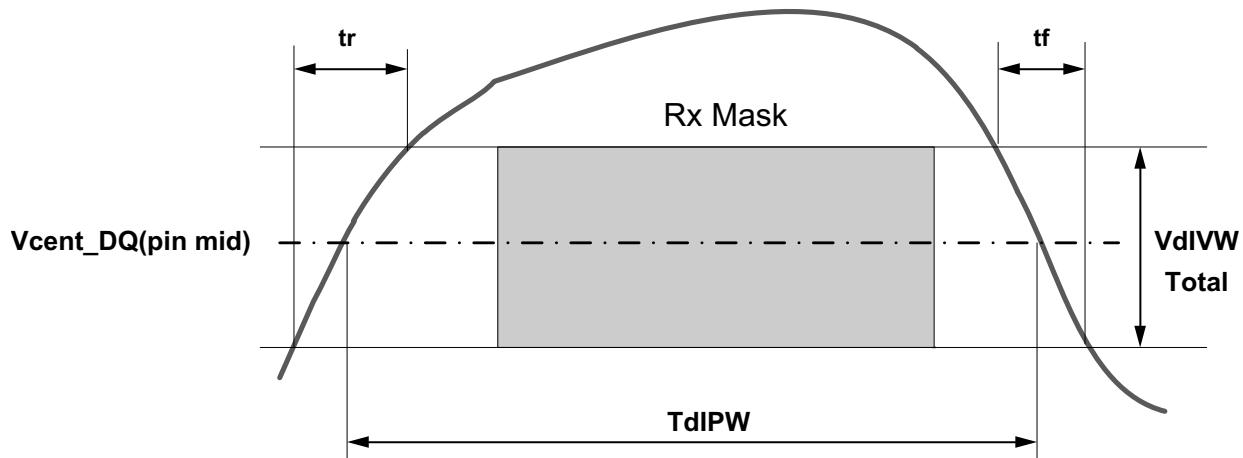
$Vcent_DQ(pin_mid)$ is defined as the midpoint between the largest $Vcent_DQ$ voltage level and the smallest $Vcent_DQ$ voltage level across all DQ pins for a given DRAM component. Each DQ $Vcent$ is defined by the center, i.e., widest opening, of the cumulative data input eye as depicted in Figure 178. This clarifies that any DRAM component level variation must be accounted for within the DRAM Rx mask. The component level $Vref$ will be set by the system to account for Ron and ODT settings.



NOTE:

1. t_{DQS2DQ} is measured at the center(midpoint) of the T_{dIVW} window.
2. DQ_z represents the max t_{DQS2DQ} in this example
3. DQ_y represents the min t_{DQS2DQ} in this example

Figure 179 — DQ to DQS t_{DQS2DQ} and t_{DQ2DQ} Timings at the DRAM pins referenced from the internal latch



Note

1. $\text{SRIN}_{\text{dIVW}} = \text{VdIVW}_{\text{Total}} / (\text{tr or tf})$, signal must be monotonic within tr and tf range.

Figure 180 — DQ TdIPW and SRIN_dIVW definition (for each input pulse)

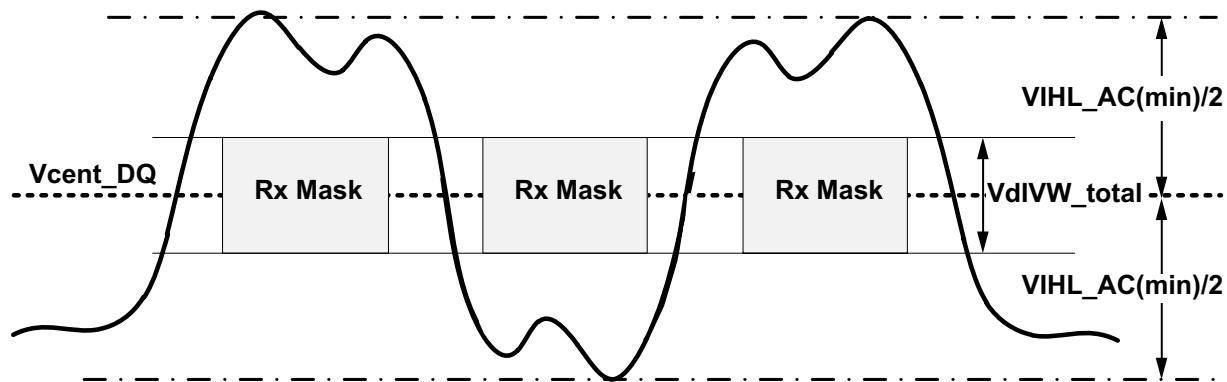


Figure 181 — DQ VIHL_AC definition (for each input pulse)

