



# **Total Ionizing Dose Test Report**

**No. 21T-RT3PE3000L-CG484-QQW04**

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July 26, 2021

## Table of Contents

I.	<b>Summary Table</b> .....	3
II.	<b>Total Ionizing Dose (TID) Testing</b> .....	3
A.	Device-Under-Test (DUT) and Irradiation Parameters .....	3
B.	Test Method.....	4
C.	Design .....	5
D.	Parametric Measurements .....	7
III.	<b>Test Results</b> .....	8
A.	Functionality .....	8
B.	Power Supply Current (ICCA and ICCI) .....	8
C.	Continuity and Input Logic Threshold (VIL/VIH).....	9
D.	Low Output-Drive Voltage (VOL and Ipd).....	10
E.	High Output-Drive Voltage (VOH and Ipu) .....	19
F.	Propagation Delay .....	28
G.	Transition Time .....	30
	<b>Appendix A: DUT Design Block Diagrams and Schematics</b> .....	42
A.	PLL Block .....	42
B.	UFROM/SRAM Block .....	43
C.	Pattern Generators Block.....	43
D.	I/O Block .....	44
E.	Array Shift Registers Block .....	44
F.	Delay Path Block .....	44
G.	Monitor Block .....	44

## **TOTAL IONIZING DOSE TEST REPORT**

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### **I. Summary Table**

Parameter	Tolerance
1. Gross Functionality	Passed 25 krad (SiO <sub>2</sub> )
2. Power Supply Current (ICCA/ICCI)	Passed 25 krad (SiO <sub>2</sub> )
3. Input Threshold (VTIL/VIH)	Passed 25 krad (SiO <sub>2</sub> )
4. Output Drive (VOL/VOH)	Passed 25 krad (SiO <sub>2</sub> )
5. Propagation Delay	Passed 25 krad (SiO <sub>2</sub> ) for 10% degradation criterion
6. Transition Characteristics	Passed 25 krad (SiO <sub>2</sub> )

### **II. Total Ionizing Dose (TID) Testing**

This testing for the flash-based FPGA is developed on the base of an extensive database from the TID testing of many generations of antifuse-based FPGAs. Early TID studies can be found in the public domain, for example, [http://www.klabs.org/index\\_klabs\\_dot\\_org.htm](http://www.klabs.org/index_klabs_dot_org.htm). Other reliability reports are also available on the Microsemi SoC Products Group website:

<http://www.microsemi.com/soc/products/milaero/hireldata.aspx>.

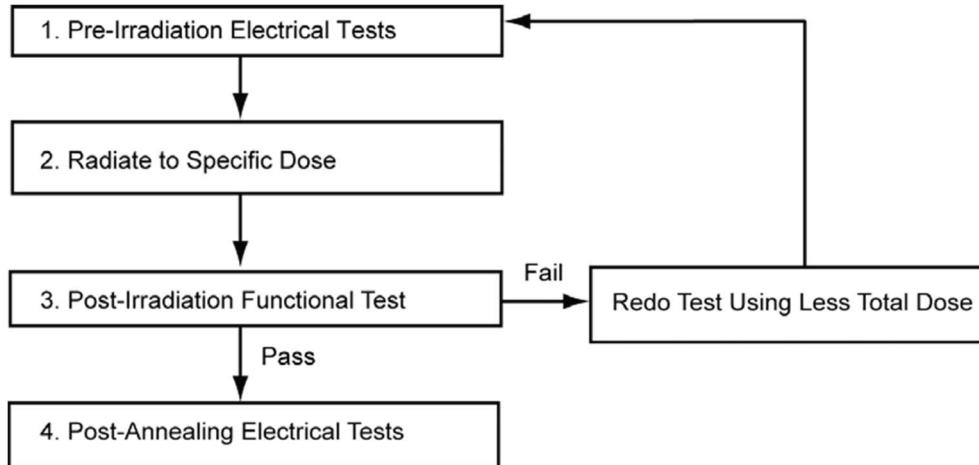
#### **A. Device-Under-Test (DUT) and Irradiation Parameters**

Table 1 lists the DUT and irradiation parameters. During irradiation each input is grounded through a jumper; during annealing each input is grounded through a resistor.

**Table 1 DUT and Irradiation Parameters**

Part Number	RT3PE3000L
Package	CG484
Foundry	United Microelectronics Corp.
Technology	0.13 μm CMOS and Embedded Flash
DUT Design	RTA3PE3KL_CG484_TID
Die Lot Number	QQW04
Quantity Tested	6
Total Dose: DUT Serial Number	25 krad(SiO <sub>2</sub> ): 17826, 17827, 17829, 17832, 17833, 17834
Radiation Facility	Defense Microelectronics Activity
Radiation Source	Co-60
Dose Rate	10 krad(SiO <sub>2</sub> )/min(±5%)
Irradiation Temperature	Room
Irradiation and Measurement Bias (VCCI/VCCA)	Static at 3.3 V/1.5 V

## B. Test Method



**Figure 1 Parametric Test Flow Chart**

The test method generally follows the guidelines in the military standard TM1019. Figure 1 is the flow chart showing the steps for parametric tests, irradiation, and post-irradiation annealing.

The accelerated aging, or rebound test mentioned in TM1019, is unnecessary because there is no adverse time dependent effect (TDE) in Microsemi products manufactured by sub-micron CMOS technology. The test data with a high dose are compared to test data with a low dose rate for devices manufactured by several generations of sub-micron CMOS technologies. The results always show the low dose rate degrades less than the high dose rate; thus indicating that the elevated rebound annealing would artificially reduce the radiation effects. Therefore, only room temperature annealing is performed in this report. The experiment is repeated on the flash-based FPGA technology and shows similar results.

The duration of the room temperature annealing is approximately 7 days.

## C. Design

DUTs use a high utilization generic design, RTA3PE3KL\_CG484\_TID, to test total dose effects in typical space applications.

Below are the descriptions by blocks. Appendix A contains the block diagrams and schematics illustrating the logic design.

### a. PLL Block

There are six dynamically configurable PLLs in the RTA3PE3000 device. All of them are configured in the following manner; with GLA coming from the PLL and GLB/GLC bypassed for other global signals. Five of the PLLs have a default multiplying factor of x4 and the last one is x16.

Dynamic configuration is applied by sending IR = 16 through the UJTAG. The lock signal of each PLL is routed out to an I/O for observation.

### b. UFROM / SRAM Block

There are 112 basic 4608-bit blocks in the RTA3PE3000 device. Each of these blocks is configured in the 512x8 configuration. The stimulus for the SRAM blocks is written into the UFROM during programming. During test/TID, the contents in the UFROM is read and written into each of the 112 SRAM blocks. The SRAM blocks are configured in a dual port mode where two different bytes of data are written/read from two different addresses at any given time. The read back data is MUXed and compared with the expected value. To ensure the original data in the UFROM is correct, its content goes through a CRC check during each test cycle.

An additional SRAM disturb mode is available. During the non-disturb mode, the dual port operation for read/write between address (port) A and address (port) B must be greater than eight to avoid operating SRAM cells in the same physical row. The disturb mode will force address A and B to be adjacent to each other all the time to stimulate the disturb violation.

### c. Pattern Generator Block

A multi-bit shift register with varying feedback length allows for different pattern configurations, as shown in Table 2 below. The pattern generator block is used to supply the stimulus for the array shift register and I/O test blocks.

### d. I/O Block

The I/O block is composed of four separate blocks, each with its own pattern generator and checker block. Each block also gets its own clock, reset, and OE from a separate PLL block. Separation of these blocks is based on the four quadrants: UL, UR, LL, LR. The reason for this scheme is to fully utilize the quadrant clocks in the device.

Since the number of bonded I/Os is different in each quadrant, the number of stages in each I/O weave block also varies slightly (from 138 to 146). The SSO of the device can be changed based on the pattern generator's configuration. The existing burn-in mode or TID will use a 25% SSO rate. The SSO can also be completely eliminated by disabling the OE of the device, which will route the signal internally instead of going through the bi-buf.

### e. Array Shift Registers Block

There are 4 individual array shift register chains used as core logic fillers. Each chain is made up of 3,500 D-FF with asynchronous reset/set. The pattern generator supplies the stimulus into the array shift-register, which gets shifted out and compared by the pattern checker. During TID, the internal toggle rate is fixed at 25% SSR.

### f. Delay Path Block

The delay path block has three individual inverter chains with input stimulus coming from a counter during TID or I/O during test. The inverter chains are 30 stages and travels across the quadrants. The path covers the outer edges and center of the die to provide better sampling of the different areas in the die.

### g. Monitor Block

This block is used to indicate that all BISTs in the design are passing. The passing monitor signal is half of the CLK. When a BIST fails, the monitor signal provides a signature that makes it possible to determine which specific block in the design that is failing. The failing monitor signal consists of up to 9 pulses. Pulse 0 is always present in the failing Monitor signal, while pulses 1-7, which represent a passing blocks in the Burn-in design, and are only present when the respective block is passing. The pulse number and the corresponding block that it represents is as follows:

1. UFROM/SRAM Block
2. I/O UR Block
3. I/O UL Block
4. I/O LR Block



**Total Ionizing Dose Test Report  
No. 21T-RT3PE3000L-CG484-QQW04**

**0-00-0000 Rev. 0**

- 5. I/O LL Block
- 6. Array 1 Block
- 7. Array 2 Block
- 8. Array 3 Block
- 9. Array 4 Block

## D. Parametric Measurements

Table 2 lists each tested electrical parameter and the corresponding logic design.

The functionality is measured on the output pins. Icc is measured on the power supplies of the logic-array (ICCA) and I/O (ICCI) respectively. The input logic thresholds (VIL/VIH) and output-drive voltages (VOL/VOH) are measured on nets listed in Row 3 and 4 of Table 2.

The propagation delays are measured on the SPEEDOUT output of the inverter chains. The delay is measured as the time delay from the time of triggering edge at the "clk" input to the time of switching state at the output SPEEDOUT. Both the low-to-high and high-to-low output transitions are measured; the propagation delay is defined as the average of these two transitions.

The transition characteristics, measured on the output SPEEDOUT, are displayed from Figure 3 through Figure 14 as oscilloscope snapshots showing the rising and falling edge during logic transitions.

**Table 2 Logic Design for Parametric Measurements**

Parameters	Logic Design
1. Functionality	All key architectural functions
2. ICC (ICCA/ICCI)	DUT power supply pins
3. Input Threshold (VIL/VIH)	Input buffers (SPEEDIN, RESETn, INPUT_SRAM_DISTURB, INPUT_SETn, INPUT_oe, INPUT_IO_Shift_En, INPUT_IO_Pattern_Length[0..2], INPUT_IO_Johnson, INPUT_FROM_SRAM_START, INPUT_A_Shift_En, INPUT_A_Pattern_Length[0..2], INPUT_A_Johnson, clk, BIST, FF, IO_Outs.UR[0..76], IO_Outs.UL[0..74], IO_Outs.LR[0..66], IO_Outs_LL[0..79])
4. Output Drive (VOL/VOH)	Output buffers (UFROM_MONITOR, SRAM_OUT[0..7], LOCK[0..5], LED, BIST_MONITOR, Array_Monitor, SPEEDOUT, Array_out[0..3])
5. Propagation Delay	Chains of inverters (clk to SPEEDOUT)
6. Transition Characteristic	Output (SPEEDOUT)

### III. Test Results

#### A. Functionality

Every DUT passes functional tests after 25 krads and annealing from results of the standard testing.

#### B. Power Supply Current (ICCA and ICCI)

Table 3 shows the pre-irradiation and post-annealing ICCA and ICCI measured at the nominal VCC at 1.5 V and 3.3 V, respectively. In most cases, the currents after irradiation and annealing are at the level as those before the irradiation.

It shows the total dose effects to ICC currents up to 25 krads are insignificant. And this indicates that the Post-annealing ICCA and ICCI for all DUTs pass the specification with very good margins.

Table 3 Post Irradiation and Post Annealing ICC

DUT	Total Dose	ICCA at 1.5 V (mA)		ICCI at 3.3 V (mA)	
		Pre-rad	Post-ann	Pre-irrad	Post-ann
17826	25 krad	320.9	191.5	45.7	44.0
17827	25 krad	318.9	190.7	46.0	44.1
17829	25 krad	322.1	192.5	45.9	44.1
17832	25 krad	321.5	192.5	45.8	44.0
17833	25 krad	319.8	257.9	46.0	44.9
17834	25 krad	320.7	191.7	45.8	44.1

## C. Continuity and Input Logic Threshold (VIL/VIH)

Standard I/O parametric tests are applied to check the total dose effects to the I/O drivability.

Table 4a and Table 4b list the pre-irradiation and post-annealing input logic thresholds. All data are within the specification limits (test specification minimum and maximum values are given in brackets); and data is presented with statistics of all the I/O pins used (~340 sample size of each DUT).

**Table 4a Pre-Irradiation and Post-Annealing Input Thresholds**

Test name		Pci_pcix_iil (uA) [-5.0, 5.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-0.1669	-0.0588	0.0870	0.0410	-0.2463	-0.0341	0.2156	0.0681
17827	25 krad	-0.3177	-0.0732	0.1380	0.0641	-0.3215	-0.0502	0.1675	0.0705
17829	25 krad	-0.1960	-0.0702	0.0742	0.0438	-0.3108	-0.0411	0.1252	0.0705
17832	25 krad	-0.1624	-0.0626	0.0742	0.0384	-0.2695	-0.0434	0.1920	0.0704
17833	25 krad	-0.3126	-0.0716	0.0870	0.0437	-0.3130	-0.0430	0.1683	0.0715
17834	25 krad	-0.1960	-0.0693	0.0870	0.0421	-0.2706	-0.0469	0.1433	0.0670

**Table 4b Pre-Irradiation and Post-Annealing Input Thresholds**

Test name		Pci_pcix_iih (uA) [-5.0, 5.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-0.1909	-0.0153	0.1720	0.0494	-0.2731	0.0124	0.2249	0.0725
17827	25 krad	-0.2423	0.0110	0.7760	0.0810	-0.2605	0.0153	0.5517	0.0807
17829	25 krad	-0.1858	-0.0163	0.1643	0.0508	-0.2605	0.0113	0.3134	0.0745
17832	25 krad	-0.1607	-0.0124	0.1200	0.0501	-0.2230	0.0151	0.2249	0.0701
17833	25 krad	-0.1858	-0.0103	0.2644	0.0525	-0.2354	0.0183	0.2499	0.0747
17834	25 krad	-0.1360	-0.0172	0.1493	0.0540	-0.2354	0.0150	0.2752	0.0762

## D. Low Output-Drive Voltage (VOL and Ipd)

The pre-irradiation and post-annealing VOL and Ipd are listed in Table 5a through Table 6h. The post-annealing data are within the specification limits (test specification minimum and maximum values are given in brackets); data is presented with the statistics of all I/O pins used (~340 sample size of each DUT). In each case, the post-annealing data varies insignificantly.

