



Total Ionizing Dose Test Report

April 24th, 2017

Nadia Rezzak, J.J. Wang, Alex Cai, Harvey Chen, Kevin Chou

Table of Contents

| | |
|---|----------|
| I. Summary Table..... | 2 |
| II. Total Ionizing Dose (TID) Testing..... | 2 |
| A. Device-Under-Test (DUT) and Irradiation Parameters | 2 |
| B. Test Method..... | 3 |
| C. Design and Parametric Measurements..... | 3 |
| III. Test Results..... | 4 |
| A. Functionality..... | 4 |
| B. Power Supply Current..... | 4 |
| C. Single-Ended Input Logic Threshold (VIL/VIH)..... | 13 |
| D. Output-Drive Voltage (VOL/VOH)..... | 14 |
| E. Propagation Delay..... | 19 |
| F. Transition Time | 19 |



I. SUMMARY TABLE

| Parameter | Tolerance |
|-------------------------------|--|
| 1. Gross Functionality | Passed 100 and 125 krad(SiO ₂) |
| 2. Power Supply Current | Passed 100 and 125 krad(SiO ₂) |
| 3. Input Threshold (VTIL/VIH) | Passed 100 and 125 krad(SiO ₂) |
| 4. Output Drive (VOL/VOH) | Passed 100 and 125 krad(SiO ₂) |
| 5. Propagation Delay | Passed 100 and 125 krad(SiO ₂) for 10% degradation criterion |
| 6. Transition Time | Passed 100 and 125 krad(SiO ₂) |

II. TOTAL IONIZING DOSE (TID) TESTING

This testing is designed on the basis of an extensive database of TID testing for Radiation-Tolerant FPGAs including flash-based FPGAs. Microsemi TID reports can be found at <http://www.microsemi.com/products/fpga-soc/radtolerant-fpgas/military-aerospace-radiation-reliability-data#tid-reports>

Electrical parameters are measured pre-irradiation and post-irradiation using the burn in design and the Automatic Test Equipment (ATE) program. The report summarizes sample pins.

A. Device-Under-Test (DUT) and Irradiation Parameters

Table 1 lists the DUT and irradiation parameters.

Table. 1. DUT and Irradiation Parameters

| | |
|----------------------------------|---|
| Part Number | RT4G150 |
| Package | LG1657 |
| Foundry | United Microelectronics Corp. |
| Technology | 65 nm |
| DUT Design | Burn in design with inverter string |
| Die Lot Number | KWJSL |
| Quantity Tested | 5 |
| Serial Number (Dose) | 9738 (125 krad), 9741 (125 krad), 9752 (125 krad), 9774 (100 krad), 9793 (100 krad) |
| Radiation Facility | Defense Microelectronics Activity |
| Radiation Source | Co-60 |
| Dose Rate | 5 krad (SiO ₂)/min |
| Irradiation Temperature | Room |
| Irradiation and Measurement Bias | Static at 1.2V/2.5V/3.3V/3.3V |
| IO Configuration | Single ended Differential Pair |

B. Test Method

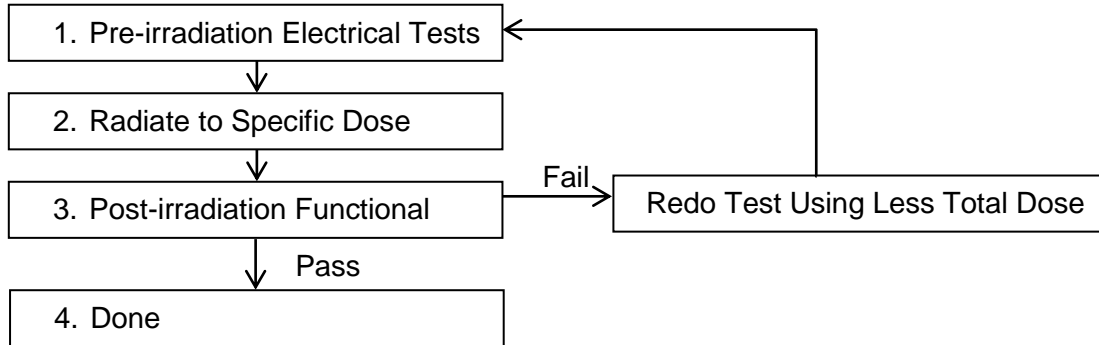


Fig. 1. Parametric test flow chart

The test method generally follows the guidelines in the military standard TM1019. Figure 1 shows the flow chart describing the steps for the functional and parametric tests.

C. Design and Parametric Measurements

RTG4 FPGA devices have different types of I/Os, such as MSIO and MSIOD, double data rate I/Os (DDRIO), and dedicated I/Os based on functional usage. For more information on I/O naming conventions and I/O description, refer to the RTG4 FPGA Pin Description. All I/Os are tested pre and post-irradiation.

Fabric functionality coverage performed by the burn in design is summarized in table 2 below. In addition to the fabric coverage the supplemental test of propagation delay is also used to determine DUT functionality. These tests are performed pre and post-irradiation and recorded as a pass/fail.

Refer to appendix A for a graphical representation of fabric functional coverage blocks used to perform the functional tests.

Table. 2. Fabric Functional Coverage

| Block | Coverage |
|----------------------|---|
| Combo Block | combinatorial macros available in the RTG4 library |
| Register Block | sequential macros available in the RTG4 library |
| UPROM | Maximum output toggle rate(checker board) compared to reference |
| Embedded SRAM Blocks | full toggle coverage on 209 fabric LSRAM & 210 uRAM blocks using dual port/ two port configurations (x18 width) |
| Shift Register Block | core utilization |
| I/O Block | I/O utilization |
| Math Block | full toggle coverage on 462 fabric math blocks with maximum width configuration |



The core power supply current I_{DD} , the I/Os power supply currents ($I_{DDI_2.5}/I_{DDI_3.3}$) and the charge pump/PLL power supply current (I_{PP_PLL}) are also monitored during irradiation in real time.

The input logic threshold (V_{IL}/V_{IH}) is measured on all single-ended inputs as well as all differential inputs, and is reported as a pass or fail, as part of the ATE test program. The output-drive voltage (V_{OL}/V_{OH}) is also measured on all pins on the MSIO MSIOD and DDRIO. This report contains the output-drive voltage measurements on selected IO pins used in the burn in design. LVTTTL and LVCMOS 2.5V standard at different sourcing and sinking currents are reported.

A 2000 stage inverter string is used to measure the propagation delay. The propagation delay is defined as the time delay from the triggering edge at the Clock input to the switching edge at the output. The propagation delay is monitored real time during irradiation and the time difference between positive switching edges of the clock and output are reported. Additionally, the transition characteristics (rise and fall) at the output of the inverter chain are measured pre and post-irradiation. Oscilloscope screen captures are shown in section III. F.

III. TEST RESULTS

A. Functionality

Every DUT passed the pre-irradiation and post-irradiation functional tests mentioned in section II.C.

B. Power Supply Current

The core power supply current (I_{DD}) is 1.2 V, the I/O bank power supply currents (I_{DDI}) are 2.5 V ($I_{DDI_2.5}$) and 3.3 V ($I_{DDI_3.3}$). The charge pump and PLL power supply current (I_{PP_PLL}) is 3.3 V. Figures 2-13 illustrate the plot of in-flux standby I_{DD} , $I_{DDI_2.5}$, $I_{DDI_3.3}$ and I_{PP_PLL} versus total dose for every DUT. Tables 3-6 summarize the pre-irradiation and post-irradiation total current (static & dynamic) I_{DD} , $I_{DDI_2.5}$, $I_{DDI_3.3}$ and I_{PP_PLL} . Due to testing malfunction the power supply current of DUT 9741 is not shown in this report.

Table. 3. Pre-irradiation and Post-irradiation I_{DD}

| DUT | Total Dose | Pre-irradiation (A) | Post-irradiation (A) | Increase (%) |
|------|------------|---------------------|----------------------|--------------|
| 9738 | 125 krad | 0.313 | 0.331 | 5.75 |
| 9752 | 125 krad | 0.333 | 0.349 | 4.80 |
| 9774 | 100 krad | 0.349 | 0.361 | 3.43 |
| 9793 | 100 krad | 0.343 | 0.361 | 5.24 |

Table. 4. Pre-irradiation and Post-irradiation $I_{DDI_2.5}$

| DUT | Total Dose | Pre-irradiation (A) | Post-irradiation (A) | Increase (%) |
|------|------------|---------------------|----------------------|--------------|
| 9738 | 125 krad | 0.012 | 0.015 | 25 |
| 9752 | 125 krad | 0.011 | 0.014 | 27.27 |
| 9774 | 100 krad | 0.011 | 0.013 | 18.18 |

| | | | | |
|------|----------|-------|-------|-------|
| 9793 | 100 krad | 0.013 | 0.015 | 15.38 |
|------|----------|-------|-------|-------|

Table. 5. Pre-irradiation and Post-irradiation $I_{DDI_3.3}$

| DUT | Total Dose | Pre-irradiation (A) | Post-irradiation (A) | Increase (%) |
|------|------------|---------------------|----------------------|--------------|
| 9738 | 125 krad | 0.042 | 0.047 | 11.90 |
| 9752 | 125 krad | 0.038 | 0.045 | 18.42 |
| 9774 | 100 krad | 0.036 | 0.041 | 13.88 |
| 9793 | 100 krad | 0.038 | 0.046 | 21.05 |

Table. 6. Pre-irradiation and Post-irradiation I_{PP_PLL}

| DUT | Total Dose | Pre-irradiation (A) | Post-irradiation (A) | Increase (%) |
|------|------------|---------------------|----------------------|--------------|
| 9738 | 125 krad | 0.0164 | 0.0173 | 5.48 |
| 9752 | 125 krad | 0.0164 | 0.0167 | 1.82 |
| 9774 | 100 krad | 0.0161 | 0.0159 | -1.24 |
| 9793 | 100 krad | 0.0162 | 0.0162 | 0 |

The following figures (2-17) show the in-beam monitoring of the currents mentioned above as a function of TID for the available DUTs.

DUT 9738

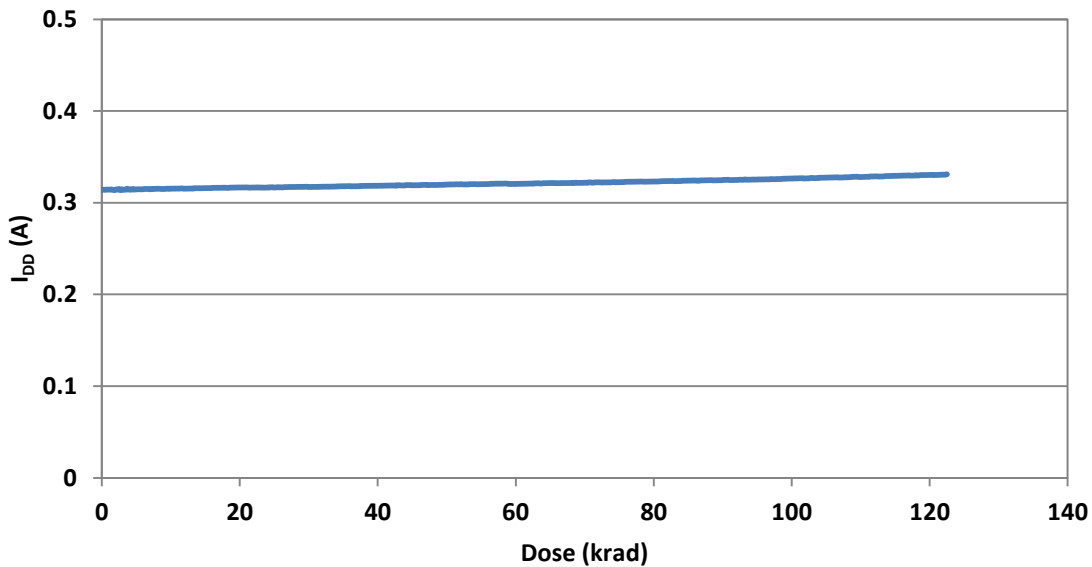


Fig. 2. DUT 9738 core power supply current (I_{DD}) versus TID

DUT 9752

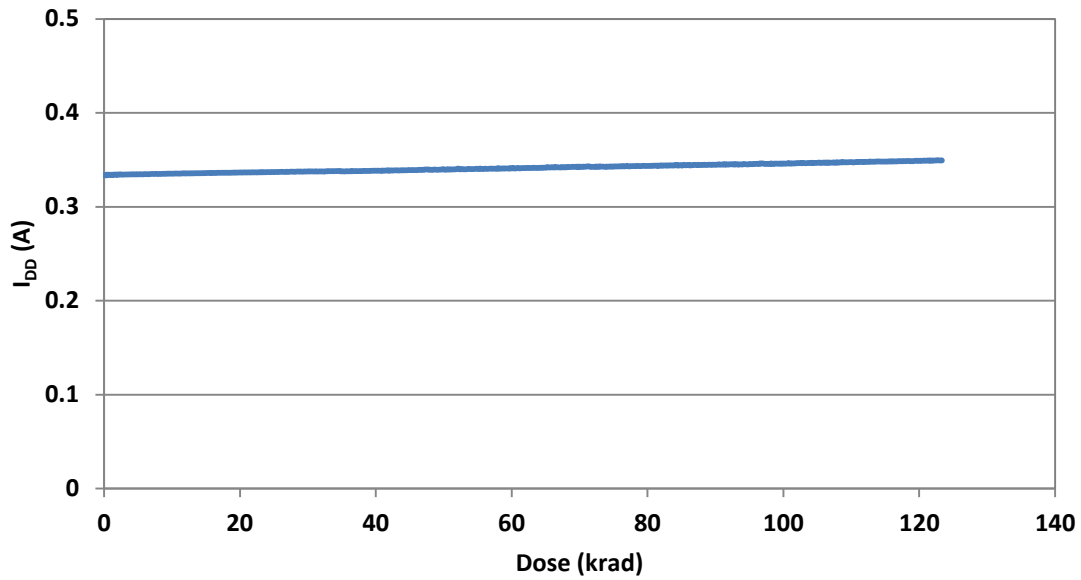


Fig. 3. DUT 9752 core power supply current (I_{DD}) versus TID

DUT 9774

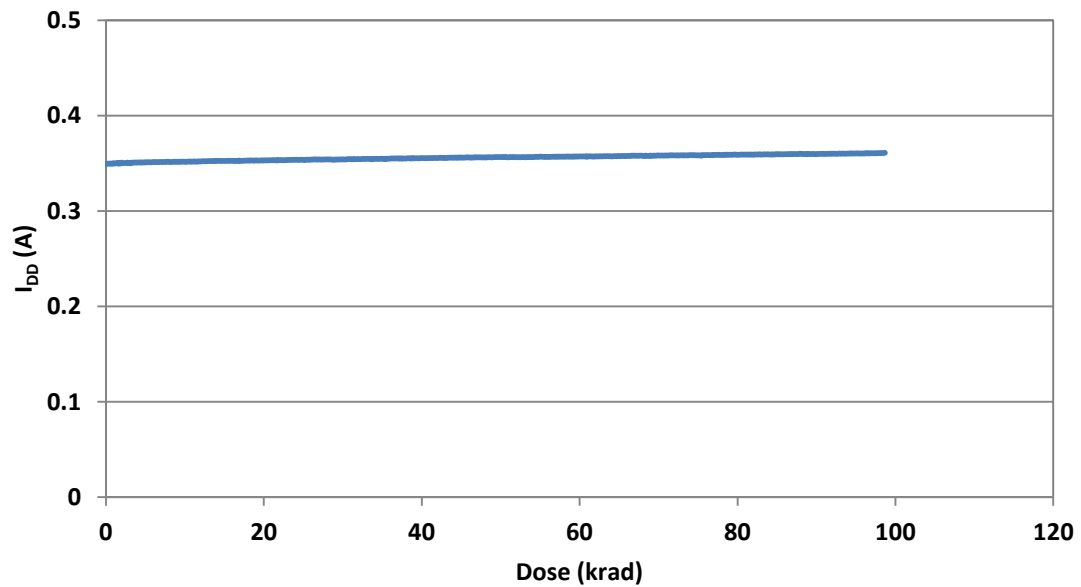


Fig. 4. DUT 9774 core power supply current (I_{DD}) versus TID

DUT 9793

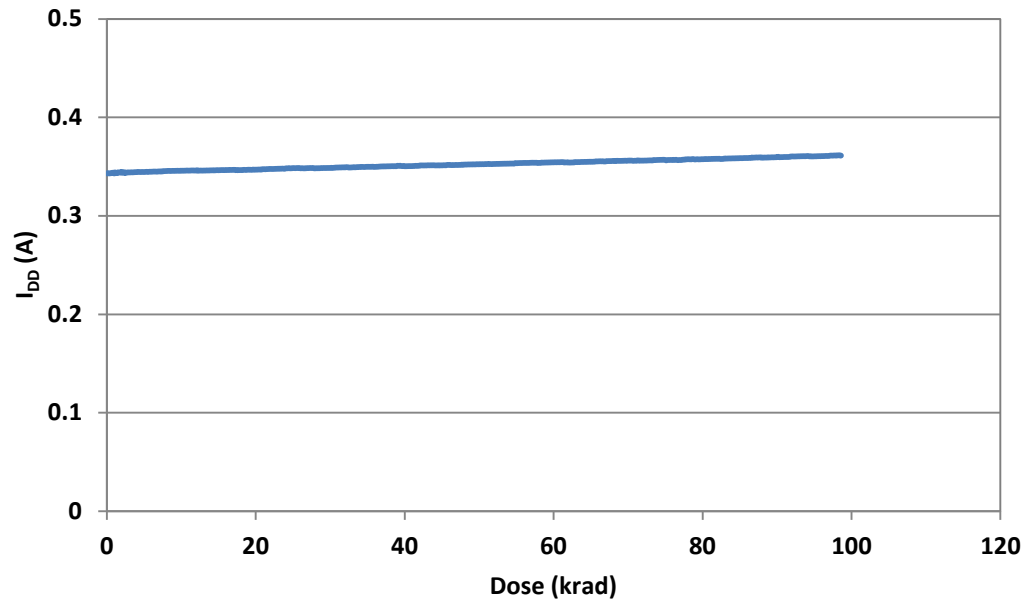


Fig. 5. DUT 9793 core power supply current (I_{DD}) versus TID

DUT 9738

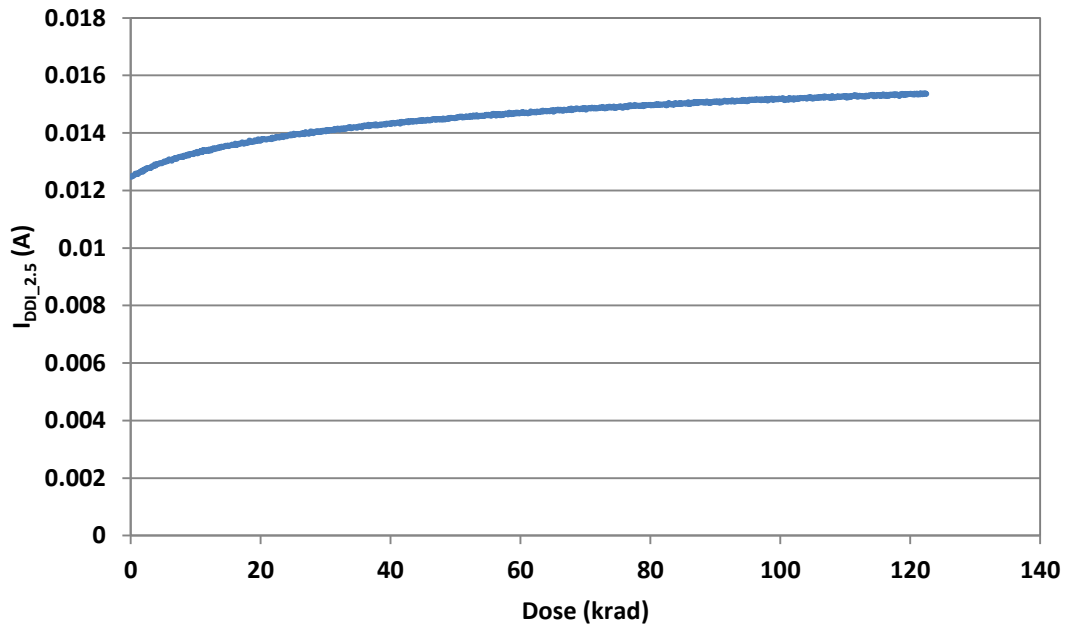


Fig. 6. DUT 9738 I/O bank 2.5V power supply current ($I_{DDI_{2.5}}$) versus TID

DUT 9752

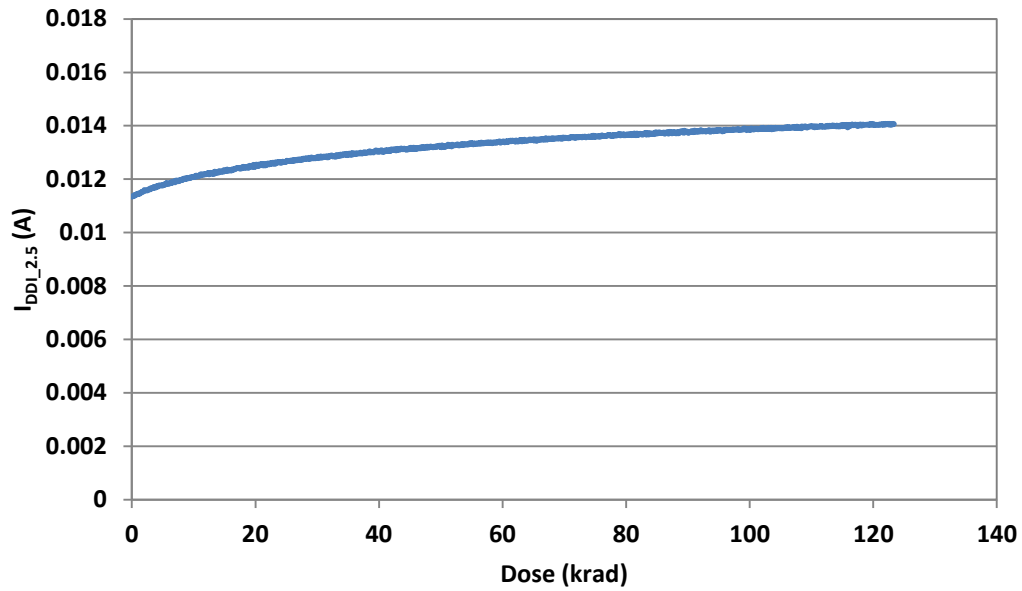


Fig. 7. DUT 9752 I/O bank 2.5V power supply current ($I_{DDI_{2.5}}$) versus TID

DUT 9774

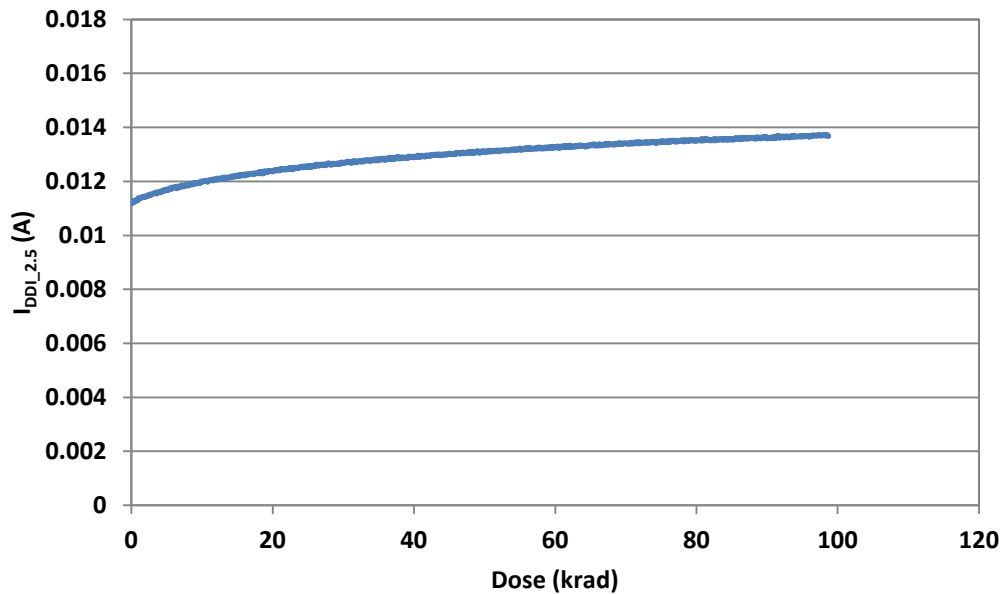


Fig. 8. DUT 9774 I/O bank 2.5V power supply current ($I_{DDI_{2.5}}$) versus TID

DUT 9793

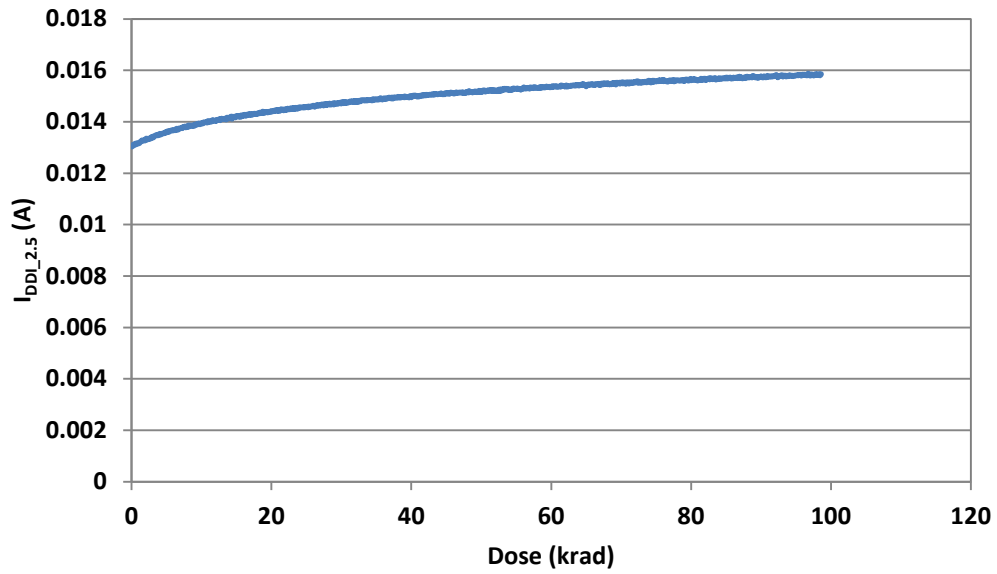


Fig. 9. DUT 9793 I/O bank 2.5V power supply current ($I_{DDI_{2.5}}$) versus TID

DUT 9738

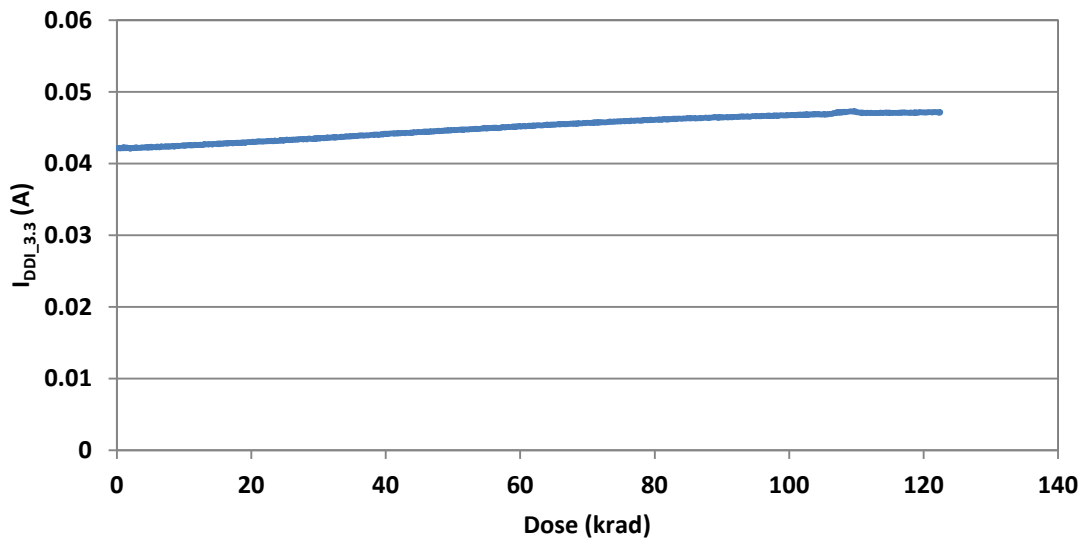


Fig. 10. DUT 9738 I/O bank 3.3V power supply current ($I_{DDI_{3.3}}$) versus TID

DUT 9752

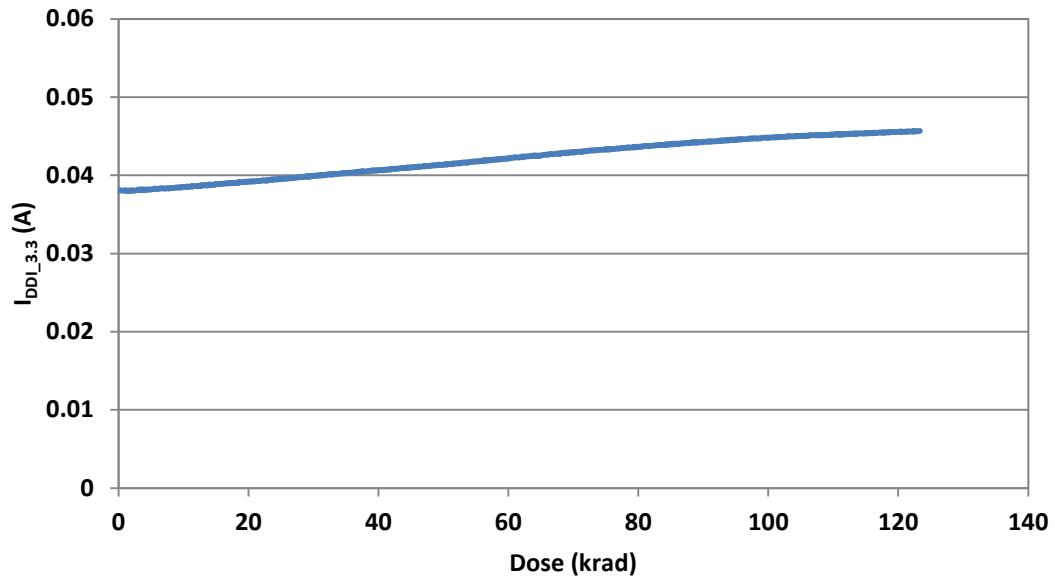


Fig. 11. DUT 9752 I/O bank 3.3V power supply current ($I_{DDI_{3.3}}$) versus TID

DUT 9774

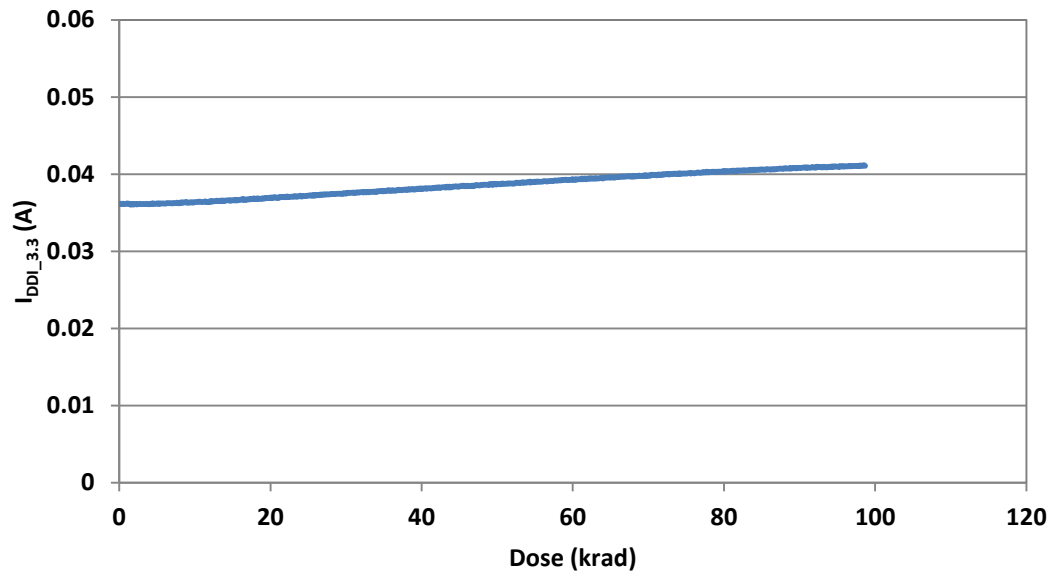


Fig. 12. DUT 9774 I/O bank 3.3V power supply current ($I_{DDI_{3.3}}$) versus TID

DUT 9793

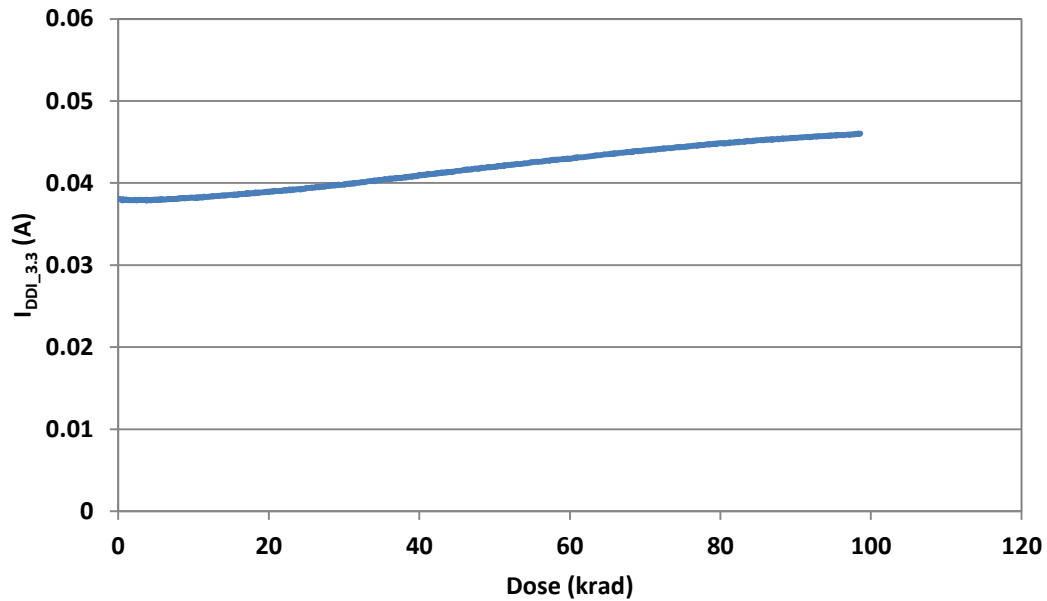


Fig. 13. DUT 9793 I/O bank 3.3V power supply current ($I_{DDI_{3.3}}$) versus TID

DUT 9738

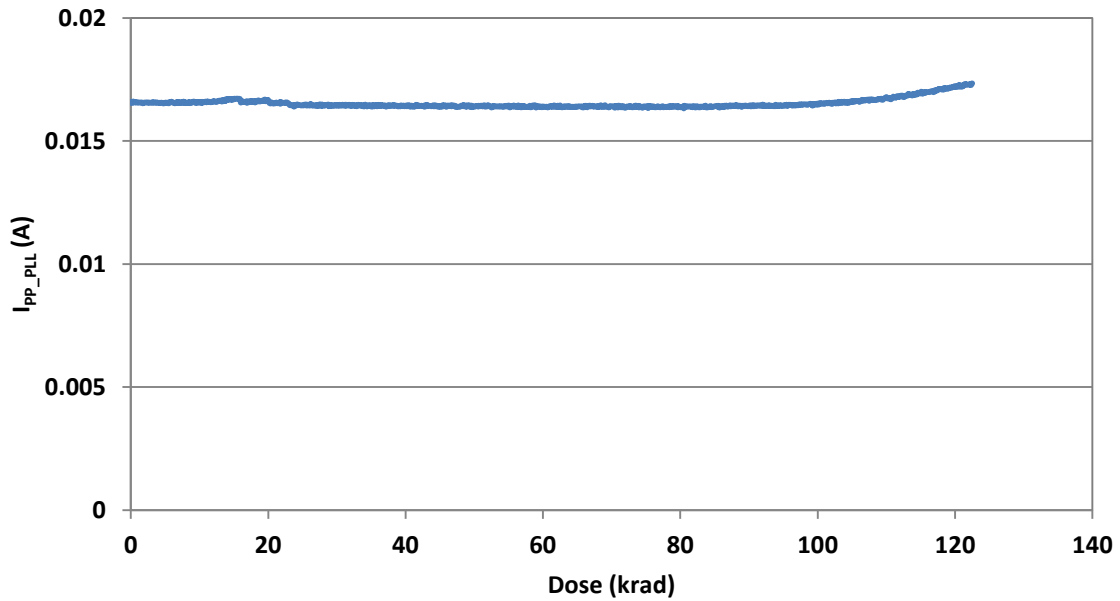


Fig. 14. DUT 9738 charge pump and PLL power supply current (I_{PP_PLL}) versus TID

DUT 9752

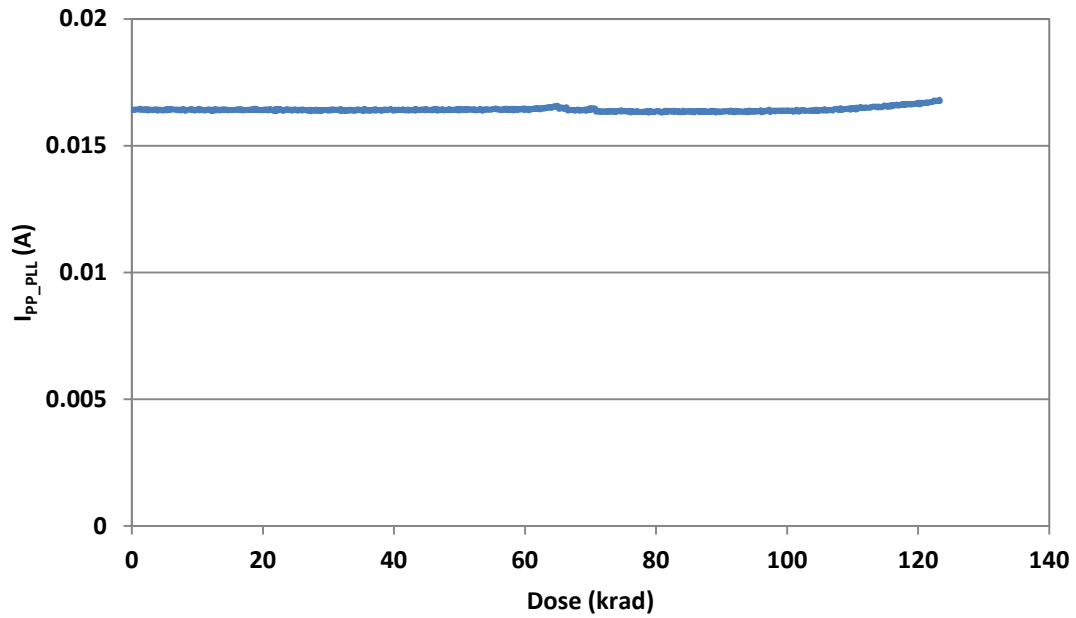


Fig. 15. DUT 9752 charge pump and PLL power supply current (I_{PP_PLL}) versus TID

DUT 9774

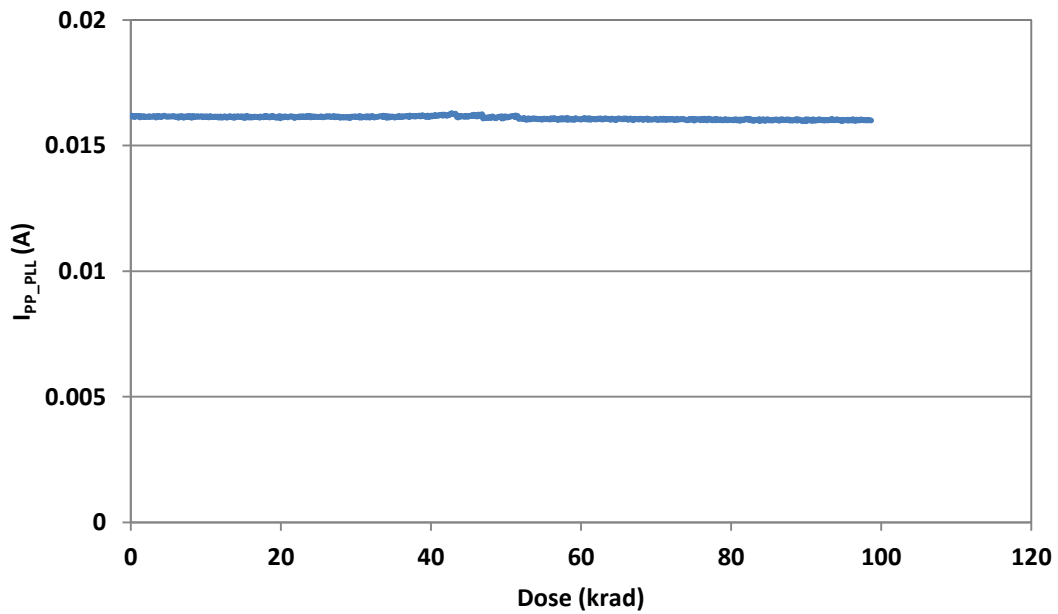


Fig. 16. DUT 9774 charge pump and PLL power supply current (I_{PP_PLL}) versus TID

DUT 9793

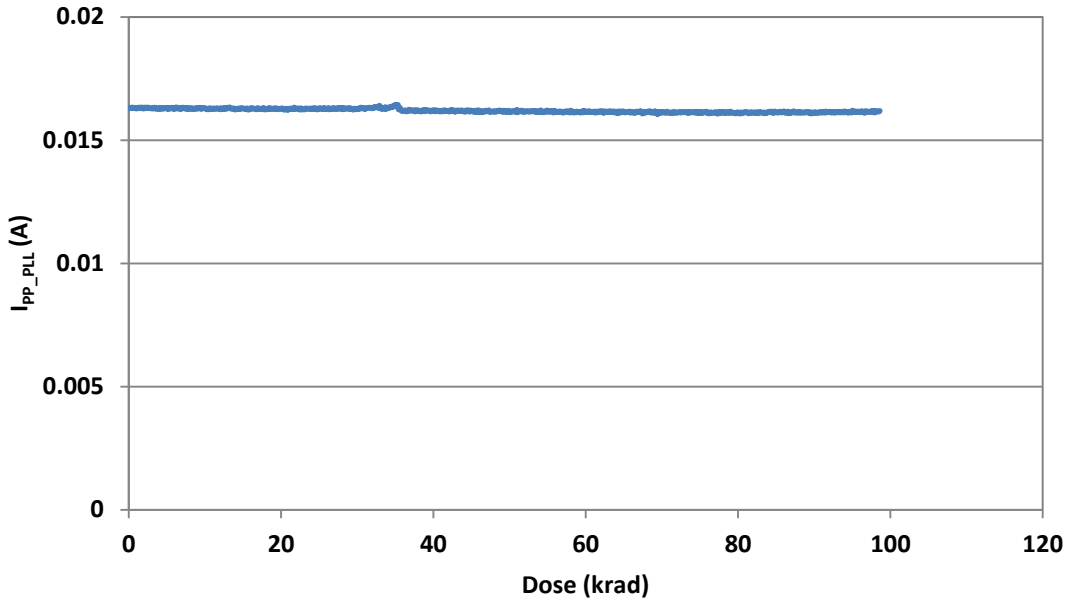


Fig. 17. DUT 9793 charge pump and PLL power supply current (I_{PP_PLL}) versus TID

C. Single-Ended Input Logic Threshold (VIL/VIH)

The input switching threshold, or trip point, is defined as the applied input voltage at which the output of the design starts to switch. VIH is the input trip point when the input is going high to low and VIL is the input trip point when the input is going low to high. The input logic threshold (VIL/VIH) is measured on all single-ended inputs as well as all differential input and recorded as pass or fail. All I/Os are tested at their respective I/O standards and are compliant to the JEDEC specs. Refer to http://www.microsemi.com/document-portal/doc_view/135193-ds0131-rtg4-fpga-datasheet for more information.

The 3 DUTs tested passed with respect to the testing specification pre and post-irradiation. This pass/fail is determined as part of the ATE test program used to perform pre and post-irradiation electrical parametric measurements.

Table. 7. VIH Summary

| DUT | Pre-irradiation | Post-irradiation |
|------|-----------------|------------------|
| 9738 | Passed | Passed |
| 9741 | Passed | Passed |
| 9752 | Passed | Passed |
| 9774 | Passed | Passed |
| 9793 | Passed | Passed |

Table. 8. VIL Summary

| DUT | Pre-irradiation | Post-irradiation |
|------|-----------------|------------------|
| 9738 | Passed | Passed |
| 9741 | Passed | Passed |
| 9752 | Passed | Passed |
| 9774 | Passed | Passed |
| 9738 | Passed | Passed |

D. Output-Drive Voltage (VOL/VOH)

The pre-irradiation and post-irradiation output-drive voltages (VOL/VOH) are performed on all available IOs. The measurements performed pre and post irradiation are within the specification limits; in each case, the radiation-induced degradation is within 10%. For the purpose of this report, the measurements presented below in tables 9 through 28 are sampled on several pins used in the burn in design.

Table. 9. LVCMOS 25 VOH – DUT 9738

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.1308 | 2.1345 | 2.1973 | 2.2029 | 2.1662 | 2.1739 | 2.1429 | 2.1547 | 2.1063 | 2.1216 | 2.0906 | 2.1074 |
| EPCSRST_N_0 | B31 | 2.1322 | 2.1351 | 2.2013 | 2.2030 | 2.1722 | 2.1738 | 2.1507 | 2.1545 | 2.1182 | 2.1208 | 2.1046 | 2.1066 |
| EPCSRST_N_1 | B32 | 2.1331 | 2.1356 | 2.2023 | 2.2047 | 2.1736 | 2.1765 | 2.1529 | 2.1566 | 2.1205 | 2.1254 | 2.1074 | 2.1123 |
| EPCSRST_N_2 | B34 | 2.1326 | 2.1349 | 2.2015 | 2.2034 | 2.1727 | 2.1747 | 2.1520 | 2.1544 | 2.1192 | 2.1225 | 2.1058 | 2.1088 |
| EPCSRST_N_3 | B35 | 2.1332 | 2.1355 | 2.2034 | 2.2048 | 2.1755 | 2.1772 | 2.1555 | 2.1571 | 2.1252 | 2.1273 | 2.1125 | 2.1144 |
| EPCSRST_N_4 | B36 | 2.1310 | 2.1345 | 2.1988 | 2.2025 | 2.1682 | 2.1739 | 2.1459 | 2.1526 | 2.1106 | 2.1200 | 2.0956 | 2.1057 |
| EPCSRST_N_5 | B37 | 2.1331 | 2.1354 | 2.2022 | 2.2042 | 2.1732 | 2.1760 | 2.1524 | 2.1558 | 2.1204 | 2.1247 | 2.1072 | 2.1114 |
| MONITOR | K23 | 2.1329 | 2.1348 | 2.2023 | 2.2037 | 2.1741 | 2.1761 | 2.1534 | 2.1566 | 2.1226 | 2.1267 | 2.1094 | 2.1136 |
| PLL_MON | L20 | 2.1329 | 2.1342 | 2.2035 | 2.2053 | 2.1761 | 2.1786 | 2.1577 | 2.1599 | 2.1281 | 2.1314 | 2.1158 | 2.1197 |
| TOGGLE_MON | L22 | 2.1327 | 2.1340 | 2.2037 | 2.2048 | 2.1762 | 2.1776 | 2.1566 | 2.1581 | 2.1271 | 2.1293 | 2.1154 | 2.1170 |

Table. 10. LVCMOS 25 VOH – DUT 9741

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.1310 | 2.1349 | 2.1978 | 2.2033 | 2.1667 | 2.1747 | 2.1435 | 2.1552 | 2.1063 | 2.1216 | 2.0918 | 2.1083 |
| EPCSRST_N_0 | B31 | 2.1330 | 2.1355 | 2.2020 | 2.2033 | 2.1730 | 2.1745 | 2.1517 | 2.1551 | 2.1182 | 2.1208 | 2.1060 | 2.1077 |
| EPCSRST_N_1 | B32 | 2.1346 | 2.1372 | 2.2028 | 2.2054 | 2.1741 | 2.1774 | 2.1536 | 2.1575 | 2.1205 | 2.1254 | 2.1081 | 2.1133 |
| EPCSRST_N_2 | B34 | 2.1334 | 2.1359 | 2.2024 | 2.2042 | 2.1735 | 2.1758 | 2.1526 | 2.1552 | 2.1192 | 2.1225 | 2.1069 | 2.1098 |
| EPCSRST_N_3 | B35 | 2.1345 | 2.1368 | 2.2042 | 2.2060 | 2.1762 | 2.1781 | 2.1561 | 2.1583 | 2.1252 | 2.1273 | 2.1130 | 2.1154 |
| EPCSRST_N_4 | B36 | 2.1305 | 2.1357 | 2.1958 | 2.2033 | 2.1639 | 2.1744 | 2.1398 | 2.1536 | 2.1106 | 2.1200 | 2.0849 | 2.1071 |
| EPCSRST_N_5 | B37 | 2.1332 | 2.1359 | 2.2026 | 2.2046 | 2.1737 | 2.1767 | 2.1529 | 2.1567 | 2.1204 | 2.1247 | 2.1077 | 2.1123 |
| MONITOR | K23 | 2.1334 | 2.1352 | 2.2030 | 2.2043 | 2.1752 | 2.1769 | 2.1548 | 2.1576 | 2.1226 | 2.1267 | 2.1113 | 2.1151 |
| PLL_MON | L20 | 2.1346 | 2.1358 | 2.2048 | 2.2063 | 2.1778 | 2.1793 | 2.1593 | 2.1609 | 2.1281 | 2.1314 | 2.1184 | 2.1208 |
| TOGGLE_MON | L22 | 2.1350 | 2.1358 | 2.2049 | 2.2057 | 2.1777 | 2.1785 | 2.1585 | 2.1594 | 2.1271 | 2.1293 | 2.1176 | 2.1186 |

Table. 11. LVCMOS 25 VOH – DUT 9752



| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.1344 | 2.1378 | 2.1997 | 2.2054 | 2.1694 | 2.1766 | 2.1463 | 2.1576 | 2.1102 | 2.1250 | 2.0947 | 2.1109 |
| EPCSRST_N_0 | B31 | 2.1365 | 2.1382 | 2.2044 | 2.2052 | 2.1757 | 2.1763 | 2.1548 | 2.1570 | 2.1228 | 2.1239 | 2.1094 | 2.1095 |
| EPCSRST_N_1 | B32 | 2.1372 | 2.1394 | 2.2051 | 2.2073 | 2.1768 | 2.1796 | 2.1567 | 2.1597 | 2.1252 | 2.1293 | 2.1121 | 2.1162 |
| EPCSRST_N_2 | B34 | 2.1360 | 2.1378 | 2.2041 | 2.2056 | 2.1757 | 2.1773 | 2.1552 | 2.1569 | 2.1235 | 2.1254 | 2.1100 | 2.1117 |
| EPCSRST_N_3 | B35 | 2.1373 | 2.1388 | 2.2061 | 2.2071 | 2.1785 | 2.1796 | 2.1587 | 2.1599 | 2.1288 | 2.1299 | 2.1165 | 2.1171 |
| EPCSRST_N_4 | B36 | 2.1365 | 2.1380 | 2.2036 | 2.2048 | 2.1746 | 2.1763 | 2.1535 | 2.1553 | 2.1205 | 2.1229 | 2.1071 | 2.1090 |
| EPCSRST_N_5 | B37 | 2.1372 | 2.1388 | 2.2048 | 2.2065 | 2.1759 | 2.1785 | 2.1554 | 2.1585 | 2.1236 | 2.1273 | 2.1100 | 2.1142 |
| MONITOR | K23 | 2.1363 | 2.1376 | 2.2050 | 2.2060 | 2.1773 | 2.1786 | 2.1570 | 2.1594 | 2.1265 | 2.1296 | 2.1139 | 2.1172 |
| PLL_MON | L20 | 2.1375 | 2.1380 | 2.2067 | 2.2077 | 2.1800 | 2.1813 | 2.1618 | 2.1627 | 2.1331 | 2.1348 | 2.1213 | 2.1186 |
| TOGGLE_MON | L22 | 2.1373 | 2.1380 | 2.2065 | 2.2070 | 2.1794 | 2.1800 | 2.1600 | 2.1607 | 2.1313 | 2.1319 | 2.1195 | 2.1201 |

Table 12. LVCMOS 25 VOH – DUT 9774

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.1313 | 2.1350 | 2.1985 | 2.2032 | 2.1682 | 2.1745 | 2.1454 | 2.1554 | 2.1098 | 2.1229 | 2.0948 | 2.1090 |
| EPCSRST_N_0 | B31 | 2.1327 | 2.1350 | 2.2017 | 2.2031 | 2.1728 | 2.1742 | 2.1511 | 2.1546 | 2.1187 | 2.1213 | 2.1052 | 2.1072 |
| EPCSRST_N_1 | B32 | 2.1338 | 2.1359 | 2.2027 | 2.2051 | 2.1743 | 2.1770 | 2.1538 | 2.1571 | 2.1222 | 2.1267 | 2.1090 | 2.1136 |
| EPCSRST_N_2 | B34 | 2.1323 | 2.1346 | 2.2013 | 2.2034 | 2.1725 | 2.1749 | 2.1517 | 2.1545 | 2.1191 | 2.1229 | 2.1058 | 2.1094 |
| EPCSRST_N_3 | B35 | 2.1339 | 2.1354 | 2.2037 | 2.2050 | 2.1757 | 2.1771 | 2.1560 | 2.1574 | 2.1258 | 2.1273 | 2.1132 | 2.1147 |
| EPCSRST_N_4 | B36 | 2.1319 | 2.1338 | 2.2005 | 2.2022 | 2.1713 | 2.1731 | 2.1501 | 2.1520 | 2.1169 | 2.1195 | 2.1029 | 2.1051 |
| EPCSRST_N_5 | B37 | 2.1328 | 2.1348 | 2.2017 | 2.2038 | 2.1733 | 2.1753 | 2.1522 | 2.1552 | 2.1202 | 2.1241 | 2.1069 | 2.1105 |
| MONITOR | K23 | 2.1326 | 2.1349 | 2.2010 | 2.2042 | 2.1723 | 2.1765 | 2.1507 | 2.1571 | 2.1184 | 2.1271 | 2.1050 | 2.1145 |
| PLL_MON | L20 | 2.1344 | 2.1360 | 2.2047 | 2.2058 | 2.1776 | 2.1789 | 2.1592 | 2.1605 | 2.1303 | 2.1319 | 2.1187 | 2.1204 |
| TOGGLE_MON | L22 | 2.1340 | 2.1347 | 2.2046 | 2.2051 | 2.1775 | 2.1779 | 2.1582 | 2.1584 | 2.1289 | 2.1297 | 2.1172 | 2.1176 |

Table 13. LVCMOS 25 VOH – DUT 9793

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.1292 | 2.1332 | 2.1960 | 2.2023 | 2.1648 | 2.1735 | 2.1409 | 2.1540 | 2.1041 | 2.1215 | 2.0882 | 2.1073 |
| EPCSRST_N_0 | B31 | 2.1317 | 2.1341 | 2.2009 | 2.2023 | 2.1717 | 2.1733 | 2.1503 | 2.1539 | 2.1178 | 2.1204 | 2.1039 | 2.1059 |
| EPCSRST_N_1 | B32 | 2.1328 | 2.1350 | 2.2017 | 2.2042 | 2.1729 | 2.1755 | 2.1523 | 2.1557 | 2.1204 | 2.1244 | 2.1072 | 2.1112 |
| EPCSRST_N_2 | B34 | 2.1319 | 2.1336 | 2.2013 | 2.2028 | 2.1724 | 2.1742 | 2.1517 | 2.1536 | 2.1196 | 2.1218 | 2.1058 | 2.1083 |
| EPCSRST_N_3 | B35 | 2.1326 | 2.1343 | 2.2031 | 2.2043 | 2.1750 | 2.1765 | 2.1550 | 2.1564 | 2.1244 | 2.1265 | 2.1120 | 2.1136 |
| EPCSRST_N_4 | B36 | 2.1310 | 2.1335 | 2.1997 | 2.2018 | 2.1702 | 2.1722 | 2.1487 | 2.1513 | 2.1151 | 2.1186 | 2.1012 | 2.1043 |
| EPCSRST_N_5 | B37 | 2.1315 | 2.1338 | 2.2007 | 2.2030 | 2.1719 | 2.1746 | 2.1507 | 2.1543 | 2.1186 | 2.1228 | 2.1049 | 2.1094 |
| MONITOR | K23 | 2.1315 | 2.1329 | 2.2019 | 2.2030 | 2.1737 | 2.1752 | 2.1529 | 2.1557 | 2.1226 | 2.1255 | 2.1100 | 2.1127 |
| PLL_MON | L20 | 2.1326 | 2.1336 | 2.2034 | 2.2046 | 2.1763 | 2.1779 | 2.1575 | 2.1592 | 2.1287 | 2.1307 | 2.1166 | 2.1188 |
| TOGGLE_MON | L22 | 2.1327 | 2.1335 | 2.2034 | 2.2041 | 2.1758 | 2.1765 | 2.1563 | 2.1569 | 2.1267 | 2.1279 | 2.1148 | 2.1156 |

Table 14. LVCMOS 25 VOL – DUT 9738

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 238.901 | 234.381 | 173.067 | 167.345 | 203.560 | 195.652 | 226.179 | 218.228 | 262.148 | 249.842 | 277.947 | 263.343 |
| EPCSRST_N_0 | B31 | 237.030 | 234.193 | 169.287 | 167.646 | 197.658 | 196.130 | 218.480 | 218.857 | 250.543 | 250.999 | 264.408 | 264.713 |
| EPCSRST_N_1 | B32 | 237.123 | 233.181 | 168.671 | 165.645 | 196.697 | 193.049 | 217.274 | 213.197 | 249.031 | 243.990 | 262.423 | 256.794 |
| EPCSRST_N_2 | B34 | 237.839 | 234.613 | 169.839 | 167.252 | 197.790 | 194.907 | 218.631 | 215.456 | 250.564 | 246.940 | 263.955 | 260.083 |
| EPCSRST_N_3 | B35 | 236.896 | 234.161 | 167.478 | 165.733 | 194.826 | 192.898 | 214.586 | 212.732 | 244.798 | 242.621 | 257.210 | 255.150 |
| EPCSRST_N_4 | B36 | 239.321 | 235.378 | 172.339 | 168.181 | 202.074 | 196.350 | 224.209 | 217.465 | 259.044 | 249.714 | 273.993 | 263.460 |
| EPCSRST_N_5 | B37 | 237.248 | 234.098 | 168.985 | 166.336 | 196.986 | 193.940 | 217.714 | 214.327 | 249.195 | 244.956 | 262.448 | 257.861 |
| MONITOR | K23 | 235.586 | 232.917 | 167.692 | 165.068 | 195.423 | 191.957 | 215.027 | 212.047 | 245.671 | 241.222 | 258.557 | 253.762 |
| PLL_MON | L20 | 235.560 | 232.554 | 166.257 | 163.875 | 192.984 | 189.831 | 212.862 | 209.036 | 241.615 | 236.814 | 253.537 | 248.403 |
| TOGGLE_MON | L22 | 235.973 | 233.115 | 166.252 | 164.275 | 192.959 | 190.810 | 212.217 | 210.055 | 240.797 | 238.284 | 252.894 | 250.303 |



Table. 15. LVCMOS 25 VOL – DUT 9741

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 238.436 | 233.853 | 172.515 | 166.880 | 202.769 | 194.999 | 225.337 | 217.474 | 261.067 | 248.937 | 276.665 | 262.463 |
| EPCSRST_N_0 | B31 | 236.251 | 233.212 | 168.533 | 166.905 | 196.854 | 195.162 | 217.212 | 217.939 | 249.074 | 249.880 | 262.788 | 263.493 |
| EPCSRST_N_1 | B32 | 235.376 | 231.512 | 167.716 | 164.754 | 195.655 | 191.957 | 216.119 | 212.004 | 247.738 | 242.659 | 260.878 | 255.488 |
| EPCSRST_N_2 | B34 | 236.633 | 233.382 | 168.771 | 166.587 | 196.760 | 194.041 | 217.538 | 214.615 | 249.119 | 245.986 | 262.561 | 259.229 |
| EPCSRST_N_3 | B35 | 235.276 | 232.491 | 166.762 | 164.829 | 194.084 | 191.894 | 213.895 | 211.690 | 243.931 | 241.554 | 256.531 | 254.020 |
| EPCSRST_N_4 | B36 | 239.622 | 234.060 | 175.115 | 167.541 | 206.421 | 195.622 | 230.188 | 216.435 | 268.176 | 248.735 | 284.796 | 262.342 |
| EPCSRST_N_5 | B37 | 236.570 | 233.571 | 168.294 | 165.846 | 196.333 | 193.187 | 216.835 | 213.473 | 248.215 | 243.990 | 261.380 | 256.819 |
| MONITOR | K23 | 234.871 | 232.088 | 166.687 | 164.277 | 193.941 | 191.052 | 213.357 | 210.841 | 243.624 | 239.890 | 256.158 | 252.342 |
| PLL_MON | L20 | 233.973 | 230.505 | 164.797 | 162.794 | 191.435 | 188.926 | 211.061 | 208.194 | 239.387 | 236.463 | 251.019 | 247.385 |
| TOGGLE_MON | L22 | 233.749 | 231.095 | 164.907 | 163.146 | 191.301 | 189.568 | 210.094 | 208.638 | 238.523 | 236.879 | 250.168 | 248.684 |

Table. 16. LVCMOS 25 VOL – DUT 9752

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 234.279 | 230.145 | 169.927 | 164.629 | 199.931 | 192.284 | 222.173 | 214.696 | 257.651 | 245.644 | 273.086 | 259.044 |
| EPCSRST_N_0 | B31 | 232.383 | 229.868 | 165.934 | 165.007 | 193.827 | 193.088 | 214.147 | 215.639 | 245.494 | 247.416 | 259.020 | 261.092 |
| EPCSRST_N_1 | B32 | 231.909 | 228.600 | 165.154 | 162.620 | 192.665 | 189.559 | 212.802 | 209.255 | 243.856 | 239.508 | 256.958 | 252.099 |
| EPCSRST_N_2 | B34 | 233.354 | 230.696 | 166.360 | 164.528 | 194.022 | 191.831 | 214.398 | 212.331 | 245.715 | 243.387 | 258.931 | 256.568 |
| EPCSRST_N_3 | B35 | 231.821 | 229.679 | 164.262 | 163.059 | 191.220 | 189.772 | 210.717 | 209.468 | 240.288 | 239.345 | 262.687 | 251.609 |
| EPCSRST_N_4 | B36 | 232.990 | 230.759 | 167.226 | 165.470 | 195.265 | 193.413 | 216.068 | 214.214 | 248.491 | 246.224 | 262.071 | 259.857 |
| EPCSRST_N_5 | B37 | 232.437 | 229.604 | 165.970 | 163.700 | 193.846 | 190.990 | 214.146 | 211.088 | 245.728 | 241.831 | 258.843 | 254.547 |
| MONITOR | K23 | 231.643 | 229.135 | 164.452 | 162.304 | 191.542 | 188.928 | 211.021 | 208.617 | 240.874 | 237.453 | 253.383 | 249.741 |
| PLL_MON | L20 | 230.297 | 228.054 | 162.342 | 160.771 | 188.603 | 186.575 | 207.965 | 205.643 | 235.799 | 233.044 | 247.406 | 244.406 |
| TOGGLE_MON | L22 | 230.759 | 228.573 | 162.734 | 161.402 | 189.052 | 187.585 | 207.871 | 206.530 | 236.425 | 234.947 | 248.033 | 246.677 |

Table. 17. LVCMOS 25 VOL – DUT 9774

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 236.929 | 232.998 | 171.045 | 166.125 | 200.760 | 194.207 | 222.788 | 216.582 | 257.526 | 247.743 | 272.684 | 260.942 |
| EPCSRST_N_0 | B31 | 235.372 | 232.722 | 168.069 | 166.716 | 196.289 | 194.949 | 216.860 | 217.613 | 248.860 | 249.603 | 262.499 | 263.053 |
| EPCSRST_N_1 | B32 | 234.886 | 231.612 | 167.339 | 164.654 | 195.077 | 191.630 | 215.289 | 211.502 | 246.532 | 241.755 | 259.458 | 254.434 |
| EPCSRST_N_2 | B34 | 236.256 | 233.395 | 168.885 | 166.486 | 196.961 | 193.990 | 217.726 | 214.402 | 249.597 | 245.647 | 262.950 | 258.765 |
| EPCSRST_N_3 | B35 | 235.163 | 232.817 | 166.309 | 164.867 | 193.419 | 191.869 | 213.204 | 211.828 | 242.964 | 241.504 | 255.074 | 253.831 |
| EPCSRST_N_4 | B36 | 237.198 | 234.763 | 169.751 | 167.930 | 198.381 | 196.200 | 219.372 | 217.151 | 251.845 | 249.438 | 265.802 | 263.184 |
| EPCSRST_N_5 | B37 | 236.231 | 233.583 | 168.294 | 166.122 | 196.295 | 193.589 | 216.885 | 213.988 | 248.516 | 244.881 | 261.757 | 257.861 |
| MONITOR | K23 | 234.632 | 231.447 | 167.818 | 163.925 | 195.963 | 190.574 | 216.559 | 210.565 | 248.321 | 239.815 | 261.684 | 252.003 |
| PLL_MON | L20 | 233.143 | 230.178 | 164.180 | 162.656 | 190.579 | 188.611 | 210.205 | 207.880 | 238.052 | 235.193 | 249.659 | 246.820 |
| TOGGLE_MON | L22 | 233.787 | 231.459 | 164.744 | 163.409 | 191.125 | 189.781 | 209.931 | 208.750 | 238.322 | 236.966 | 249.930 | 248.948 |

Table. 18. LVCMOS 25 VOL – DUT 9793

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 8mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 239.039 | 234.934 | 173.356 | 167.420 | 203.987 | 195.389 | 226.769 | 218.090 | 263.077 | 249.201 | 279.102 | 262.576 |
| EPCSRST_N_0 | B31 | 236.578 | 233.916 | 168.960 | 167.508 | 197.193 | 195.829 | 217.814 | 218.631 | 249.953 | 250.659 | 263.629 | 264.461 |
| EPCSRST_N_1 | B32 | 236.243 | 233.018 | 168.307 | 165.871 | 196.283 | 193.187 | 216.835 | 213.335 | 248.177 | 243.751 | 261.506 | 256.781 |
| EPCSRST_N_2 | B34 | 237.273 | 234.700 | 169.211 | 167.315 | 197.099 | 194.907 | 217.714 | 215.381 | 249.295 | 246.789 | 262.435 | 259.895 |
| EPCSRST_N_3 | B35 | 236.620 | 234.449 | 167.440 | 165.972 | 194.725 | 193.262 | 214.536 | 213.109 | 244.522 | 243.048 | 256.971 | 255.539 |
| EPCSRST_N_4 | B36 | 238.090 | 235.567 | 170.643 | 168.683 | 199.461 | 197.091 | 220.628 | 218.168 | 253.441 | 250.492 | 267.460 | 264.213 |
| EPCSRST_N_5 | B37 | 237.612 | 234.826 | 169.375 | 167.114 | 197.627 | 194.543 | 218.317 | 215.055 | 250.150 | 245.998 | 263.566 | 258.991 |
| MONITOR | K23 | 236.026 | 233.935 | 167.479 | 165.508 | 194.845 | 192.535 | 214.424 | 212.248 | 244.441 | 241.499 | 257.075 | 253.862 |
| PLL_MON | L20 | 234.603 | 232.453 | 165.326 | 163.486 | 191.901 | 189.856 | 211.653 | 209.577 | 239.802 | 236.777 | 251.699 | 248.290 |
| TOGGLE_MON | L22 | 234.591 | 232.412 | 165.573 | 164.262 | 192.432 | 191.010 | 211.300 | 210.143 | 240.156 | 238.798 | 252.103 | 250.817 |



Table. 19. LVTTTL VOH – DUT 9738

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.9180 | 2.9209 | 2.9063 | 2.9112 | 2.8828 | 2.8919 | 2.8601 | 2.8730 | 2.8369 | 2.8547 |
| EPCSRST_N_0 | B31 | 2.9198 | 2.9209 | 2.9099 | 2.9112 | 2.8910 | 2.8918 | 2.8719 | 2.8721 | 2.8529 | 2.8534 |
| EPCSRST_N_1 | B32 | 2.9205 | 2.9217 | 2.9113 | 2.9130 | 2.8926 | 2.8952 | 2.8742 | 2.8777 | 2.8557 | 2.8601 |
| EPCSRST_N_2 | B34 | 2.9200 | 2.9209 | 2.9103 | 2.9115 | 2.8914 | 2.8932 | 2.8727 | 2.8748 | 2.8540 | 2.8566 |
| EPCSRST_N_3 | B35 | 2.9208 | 2.9214 | 2.9122 | 2.9130 | 2.8955 | 2.8962 | 2.8787 | 2.8794 | 2.8617 | 2.8627 |
| EPCSRST_N_4 | B36 | 2.9185 | 2.9203 | 2.9076 | 2.9110 | 2.8853 | 2.8915 | 2.8635 | 2.8720 | 2.8419 | 2.8528 |
| EPCSRST_N_5 | B37 | 2.9203 | 2.9212 | 2.9109 | 2.9124 | 2.8923 | 2.8946 | 2.8739 | 2.8768 | 2.8555 | 2.8593 |
| MONITOR | K23 | 2.9196 | 2.9214 | 2.9106 | 2.9124 | 2.8929 | 2.8955 | 2.8754 | 2.8790 | 2.8580 | 2.8627 |
| PLL_MON | L20 | 2.9196 | 2.9208 | 2.9118 | 2.9132 | 2.8958 | 2.8991 | 2.8802 | 2.8842 | 2.8651 | 2.8687 |
| TOGGLE_MON | L22 | 2.9193 | 2.9208 | 2.9119 | 2.9132 | 2.8961 | 2.8978 | 2.8805 | 2.8821 | 2.8646 | 2.8665 |

Table. 20. LVTTTL VOH – DUT 9741

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.9181 | 2.9213 | 2.9065 | 2.9119 | 2.8837 | 2.8927 | 2.8607 | 2.8734 | 2.8379 | 2.8554 |
| EPCSRST_N_0 | B31 | 2.9201 | 2.9213 | 2.9108 | 2.9118 | 2.8918 | 2.8924 | 2.8730 | 2.8730 | 2.8540 | 2.8546 |
| EPCSRST_N_1 | B32 | 2.9217 | 2.9229 | 2.9122 | 2.9140 | 2.8937 | 2.8966 | 2.8750 | 2.8790 | 2.8568 | 2.8613 |
| EPCSRST_N_2 | B34 | 2.9206 | 2.9217 | 2.9114 | 2.9125 | 2.8928 | 2.8942 | 2.8739 | 2.8756 | 2.8554 | 2.8572 |
| EPCSRST_N_3 | B35 | 2.9220 | 2.9228 | 2.9133 | 2.9143 | 2.8963 | 2.8973 | 2.8792 | 2.8806 | 2.8622 | 2.8637 |
| EPCSRST_N_4 | B36 | 2.9177 | 2.9217 | 2.9049 | 2.9119 | 2.8798 | 2.8924 | 2.8549 | 2.8732 | 2.8297 | 2.8539 |
| EPCSRST_N_5 | B37 | 2.9207 | 2.9218 | 2.9116 | 2.9129 | 2.8929 | 2.8954 | 2.8746 | 2.8779 | 2.8564 | 2.8602 |
| MONITOR | K23 | 2.9201 | 2.9215 | 2.9114 | 2.9129 | 2.8944 | 2.8966 | 2.8773 | 2.8800 | 2.8601 | 2.8638 |
| PLL_MON | L20 | 2.9211 | 2.9229 | 2.9135 | 2.9148 | 2.8977 | 2.9002 | 2.8824 | 2.8851 | 2.8677 | 2.8704 |
| TOGGLE_MON | L22 | 2.9217 | 2.9223 | 2.9134 | 2.9146 | 2.8978 | 2.8989 | 2.8825 | 2.8835 | 2.8670 | 2.8680 |

Table. 21. LVTTTL VOH – DUT 9752

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.9215 | 2.9239 | 2.9099 | 2.9146 | 2.8870 | 2.8955 | 2.8640 | 2.8766 | 2.8414 | 2.8586 |
| EPCSRST_N_0 | B31 | 2.9235 | 2.9243 | 2.9139 | 2.9142 | 2.8953 | 2.8949 | 2.8766 | 2.8753 | 2.8580 | 2.8568 |
| EPCSRST_N_1 | B32 | 2.9245 | 2.9252 | 2.9151 | 2.9163 | 2.8971 | 2.8991 | 2.8790 | 2.8819 | 2.8609 | 2.8646 |
| EPCSRST_N_2 | B34 | 2.9234 | 2.9238 | 2.9140 | 2.9146 | 2.8955 | 2.8963 | 2.8769 | 2.8778 | 2.8587 | 2.8596 |
| EPCSRST_N_3 | B35 | 2.9246 | 2.9248 | 2.9160 | 2.9161 | 2.8992 | 2.8995 | 2.8826 | 2.8825 | 2.8657 | 2.8657 |
| EPCSRST_N_4 | B36 | 2.9234 | 2.9239 | 2.9134 | 2.9140 | 2.8940 | 2.8949 | 2.8745 | 2.8754 | 2.8551 | 2.8563 |
| EPCSRST_N_5 | B37 | 2.9244 | 2.9249 | 2.9146 | 2.9159 | 2.8958 | 2.8979 | 2.8771 | 2.8799 | 2.8587 | 2.8622 |
| MONITOR | K23 | 2.9229 | 2.9241 | 2.9140 | 2.9156 | 2.8971 | 2.8990 | 2.8799 | 2.8825 | 2.8628 | 2.8664 |
| PLL_MON | L20 | 2.9236 | 2.9244 | 2.9162 | 2.9173 | 2.9007 | 2.9030 | 2.8859 | 2.8875 | 2.8711 | 2.8731 |
| TOGGLE_MON | L22 | 2.9238 | 2.9245 | 2.9159 | 2.9168 | 2.9000 | 2.9008 | 2.8843 | 2.8852 | 2.8689 | 2.8696 |

Table. 22. LVTTTL VOH – DUT 9774

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.9190 | 2.9212 | 2.9078 | 2.9119 | 2.8857 | 2.8930 | 2.8635 | 2.8743 | 2.8417 | 2.8566 |
| EPCSRST_N_0 | B31 | 2.9203 | 2.9212 | 2.9108 | 2.9117 | 2.8917 | 2.8921 | 2.8728 | 2.8727 | 2.8537 | 2.8544 |
| EPCSRST_N_1 | B32 | 2.9215 | 2.9222 | 2.9118 | 2.9134 | 2.8938 | 2.8961 | 2.8758 | 2.8790 | 2.8576 | 2.8619 |
| EPCSRST_N_2 | B34 | 2.9201 | 2.9210 | 2.9104 | 2.9116 | 2.8917 | 2.8934 | 2.8728 | 2.8752 | 2.8541 | 2.8572 |
| EPCSRST_N_3 | B35 | 2.9215 | 2.9215 | 2.9129 | 2.9136 | 2.8961 | 2.8968 | 2.8795 | 2.8797 | 2.8630 | 2.8632 |
| EPCSRST_N_4 | B36 | 2.9195 | 2.9202 | 2.9097 | 2.9103 | 2.8899 | 2.8910 | 2.8705 | 2.8716 | 2.8511 | 2.8526 |
| EPCSRST_N_5 | B37 | 2.9203 | 2.9211 | 2.9111 | 2.9123 | 2.8924 | 2.8943 | 2.8739 | 2.8761 | 2.8555 | 2.8585 |
| MONITOR | K23 | 2.9194 | 2.9217 | 2.9101 | 2.9132 | 2.8909 | 2.8964 | 2.8720 | 2.8798 | 2.8530 | 2.8635 |
| PLL_MON | L20 | 2.9212 | 2.9223 | 2.9135 | 2.9149 | 2.8980 | 2.9001 | 2.8830 | 2.8851 | 2.8685 | 2.8706 |
| TOGGLE_MON | L22 | 2.9210 | 2.9216 | 2.9133 | 2.9141 | 2.8978 | 2.8981 | 2.8823 | 2.8828 | 2.8670 | 2.8673 |

Table. 23. LVTTTL VOH – DUT 9793

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad | Pre-rad | Post-rad |
| TID_BUF_OUT | A33 | 2.9169 | 2.9203 | 2.9050 | 2.9105 | 2.8814 | 2.8920 | 2.8579 | 2.8730 | 2.8343 | 2.8550 |
| EPCSRST_N_0 | B31 | 2.9193 | 2.9206 | 2.9098 | 2.9108 | 2.8907 | 2.8915 | 2.8716 | 2.8716 | 2.8523 | 2.8531 |
| EPCSRST_N_1 | B32 | 2.9203 | 2.9212 | 2.9104 | 2.9121 | 2.8921 | 2.8945 | 2.8740 | 2.8771 | 2.8557 | 2.8596 |
| EPCSRST_N_2 | B34 | 2.9195 | 2.9201 | 2.9103 | 2.9111 | 2.8916 | 2.8929 | 2.8731 | 2.8745 | 2.8547 | 2.8562 |
| EPCSRST_N_3 | B35 | 2.9203 | 2.9207 | 2.9119 | 2.9122 | 2.8951 | 2.8954 | 2.8780 | 2.8785 | 2.8613 | 2.8617 |
| EPCSRST_N_4 | B36 | 2.9188 | 2.9197 | 2.9086 | 2.9099 | 2.8886 | 2.8901 | 2.8690 | 2.8710 | 2.8490 | 2.8515 |
| EPCSRST_N_5 | B37 | 2.9190 | 2.9201 | 2.9095 | 2.9109 | 2.8906 | 2.8932 | 2.8720 | 2.8752 | 2.8535 | 2.8575 |
| MONITOR | K23 | 2.9188 | 2.9200 | 2.9104 | 2.9112 | 2.8930 | 2.8950 | 2.8758 | 2.8784 | 2.8587 | 2.8618 |
| PLL_MON | L20 | 2.9198 | 2.9208 | 2.9123 | 2.9135 | 2.8964 | 2.8983 | 2.8812 | 2.8835 | 2.8663 | 2.8689 |
| TOGGLE_MON | L22 | 2.9199 | 2.9207 | 2.9116 | 2.9126 | 2.8957 | 2.8967 | 2.8802 | 2.8809 | 2.8643 | 2.8655 |

Table. 24. LVTTTL VOL – DUT 9738

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad |
| TID_BUF_OUT | A33 | 218.759 | 215.000 | 229.633 | 228.134 | 252.474 | 242.834 | 275.158 | 261.673 | 298.531 | 282.185 |
| EPCSRST_N_0 | B31 | 217.041 | 215.063 | 226.164 | 228.384 | 244.600 | 243.524 | 263.847 | 262.864 | 283.246 | 283.907 |
| EPCSRST_N_1 | B32 | 217.063 | 213.848 | 225.470 | 222.598 | 243.532 | 239.004 | 262.001 | 256.630 | 281.040 | 274.996 |
| EPCSRST_N_2 | B34 | 217.751 | 214.973 | 226.657 | 224.317 | 244.845 | 241.411 | 263.626 | 259.942 | 282.849 | 278.812 |
| EPCSRST_N_3 | B35 | 216.876 | 214.723 | 224.470 | 223.067 | 240.938 | 238.754 | 257.845 | 255.630 | 275.123 | 273.126 |
| EPCSRST_N_4 | B36 | 219.220 | 215.754 | 229.501 | 225.535 | 250.845 | 243.630 | 272.720 | 262.786 | 294.846 | 282.754 |
| EPCSRST_N_5 | B37 | 217.282 | 214.535 | 225.845 | 223.723 | 244.063 | 240.254 | 262.470 | 258.005 | 281.040 | 276.264 |
| MONITOR | K23 | 215.592 | 213.472 | 223.686 | 222.601 | 241.625 | 237.702 | 258.970 | 254.304 | 276.529 | 271.528 |
| PLL_MON | L20 | 215.401 | 213.137 | 224.309 | 221.168 | 238.344 | 234.949 | 253.910 | 249.543 | 270.645 | 265.347 |
| TOGGLE_MON | L22 | 215.906 | 213.796 | 223.127 | 221.212 | 238.476 | 236.198 | 253.949 | 251.654 | 270.017 | 267.529 |

Table. 25. LVTTTL VOL – DUT 9741

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad |
| TID_BUF_OUT | A33 | 218.290 | 214.467 | 228.945 | 227.726 | 251.817 | 242.239 | 274.252 | 260.983 | 297.375 | 281.494 |
| EPCSRST_N_0 | B31 | 216.478 | 214.279 | 225.227 | 227.538 | 243.850 | 242.458 | 262.347 | 261.955 | 281.626 | 282.789 |
| EPCSRST_N_1 | B32 | 215.532 | 212.348 | 224.157 | 221.410 | 242.407 | 237.817 | 260.907 | 255.380 | 279.671 | 273.640 |
| EPCSRST_N_2 | B34 | 216.688 | 214.098 | 225.095 | 223.348 | 243.782 | 240.536 | 262.313 | 258.848 | 281.216 | 277.921 |
| EPCSRST_N_3 | B35 | 215.438 | 212.910 | 223.188 | 221.785 | 239.813 | 237.629 | 256.813 | 254.661 | 274.420 | 271.946 |
| EPCSRST_N_4 | B36 | 219.532 | 214.410 | 231.688 | 224.348 | 256.532 | 242.567 | 281.407 | 261.567 | 306.692 | 281.474 |
| EPCSRST_N_5 | B37 | 216.813 | 214.066 | 224.751 | 222.817 | 243.095 | 239.473 | 261.407 | 256.848 | 279.909 | 275.184 |
| MONITOR | K23 | 214.936 | 212.721 | 222.530 | 221.538 | 240.031 | 236.765 | 256.782 | 253.179 | 274.030 | 270.121 |
| PLL_MON | L20 | 214.088 | 211.637 | 222.715 | 219.574 | 236.406 | 233.887 | 251.722 | 248.543 | 267.989 | 264.341 |
| TOGGLE_MON | L22 | 213.687 | 211.919 | 221.220 | 219.710 | 236.600 | 234.978 | 251.636 | 250.121 | 267.240 | 265.948 |

Table. 26. LVTTTL VOL – DUT 9752

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad |
| TID_BUF_OUT | A33 | 214.322 | 210.800 | 225.540 | 224.090 | 247.755 | 238.509 | 270.128 | 257.316 | 293.344 | 277.534 |
| EPCSRST_N_0 | B31 | 212.447 | 210.894 | 221.353 | 224.497 | 239.632 | 239.669 | 258.254 | 258.852 | 277.369 | 279.897 |
| EPCSRST_N_1 | B32 | 212.251 | 209.348 | 220.720 | 218.535 | 238.345 | 234.629 | 256.438 | 251.942 | 274.960 | 269.774 |
| EPCSRST_N_2 | B34 | 213.126 | 211.160 | 222.001 | 220.223 | 240.157 | 237.692 | 258.345 | 255.786 | 277.234 | 274.795 |
| EPCSRST_N_3 | B35 | 212.063 | 210.066 | 219.688 | 218.879 | 236.470 | 234.754 | 252.969 | 251.755 | 270.073 | 269.109 |
| EPCSRST_N_4 | B36 | 213.407 | 211.254 | 222.845 | 221.379 | 241.845 | 239.504 | 260.626 | 258.692 | 280.738 | 278.561 |
| EPCSRST_N_5 | B37 | 212.563 | 210.254 | 221.407 | 219.379 | 239.845 | 236.286 | 258.345 | 254.286 | 277.208 | 272.523 |
| MONITOR | K23 | 211.998 | 209.908 | 219.499 | 218.975 | 236.656 | 233.826 | 253.500 | 249.771 | 270.953 | 267.017 |
| PLL_MON | L20 | 210.806 | 208.543 | 219.308 | 217.324 | 232.811 | 230.730 | 247.721 | 245.324 | 263.834 | 260.960 |
| TOGGLE_MON | L22 | 210.749 | 209.072 | 218.001 | 216.800 | 233.568 | 232.193 | 249.041 | 247.555 | 264.929 | 263.589 |

Table. 27. LVTTTL VOL – DUT 9774



| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad |
| TID_BUF_OUT | A33 | 216.541 | 213.433 | 226.852 | 226.347 | 248.630 | 240.734 | 270.440 | 259.416 | 292.502 | 279.382 |
| EPCSRST_N_0 | B31 | 215.197 | 213.276 | 224.102 | 226.692 | 242.850 | 241.800 | 261.629 | 260.983 | 281.023 | 281.959 |
| EPCSRST_N_1 | B32 | 214.813 | 211.910 | 223.470 | 221.098 | 241.126 | 237.254 | 258.970 | 254.067 | 277.560 | 272.172 |
| EPCSRST_N_2 | B34 | 216.376 | 213.629 | 225.345 | 223.067 | 243.532 | 240.192 | 262.376 | 258.255 | 281.517 | 276.967 |
| EPCSRST_N_3 | B35 | 214.970 | 213.004 | 222.563 | 221.473 | 239.157 | 237.286 | 255.532 | 254.067 | 272.849 | 271.356 |
| EPCSRST_N_4 | B36 | 216.907 | 214.879 | 226.438 | 224.817 | 245.220 | 243.036 | 264.532 | 262.005 | 284.658 | 281.963 |
| EPCSRST_N_5 | B37 | 216.063 | 213.848 | 224.470 | 222.598 | 242.688 | 239.661 | 261.376 | 257.411 | 279.997 | 276.000 |
| MONITOR | K23 | 214.467 | 211.815 | 223.061 | 220.569 | 242.375 | 235.858 | 261.157 | 252.116 | 280.133 | 269.304 |
| PLL_MON | L20 | 212.775 | 210.793 | 221.340 | 218.762 | 235.124 | 232.824 | 250.034 | 247.605 | 266.100 | 263.323 |
| TOGGLE_MON | L22 | 213.437 | 211.888 | 220.439 | 219.553 | 235.631 | 234.477 | 250.761 | 249.870 | 266.424 | 265.898 |

Table. 28. LVTTTL VOL – DUT 9793

| Pin Name | Pin # | 2mA | | 4mA | | 6mA | | 12mA | | 16mA | |
|-------------|-------|---------|----------|---------|----------|---------|----------|---------|----------|---------|----------|
| | | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad | Pre Rad | Post Rad |
| TID_BUF_OUT | A33 | 218.759 | 215.407 | 229.477 | 228.165 | 252.942 | 242.396 | 276.346 | 261.046 | 299.987 | 281.154 |
| EPCSRST_N_0 | B31 | 216.447 | 214.624 | 224.633 | 228.008 | 243.881 | 242.928 | 263.066 | 262.394 | 282.367 | 283.442 |
| EPCSRST_N_1 | B32 | 216.220 | 213.379 | 224.751 | 222.692 | 242.845 | 239.098 | 261.001 | 256.723 | 279.909 | 274.733 |
| EPCSRST_N_2 | B34 | 217.032 | 214.879 | 225.563 | 224.098 | 243.907 | 241.348 | 262.032 | 259.442 | 281.040 | 278.498 |
| EPCSRST_N_3 | B35 | 216.345 | 214.473 | 223.970 | 223.067 | 240.595 | 239.004 | 257.563 | 255.911 | 274.658 | 273.264 |
| EPCSRST_N_4 | B36 | 217.720 | 215.848 | 226.938 | 225.910 | 246.938 | 244.192 | 266.470 | 263.130 | 286.731 | 283.294 |
| EPCSRST_N_5 | B37 | 217.563 | 215.129 | 225.876 | 224.285 | 244.376 | 241.036 | 263.220 | 258.911 | 282.233 | 277.293 |
| MONITOR | K23 | 215.873 | 214.035 | 223.030 | 222.945 | 240.875 | 238.203 | 257.844 | 254.492 | 274.733 | 271.402 |
| PLL_MON | L20 | 214.276 | 212.762 | 222.903 | 220.824 | 237.031 | 234.699 | 252.159 | 249.543 | 268.354 | 265.045 |
| TOGGLE_MON | L22 | 214.312 | 212.576 | 221.721 | 220.899 | 237.538 | 236.323 | 253.136 | 251.998 | 269.125 | 267.980 |

E. Propagation Delay

Table 29 lists the pre-irradiation and post-irradiation propagation delay measurements. It shows that the change due to radiation on each DUT is not significant and every DUT passes the 10% degradation criterion.

Table. 29. Pre-irradiation and Post-irradiation Propagation Delay Change

| DUT | Total Dose | Pre-irradiation (µs) | Post-irradiation (µs) | Change Degradation (%) |
|------|------------|----------------------|-----------------------|------------------------|
| 9738 | 125 krad | 0.461 | 0.461 | 0 |
| 9741 | 125 krad | 0.464 | 0.462 | -0.43 |
| 9752 | 125 krad | 0.460 | 0.457 | -0.65 |
| 9774 | 100 krad | 0.458 | 0.457 | -0.21 |
| 9793 | 100 krad | 0.458 | 0.458 | 0 |

F. Transition Time

The figures below show the pre-irradiation and post-annealing transitions edges. In each case the radiation induced transition degradation is not observable.

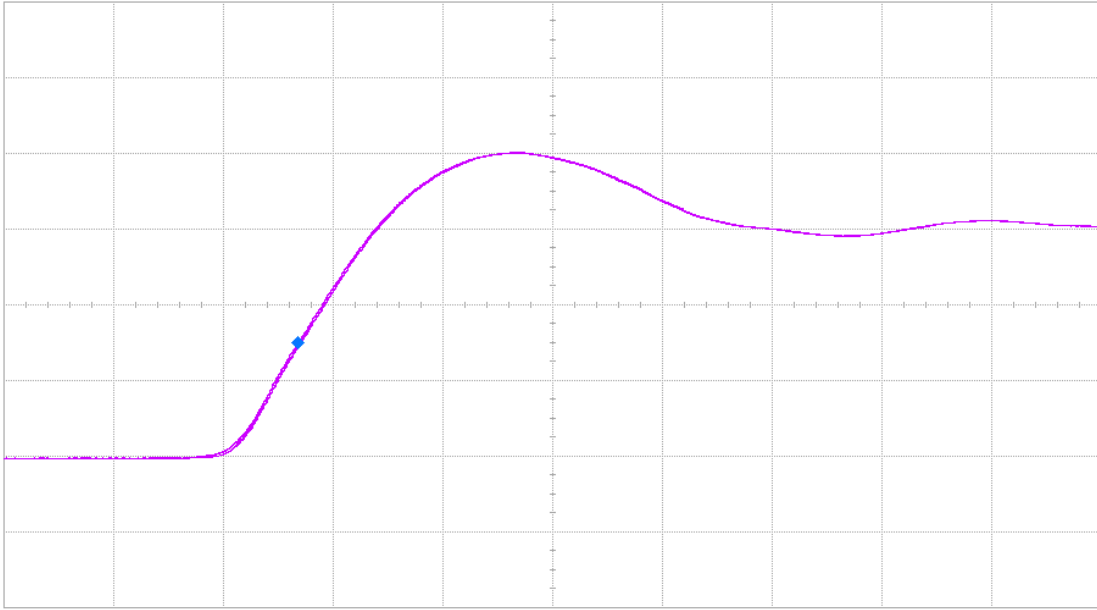


Fig. 18 (a). DUT 9738 pre-irradiation rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

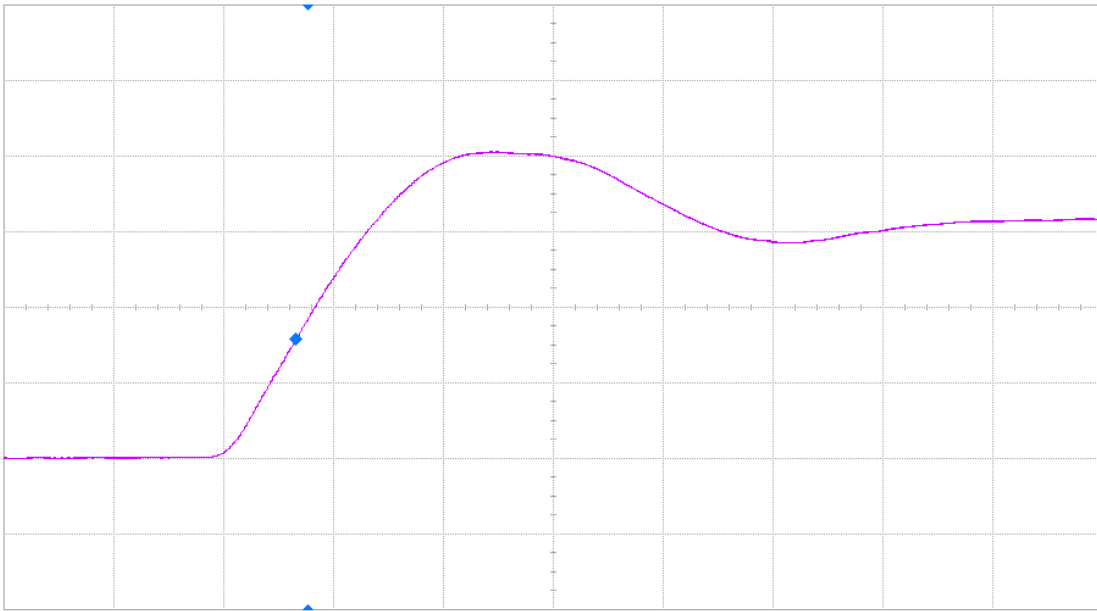


Fig. 18 (b). DUT 9738 post-annealing rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

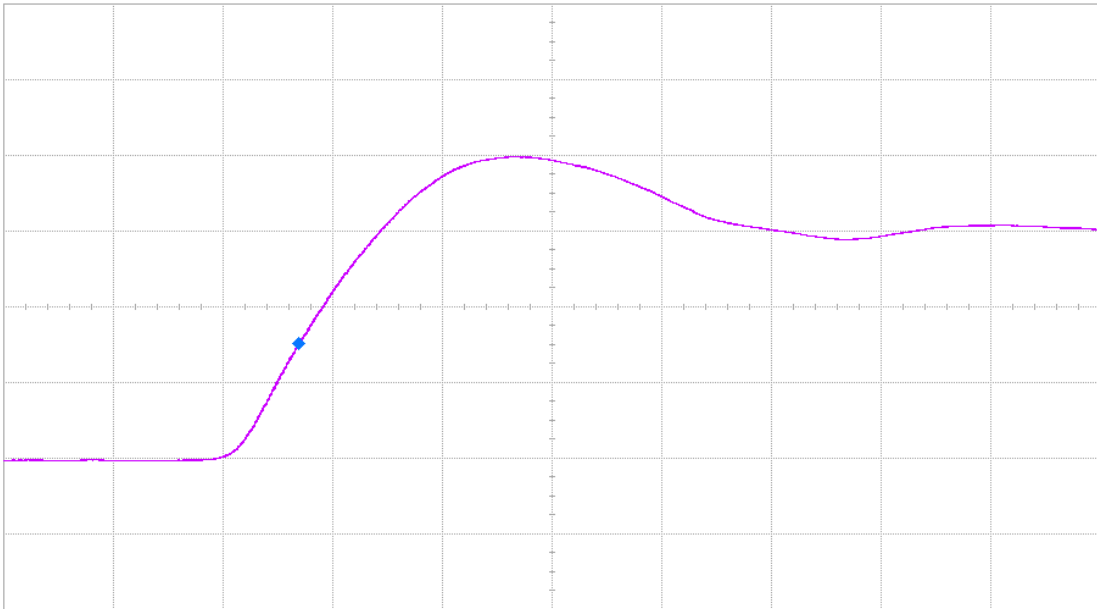


Fig. 19 (a). DUT 9741 pre-irradiation rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

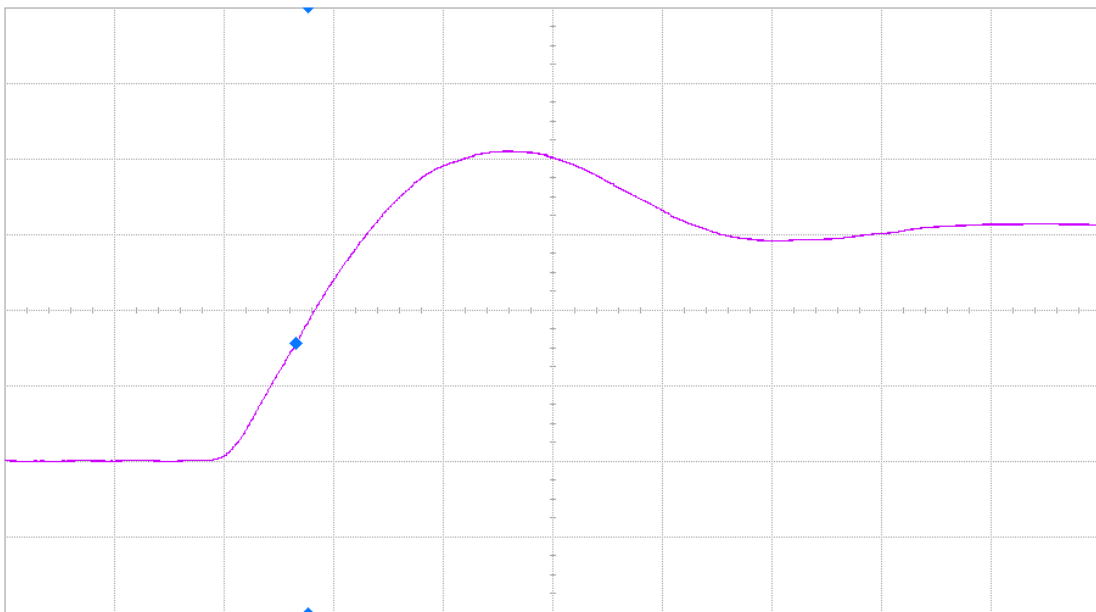


Fig. 19 (b). DUT 9741 post-annealing rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

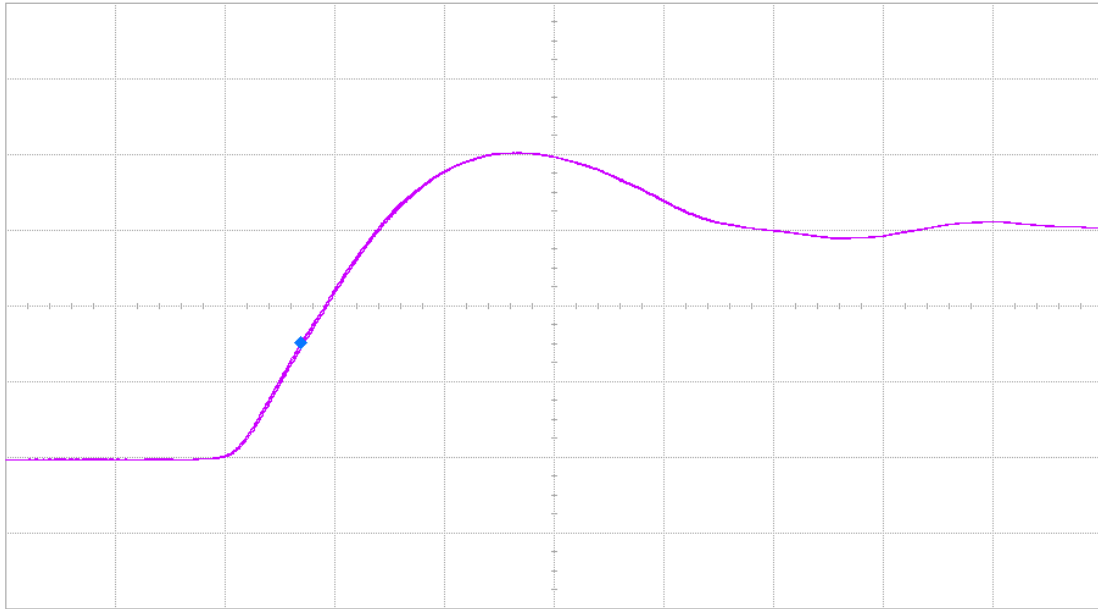


Fig. 20 (a). DUT 9752 pre-irradiation rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

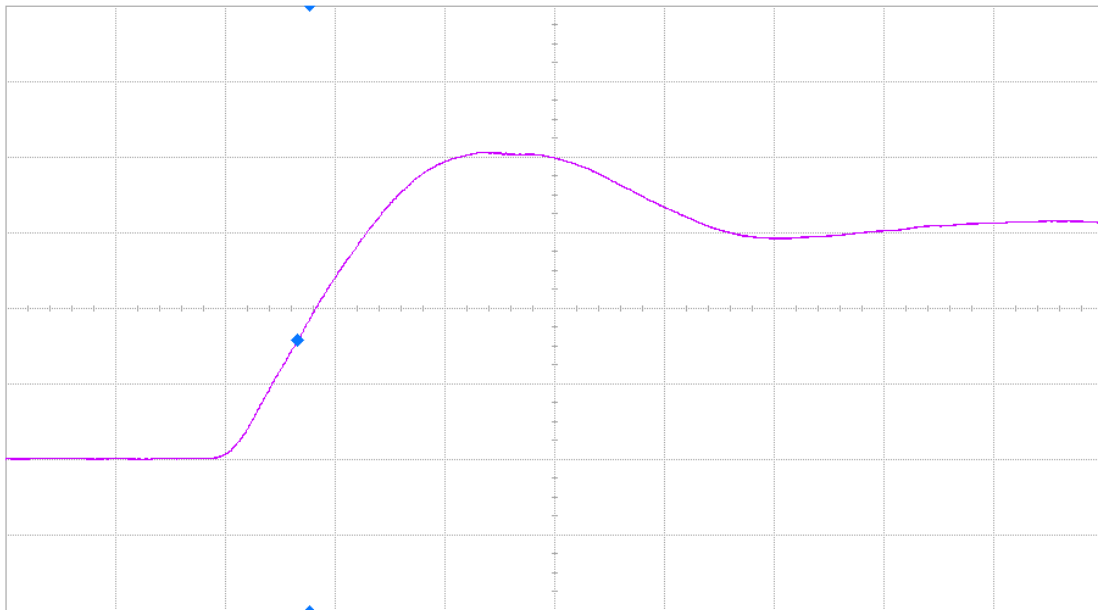


Fig. 20 (b). DUT 9752 post-annealing rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

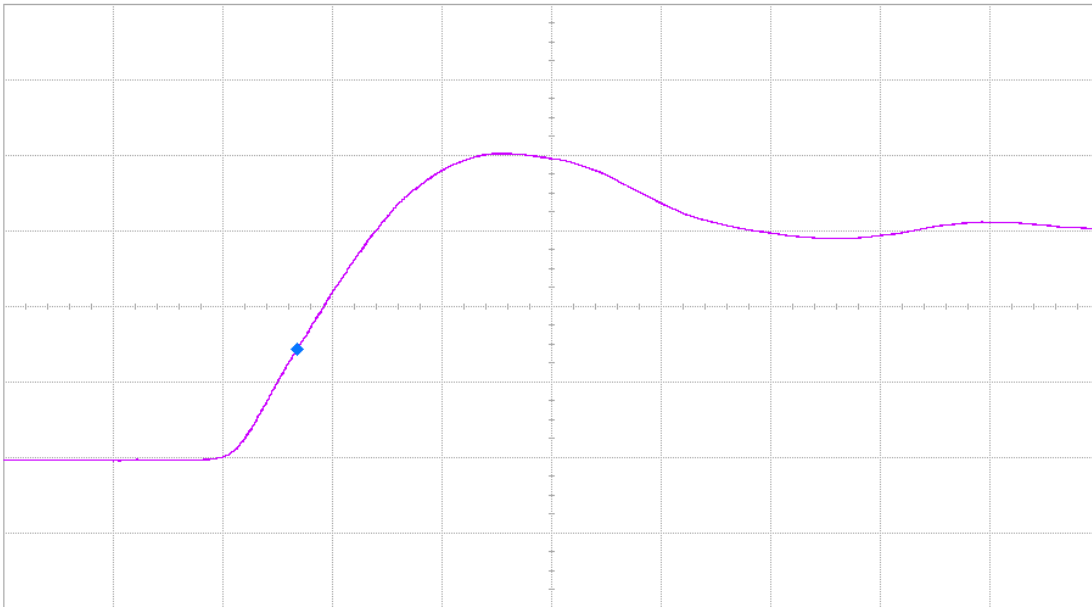


Fig. 21 (a). DUT 9774 pre-irradiation rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

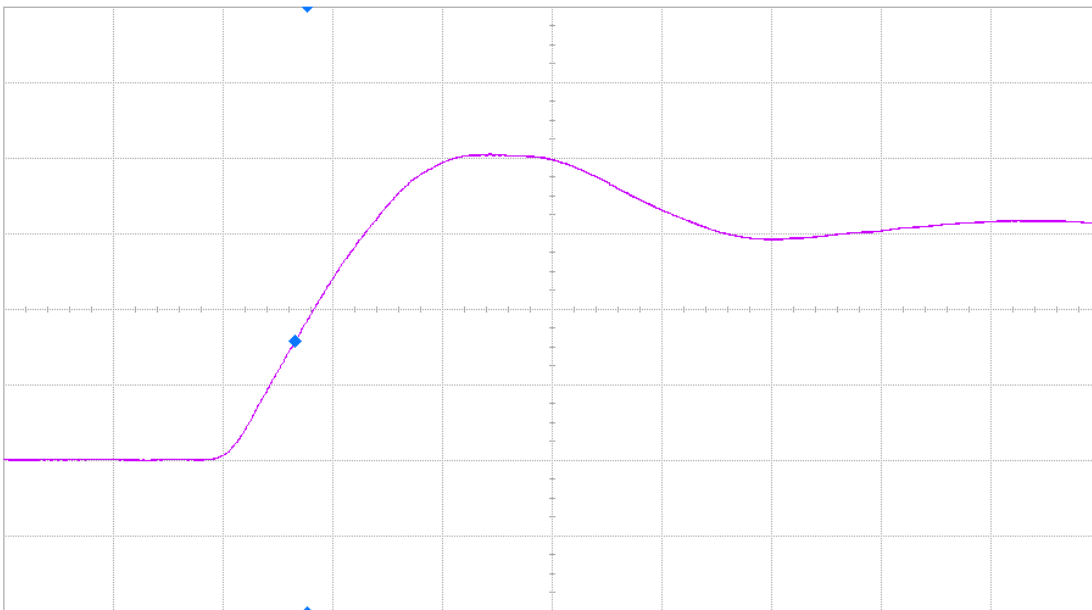


Fig. 21 (b). DUT 9774 post-annealing rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

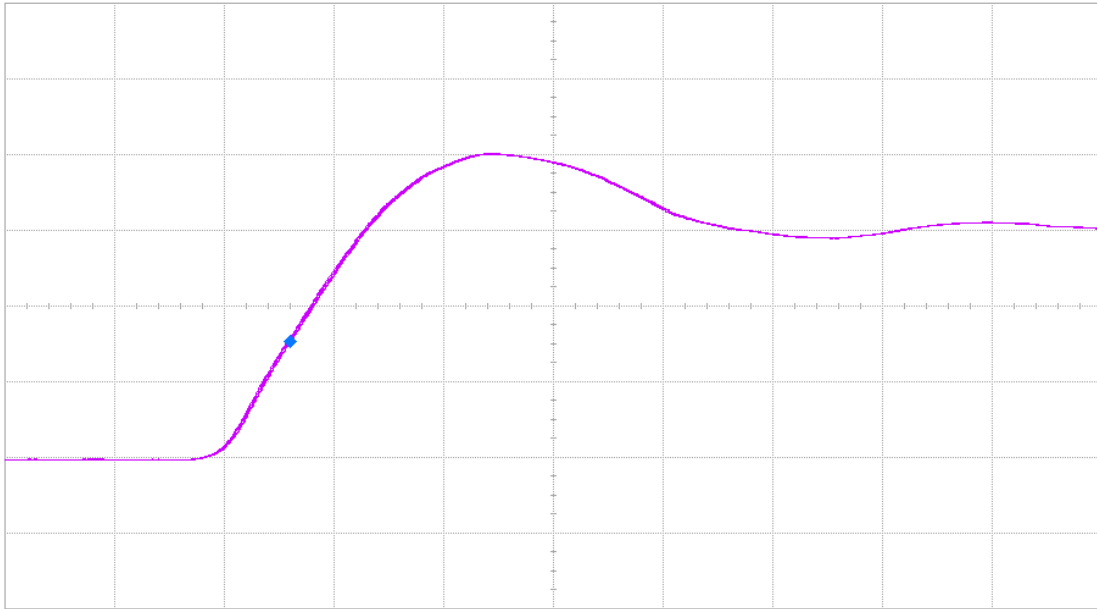


Fig. 22 (a). DUT 9793 pre-irradiation rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

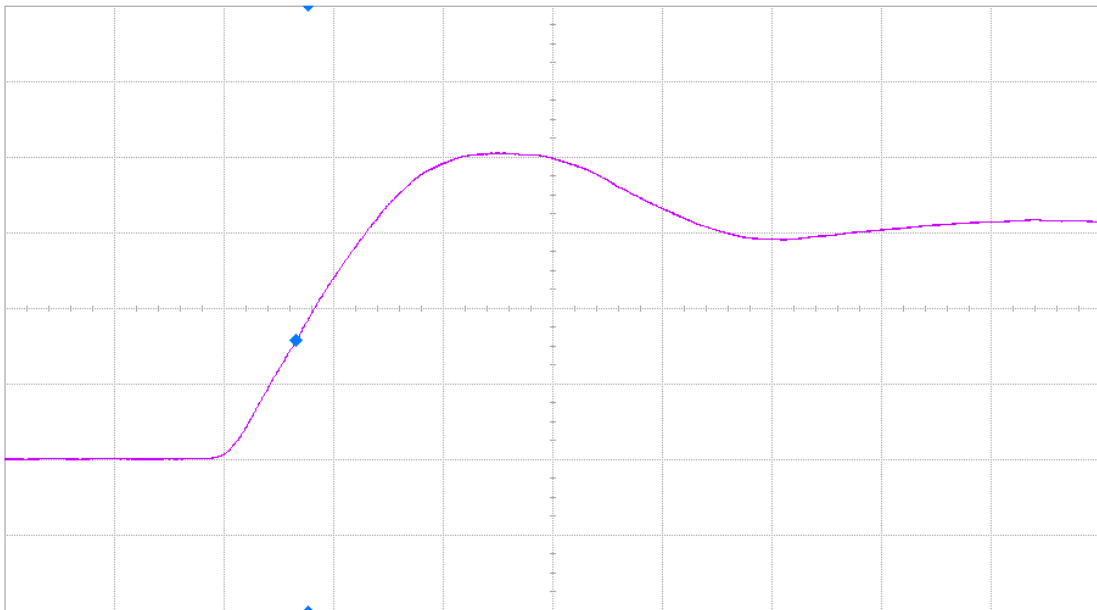


Fig. 22 (b). DUT 9793 post-annealing rising edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

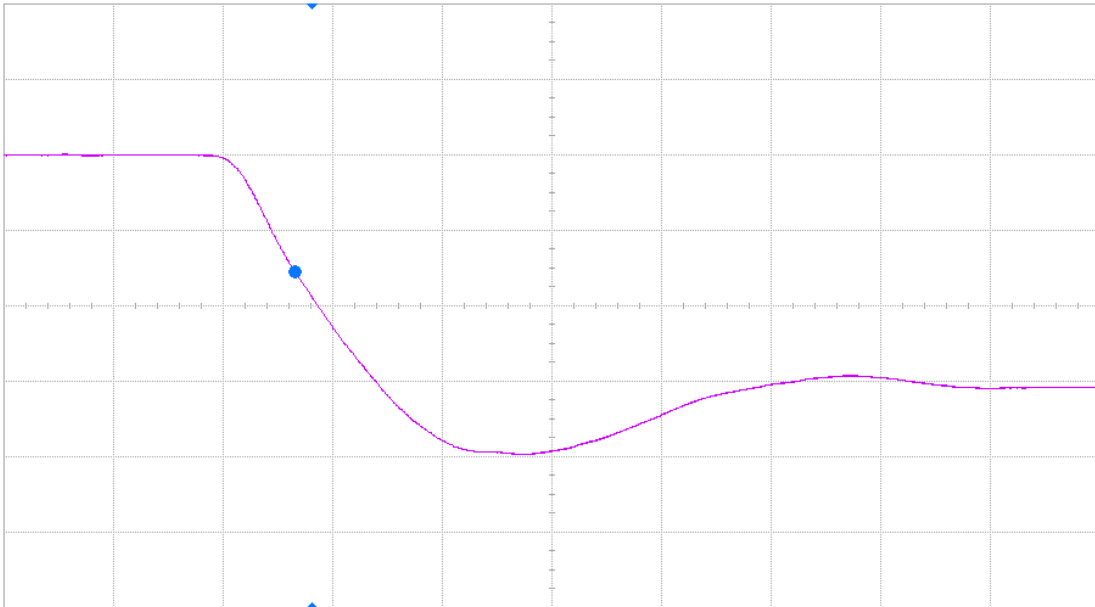


Fig. 23 (a). DUT 9738 pre-irradiation Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

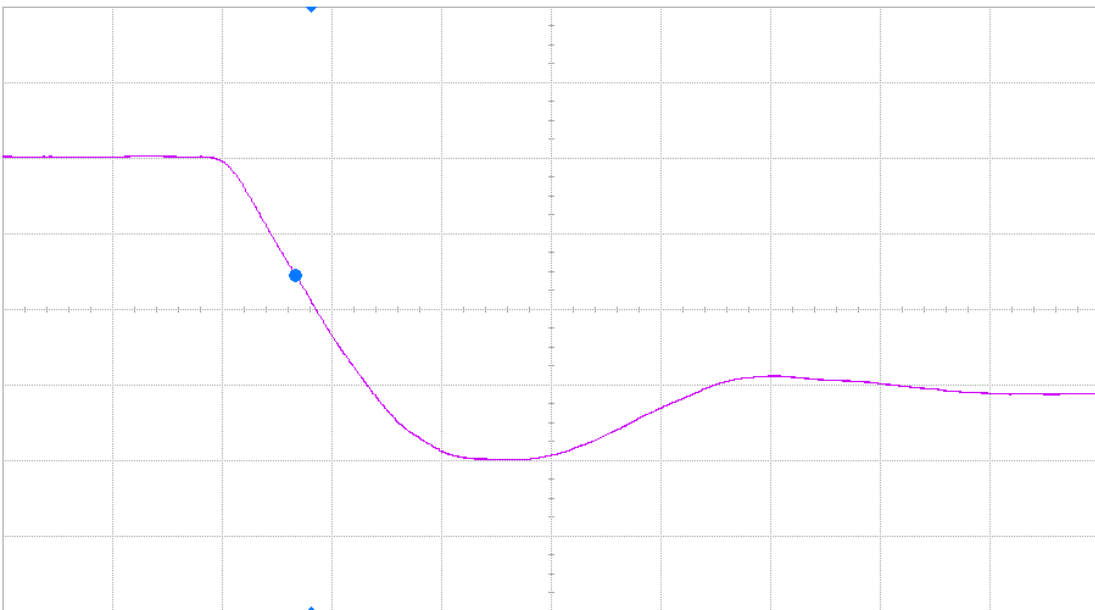


Fig. 23 (b). DUT 9738 post-annealing Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

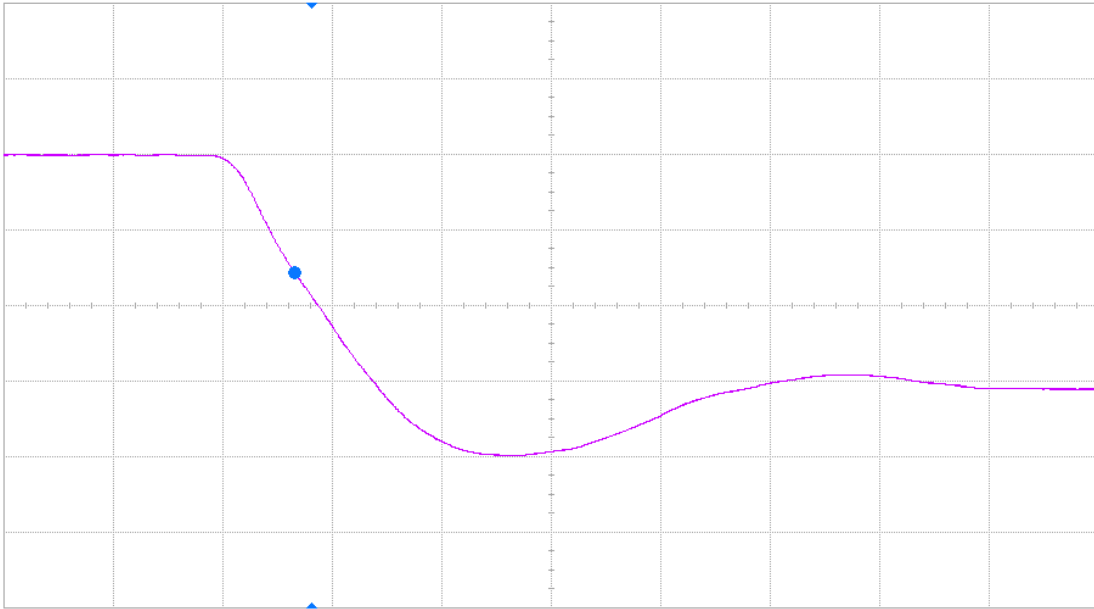


Fig. 24 (a). DUT 9741 pre-irradiation Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

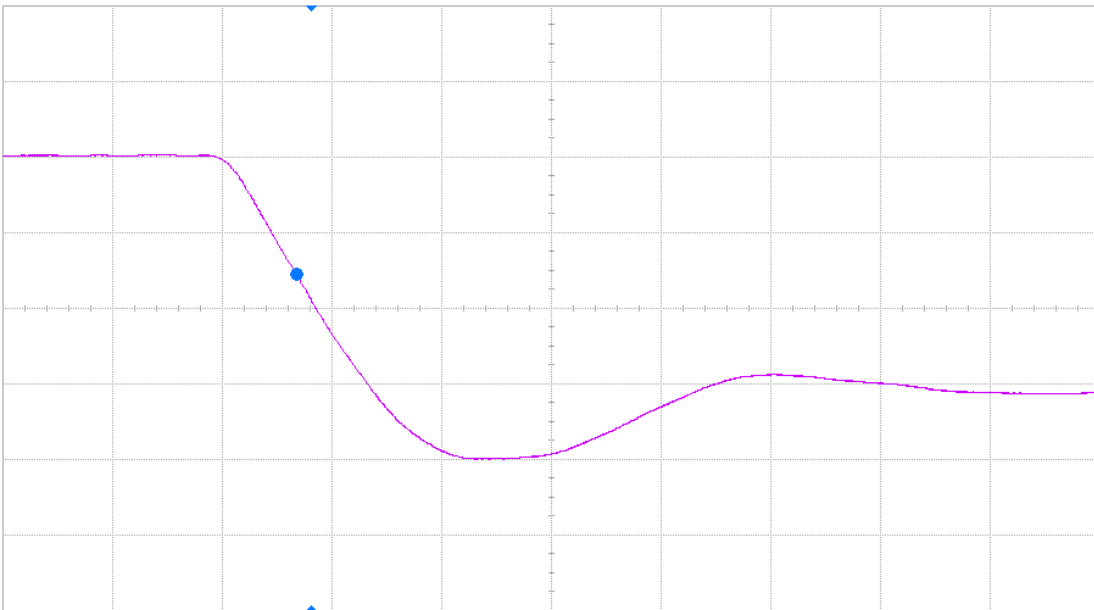


Fig. 24 (b). DUT 9741 post-annealing Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

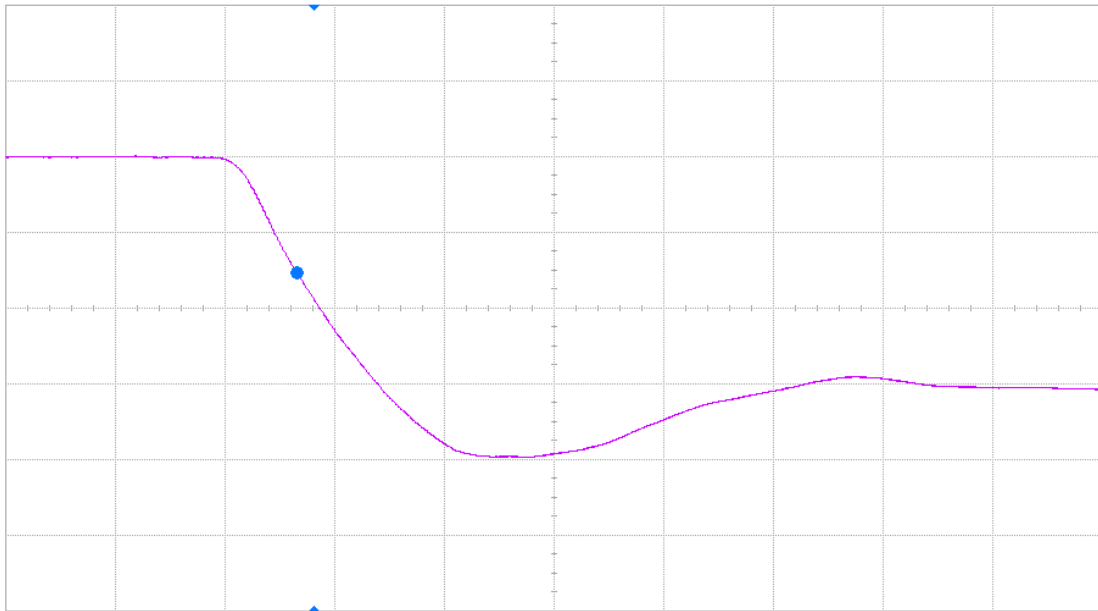


Fig. 25 (a). DUT 9752 pre-irradiation Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

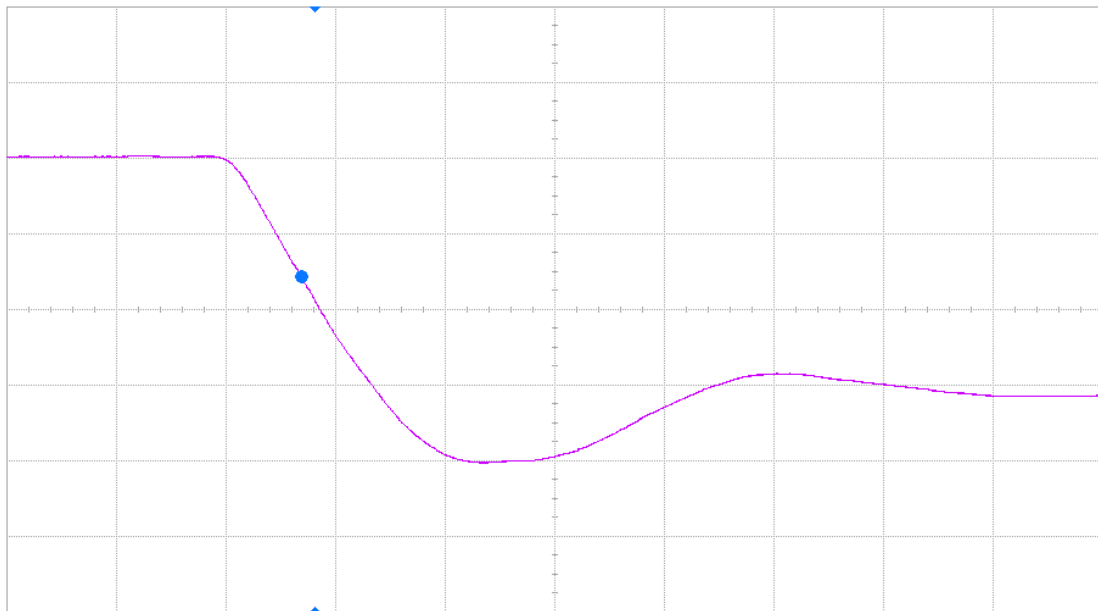


Fig. 25 (b). DUT 9752 post-annealing Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

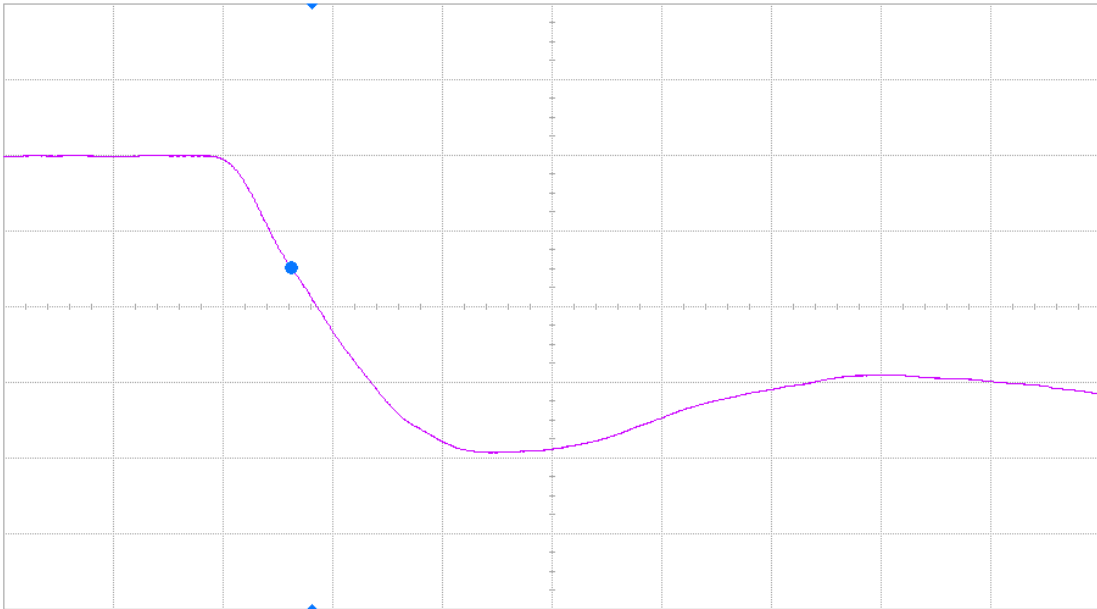


Fig. 26 (a). DUT 9774 pre-irradiation Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

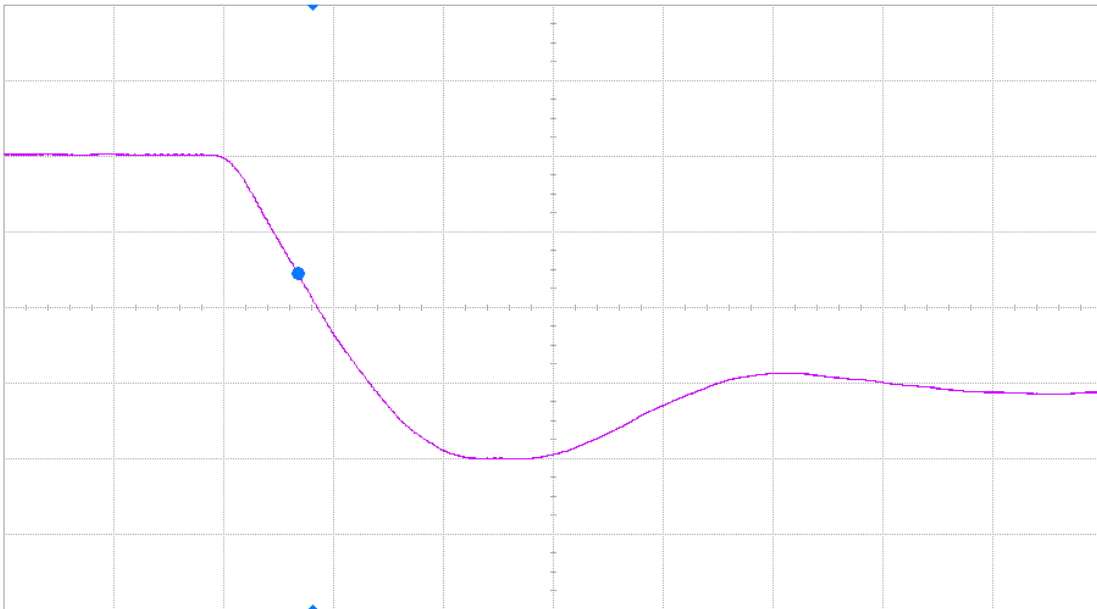


Fig. 26 (b). DUT 9774 post-annealing Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

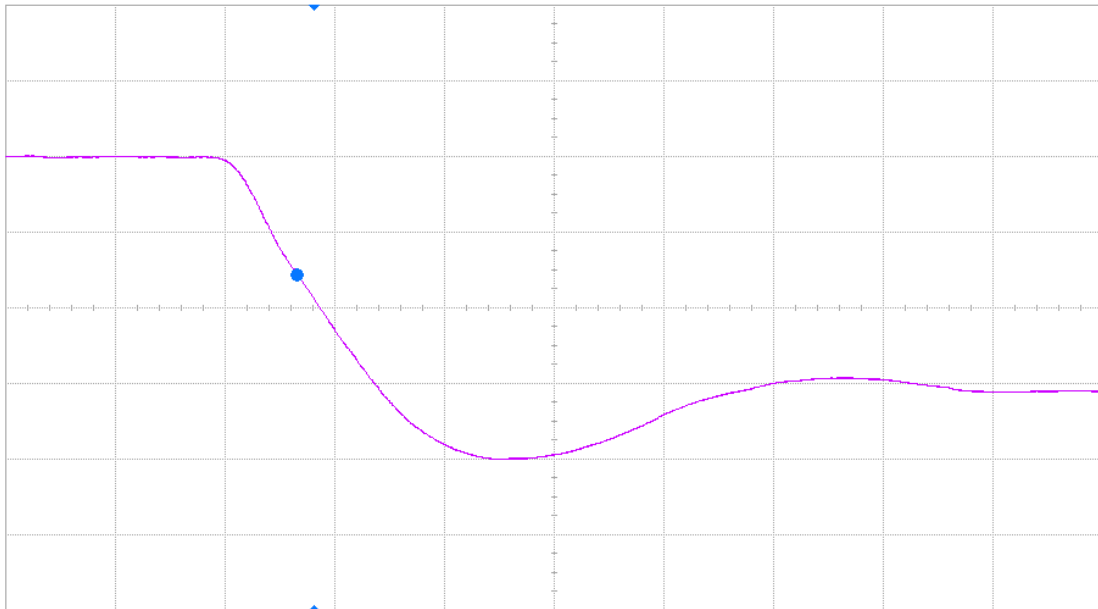


Fig. 27 (a). DUT 9793 pre-irradiation Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

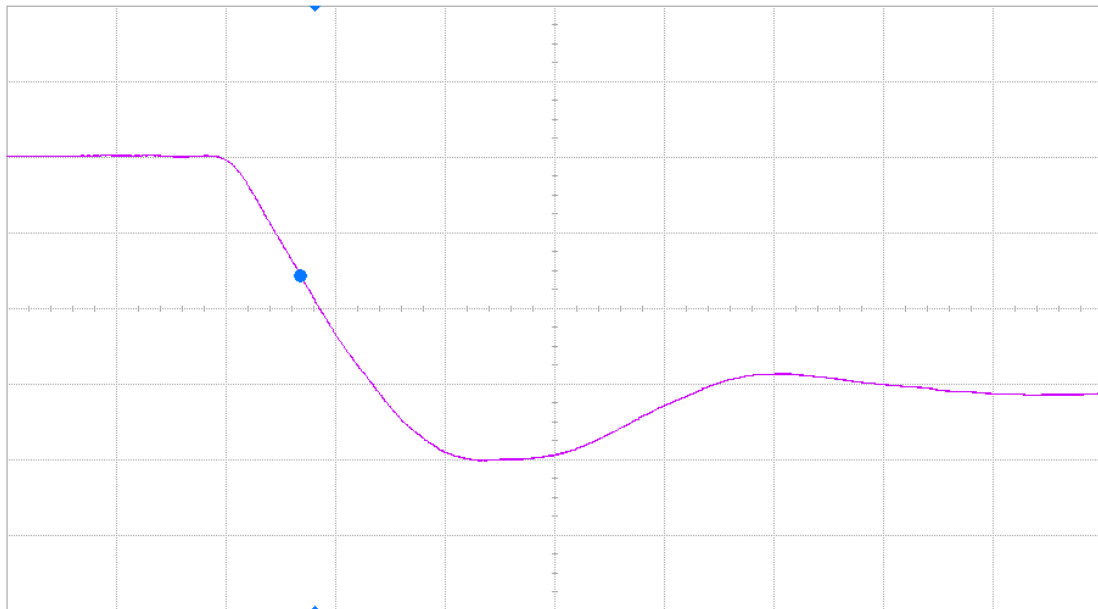


Fig. 27 (b). DUT 9793 post-annealing Falling edge, abscissa scale is 1V/div and ordinate scale is 2ns/div

Appendix A

Table. 30. High level block diagrams of blocks used to perform fabric functional coverage pre and post-irradiation

| Block | Coverage |
|----------------------|---|
| Combo Block | combinatorial macros available in the RTG4 library |
| Register Block | sequential macros available in the RTG4 library |
| UPROM | |
| Embedded SRAM Blocks | full toggle coverage on 209 fabric LSRAM & 210 uRAM blocks using dual port/ two port configurations (x18 width) |
| Shift Register Block | core utilization |
| IO Block | IO utilization |
| Math Block | full toggle coverage on 462 fabric math blocks with maximum width configuration |

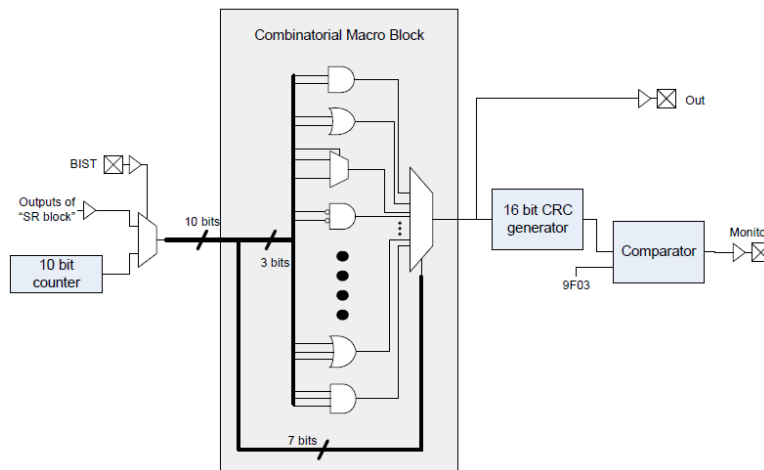


Fig. 28. Combo Block

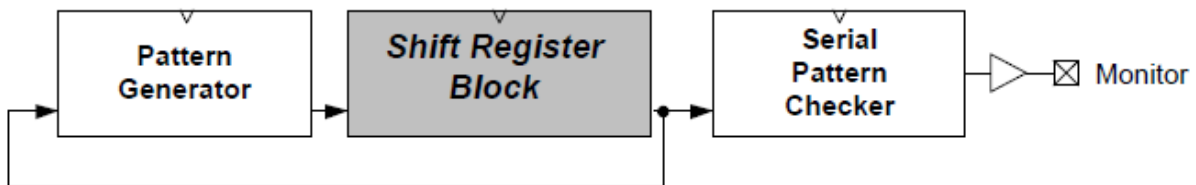


Fig. 29. Shift Register Block

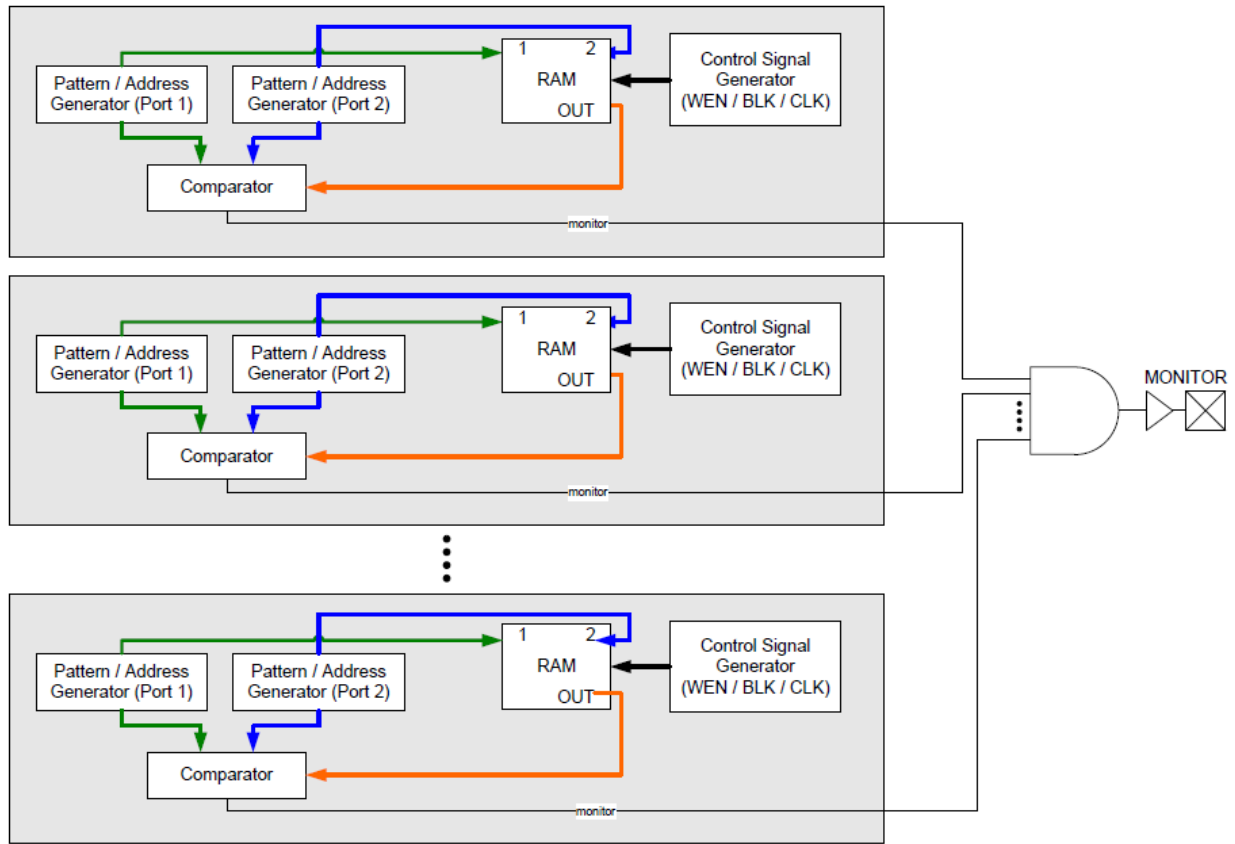


Fig. 30. Embedded Ram Blocks

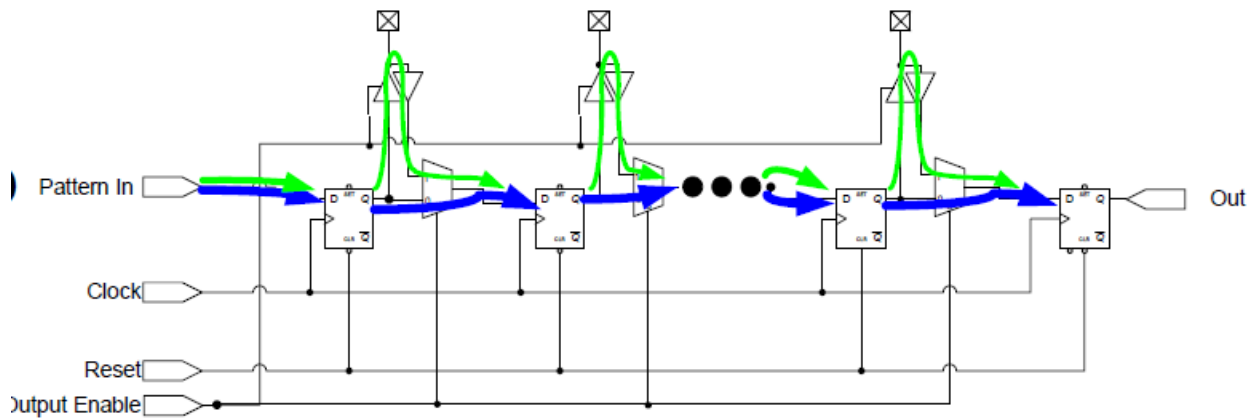


Fig. 31. IO Block

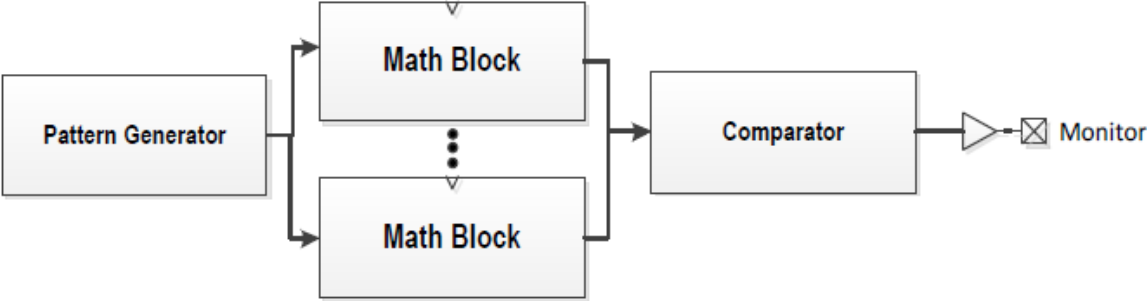


Fig. 32. Math Block