Table 134—DRAM DQs In Receive Mode

* UI=tCK(avg)min/2

| Symbol | Parameter | 1600/1867 ^A | | 2133/2400 | | 3200 | | 4266 | | Unit | NOTE |
|-------------------|--|------------------------|------|-----------|------|------|------|------|------|----------|--------------|
| | | min | max | min | max | min | max | min | max | | |
| VdIVW_total | Rx Mask voltage - p-p total | - | 140 | - | 140 | - | 140 | - | 120 | mV | 1,2,3,4 |
| TdIVW_total | Rx timing window total (At VdIVW voltage levels) | - | 0.22 | - | 0.22 | - | 0.25 | - | 0.25 | UI* | 1,2,4 |
| TdIVW_1bit | Rx timing window 1 bit toggle (At VdIVW voltage levels) | - | TBD | - | TBD | - | TBD | - | TBD | UI* | 1,2,4, 12 |
| VIHL_AC | DQ AC input pulse amplitude pk-pk | 180 | - | 180 | - | 180 | - | 170 | - | mV | 5,13 |
| TdIPW_DQ | Input pulse width (At Vcent_DQ) | 0.45 | | 0.45 | | 0.45 | | 0.45 | | UI* | 8 6 |
| tDQS2DQ | DQ to DQS offset | 200 | 800 | 200 | 800 | 200 | 800 | 200 | 800 | ps | 7 |
| tDQ2DQ | DQ to DQ offset | - | 30 | - | 30 | - | 30 | - | 30 | ps | 8 |
| tDQS2DQ_temp | DQ to DQS offset temperature variation | - | 0.6 | - | 0.6 | - | 0.6 | - | 0.6 | ps/°C | 9 |
| tDQS2DQ_volt | DQ to DQS offset voltage variation | - | 33 | - | 33 | - | 33 | - | 33 | ps/50 mV | 10 |
| SRIN_dIVW | Input Slew Rate over VdIVW_total | 1 | 7 | 1 | 7 | 1 | 7 | 1 | 7 | V/ns | 11 |
| tDQS2DQ_rank2rank | DQ to DQS offset rank to rank variation | - | 200 | - | 200 | - | 200 | - | 200 | ps | 14,15,16 |

A. The Rx voltage and absolute timing requirements apply for all DQ operating frequencies at or below 1600 for all speed bins. For example TdIVW_total(ps) = 137.5ps at or below 1600 operating frequencies.

Notes to Table 134

NOTE 1 Data Rx mask voltage and timing parameters are applied per pin and includes the DRAM DQ to DQS voltage AC noise impact for frequencies >20 MHz and max voltage of 45mv pk-pk from DC-20MHz at a fixed temperature on the package. The voltage supply noise must comply to the component Min-Max DC operating conditions.

NOTE 2 The design specification is a BER <TBD. The BER will be characterized and extrapolated if necessary using a dual dirac method.

NOTE 3 Rx mask voltage VdIVW total(max) must be centered around Vcent_DQ(pin_mid).

NOTE 4 Vcent_DQ must be within the adjustment range of the DQ internal Vref.

NOTE 5 DQ only input pulse amplitude into the receiver must meet or exceed VIHL AC at any point over the total UI. No timing requirement above level. VIHL AC is the peak to peak voltage centered around Vcent_DQ(pin_mid) such that VIHL_AC/2 min must be met both above and below Vcent_DQ.

NOTE 6 DQ only minimum input pulse width defined at the Vcent_DQ(pin_mid).