**Table 5a Pre-Irradiation and Post-Annealing VOL**

Test name		cmos18_vol_5x (mV) [0.0, 405.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	150.118	157.3344	196.7281	4.8040	149.468	156.5953	173.3442	4.0324
17827	25 krad	147.2446	155.1476	173.3897	4.0365	146.3318	154.8437	171.3369	4.0155
17829	25 krad	149.0512	156.4650	181.3583	4.4278	148.2135	155.9240	172.7169	3.9810
17832	25 krad	149.7415	156.9326	181.1073	4.6009	148.2135	156.2882	175.3203	4.1190
17833	25 krad	148.863	156.3036	174.193	4.5163	147.4608	155.6525	172.466	3.9417
17834	25 krad	149.4277	156.5552	174.9462	4.2301	149.1544	156.7278	173.7833	3.9583

**Table 5b Pre-Irradiation and Post-Annealing VOL**

Test name		cmos15_vol_2x (mV) [0.0, 320.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	82.2762	83.7444	90.5197	0.8427	82.5561	83.9203	86.6515	0.7096
17827	25 krad	80.8217	82.4497	85.4429	0.7149	80.7213	82.4052	85.0833	0.7168
17829	25 krad	81.2444	83.1798	87.8849	0.8524	81.5102	83.3268	85.8988	0.7710
17832	25 krad	81.9975	83.4637	87.1948	0.7994	81.8504	83.6455	86.9665	0.7228
17833	25 krad	81.3072	82.8347	85.7519	0.8013	81.2859	82.9794	85.9615	0.7097
17834	25 krad	81.7113	83.3432	86.8301	0.7480	82.4522	83.9541	86.4633	0.6815

**Table 5c Pre-Irradiation and Post-Annealing VOL**

Test name		cmos15_vol_3x (mV) [0.0, 320.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	87.4265	89.9551	103.0037	1.5966	87.665	90.0128	95.6846	1.3438
17827	25 krad	85.5885	88.5984	94.5387	1.3421	85.4884	88.5961	93.9909	1.3384
17829	25 krad	86.6717	89.4033	98.1732	1.5123	86.5346	89.4017	94.9319	1.3487
17832	25 krad	87.2067	89.6281	97.6713	1.5214	86.8684	89.7613	96.0978	1.3642
17833	25 krad	86.4535	89.0141	94.7856	1.5136	86.3039	89.1096	94.7437	1.3179
17834	25 krad	86.9862	89.5264	95.8676	1.4123	87.2254	90.0516	95.6219	1.3096

Table 5d Pre-Irradiation and Post-Annealing VOL

Test name		cmos15_vol_4x (mV) [0.0, 320.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	116.0439	119.5912	139.3266	2.4099	116.0983	119.6327	128.0532	2.0172
17827	25 krad	113.5	117.8202	126.7189	2.0245	113.1502	117.7291	125.9832	2.0112
17829	25 krad	114.7257	118.8680	131.924	2.2778	114.4827	118.8088	127.175	2.0315
17832	25 krad	115.5745	119.3073	131.6104	2.3059	115.2201	119.3356	128.9708	2.0583
17833	25 krad	114.8841	118.3987	127.248	2.2706	114.2793	118.4801	126.8614	1.9805
17834	25 krad	115.3548	119.0264	128.566	2.1304	115.7388	119.7362	127.9905	1.9742

Table 5e Pre-Irradiation and Post-Annealing VOL

Test name		cmos15_vol_5x (mV) [0.0, 320.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	173.7751	181.1315	220.6297	4.8075	174.0563	181.0558	197.8089	4.0456
17827	25 krad	169.8246	178.2792	196.5369	4.0550	169.4146	178.2172	194.8605	4.0247
17829	25 krad	172.4693	179.7365	206.1381	4.5013	171.9491	179.8270	196.7424	4.0188
17832	25 krad	173.5654	180.7309	205.1971	4.6395	172.3	180.5797	199.6287	4.1065
17833	25 krad	171.8298	179.3508	197.0379	4.5539	170.7946	179.2878	196.1152	3.9680
17834	25 krad	173.3486	180.2528	199.109	4.2650	173.5545	181.2069	197.7461	3.9491

Table 5f Pre-Irradiation and Post-Annealing VOL

Test name		cmos12_vol_2x (mV) [0.0, 285.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	104.8089	106.8631	113.6685	0.9460	105.0403	106.9461	109.7361	0.8156
17827	25 krad	102.7117	104.7343	107.7746	0.7952	102.4869	104.4735	107.3524	0.8031
17829	25 krad	103.4617	105.9721	110.72	1.0614	103.4677	106.0350	108.7324	0.9693
17832	25 krad	104.5286	106.4742	110.2181	0.8921	104.4941	106.6268	110.0783	0.8288
17833	25 krad	103.1175	105.1855	108.4616	0.9082	103.1142	105.2504	108.3561	0.8243
17834	25 krad	104.4099	106.4114	109.9888	0.8506	105.062	107.0031	109.4407	0.7950

Table 5g Pre-Irradiation and Post-Annealing VOL

Test name		cmos12_vol_3x (mV) [0.0, 285.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	53.271	54.6594	61.3485	0.8233	53.3736	54.6152	57.4194	0.6943
17827	25 krad	52.0948	53.6629	56.7127	0.6877	51.8051	53.4992	56.353	0.6830
17829	25 krad	52.7678	54.2345	58.9646	0.7959	52.5572	54.2195	56.9803	0.7198
17832	25 krad	53.0648	54.4477	58.2118	0.7678	52.8714	54.4413	57.7461	0.7087
17833	25 krad	52.4147	53.9207	57.0198	0.7803	52.2441	53.9174	56.7294	0.6811
17834	25 krad	52.9648	54.4084	57.6464	0.7249	53.1224	54.6781	57.4821	0.6758

Table 5h Pre-Irradiation and Post-Annealing VOL

Test name		cmos12_vol_3xE1 (mV) [-100.0, 100.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.627	2.9669	3.3584	0.1242	2.5562	2.9334	3.2208	0.1174
17827	25 krad	2.4455	2.8222	3.2001	0.1210	2.5017	2.8706	3.1304	0.1322
17829	25 krad	2.5904	2.9433	3.2956	0.1297	2.5645	2.8795	3.2344	0.1280
17832	25 krad	2.5669	2.9498	3.3272	0.1253	2.5645	2.9204	3.2478	0.1300
17833	25 krad	2.5669	2.9190	3.2919	0.1264	2.5017	2.8576	3.2208	0.1228
17834	25 krad	2.5015	2.9433	3.2014	0.1317	2.5562	2.9204	3.2727	0.1306

Table 5i Pre-Irradiation and Post-Annealing VOL

Test name		cmos12_vol_3xE2 (mV) [-100.0, 100.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.065	2.4748	2.8563	0.1406	2.0916	2.4404	2.7189	0.1157
17827	25 krad	1.924	2.3637	2.7592	0.1243	1.9275	2.3911	2.6913	0.1190
17829	25 krad	2.1277	2.4748	2.8563	0.1248	2.0621	2.4304	2.8949	0.1251
17832	25 krad	2.065	2.4797	2.852	0.1323	2.1249	2.4404	2.7817	0.1254
17833	25 krad	2.1277	2.4649	2.7935	0.1225	2.1161	2.4053	2.754	0.1168
17834	25 krad	2.1277	2.4649	2.7787	0.1169	2.179	2.4541	2.8319	0.1187

Table 5j Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_1x12 (mV) [0.0, 360.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	203.1528	205.9469	219.4052	1.6254	203.3748	205.8203	211.3849	1.3639
17827	25 krad	201.2902	204.5629	210.2489	1.4052	200.6402	204.0347	209.1955	1.3910
17829	25 krad	202.1189	205.1808	214.6393	1.5833	201.5778	205.0512	210.1338	1.4354
17832	25 krad	202.5876	205.4782	213.5455	1.5593	202.1593	205.4061	211.7689	1.3969
17833	25 krad	202.7439	205.4148	211.1236	1.4931	202.3937	205.2076	210.9158	1.3175
17834	25 krad	201.8999	204.9607	211.8842	1.4489	202.3591	205.7867	210.8376	1.3139

Table 5k Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_1x (mV) [0.0, 360.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	202.9179	205.8991	219.0927	1.6118	203.3314	205.8749	211.2285	1.3644
17827	25 krad	201.1332	204.5407	210.4834	1.3994	200.8746	203.9566	208.9609	1.3872
17829	25 krad	202.1189	205.1439	214.4831	1.5857	201.5778	205.0422	210.2902	1.4232
17832	25 krad	202.3533	205.5350	213.233	1.5465	202.0812	205.4061	212.0037	1.4054
17833	25 krad	202.5627	205.3786	210.9467	1.4902	202.6282	205.2499	210.994	1.3209
17834	25 krad	201.8999	205.0247	211.8842	1.4481	202.3591	205.7460	210.6812	1.3238

Table 5l Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_1xE1 (mV) [0.0, 200.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	4.4293	5.0520	5.5981	0.2134	4.4558	5.0076	5.659	0.2004
17827	25 krad	4.6644	5.1332	5.7188	0.1816	4.534	5.0033	5.7109	0.2006
17829	25 krad	4.4293	5.0198	5.6256	0.2134	4.4049	5.0036	5.4245	0.1978
17832	25 krad	4.5075	5.0266	5.6762	0.2231	4.3004	5.0076	5.6796	0.2067
17833	25 krad	4.4693	5.0000	5.6762	0.2091	4.534	5.0033	5.659	0.1988
17834	25 krad	4.4293	5.0000	5.563	0.2111	4.4566	5.0305	5.5027	0.2071

Table 5m Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_1xE2 (mV) [0.0, 200.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	4.6639	5.1760	5.8322	0.2122	4.4049	5.1869	5.8671	0.2018
17827	25 krad	4.6644	5.2961	5.74	0.1772	4.6904	5.1317	5.6327	0.1926
17829	25 krad	4.5857	5.1760	5.8322	0.2201	4.6122	5.1598	5.659	0.2083
17832	25 krad	4.4293	5.1760	5.8322	0.2103	4.6129	5.1901	5.789	0.2046
17833	25 krad	4.6291	5.1300	5.7542	0.2134	4.4566	5.1598	5.659	0.2025
17834	25 krad	4.6291	5.1564	5.8322	0.2264	4.6122	5.1598	5.789	0.2184

Table 5n Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_2x (mV) [0.0, 360.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	212.262	218.0546	244.3283	3.1705	212.6303	217.6646	228.1967	2.5710
17827	25 krad	210.3553	216.4304	228.1553	2.6106	209.2702	215.7974	226.1636	2.5542
17829	25 krad	211.8709	217.1965	234.6403	2.9673	211.2238	216.7803	226.6328	2.5202
17832	25 krad	212.1838	217.5511	232.9215	3.0078	210.833	217.2479	230.8672	2.6413
17833	25 krad	211.8709	217.4729	230.3992	2.9382	211.2238	217.0475	227.6493	2.5057
17834	25 krad	211.8709	217.1117	230.9461	2.7709	212.3177	217.5162	227.7275	2.4914

Table 5o Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_3x (mV) [0.0, 360.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	172.6823	180.4475	219.7177	4.7652	172.8561	179.7015	196.7626	4.0476
17827	25 krad	171.0471	178.8880	197.0341	4.0345	170.3556	178.4361	194.5732	3.9771
17829	25 krad	172.4476	179.7158	205.8108	4.4147	171.2933	179.0764	195.9807	3.9656
17832	25 krad	172.5258	180.0927	204.2482	4.6064	171.4496	179.3419	198.4627	4.1165
17833	25 krad	172.9169	179.9502	198.0565	4.4671	171.9184	179.3890	195.9807	3.9125
17834	25 krad	172.3694	179.6235	198.369	4.2174	172.1529	179.7646	196.919	3.9451

Table 5p Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_4x (mV) [0.0, 400.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	204.2053	213.9193	266.2825	6.3558	203.8784	212.9066	234.9996	5.3915
17827	25 krad	201.5247	212.0649	236.2092	5.3667	201.1435	211.5694	233.2011	5.3197
17829	25 krad	203.4231	213.0983	247.5316	5.8919	202.3937	212.3508	234.5304	5.2910
17832	25 krad	203.5013	213.5629	245.4221	6.1518	202.003	212.5522	237.8334	5.4777
17833	25 krad	203.5795	213.2789	237.6646	5.9951	202.55	212.5941	234.6868	5.2008
17834	25 krad	202.9538	212.8590	237.5083	5.6495	202.7844	213.0210	235.8597	5.2807

Table 5q Pre-Irradiation and Post-Annealing VOL

Test name		lvttl_vol_5x (mV) [0.0, 400.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	230.0182	245.4406	323.3165	9.5361	229.5871	243.6791	276.9117	8.0560
17827	25 krad	227.2352	242.8605	279.5287	8.0668	226.3051	242.2949	275.1914	7.9608
17829	25 krad	229.5488	244.2960	292.8463	8.7918	227.7117	243.2209	276.7552	7.9100
17832	25 krad	229.3924	245.0314	292.1431	9.2659	227.4772	243.4182	282.2134	8.2205
17833	25 krad	229.7835	244.8164	281.4912	8.9915	228.1024	243.3907	276.8335	7.8010
17834	25 krad	229.0795	244.1877	281.0225	8.4961	228.4931	243.7678	277.9282	7.8983

Table 6a Pre-Irradiation and Post-Annealing IpD

Test name		cmos18_ipd_weak (cmos18_ipd_weak_min) (uA) [4.1, 16.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	9.6223	9.8730	10.0897	0.0877	9.5842	9.9276	10.2661	0.1043
17827	25 krad	9.6873	9.9190	10.2003	0.0878	9.729	10.0168	10.2821	0.0886
17829	25 krad	9.662	9.9535	10.1636	0.0989	9.6114	10.0021	10.2749	0.1167
17832	25 krad	9.6168	9.9048	10.143	0.0898	9.634	9.9648	10.2131	0.1048
17833	25 krad	9.4664	9.7582	9.9588	0.0810	9.5591	9.8116	10.0709	0.0932
17834	25 krad	9.6389	9.8802	10.1083	0.0850	9.6129	9.8901	10.2382	0.1022

Table 6b Pre-Irradiation and Post-Annealing IpD

Test name		cmos18_ipd_weak (cmos18_ipd_weak_max) (uA) [4.1, 20.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	12.1991	12.4232	12.6551	0.1010	12.1286	12.4707	12.7832	0.1172
17827	25 krad	12.2187	12.4875	12.8008	0.0933	12.2578	12.5594	12.8588	0.0987
17829	25 krad	12.2233	12.5168	12.7594	0.1150	12.1536	12.5529	12.8245	0.1295
17832	25 krad	12.149	12.4668	12.7229	0.1072	12.1425	12.4960	12.8059	0.1214
17833	25 krad	11.9952	12.2634	12.526	0.0948	11.998	12.2857	12.5519	0.1059
17834	25 krad	12.1741	12.4382	12.7503	0.1005	12.1235	12.4124	12.7344	0.1120

Table 6c Pre-Irradiation and Post-Annealing IpD

Test name		cmos15_ipd_weak (cmos15_ipd_weak_minU) (uA) [2.4, 21.7]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	5.9816	6.1739	6.3462	0.0644	5.9171	6.1952	6.4449	0.0879
17827	25 krad	5.9166	6.2167	6.4654	0.0772	5.9695	6.2492	6.4699	0.0781
17829	25 krad	5.999	6.2161	6.3953	0.0718	5.9171	6.2454	6.5037	0.0913
17832	25 krad	5.9816	6.1933	6.3764	0.0662	5.967	6.2179	6.4476	0.0865
17833	25 krad	5.8813	6.1088	6.27	0.0605	5.8888	6.1267	6.3699	0.0792
17834	25 krad	5.9565	6.1742	6.3936	0.0604	5.9198	6.1626	6.3705	0.0813

Table 6d Pre-Irradiation and Post-Annealing IpD

Test name		cmos15_ipd_weak (cmos15_ipd_weak_maxU) (uA) [2.4, 21.7]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	8.3167	8.5428	8.7375	0.0773	8.287	8.5753	8.8411	0.0948
17827	25 krad	8.3706	8.5884	8.8969	0.0816	8.3618	8.6454	8.8461	0.0831
17829	25 krad	8.3712	8.6028	8.8202	0.0894	8.2371	8.6354	8.9177	0.1061
17832	25 krad	8.3382	8.5723	8.7952	0.0791	8.3085	8.5997	8.865	0.1012
17833	25 krad	8.1878	8.4441	8.6378	0.0726	8.2076	8.4727	8.7417	0.0892
17834	25 krad	8.2881	8.5477	8.7873	0.0735	8.2829	8.5425	8.7649	0.0920

Table 6e Pre-Irradiation and Post-Annealing IpD

Test name		cmos12_ipd_weak (cmos12_ipd_weak_minU) (uA) [0.8, 21.7]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	3.3742	3.5664	3.7277	0.0562	3.3477	3.6101	3.8692	0.0767
17827	25 krad	3.3022	3.6010	3.8188	0.0688	3.4095	3.6479	3.8356	0.0719
17829	25 krad	3.4437	3.5897	3.739	0.0536	3.3726	3.6326	3.8831	0.0822
17832	25 krad	3.3742	3.5808	3.7138	0.0521	3.3311	3.6214	3.8426	0.0792
17833	25 krad	3.3492	3.5385	3.7011	0.0493	3.3561	3.5775	3.8192	0.0711
17834	25 krad	3.383	3.5621	3.7277	0.0490	3.3628	3.5870	3.7926	0.0736

Table 6f Pre-Irradiation and Post-Annealing IpD

Test name		cmos12_ipd_weak (cmos12_ipd_weak_minU) (uA) [1.4, 15.8]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	3.3742	3.5664	3.7277	0.0562	3.3477	3.6101	3.8692	0.0767
17827	25 krad	3.3022	3.6010	3.8188	0.0688	3.4095	3.6479	3.8356	0.0719
17829	25 krad	3.4437	3.5897	3.739	0.0536	3.3726	3.6326	3.8831	0.0822
17832	25 krad	3.3742	3.5808	3.7138	0.0521	3.3311	3.6214	3.8426	0.0792
17833	25 krad	3.3492	3.5385	3.7011	0.0493	3.3561	3.5775	3.8192	0.0711
17834	25 krad	3.383	3.5621	3.7277	0.0490	3.3628	3.5870	3.7926	0.0736

Table 6g Pre-Irradiation and Post-Annealing IpD

Test name		lvttl_ipd_weak_(lvttl_ipd_weak_min) (uA) [8.9, 27.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	17.051	17.3453	17.5762	0.1172	17.043	17.3900	17.7414	0.1256
17827	25 krad	17.0921	17.3672	17.67	0.1063	17.1206	17.4362	17.7072	0.1046
17829	25 krad	17.0632	17.4147	17.6485	0.1272	17.018	17.4704	17.7762	0.1458
17832	25 krad	17.0127	17.3805	17.6907	0.1256	17.0378	17.4239	17.7373	0.1364
17833	25 krad	16.6617	17.0324	17.3115	0.1205	16.6211	17.0683	17.3425	0.1274
17834	25 krad	17.0127	17.3410	17.6604	0.1198	17.0043	17.3015	17.6786	0.1325

Table 6h Pre-Irradiation and Post-Annealing IpD

Test name		Ivttl_ipd_weak_(Ivttle_ipd_ipd_weak_max) (uA) [8.9, 29.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	18.9181	19.1703	19.4275	0.1144	18.889	19.2133	19.5537	0.1268
17827	25 krad	18.9153	19.1738	19.4999	0.1044	18.9307	19.2791	19.5458	0.1028
17829	25 krad	18.9431	19.2582	19.5071	0.1259	18.9139	19.3096	19.625	0.1409
17832	25 krad	18.8504	19.2068	19.5046	0.1259	18.9137	19.2476	19.5646	0.1338
17833	25 krad	18.3916	18.8085	19.0562	0.1218	18.5244	18.8655	19.1766	0.1281
17834	25 krad	18.893	19.1706	19.5526	0.1220	18.8087	19.1497	19.4957	0.1344

## E. High Output-Drive Voltage (VOH and Ipu)

The pre-irradiation and post-annealing VOH are listed in Table 7a through Table 8j. The post-annealing data are within the specification limits (test specification minimum and maximum are given in brackets); data is presented with statistics of all the I/O pins used (~340 sample size of each DUT). In each case, the post-annealing data varies insignificantly.

Table 7a Pre-Irradiation and Post-Annealing VOH

Test name		cmos18_voh_5x (V) [1.3, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.4313	1.4699	1.4769	0.0047	1.4522	1.4693	1.4773	0.0040
17827	25 krad	1.454	1.4733	1.4819	0.0042	1.4559	1.4734	1.4823	0.0042
17829	25 krad	1.4476	1.4718	1.4792	0.0044	1.454	1.4711	1.4795	0.0040
17832	25 krad	1.4459	1.4700	1.4779	0.0048	1.451	1.4694	1.4776	0.0043
17833	25 krad	1.4538	1.4733	1.4828	0.0050	1.4539	1.4727	1.4823	0.0044
17834	25 krad	1.4537	1.4713	1.4787	0.0045	1.4515	1.4699	1.4777	0.0041

Table 7b Pre-Irradiation and Post-Annealing VOH

Test name		cmos15_voh_2x (V) [1.1, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.2335	1.2404	1.2433	0.0013	1.2317	1.2355	1.2386	0.0012
17827	25 krad	1.2401	1.2434	1.2456	0.0011	1.237	1.2404	1.2427	0.0010
17829	25 krad	1.2373	1.2422	1.2457	0.0014	1.2342	1.2374	1.2417	0.0013
17832	25 krad	1.2355	1.2407	1.2438	0.0013	1.2312	1.2359	1.2387	0.0012
17833	25 krad	1.2393	1.2440	1.248	0.0018	1.2349	1.2393	1.243	0.0017
17834	25 krad	1.2379	1.2418	1.2452	0.0014	1.232	1.2365	1.2396	0.0014

Table 7c Pre-Irradiation and Post-Annealing VOH

Test name		cmos15_voh_3x (V) [1.1, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.2205	1.2339	1.2374	0.0018	1.2223	1.2289	1.2321	0.0016
17827	25 krad	1.2304	1.2368	1.2398	0.0016	1.2276	1.2339	1.2377	0.0016
17829	25 krad	1.2268	1.2358	1.2394	0.0019	1.2254	1.2310	1.2351	0.0017
17832	25 krad	1.2252	1.2341	1.2373	0.0019	1.2223	1.2295	1.2324	0.0017
17833	25 krad	1.2298	1.2377	1.2425	0.0023	1.2254	1.2329	1.2382	0.0022
17834	25 krad	1.2287	1.2353	1.2389	0.0019	1.2234	1.2299	1.2335	0.0018

Table 7d Pre-Irradiation and Post-Annealing VOH

Test name		cmos15_voh_4x (V) [1.1, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.1779	1.1972	1.2016	0.0026	1.1832	1.1923	1.1966	0.0023
17827	25 krad	1.1911	1.2014	1.2062	0.0023	1.1893	1.1984	1.2035	0.0023
17829	25 krad	1.1862	1.1997	1.2047	0.0026	1.1865	1.1946	1.1999	0.0024
17832	25 krad	1.1849	1.1976	1.2021	0.0027	1.1829	1.1928	1.1971	0.0024
17833	25 krad	1.1912	1.2021	1.2085	0.0032	1.1863	1.1971	1.2041	0.0030
17834	25 krad	1.1899	1.1989	1.2037	0.0027	1.1835	1.1935	1.1978	0.0025

Table 7e Pre-Irradiation and Post-Annealing VOH

Test name		cmos15_voh_5x (V) [1.1, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.1413	1.1804	1.1876	0.0048	1.1583	1.1760	1.1841	0.0041
17827	25 krad	1.1656	1.1848	1.1937	0.0043	1.1644	1.1819	1.1905	0.0042
17829	25 krad	1.1571	1.1831	1.1908	0.0045	1.1616	1.1786	1.1866	0.0041
17832	25 krad	1.1555	1.1808	1.1889	0.0049	1.1577	1.1763	1.1846	0.0043
17833	25 krad	1.1648	1.1852	1.1954	0.0053	1.1618	1.1807	1.1916	0.0047
17834	25 krad	1.1647	1.1823	1.19	0.0046	1.1582	1.1770	1.1853	0.0042

Table 7f Pre-Irradiation and Post-Annealing VOH

Test name		cmos12_voh_2x (V) [0.8, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	917.7205	925.3348	930.3758	1.8611	919.355	923.0954	927.8406	1.7729
17827	25 krad	928.2256	932.3174	935.0178	1.3667	928.7383	932.1788	934.8167	1.3353
17829	25 krad	922.7207	928.8134	934.3969	2.0619	922.3264	926.6210	932.9981	2.0017
17832	25 krad	920.0643	926.3146	930.6687	1.7497	918.7294	924.0897	928.7169	1.6691
17833	25 krad	926.6271	931.9129	937.8755	2.6320	924.5158	929.7462	935.7543	2.5495
17834	25 krad	921.6269	928.0099	932.5196	2.1490	918.2603	925.3400	930.8101	2.1305

Table 7g Pre-Irradiation and Post-Annealing VOH

Test name		cmos12_voh_3x (V) [0.9, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.0316	1.0385	1.0408	0.0010	1.0335	1.0368	1.0388	0.0009
17827	25 krad	1.0369	1.0403	1.0422	0.0009	1.037	1.0401	1.0422	0.0009
17829	25 krad	1.0351	1.0398	1.0422	0.0011	1.0351	1.0381	1.0407	0.0010
17832	25 krad	1.0338	1.0387	1.0409	0.0011	1.0332	1.0371	1.0391	0.0010
17833	25 krad	1.0368	1.0411	1.044	0.0014	1.0354	1.0393	1.0428	0.0013
17834	25 krad	1.036	1.0395	1.0417	0.0011	1.0337	1.0376	1.0405	0.0010

Table 7h Pre-Irradiation and Post-Annealing VOH

Test name		cmos12_voh_3xE1 (V) [1.0, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.1341	1.1349	1.1356	0.0003	1.1327	1.1334	1.134	0.0003
17827	25 krad	1.1329	1.1337	1.1343	0.0002	1.1327	1.1335	1.1343	0.0003
17829	25 krad	1.1342	1.1350	1.1358	0.0003	1.1327	1.1334	1.1341	0.0003
17832	25 krad	1.1342	1.1349	1.1358	0.0003	1.1325	1.1334	1.1341	0.0003
17833	25 krad	1.1342	1.1350	1.1358	0.0003	1.1327	1.1335	1.1343	0.0003
17834	25 krad	1.1343	1.1349	1.1357	0.0003	1.1327	1.1334	1.1343	0.0003

Table 7i Pre-Irradiation and Post-Annealing VOH

Test name		cmos12_voh_3xE2 (V) [1.3, 2.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	1.3961	1.3969	1.3976	0.0003	1.392	1.3926	1.3933	0.0002
17827	25 krad	1.3948	1.3955	1.3963	0.0003	1.3921	1.3927	1.3934	0.0002
17829	25 krad	1.3962	1.3969	1.3978	0.0003	1.392	1.3926	1.3933	0.0002
17832	25 krad	1.3962	1.3969	1.3976	0.0003	1.3918	1.3926	1.3933	0.0002
17833	25 krad	1.3961	1.3970	1.3978	0.0003	1.3921	1.3926	1.3934	0.0003
17834	25 krad	1.3961	1.3969	1.3978	0.0003	1.392	1.3926	1.3934	0.0002

Table 7j Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_1x12 (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6298	2.6423	2.648	0.0025	2.631	2.6384	2.6436	0.0023
17827	25 krad	2.6409	2.6483	2.6527	0.0021	2.6387	2.6458	2.65	0.0020
17829	25 krad	2.6367	2.6451	2.6516	0.0026	2.6352	2.6414	2.649	0.0025
17832	25 krad	2.6334	2.6425	2.6484	0.0025	2.6302	2.6387	2.6442	0.0023
17833	25 krad	2.6391	2.6481	2.6551	0.0033	2.6353	2.6444	2.6514	0.0032
17834	25 krad	2.6366	2.6449	2.6499	0.0028	2.6315	2.6400	2.6461	0.0026

Table 7k Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_1x (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6302	2.6421	2.6479	0.0025	2.631	2.6384	2.6437	0.0023
17827	25 krad	2.6408	2.6485	2.6527	0.0020	2.6388	2.6458	2.6499	0.0020
17829	25 krad	2.6366	2.6453	2.6516	0.0026	2.6353	2.6414	2.6489	0.0025
17832	25 krad	2.6337	2.6425	2.6485	0.0025	2.6302	2.6387	2.6445	0.0023
17833	25 krad	2.6392	2.6482	2.6551	0.0033	2.636	2.6443	2.6514	0.0031
17834	25 krad	2.6369	2.6449	2.6501	0.0027	2.6316	2.6399	2.6459	0.0026

Table 7l Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_1xE1 (V) [2.8, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.9908	2.9917	2.9924	0.0003	2.9877	2.9882	2.9888	0.0002
17827	25 krad	2.9906	2.9912	2.9917	0.0002	2.9878	2.9883	2.9891	0.0002
17829	25 krad	2.9909	2.9918	2.9924	0.0003	2.9878	2.9882	2.9889	0.0002
17832	25 krad	2.9909	2.9918	2.9924	0.0003	2.9877	2.9882	2.9888	0.0002
17833	25 krad	2.991	2.9919	2.9929	0.0003	2.9878	2.9883	2.9889	0.0002
17834	25 krad	2.9909	2.9918	2.9928	0.0003	2.9876	2.9882	2.9891	0.0002

Table 7m Pre-Irradiation and Post-Annealing VOH

Test name		Ivttl_voh_1xE2 (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6906	2.6915	2.6922	0.0003	2.6876	2.6881	2.6887	0.0002
17827	25 krad	2.688	2.6885	2.6891	0.0002	2.6876	2.6882	2.6889	0.0002
17829	25 krad	2.6906	2.6916	2.6922	0.0003	2.6876	2.6881	2.6888	0.0002
17832	25 krad	2.6906	2.6915	2.6922	0.0003	2.6875	2.6881	2.6887	0.0002
17833	25 krad	2.6908	2.6916	2.6922	0.0003	2.6875	2.6882	2.6888	0.0002
17834	25 krad	2.6905	2.6916	2.6922	0.0003	2.6876	2.6881	2.6887	0.0002

Table 7n Pre-Irradiation and Post-Annealing VOH

Test name		Ivttl_voh_2x (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6038	2.6295	2.6373	0.0039	2.6125	2.6258	2.6332	0.0036
17827	25 krad	2.6217	2.6360	2.6432	0.0035	2.6201	2.6330	2.6404	0.0036
17829	25 krad	2.6148	2.6326	2.6402	0.0039	2.6169	2.6286	2.6364	0.0038
17832	25 krad	2.6124	2.6295	2.6368	0.0040	2.6117	2.6260	2.6333	0.0038
17833	25 krad	2.6194	2.6354	2.646	0.0047	2.6168	2.6316	2.6422	0.0046
17834	25 krad	2.6191	2.6316	2.6385	0.0038	2.6135	2.6272	2.6344	0.0039

Table 7o Pre-Irradiation and Post-Annealing VOH

Test name		Ivttl_voh_3x (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6684	2.7060	2.7137	0.0048	2.6849	2.7031	2.7115	0.0041
17827	25 krad	2.691	2.7107	2.7203	0.0043	2.6901	2.7080	2.7178	0.0042
17829	25 krad	2.6831	2.7083	2.716	0.0046	2.6876	2.7051	2.7141	0.0041
17832	25 krad	2.6817	2.7061	2.7148	0.0050	2.6842	2.7030	2.7119	0.0044
17833	25 krad	2.6901	2.7106	2.7208	0.0054	2.6876	2.7073	2.7182	0.0047
17834	25 krad	2.6904	2.7079	2.7162	0.0047	2.685	2.7040	2.7128	0.0043

Table 7p Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_4x (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6309	2.6815	2.6911	0.0063	2.6553	2.6789	2.6897	0.0054
17827	25 krad	2.6608	2.6866	2.6984	0.0056	2.6605	2.6841	2.6961	0.0056
17829	25 krad	2.6509	2.6841	2.6942	0.0060	2.6578	2.6811	2.6928	0.0054
17832	25 krad	2.6495	2.6815	2.6927	0.0065	2.6537	2.6788	2.6901	0.0058
17833	25 krad	2.6597	2.6862	2.6994	0.0068	2.6582	2.6832	2.6967	0.0061
17834	25 krad	2.6605	2.6836	2.6942	0.0060	2.6549	2.6796	2.691	0.0056

Table 7q Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_5x (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	2.6519	2.7280	2.7421	0.0094	2.6917	2.7259	2.7413	0.0081
17827	25 krad	2.6945	2.7321	2.7486	0.0083	2.6954	2.7295	2.7461	0.0082
17829	25 krad	2.683	2.7297	2.7445	0.0088	2.693	2.7273	2.7436	0.0080
17832	25 krad	2.6815	2.7279	2.7439	0.0094	2.6879	2.7258	2.7418	0.0085
17833	25 krad	2.6932	2.7310	2.7484	0.0095	2.693	2.7292	2.7466	0.0084
17834	25 krad	2.6952	2.7291	2.7443	0.0087	2.6902	2.7262	2.7427	0.0081

Table 8a Pre-Irradiation and Post-Annealing Ipu

Test name		cmos18_ipu_weak (cmos18_ipu_weak_Min.U) (uA) [-18.0, -6.5]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-14.4676	-14.0529	-13.622	0.1447	-14.4011	-13.9494	-13.5408	0.1474
17827	25 krad	-14.6319	-14.1895	-13.6215	0.1933	-14.6108	-14.1703	-13.6534	0.1883
17829	25 krad	-14.6664	-14.1892	-13.7198	0.1841	-14.6629	-14.0751	-13.5741	0.1841
17832	25 krad	-14.4393	-14.0968	-13.595	0.1486	-14.425	-13.9778	-13.5345	0.1519
17833	25 krad	-14.7607	-14.3264	-14.0488	0.1580	-14.7526	-14.2174	-13.8344	0.1701
17834	25 krad	-14.5764	-14.1692	-13.6701	0.1780	-14.4201	-14.0133	-13.4607	0.1734

Table 8b Pre-Irradiation and Post-Annealing Ipu

Test name		cmos18_ipu_weak (cmos18_ipu_weak_Max.U) (uA) [-25.0,-6.5]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-17.778	-17.3055	-16.8473	0.1636	-17.6076	-17.0740	-16.6464	0.1615
17827	25 krad	-17.9394	-17.4527	-16.8669	0.2199	-17.8259	-17.3087	-16.7574	0.2166
17829	25 krad	-18.002	-17.4311	-16.9206	0.2138	-17.7956	-17.2155	-16.6561	0.2078
17832	25 krad	-17.7075	-17.3492	-16.8034	0.1700	-17.5732	-17.0990	-16.5649	0.1682
17833	25 krad	-18.0702	-17.5956	-17.2212	0.1743	-17.9292	-17.3576	-16.933	0.1894
17834	25 krad	-17.8824	-17.4318	-16.8723	0.2041	-17.6163	-17.1302	-16.478	0.1953

Table 8c Pre-Irradiation and Post-Annealing Ipu

Test name		cmos15_ipu_weak (cmos15_ipu_weak_Min.U) (uA) [-21.7,-3.8]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-9.502	-9.1515	-8.865	0.1073	-9.2906	-8.9696	-8.6569	0.1082
17827	25 krad	-9.5703	-9.2228	-8.8283	0.1414	-9.4868	-9.1228	-8.747	0.1352
17829	25 krad	-9.6054	-9.2453	-8.9112	0.1290	-9.4277	-9.0544	-8.6879	0.1307
17832	25 krad	-9.4661	-9.1800	-8.7918	0.1094	-9.3194	-8.9934	-8.6966	0.1164
17833	25 krad	-9.6983	-9.3505	-9.0898	0.1190	-9.6001	-9.1627	-8.8287	0.1348
17834	25 krad	-9.5622	-9.2267	-8.9162	0.1252	-9.3448	-9.0105	-8.633	0.1287

Table 8d Pre-Irradiation and Post-Annealing Ipu

Test name		cmos15_ipu_weak (cmos15_ipu_weak_Max.U) (uA) [-21.7,-3.8]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-12.6619	-12.2556	-11.8719	0.1293	-12.4972	-12.0738	-11.7124	0.1283
17827	25 krad	-12.8278	-12.3617	-11.874	0.1702	-12.6265	-12.2633	-11.8263	0.1636
17829	25 krad	-12.7617	-12.3653	-11.9461	0.1611	-12.658	-12.1841	-11.7198	0.1584
17832	25 krad	-12.6144	-12.2909	-11.8188	0.1333	-12.501	-12.0894	-11.7214	0.1375
17833	25 krad	-12.9005	-12.4857	-12.2154	0.1421	-12.7517	-12.3119	-11.9595	0.1558
17834	25 krad	-12.6984	-12.3495	-11.8939	0.1564	-12.4973	-12.1259	-11.7006	0.1564

Table 8e Pre-Irradiation and Post-Annealing Ipu

Test name		cmos12_ipu_weak (cmos12_ipu_weak_Min.U) (uA) [-21.7,-1.4]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-5.8405	-5.5762	-5.3626	0.0768	-5.7945	-5.5040	-5.2443	0.0918
17827	25 krad	-5.9621	-5.6361	-5.3185	0.1034	-5.9954	-5.6306	-5.314	0.1053
17829	25 krad	-5.8636	-5.6434	-5.4002	0.0885	-5.9047	-5.5674	-5.3051	0.0999
17832	25 krad	-5.8241	-5.5984	-5.2875	0.0816	-5.8196	-5.5206	-5.2823	0.0932
17833	25 krad	-5.9919	-5.7213	-5.4944	0.0912	-6.0234	-5.6490	-5.3619	0.1070
17834	25 krad	-5.8769	-5.6272	-5.3894	0.0886	-5.8196	-5.5394	-5.2443	0.0997

Table 8f Pre-Irradiation and Post-Annealing Ipu

Test name		cmos12_ipu_weak (cmos12_ipu_weak_Max.U) (uA) [-15.8,-3.8]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-7.4455	-7.1333	-6.8965	0.0927	-7.3366	-7.0427	-6.7283	0.0997
17827	25 krad	-7.5156	-7.1985	-6.8454	0.1198	-7.4774	-7.1801	-6.8621	0.1183
17829	25 krad	-7.4938	-7.2038	-6.9264	0.1078	-7.4953	-7.1143	-6.8204	0.1130
17832	25 krad	-7.4065	-7.1559	-6.8621	0.0951	-7.3789	-7.0539	-6.762	0.1054
17833	25 krad	-7.5902	-7.2931	-7.0723	0.1024	-7.5992	-7.2038	-6.8952	0.1185
17834	25 krad	-7.438	-7.1918	-6.8905	0.1022	-7.3618	-7.0742	-6.7703	0.1105

Table 8g Pre-Irradiation and Post-Annealing Ipu

Test name		lvttl_ipu_weak_ (lvttl_ipu_weak_Min.U) (uA) [-102.0, -12.7]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-35.4334	-34.6366	-33.9487	0.2546	-35.0936	-34.2941	-33.677	0.2459
17827	25 krad	-35.6799	-34.9000	-34.0426	0.3059	-35.4083	-34.6986	-33.9797	0.2984
17829	25 krad	-35.7126	-34.8793	-34.1237	0.3237	-35.4639	-34.5514	-33.8341	0.3152
17832	25 krad	-35.2165	-34.7005	-33.8668	0.2591	-34.9636	-34.3175	-33.4953	0.2529
17833	25 krad	-35.8238	-35.1066	-34.4973	0.2874	-35.5377	-34.7157	-34.0474	0.2968
17834	25 krad	-35.6198	-34.8561	-34.034	0.3157	-35.1208	-34.3841	-33.4755	0.2978

Table 8h Pre-Irradiation and Post-Annealing Ipu

Test name		lvttl_ipu_weak_(lvttl_ipu_weak_Max.U) (uA) [-112.0, -12.7]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
17826	25 krad	-72.3254	-70.7950	-69.5015	0.4827	-72.0176	-70.4813	-69.3379	0.4647
17827	25 krad	-72.7896	-71.5091	-69.9419	0.5560	-72.5323	-71.3954	-69.9841	0.5392
17829	25 krad	-73.0759	-71.2741	-69.852	0.6090	-72.7804	-70.9898	-69.6292	0.6002
17832	25 krad	-71.9017	-70.8952	-69.2331	0.4860	-71.5465	-70.5857	-69.0341	0.4714
17833	25 krad	-73.1118	-71.6817	-70.4937	0.5590	-72.8563	-71.3320	-70.0764	0.5582
17834	25 krad	-72.7045	-71.2088	-69.8334	0.5893	-72.0025	-70.7005	-69.281	0.5634

## F. Propagation Delay

DUTs are irradiated to 25 krads. Table 9a and Table 9b lists the pre-irradiation, post-30-krad-irradiation, and post-annealing propagation delay at 1.5 V VCC and lists the degradation in percentage.

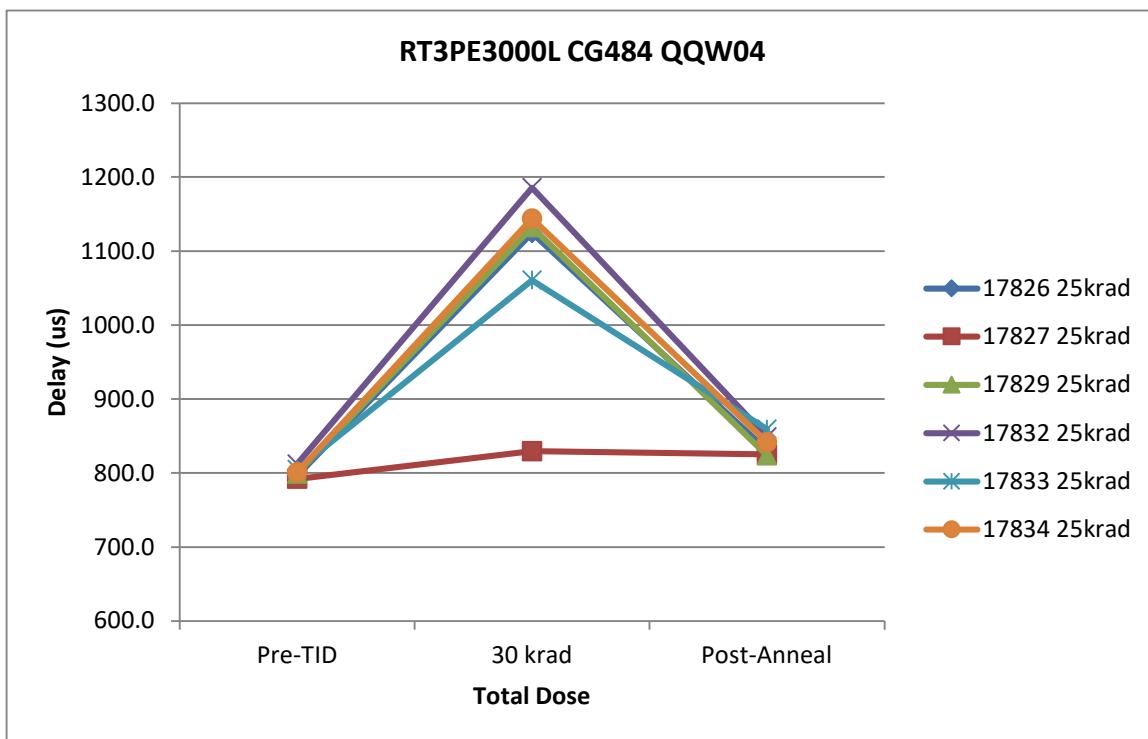
**Table 9 Propagation Delay to Irradiation Dose, Vcc =1.5V**

DUT	Pre-Irradiation (ns)	Post-25 krad(ns)	Post-Annealing (ns)
17826	796.65	1124.7	830.75
17827	792.2	829.7	825.45
17829	799.45	1132.45	823.85
17832	812.4	1185.75	848.9
17833	804.95	1060.75	859.5
17834	801.05	1144.15	841.6

**Table 9b Radiation-Induced Propagation Delay Degradation in Percentage, Vcc=1.5 V**

DUT	(Compared to Pre-irradiation)	Post-25 krad(%)	Post-Annealing (%)
17826	-	41.18%	4.28%
17827	-	4.73%	4.20%
17829	-	41.65%	3.05%
17832	-	45.96%	4.49%
17833	-	31.78%	6.78%
17834	-	42.83%	5.06%

Figure 2 has the percentage of the degradation on propagation delay in Tables 9b plotted.



**Figure 2 Degradation of Propagation Delay versus TID and Annealing**

## G. Transition Time

Figures 3a to Figure 14b show pre-irradiation and post-annealing transition edges. In each case, the radiation effect is not significant.

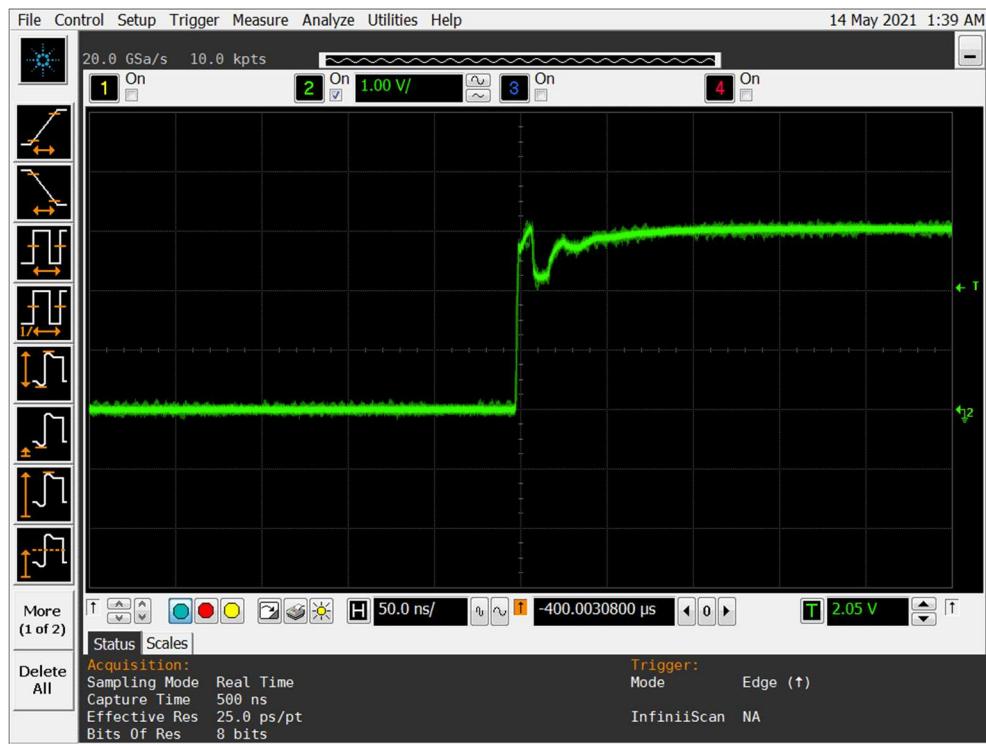


Figure 3a DUT 17826 Pre-Irradiation Rising Edge

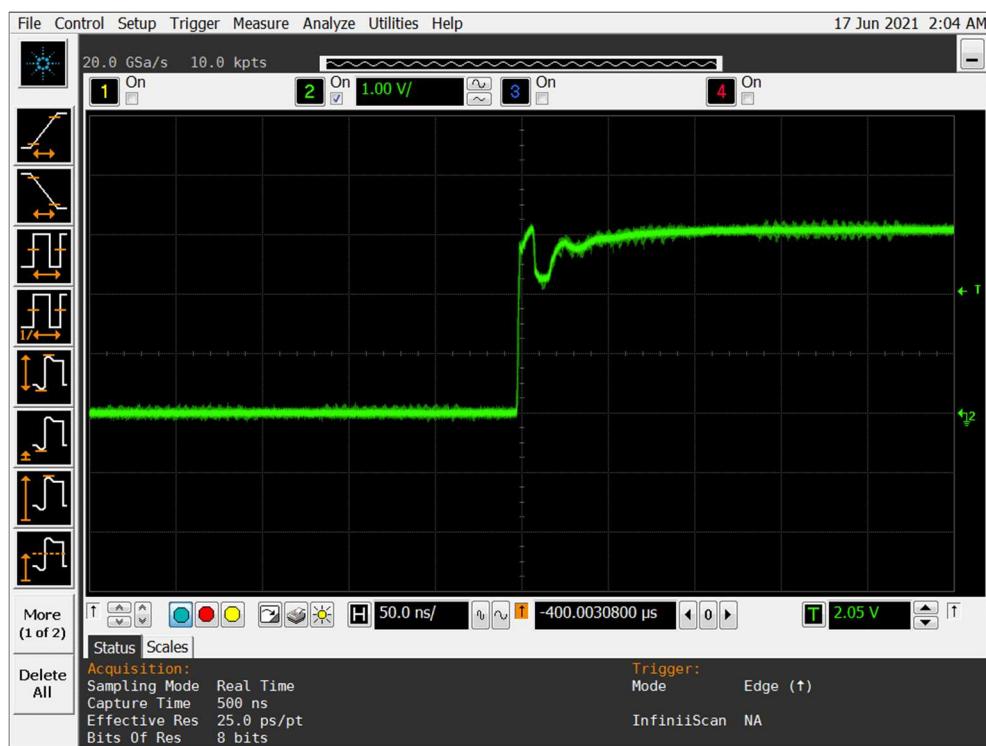


Figure 3b DUT 17826 Post-Annealing Rising Edge

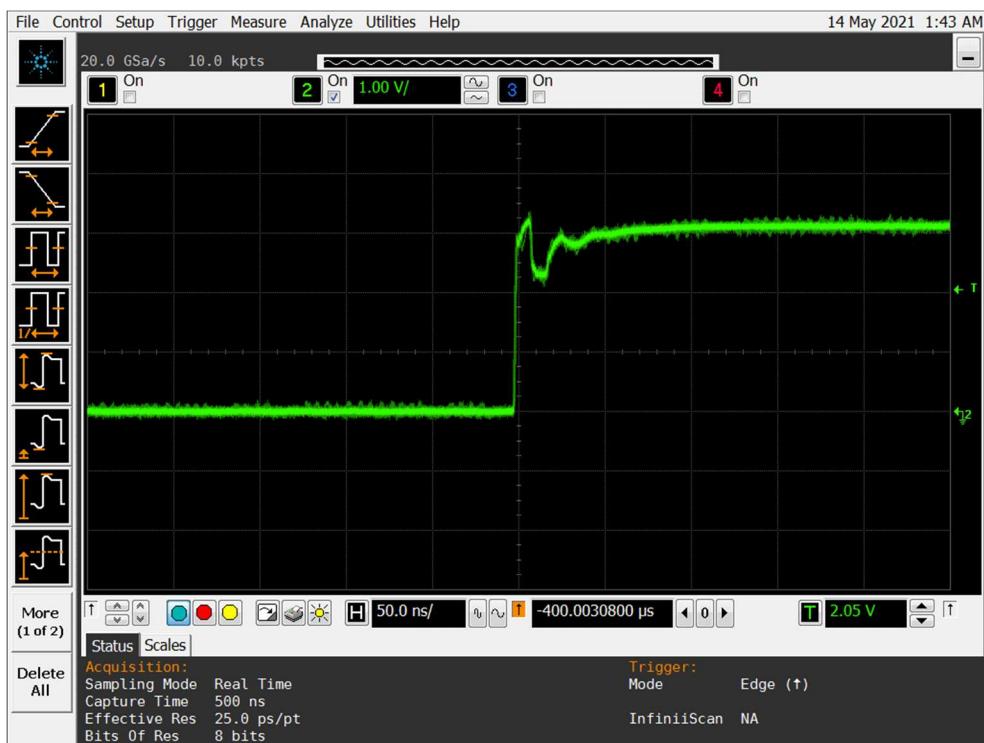


Figure 4a DUT 17827 Pre-Irradiation Rising Edge

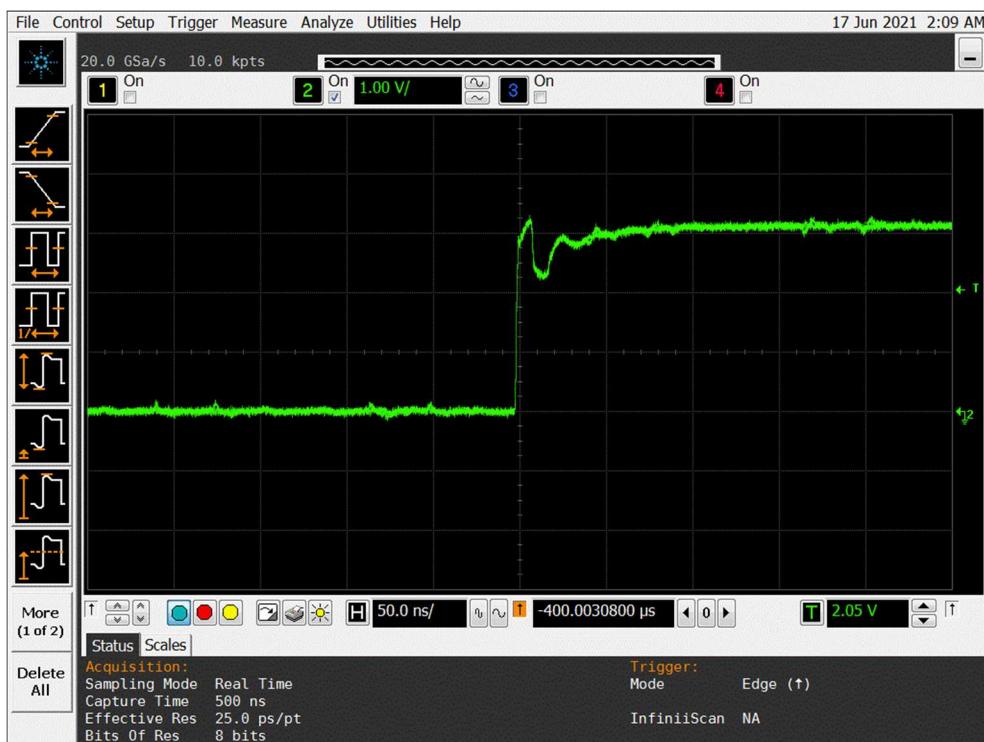


Figure 4b DUT 17827 Post-Annealing Rising Edge

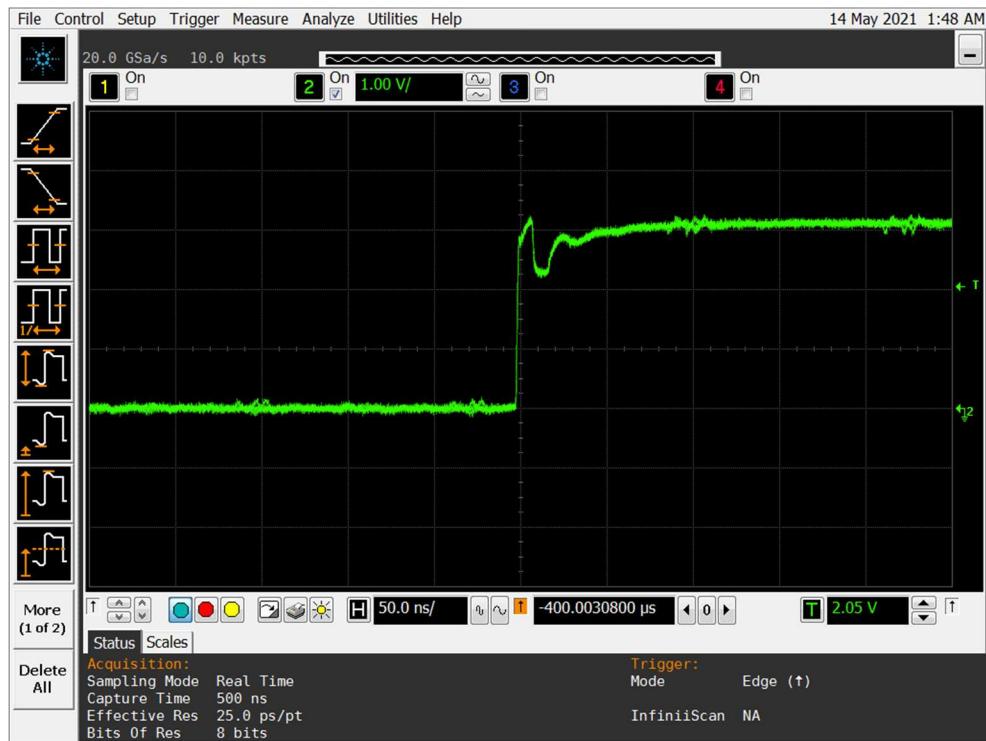


Figure 5a DUT 17829 Pre-Irradiation Rising Edge

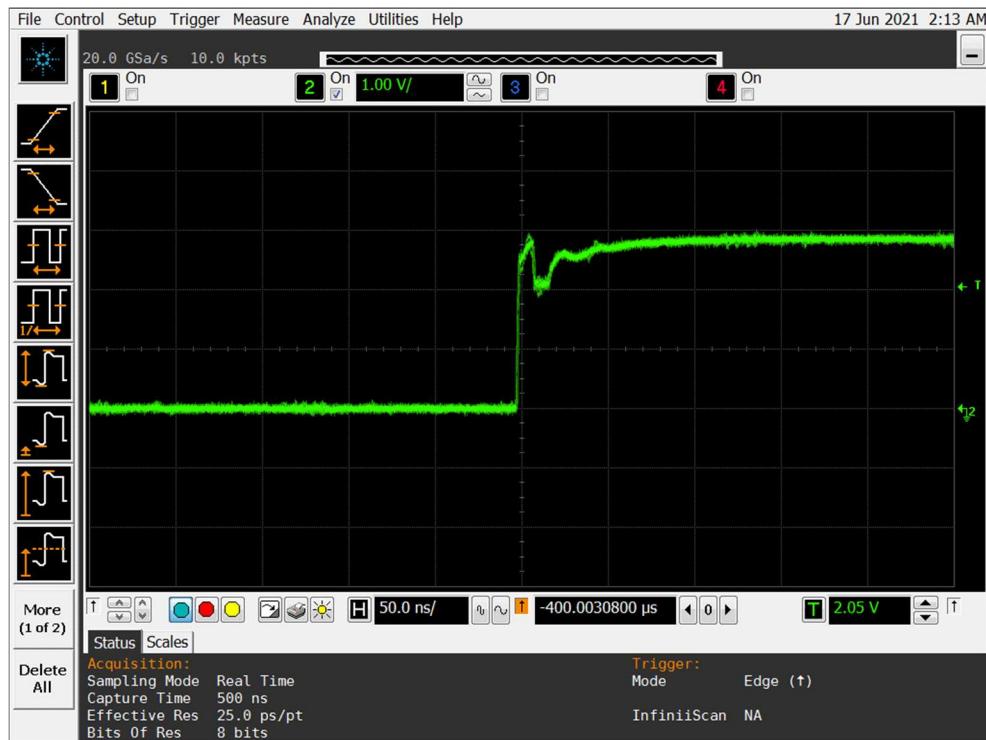


Figure 5b DUT 17829 Post-Annealing Rising Edge

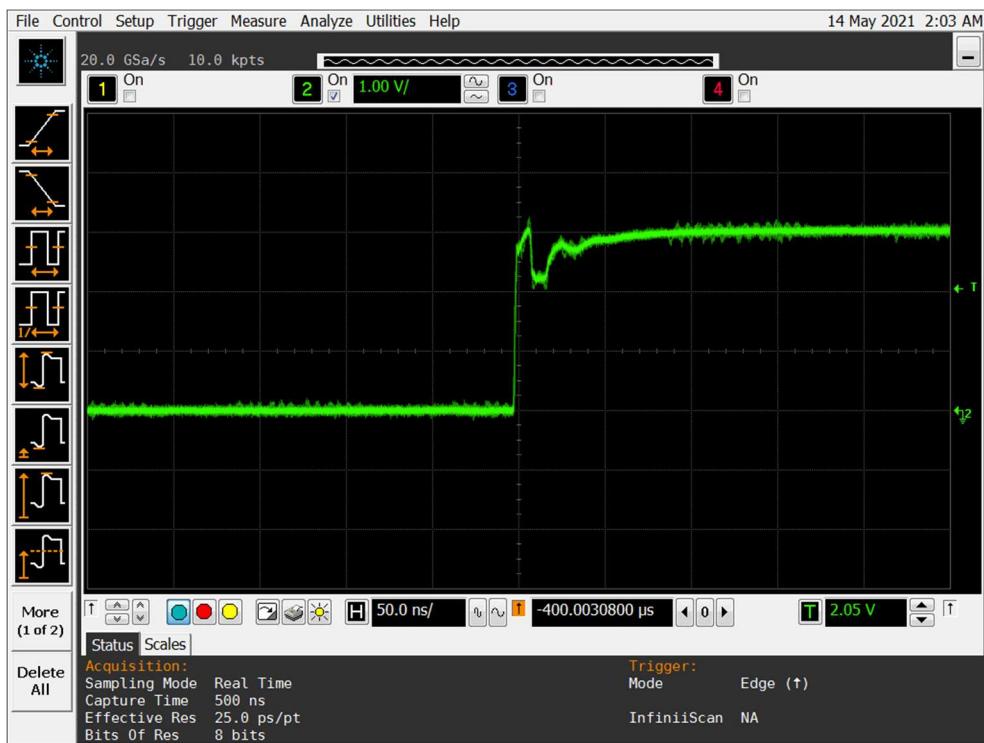


Figure 6a DUT 17832 Pre-Irradiation Rising Edge

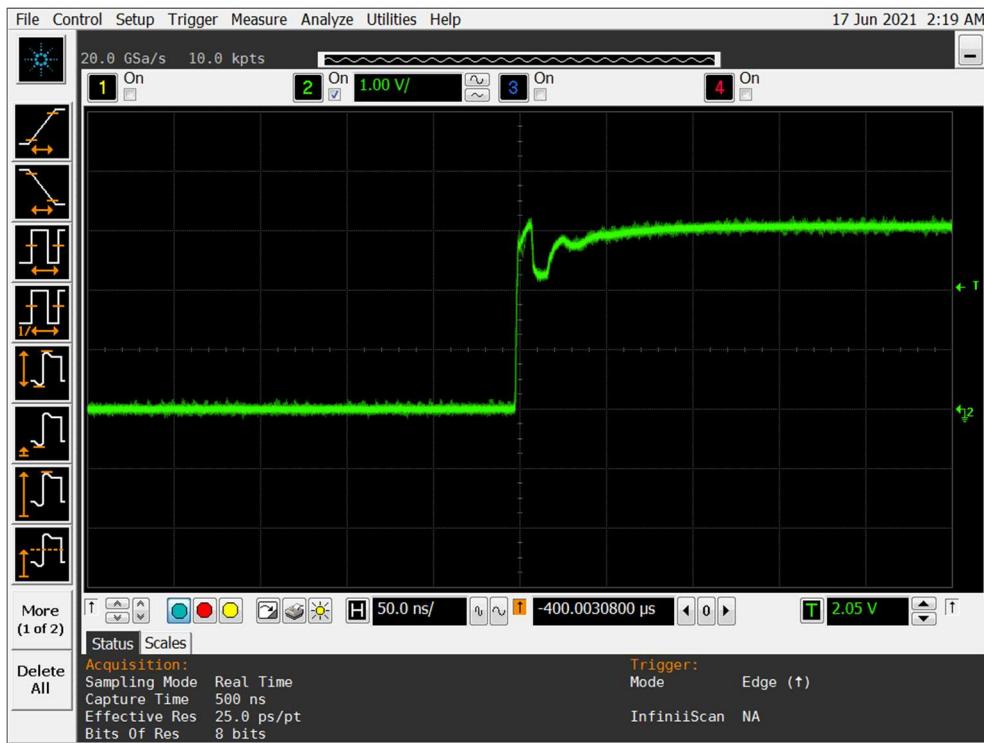


Figure 6b DUT 17832 Post-Annealing Rising Edge

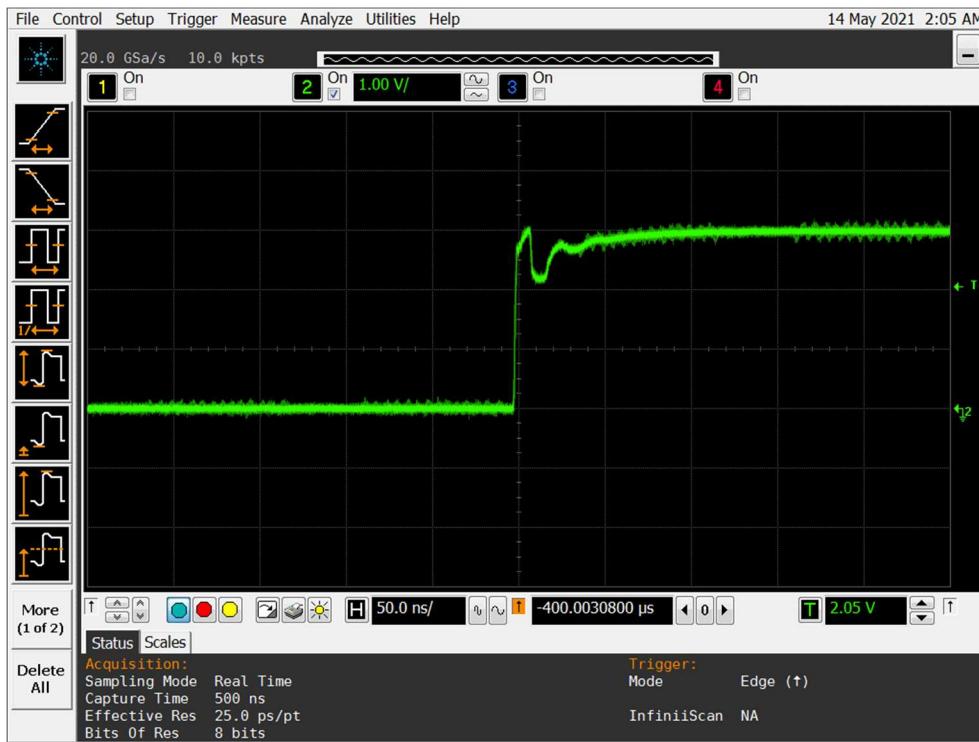


Figure 7a DUT 17833 Pre-Irradiation Rising Edge

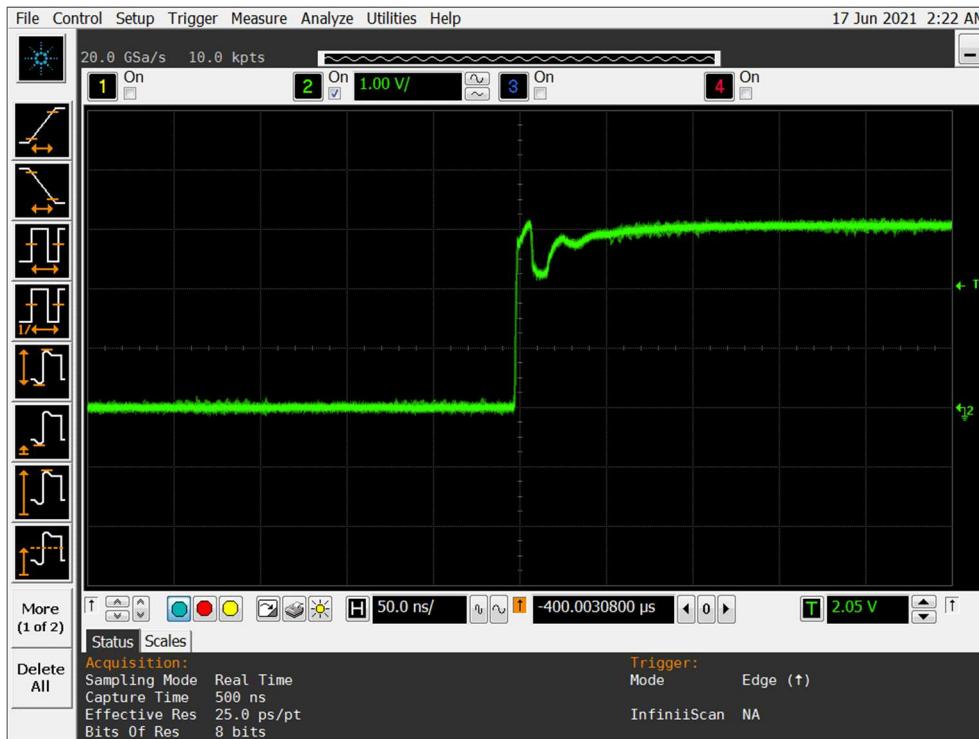


Figure 7b DUT 17833 Post-Annealing Rising Edge

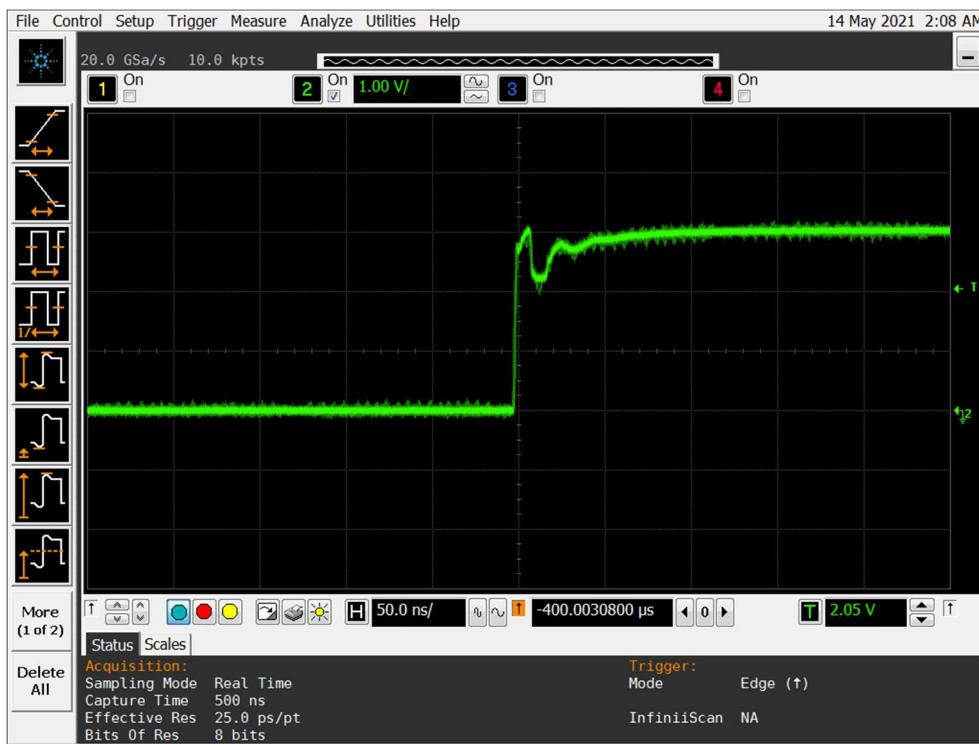


Figure 8a DUT 17834 Pre-Irradiation Rising Edge

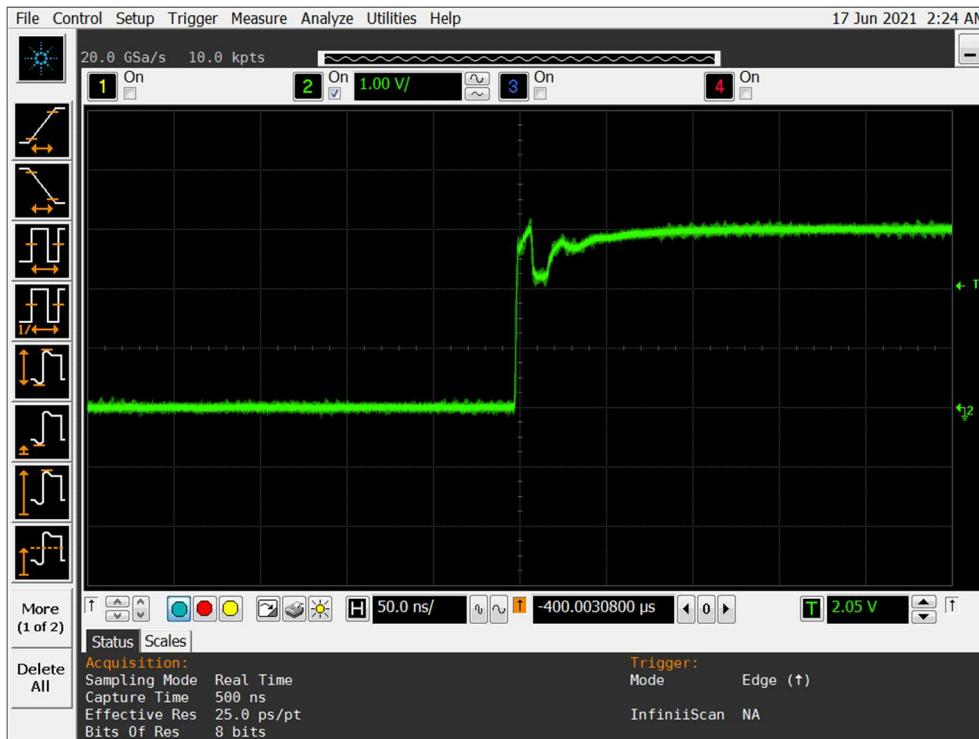


Figure 8b DUT 17834 Post-Annealing Rising Edge

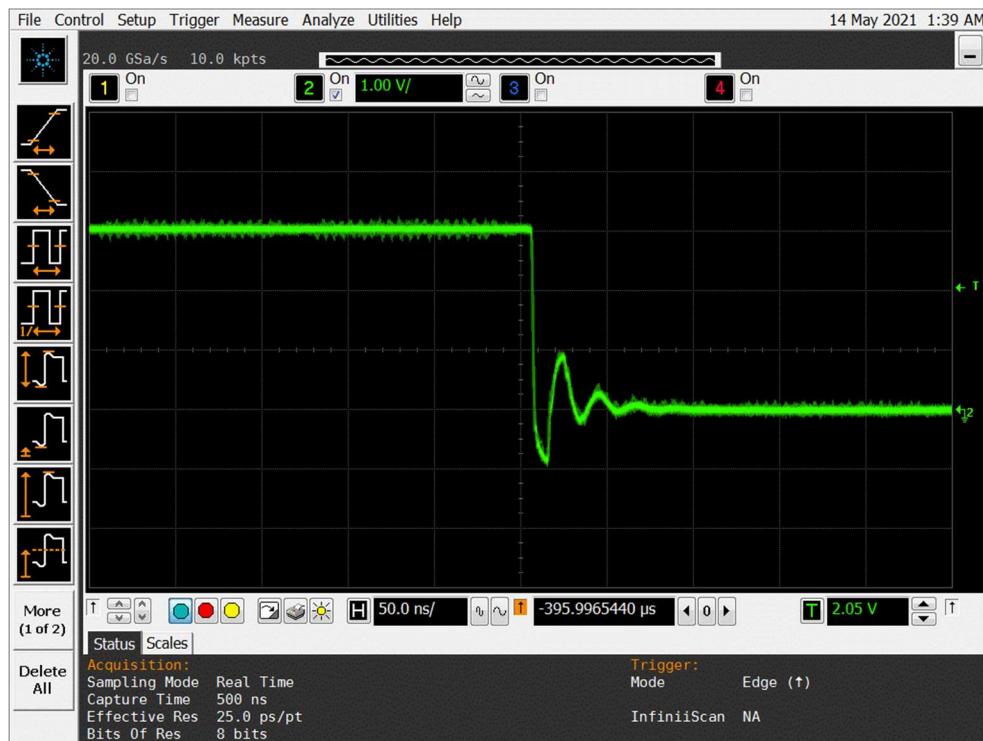


Figure 9a DUT 17826 Pre-Irradiation Falling Edge

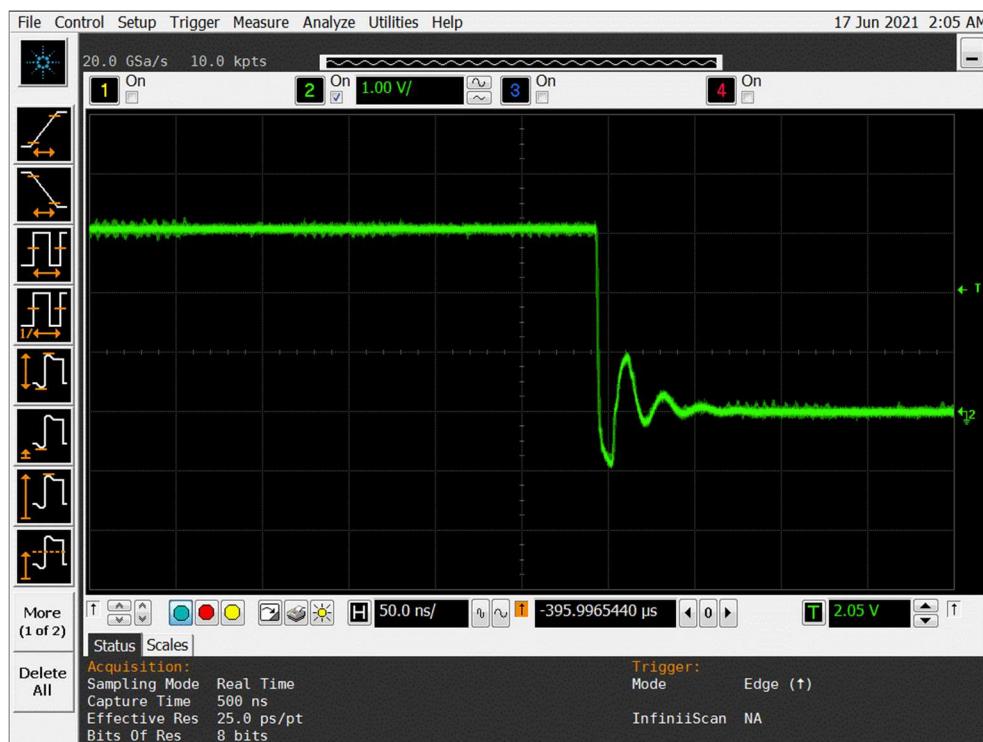


Figure 9b DUT 17826 Post-Annealing Falling Edge

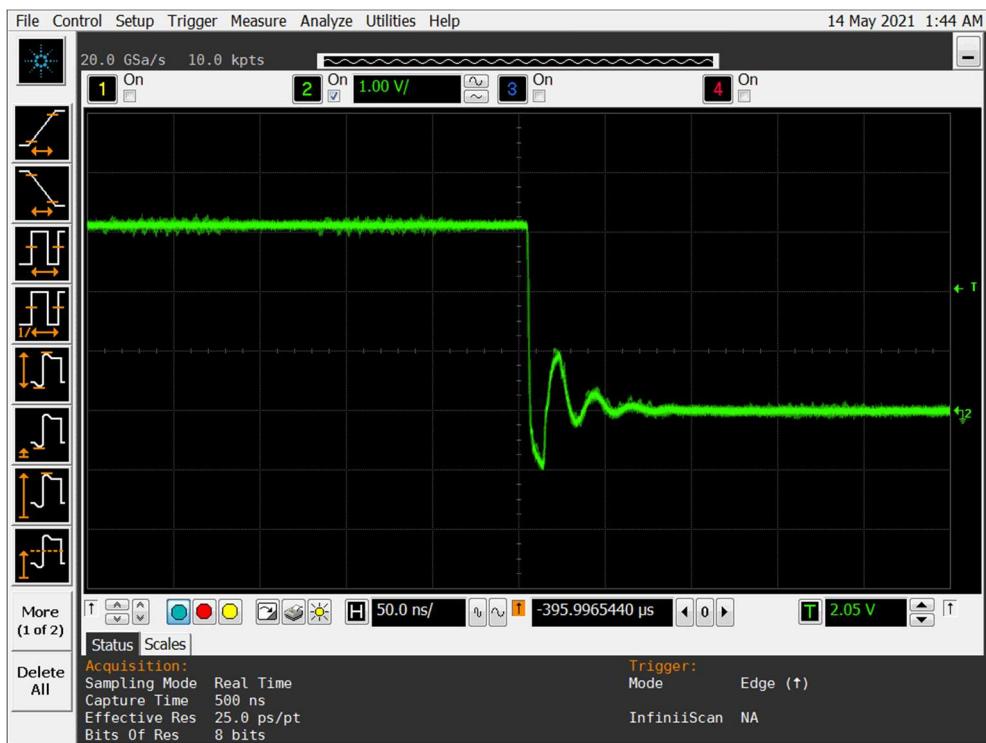


Figure 10a DUT 17827 Pre-Irradiation Falling Edge

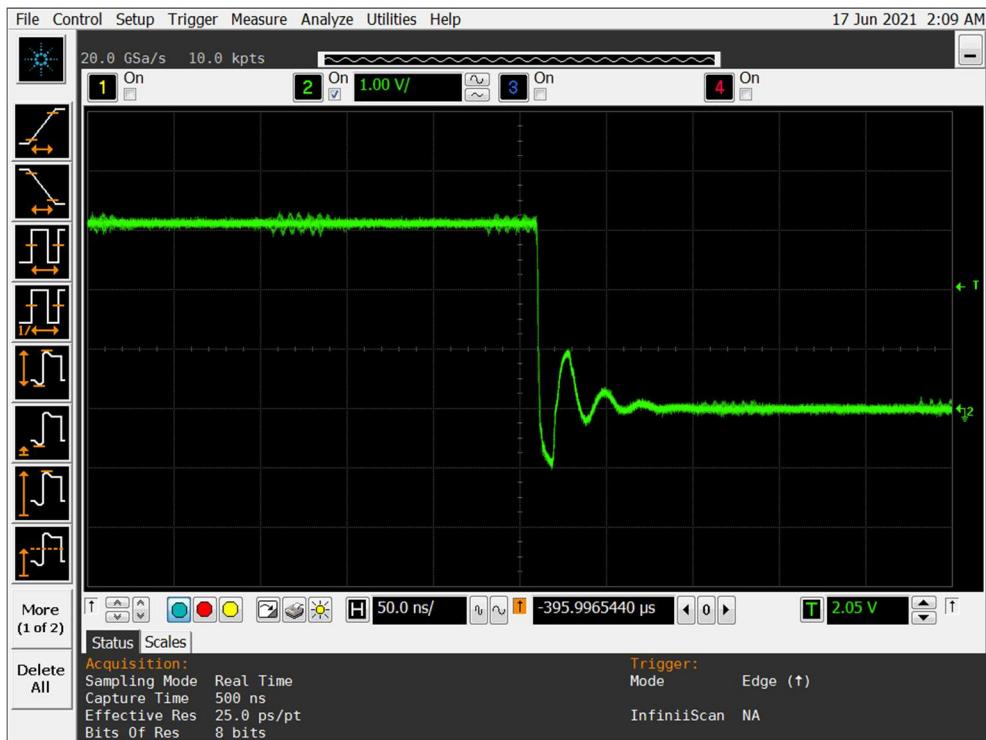


Figure 10b DUT 17827 Post-Annealing Falling Edge

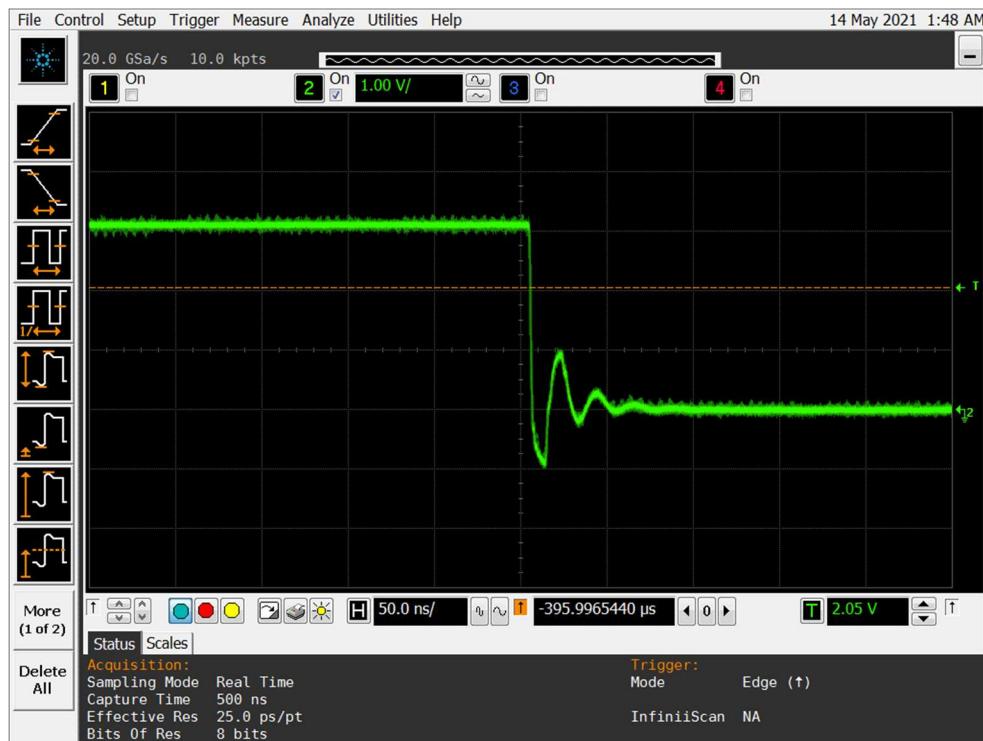


Figure 11a DUT 17829 Pre-Irradiation Falling Edge

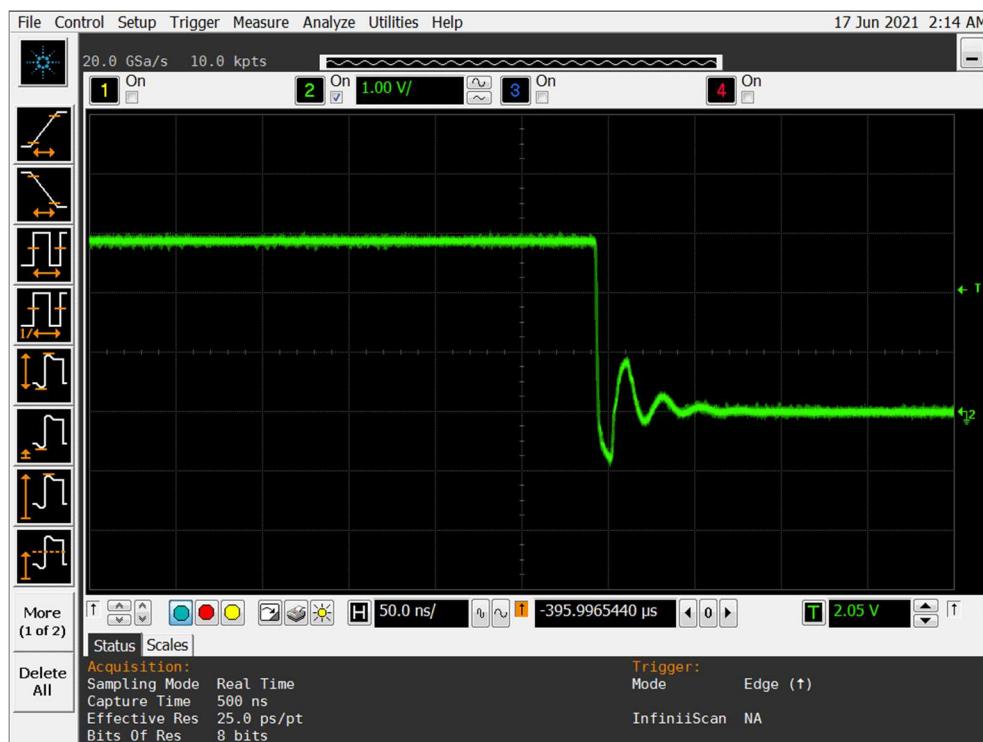


Figure 11b DUT 17829 Post-Annealing Falling Edge

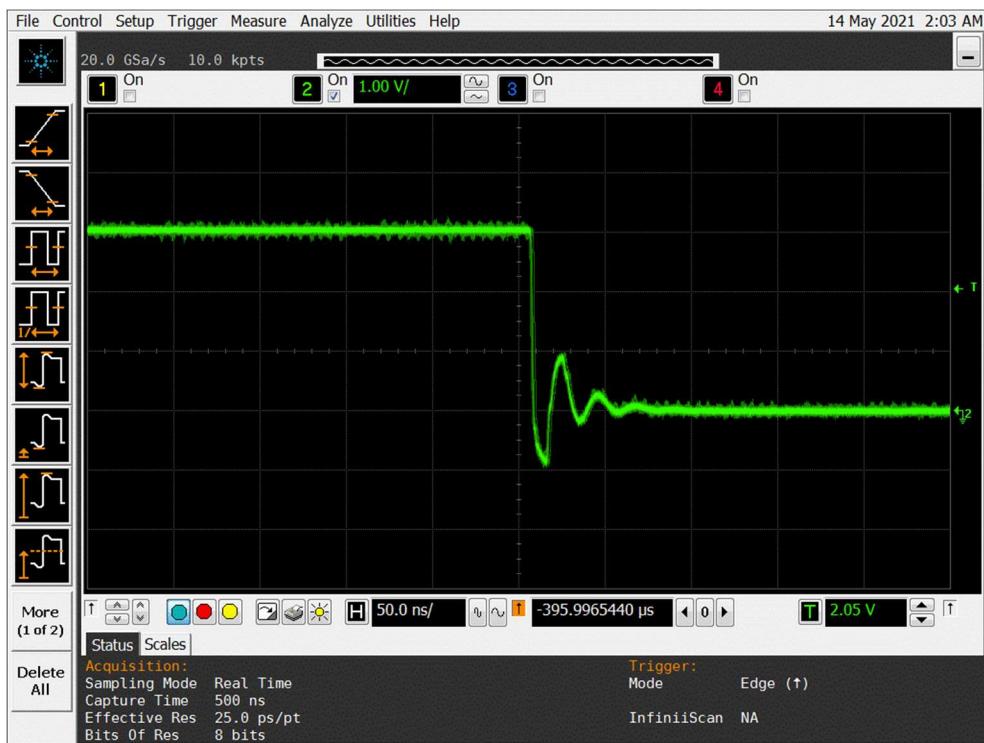


Figure 12a DUT 17832 Pre-Irradiation Falling Edge

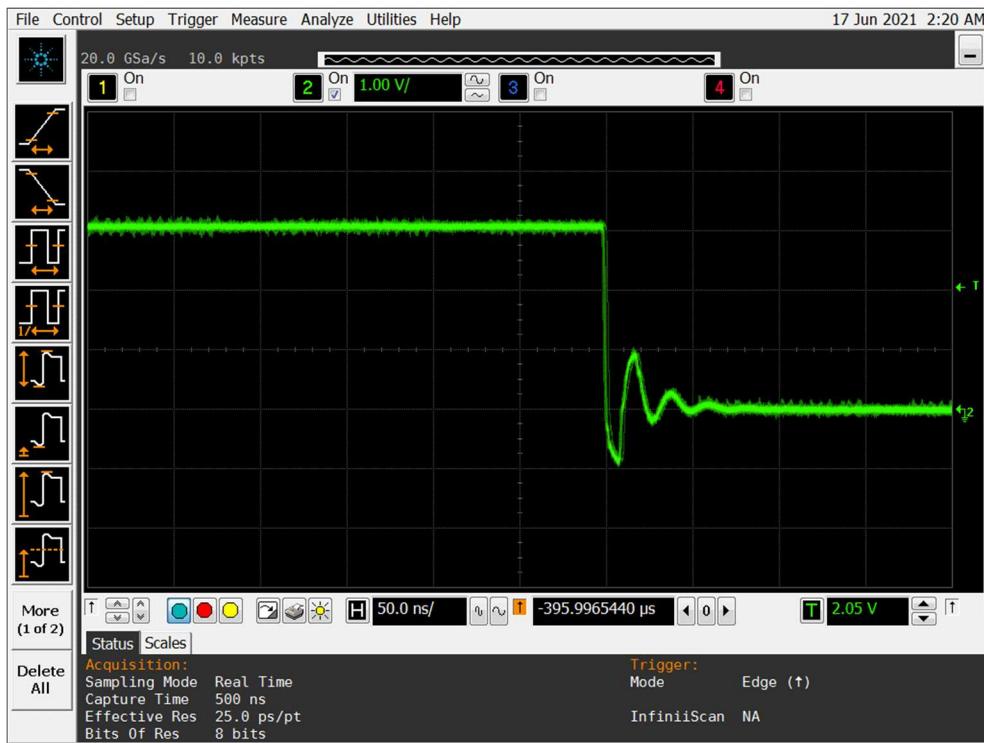


Figure 12b DUT 17832 Post-Annealing Falling Edge

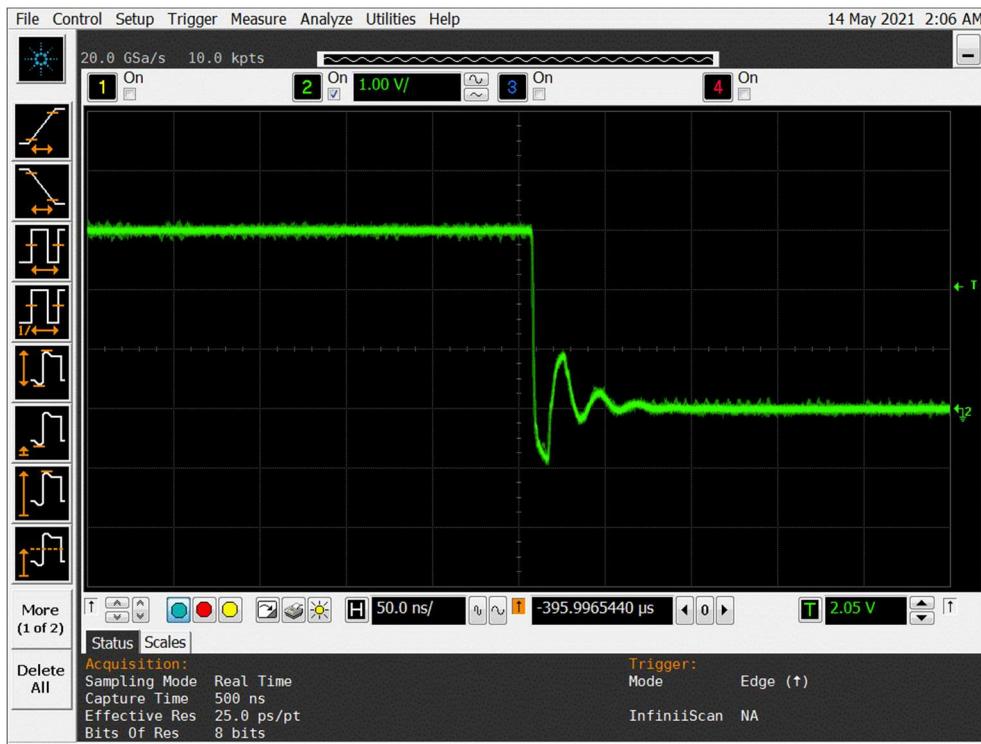


Figure 13a DUT 17833 Pre-Irradiation Falling Edge

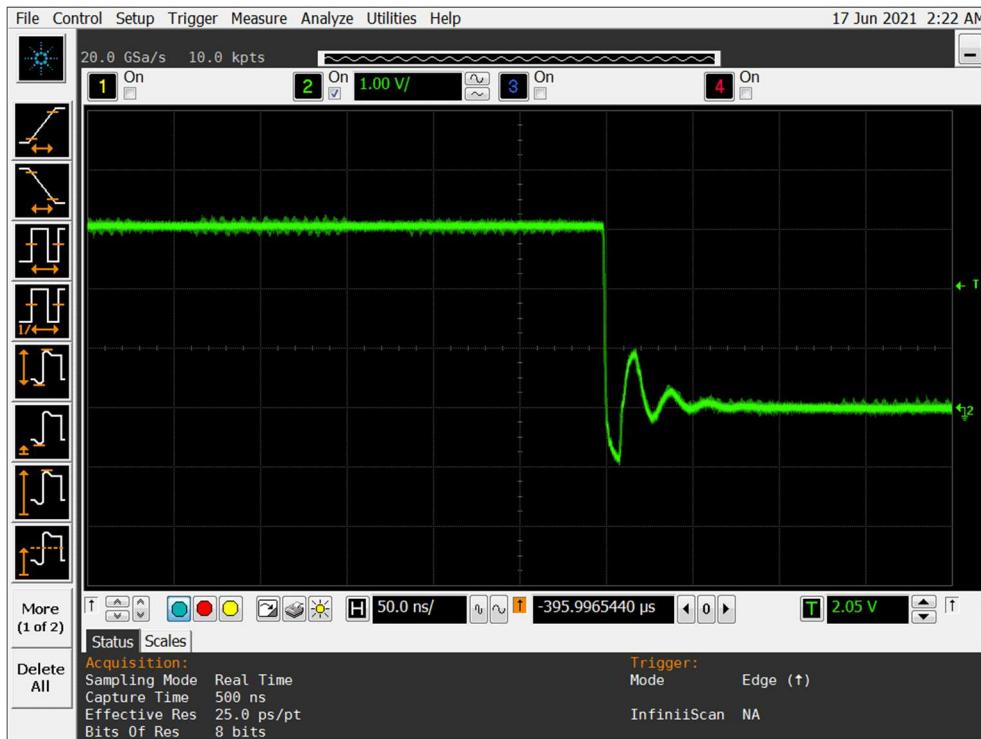


Figure 13b DUT 17833 Post-Annealing Falling Edge

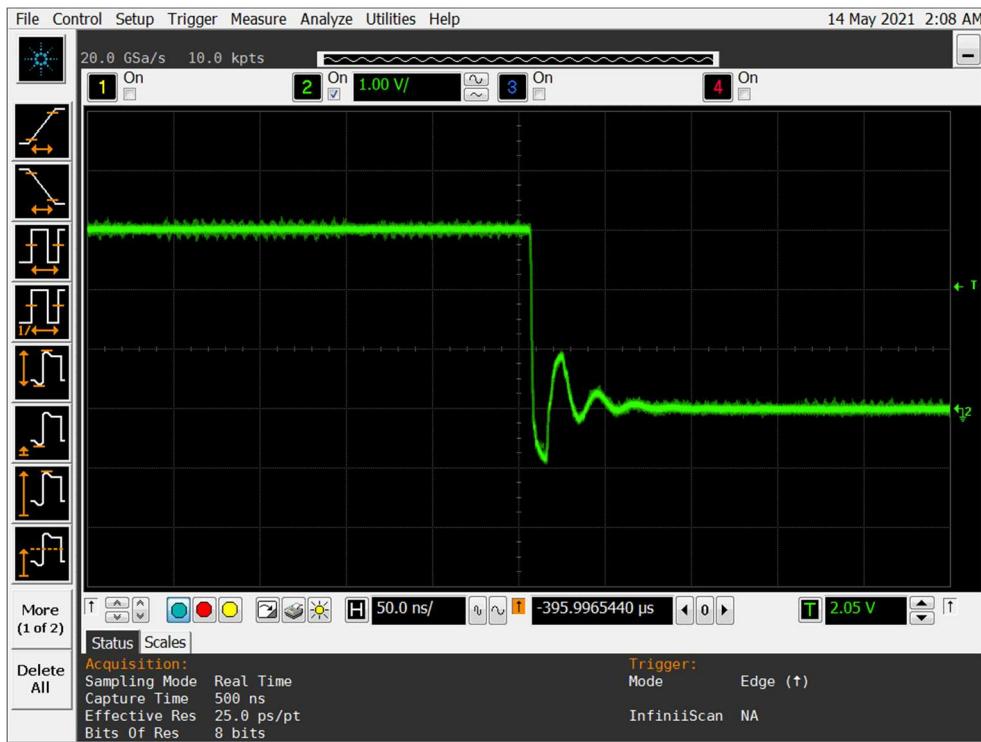


Figure 14a DUT 17834 Pre-Irradiation Falling Edge

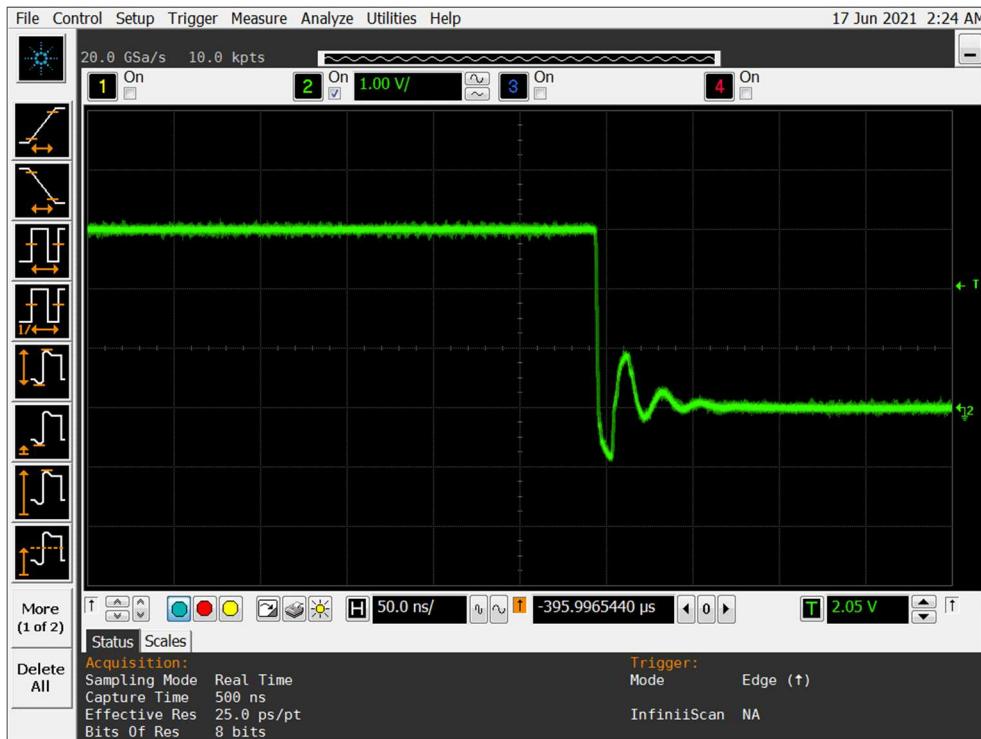


Figure 14b DUT 17834 Post-Annealing Falling Edge

## Appendix A: DUT Design Block Diagrams and Schematics

### A. PLL Block

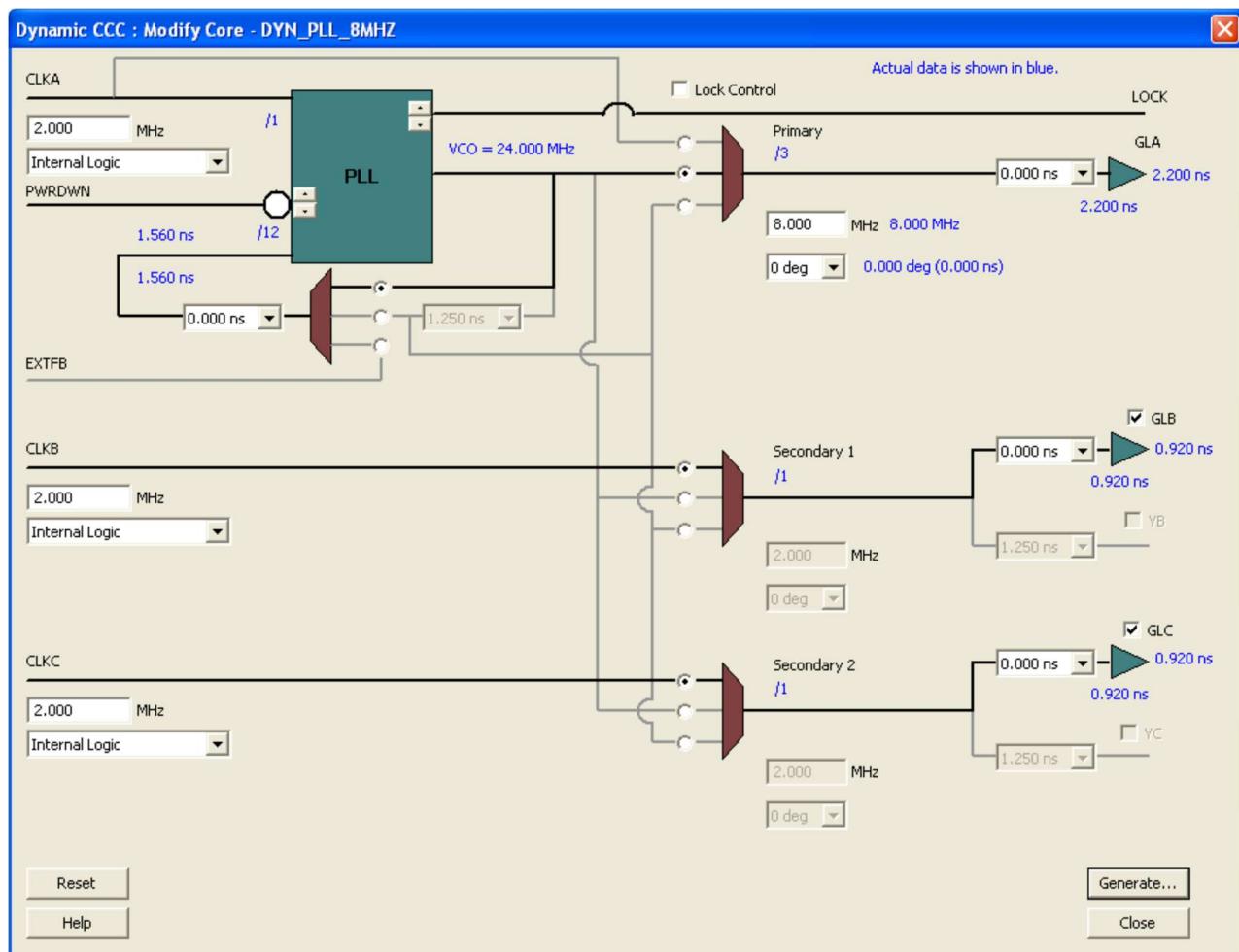
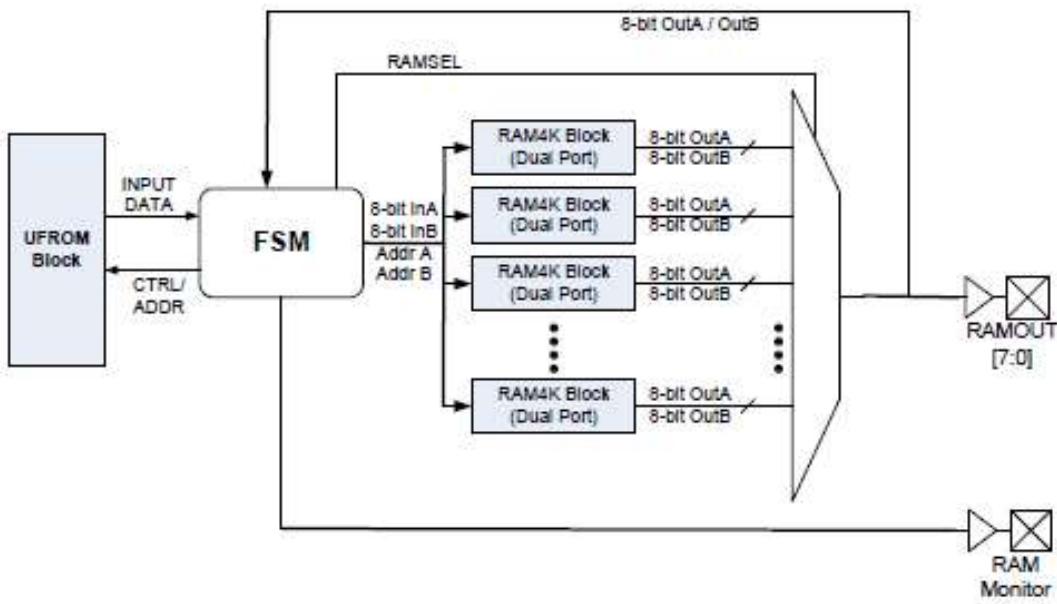


Table 10 lists the signals that go through each of the PLLs:

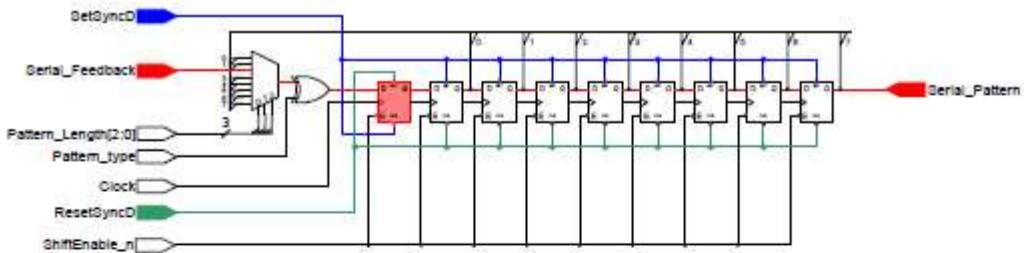
Table 10 Signals Through PLLs

PLL	Multiply-by	GLA	GLB	GLC
0	x4	CLK – upper right I/O	Reset – upper right I/O	OE-upper right I/O
1	x4	CLK – upper left I/O	Reset – upper left I/O	OE – upper left I/O
2	x4	CLK – lower right I/O	Reset – lower right I/O	OE – lower right I/O
3	x4	CLK – lower left I/O	Reset – lower left I/O	OE – lower left I/O
4	x16	CLK – array shift registers	Reset – array shift registers	SET – array shift registers
5	x4	CLK = SRAM block	Reset – SRAM block	Original CLK

## B. UFROM/SRAM Block

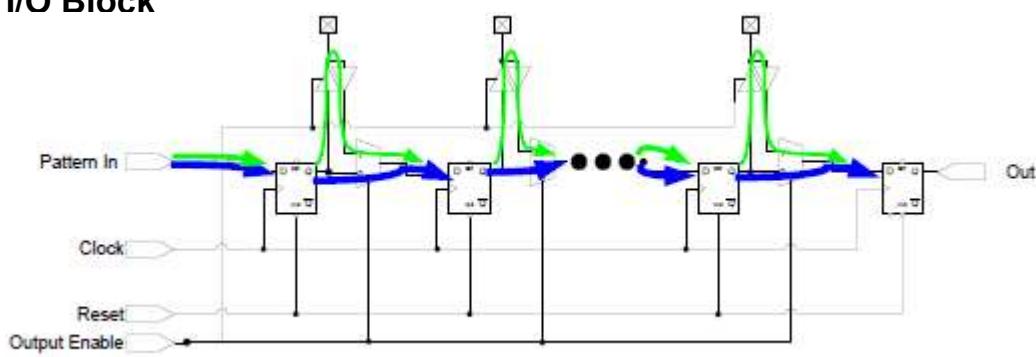


## C. Pattern Generators Block

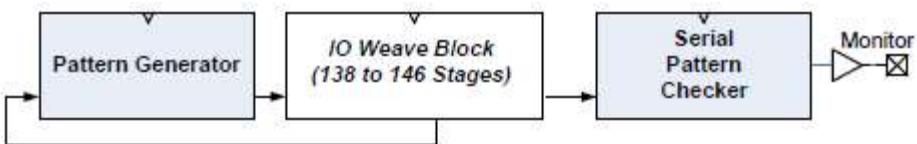


Type	Pattern	n	n	Code Length	Δ Bits	Switching Rate
0	000 1 0 0 0 0 1 1			2	2	100.00%
0	001 1 0 0 0 0 1 0 0 0 1 1			3	2	66.67%
0	010 One hot I/O at a time switching in entire I/O ring			#Bits+5	2	N/A
0	011 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 1			5	2	40.00%
0	100 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 1			6	2	33.33%
0	101 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0			7	2	28.57%
0	110 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0			8	2	25.00%
0	111 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0			9	2	22.22%
1	000 1 0 - 1 1 - 0 1 - 0 0 - 1			2	1	50.00%
1	001 1 0 0 - 1 1 0 - 1 1 1 - 0 1 1 - 0 0 0 - 1			3	1	33.33%
1	010 Wave of 0's followed by wave of 1's			#Bits+9	1	N/A
1	011 1 0 0 0 0 - 1 1 0 0 0 - 1 1 1 0 0 - 1 1 1 1 1 0 - 1 1 1 1 1 1 - 0 0 1 1 1 1			5	1	20.00%
1	100 1 0 0 0 0 0 - 1 1 0 0 0 0 - 1 1 1 0 0 0 - 1 1 1 1 0 0 - 1 1 1 1 1 0 - 1 1 1 1 1 1 - 1 1 1 1 1 1			6	1	16.67%
1	101 1 0 0 0 0 0 0 - 1 1 0 0 0 0 0 - 1 1 1 0 0 0 0 - 1 1 1 1 0 0 0 - 1 1 1 1 1 0 0 - 1 1 1 1 1 1 0			7	1	14.29%
1	110 1 0 0 0 0 0 0 0 - 1 1 0 0 0 0 0 0 - 1 1 1 0 0 0 0 0 - 1 1 1 1 0 0 0 0 - 1 1 1 1 1 0 0			8	1	12.50%
1	111 1 0 0 0 0 0 0 0 0 - 1 1 0 0 0 0 0 0 0 - 1 1 1 0 0 0 0 0 0 - 1 1 1 1 0 0 0 0 0			9	1	11.11%

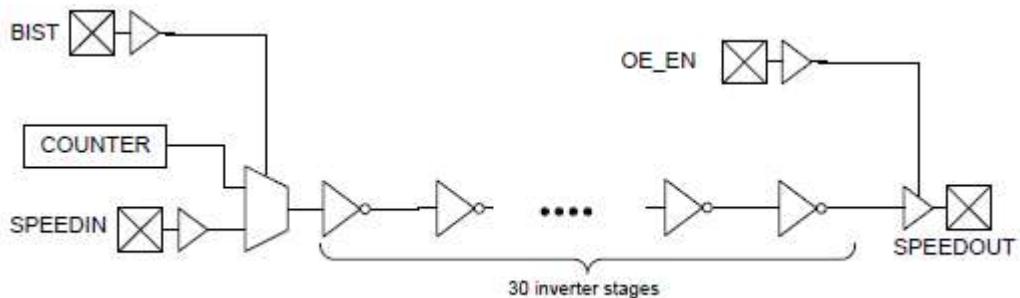
## D. I/O Block



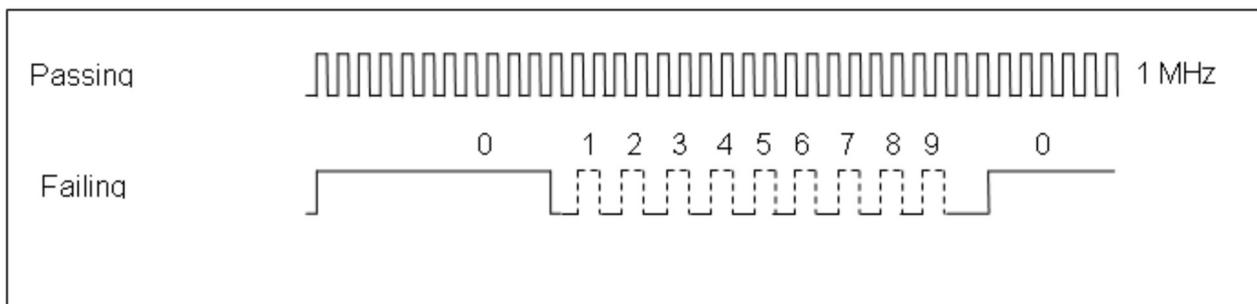
## E. Array Shift Registers Block



## F. Delay Path Block



## G. Monitor Block





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