NOTE 7 DQ to DQS offset is within byte from DRAM pin to DRAM internal latch. Includes all DRAM process, voltage and temperature variation.

NOTE 8 DQ to DQ offset defined within byte from DRAM pin to DRAM internal latch for a given component.

NOTE 9 TDQS2DQ max delay variation as a function of temperature.

NOTE 10 TDQS2DQ max delay variation as a function of the DC voltage variation for V_{DDQ} and V_{DD2} . It includes the V_{DDQ} and V_{DD2} AC noise impact for frequencies > 20MHz and max voltage of 45mv pk-pk from DC-20MHz at a fixed temperature on the package. For tester measurement $V_{DDQ} = V_{DD2}$ is assumed.

NOTE 11 Input slew rate over VdIVW Mask centered at Vcent_DQ(pin_mid).

NOTE 12 Rx mask defined for a one pin toggling with other DQ signals in a steady state.

NOTE 13 VIHL_AC does not have to be met when no transitions are occurring.

NOTE 14 The same voltage and temperature are applied to tDQS2DQ_rank2rank.

NOTE 15 tDQS2DQ_rank2rank parameter is applied to multi-ranks per byte lane within a package consisting of the same design dies.

NOTE 16 tDQS2DQ_rabk2rank support was added to JESD209-4B, some older devices designed to support JESD209-4 and JESD209-4A may not support this parameter. Refer to vendor datasheet.

Annex A (informative) Differences Between Revisions

This table briefly describes most of the changes made to entries that appear in this standard, JESD209-4B, compared to its predecessor, JESD209-4A (November 2015). If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

| Page | Term and description of change |
|-------------|---|
| 5 | Extended the range of devices to which this specification applies. |
| 7 | Added Pad Order for single channel. |
| 8 | 272 ball package (MO-273) was updated. |
| 9 | Added 376 ball package (MO-317A). |
| 10 | Added 144 ball Package (MO-323A). |
| 11-12 | 200 ball package (MO-311) was updated. |
| 13 | 203 ball package (MO-311) was updated. |
| 14 | 432-ball package (MO-313) was updated. |
| 15 | 324 Ball package (MO-315) was updated. |
| 16 | 275 ball package (MO-276) was updated. |
| 17 | Added 254 ball eMMC MCP Two-Channel FBGA package (MO-276). |
| 18 | Added 254 ball UFS MCP Two-Channel FBGA package (MO-276). |
| 19 | Added 254 ball eMMC MCP One Channel FBGA package (MO-276). |
| 20 | Added the information of Byte-Mode Packaging. |
| 21 | Added the information of Byte-Mode ZQ wiring. |
| 22 | Pad Definition and Description was updated. |
| 23 | Functional Description was updated. |
| 24-25 | Addressing table for dual channel Device was updated. |
| 26-27 | Added addressing table for single channel Device. |
| 30 | Figure - LPDDR4:Simplified Bus Interface State Diagram -2 was updated. |
| 35 | Added MR30 and MR39 definition into Table - Mode Register Assignment in LPDDR4 SDRAM. |
| 36 | MR0 Register Information was updated. |
| 37 | MR1 Register Information was updated. |
| 38 | Burst Sequence for Write was updated. |
| 41 | MR3 Register Information was updated. |
| 42-43 | MR4 Register Information was updated. |
| 45 | MR8 Register Information was updated. |
| 46 | MR11 Register Information was updated. |
| 47-48 | MR12 Register Information was updated. |
| 49 | MR13 Register Information was updated. |
| 53 | MR16 Register Information was updated. |
| 54 | MR17 Register Information was updated. |
| 63 | Added MR30 Register Information. |
| 65 | Added MR39 Register Information. |
| 69 | Core AC Timing was updated. |
| 81 | Added tRPRE Calculation for ATE(Automatic Test Equipment). |
| 82 | Added tRPST Calculation for ATE(Automatic Test Equipment). |
| 83 | Read AC Timing was updated. |
| 88-90 | Figure of write timing was updated. |
| 95-100 | Added Write and Masked Write operation DQS controls (WDQS Control). |
| 128-129 | Masked Write Timing constraints for BL16 was updated. |
| 132 | Figure- Masked Write Command w/ Write DBI Enabled; DM Enabled. |
| 133 | Figure - Write Command w/ Write DBI Enabled; DM Enabled. |
| 139-140 | Added Auto-PRECHARGE Operation. |
| 147 | Table - Bank and Refresh counter increment behavior was updated. |
| 149 | Figure - All Bank Refresh Operation was updated. |
| 149 | Figure - Per Bank Refresh Operation was updated. |
| 150 | Added per bank refresh restriction. |
| 153 | Added Figure - Burst Read operation followed by Per Bank Refresh. |

- 153 Added Figure - Burst Read with Auto-Precharge operation followed by Per Bank Refresh.
- 154-155 Refresh Requirement was updated.
- 156 Self Refresh Operation was updated.
- 159 Self Refresh Abort definition was updated.
- 161 Table - DQ output mapping was updated.
- 167 Table - MRR/MRW Timing Constraints: DQ ODT is Disable was updated.
- 168 Table - MRR/MRW Timing Constraints: DQ ODT is Enable was updated.
- 176 Table - CA Internal VREF Specifications was updated.
- 182 Table - DQ Internal VREF Specifications was updated.
- 185 Training Sequence for multi-rank systems was updated.
- 187 Figure - Entering Command Bus Training Mode and CA Training Pattern Input and Output with VREFCA Value Update was updated.
- 188 Figure - Consecutive VREFCA Value Update was updated.
- 189 Figure - Exiting Command Bus Training Mode with Valid Command was updated.
- 190 Figure - Exiting Command Bus Training Mode with Power Down Entry was updated.
- 191-192 Table - Command Bus Training AC Timing was updated.
- 193-194 Frequency Set Point was updated.
 - 199 Mode Register Write-WR Leveling Mode was updated.
 - 201 Figure - Clock Stop and Timing during Write Leveling was updated.
 - 210 Figure - Write to MPC [Write FIFO] Operation Timing was updated.
 - 211 Figure - MPC [Write FIFO] to MPC [Read FIFO] Timing was updated.
 - 212 Figure - MPC [Read FIFO] to Read Timing was updated.
 - 213 Figure - MPC [Write FIFO] with DQ ODT Timing was updated.
 - 219 Table - DQS Interval Oscillator AC Timing was updated.
 - 226 Table - Timing Constraints for Training Commands was updated.
 - 227 Thermal Offset was updated.
 - 230 ZQ Calibration was updated.
 - 231 Section title: Multi-Channel Considerations for Dual Channel Devices was updated.
- 245-249 Added NT ODT definition with the announcement that this function will be removed in the future.
- 251 Power-Down Mode was updated.
- 258-259 Input Clock Stop and Frequency Change was updated.
- 260-261 Truth Tables was updated.
- 265-267 Post Package Repair (PPR) was updated.
 - 269 Recommended DC Operating Conditions was updated.
 - 273 1.1V High speed LVCMOS (HS_LLVCMOS) was updated.
 - 274 LPDDR4 AC Over/Ubershoot was updated.
- 275-279 Differential Input Voltage for CK was updated.
- 280-284 Differential Input Voltage for DQS was updated.
- 302 Table - LPDDR4 IDD Specification Parameters and Operating Conditions was updated.
- 303-304 Added Clock Specification.
 - 305 Table - Clock AC Timings was updated.
 - 309 Table - DRAM CMD/ADR, CS was updated.
- 310-318 DRAM Data Timing was updated.



Standard Improvement Form

JEDEC

The purpose of this form is to provide the Technical Committees of JEDEC with input from the industry regarding usage of the subject standard. Individuals or companies are invited to submit comments to JEDEC. All comments will be collected and dispersed to the appropriate committee(s).

If you can provide input, please complete this form and return to:

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1. I recommend changes to the following:

Requirement, clause number _____

Test method number Clause number

The referenced clause number has proven to be:

Unclear Too Rigid In Error

Other _____

- ## 2. Recommendations for correction:

- ### 3. Other suggestions for document improvement:

Submitted by

Name: _____

Phone: _____

Company: _____

E-mail: _____

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Date:

