Total Ionizing Dose Test Report

No. 17T-RT3PE3000L-CG484-QMPWN

March 24, 2017

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Solomon Wolday and Hatim Khokhar

(408) 643-6388, (408) 643-6410

solomon.wolday@microsemi.com, yaron.milwid@microsemi.com

I. Summary Table

Parameter	Tolerance
1. Gross Functionality	Passed 25 krad (SiO_2)
2. Power Supply Current (ICCA/ICCI)	Passed 25 krad (SiO_2)
3. Input Threshold (VTIL/VIH)	Passed 25 krad (SiO_2)
4. Output Drive (VOL/VOH)	Passed 25 krad (SiO_2)
5. Propagation Delay	Passed 25 krad (SiO_2) for 10% degradation criterion
6. Transition Characteristics	Passed 25 krad (SiO_2)

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. 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	QMPWN
Quantity Tested	6
Total Dose: DUT Serial Number	25 krad(SiO2): 9398, 9400, 9403, 9416, 9434, 9440
Radiation Facility	Defense Microelectronics Activity
Radiation Source	Co-60
Dose Rate	10 krad(SiO2)/min(±5%)
Irradiation Temperature	Room
Irradiation and Measurement Bias (VCCI/VCCA)	Static at 3.3 V/1.5 V

B. Test Method

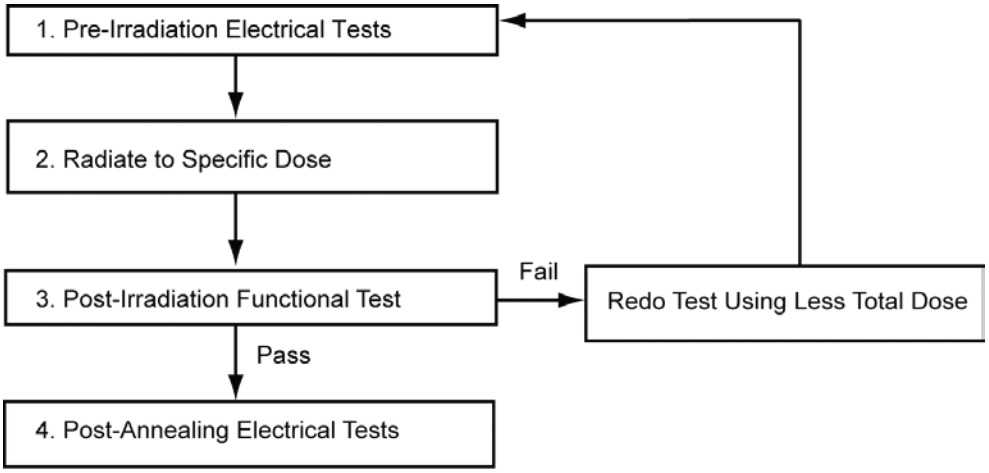


Figure 1 Parametric Test Flow Chart

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
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. I_{CC} 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
9398	25 krad	3.4	3.5	0.1	0.2
9400	25 krad	3.6	3.5	0.1	0.1
9403	25 krad	3.1	3.1	0.1	0.1
9416	25 krad	3.3	3.3	0.1	0.1
9434	25 krad	3.4	3.3	0.1	0.1
9440	25 krad	3.5	3.4	0.1	0.1

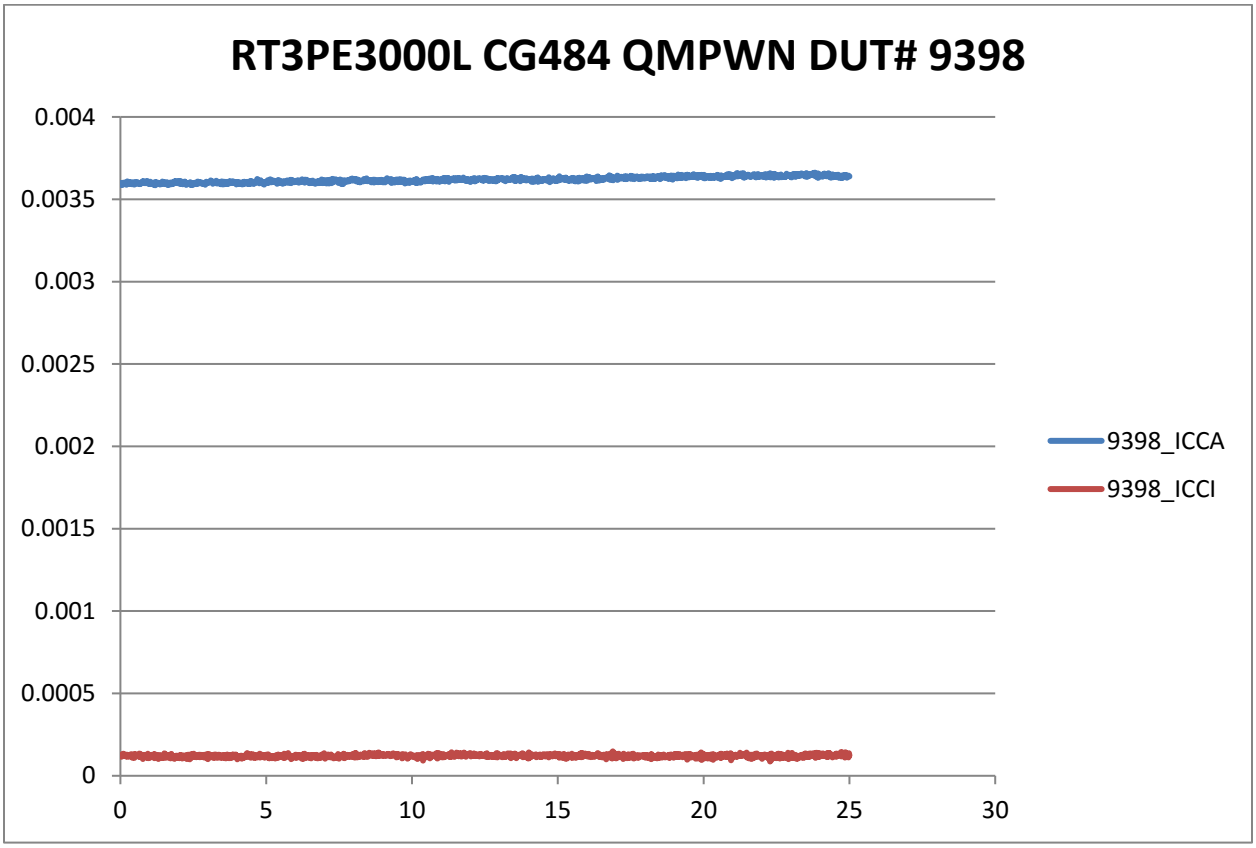


Figure 2 DUT 9398 Influx ICCA and ICCI

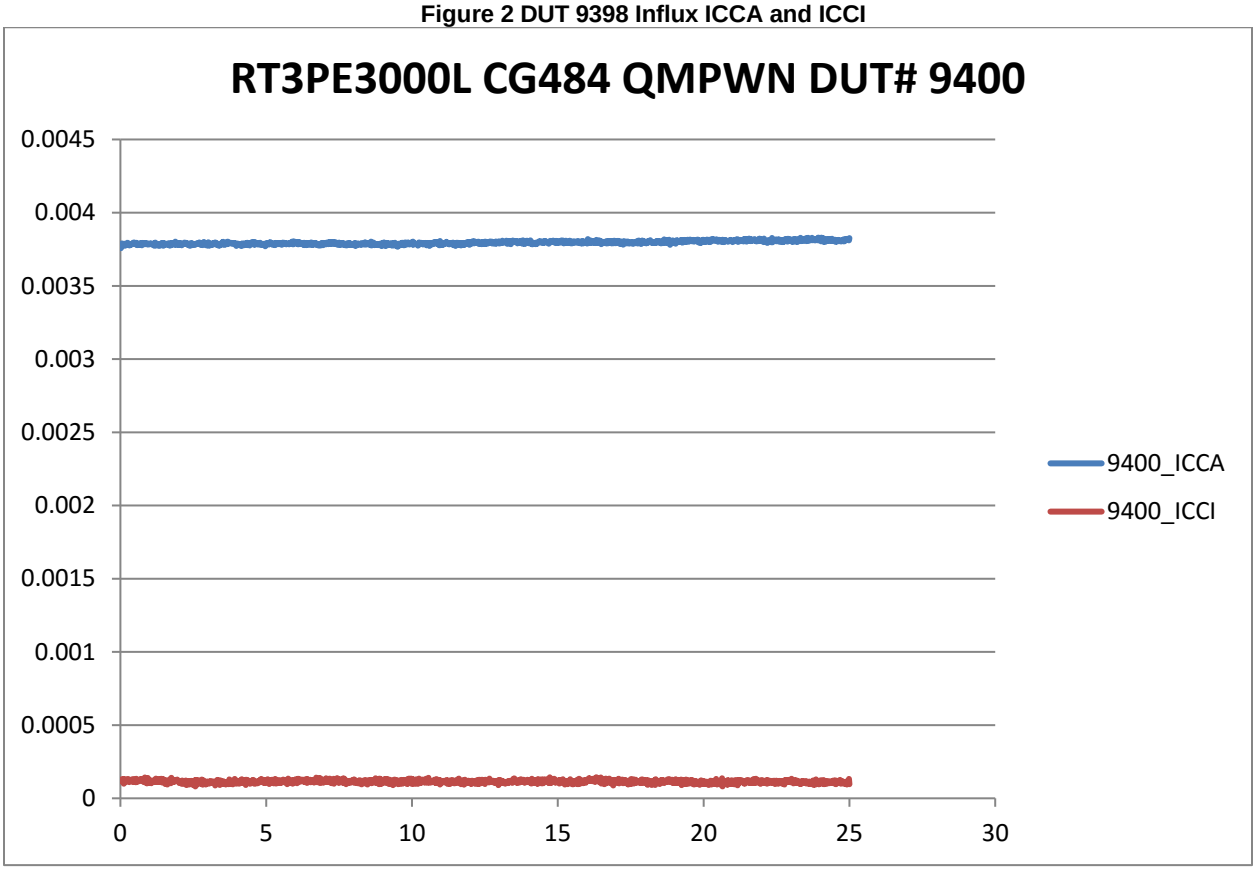


Figure 3 DUT 9400 Influx ICCA and ICCI

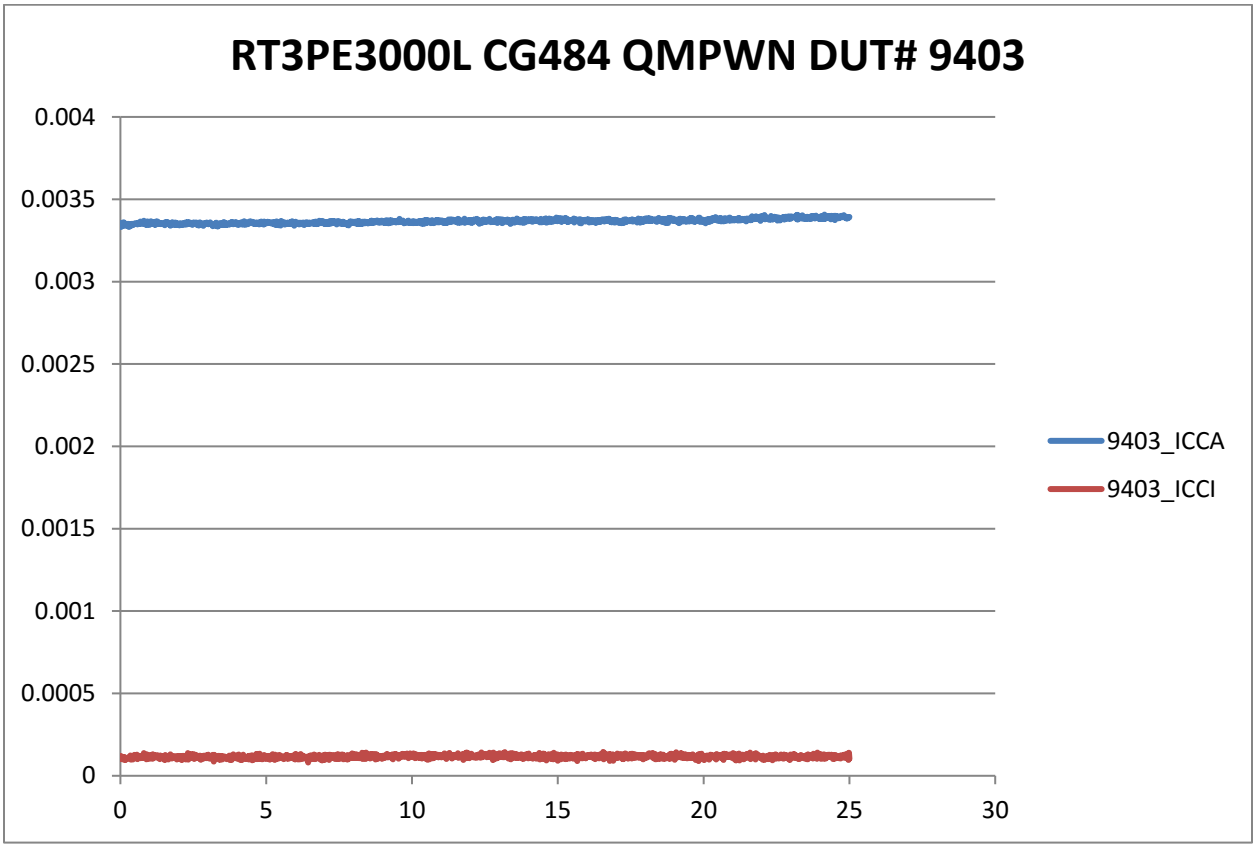


Figure 4 DUT 9403 Influx ICCA and ICCI

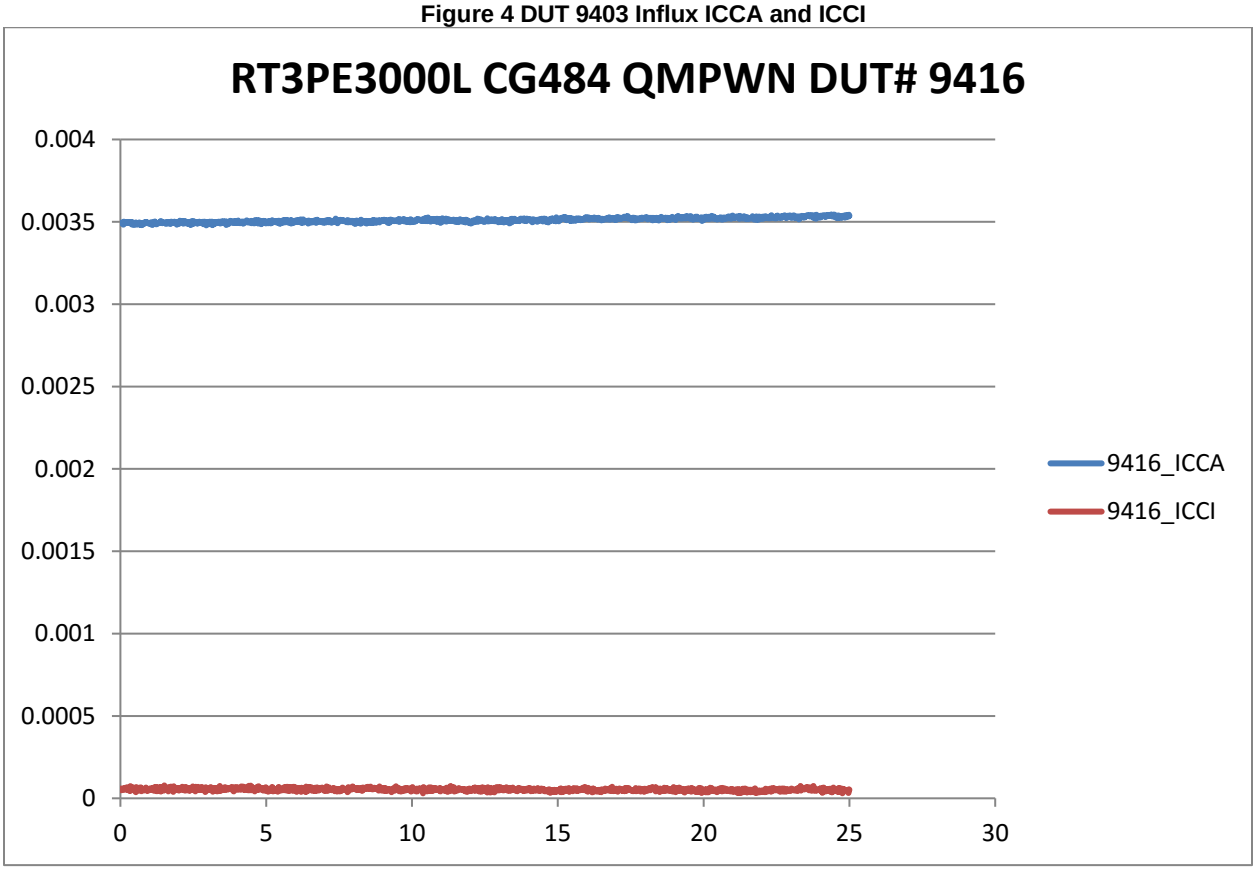


Figure 5 DUT 9416 Influx ICCA and ICCI

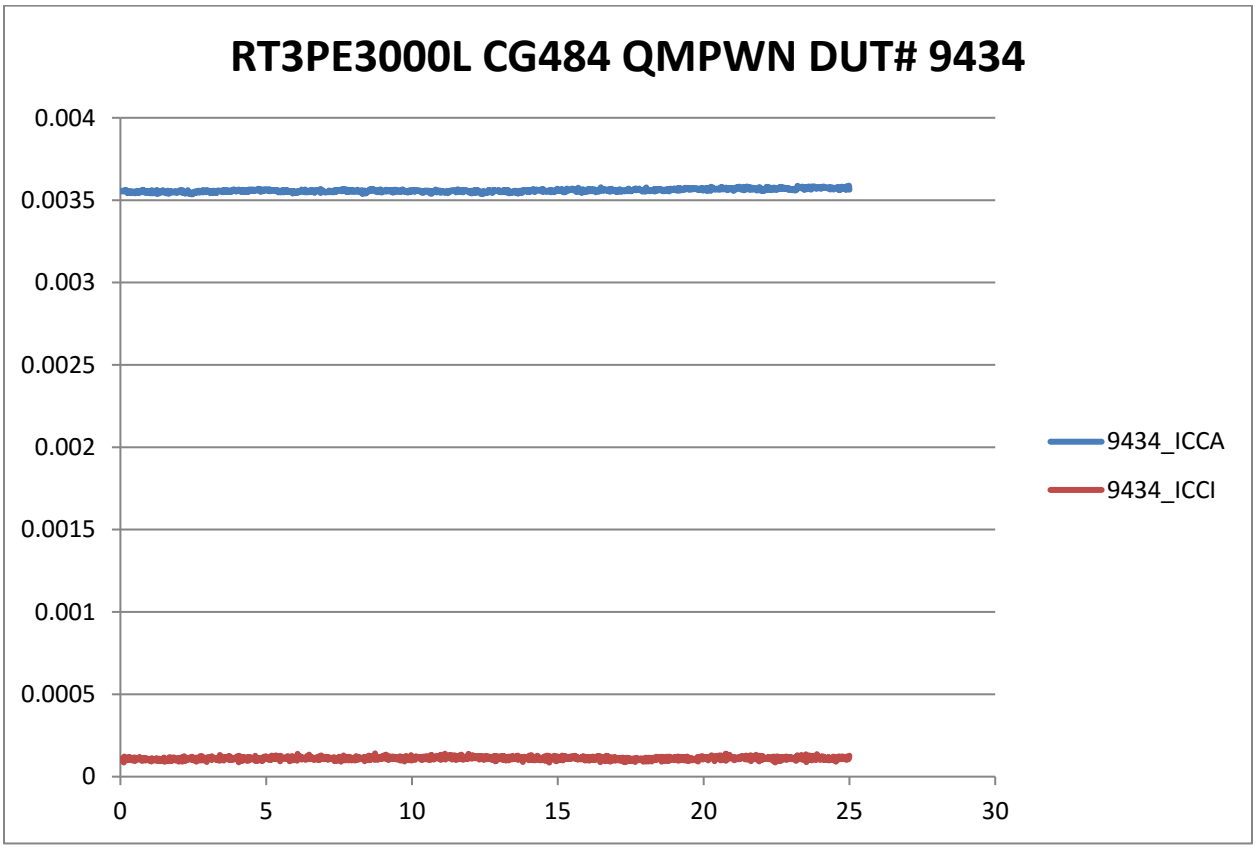


Figure 6 DUT 9434 Influx ICCA and ICCI

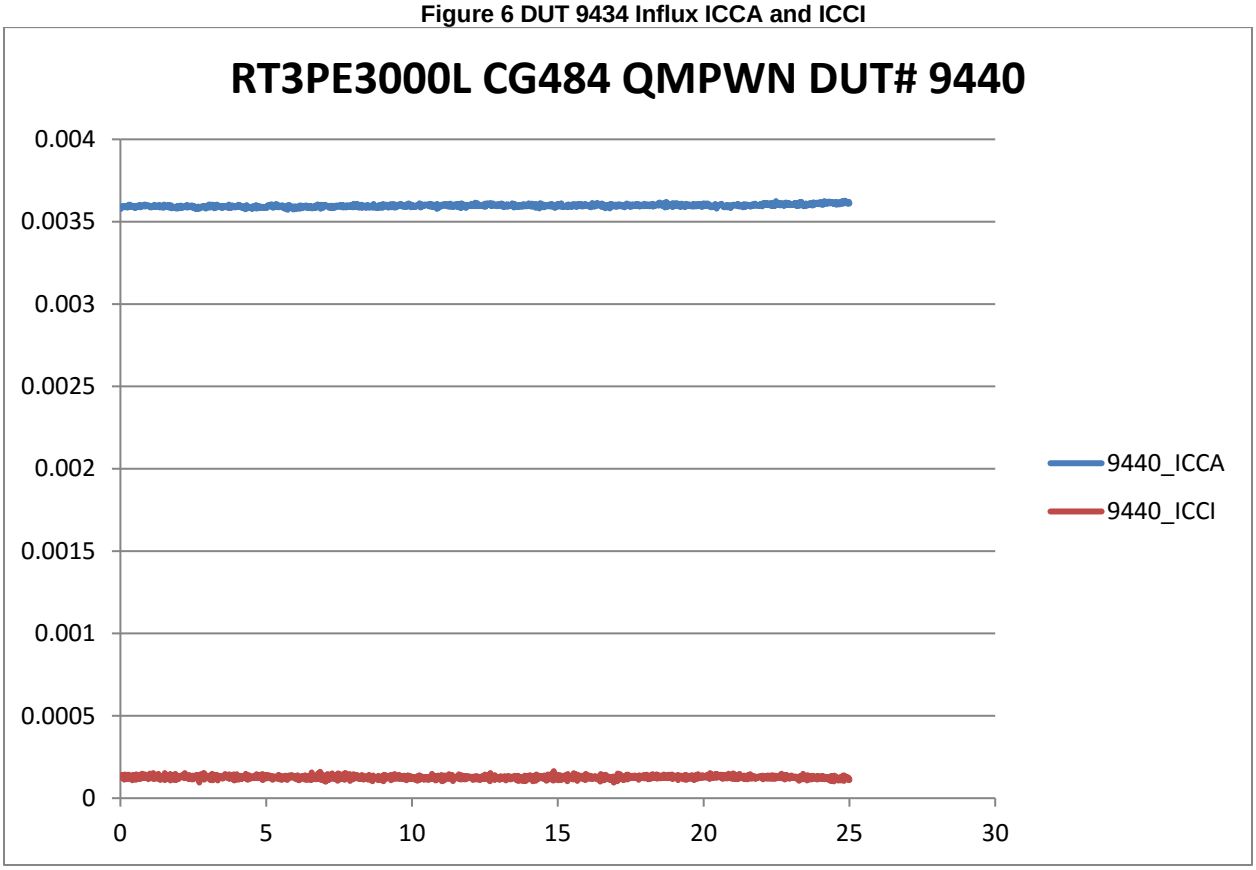


Figure 7 DUT 9440 Influx ICCA and ICCI

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.
9398	25 krad	-0.3865	-0.0799	0.2677	0.0899	-0.3068	-0.0589	0.2190	0.0713
9400	25 krad	-0.3932	-0.0855	0.2671	0.0894	-0.3247	-0.0669	0.1938	0.0713
9403	25 krad	-0.3865	-0.0643	0.2426	0.0885	-0.3318	-0.0525	0.2156	0.0700
9416	25 krad	-0.3615	-0.0635	0.2426	0.0875	-0.3078	-0.0384	0.2190	0.0720
9434	25 krad	-0.6575	-0.0612	0.2677	0.0911	-0.6018	-0.0441	0.1938	0.0744
9440	25 krad	-0.4266	-0.0904	0.2671	0.0915	-0.3329	-0.0583	0.2156	0.0726

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.
9398	25 krad	-0.3008	0.0427	0.3423	0.0882	-0.2258	0.0358	0.3159	0.0756
9400	25 krad	-0.2756	0.0437	0.3172	0.0865	-0.2508	0.0340	0.3923	0.0724
9403	25 krad	-0.3008	0.0455	0.3179	0.0855	-0.2258	0.0331	0.3452	0.0714
9416	25 krad	-0.2364	0.0460	0.7211	0.0950	-0.2508	0.0398	0.7088	0.0813
9434	25 krad	-0.2756	0.0394	0.4120	0.0902	-0.2508	0.0349	0.4006	0.0755
9440	25 krad	-0.2504	0.0409	0.3172	0.0882	-0.2759	0.0338	0.3409	0.0738

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.
9398	25 krad	149.8204	158.4418	183.1483	5.7268	149.0907	158.8885	184.056	5.9035
9400	25 krad	148.3833	157.5828	182.3935	5.8404	147.8973	157.8431	180.9762	5.8172
9403	25 krad	149.2637	158.8069	177.9278	5.4786	149.3419	159.6760	180.6081	5.6112
9416	25 krad	148.6349	157.6251	184.8465	5.6904	148.4626	158.4909	180.1591	5.8215
9434	25 krad	147.6917	157.6879	180.1378	5.5223	147.9287	158.3276	179.0906	5.6444
9440	25 krad	148.9727	158.7278	185.1682	5.7203	148.5254	158.0315	178.9649	5.6118

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.
9398	25 krad	80.5947	82.6736	86.7261	0.9757	80.7835	82.9310	87.1356	0.9771
9400	25 krad	80.1219	81.9145	86.2858	1.0486	80.1548	82.1037	85.6271	0.9941
9403	25 krad	81.2274	83.1714	86.401	0.9714	81.5379	83.4965	86.5705	0.9442
9416	25 krad	80.4099	82.3185	86.6632	0.9822	80.6577	82.3589	85.8157	0.9859
9434	25 krad	79.8703	82.2557	85.8176	0.9842	80.2845	82.4218	85.6245	0.9786
9440	25 krad	76.6981	82.7984	87.704	1.1903	80.5948	82.5438	86.3185	0.9473

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.
9398	25 krad	86.4652	89.5190	97.7961	1.8954	86.3789	89.7763	98.2607	1.9449
9400	25 krad	85.6498	88.7101	97.1042	1.9800	85.9071	89.0194	96.5008	1.9192
9403	25 krad	86.3835	89.9339	96.0979	1.8435	87.1005	90.4040	97.1937	1.8558
9416	25 krad	86.0062	89.1439	98.1735	1.8945	85.9071	89.3363	96.6265	1.9084
9434	25 krad	85.2517	88.9904	95.7527	1.8482	85.6899	89.2080	95.9351	1.8759
9440	25 krad	82.6058	89.6643	99.5255	1.9767	86.1274	89.3397	96.4379	1.8645

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.
9398	25 krad	114.5951	119.1184	131.7609	2.8762	114.5976	119.5717	132.2646	2.9281
9400	25 krad	113.6106	118.0751	130.7545	2.9534	113.7305	118.5031	129.6876	2.8941
9403	25 krad	114.6167	119.7100	128.9934	2.7473	115.5506	120.3852	130.6349	2.7924
9416	25 krad	114.0508	118.6174	132.327	2.8390	114.0445	118.8827	129.7504	2.8965
9434	25 krad	112.9818	118.4565	128.3246	2.7513	113.5341	118.8072	128.7448	2.8145
9440	25 krad	108.1847	119.3974	134.1095	3.0738	114.2958	118.9435	129.6247	2.7991

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.
9398	25 krad	172.277	181.1784	205.8544	5.7054	172.2663	181.9519	207.2491	5.8817
9400	25 krad	170.9573	179.9926	204.9738	5.8708	170.5078	180.4312	203.2264	5.8046
9403	25 krad	172.3407	182.0647	200.9483	5.4849	173.2712	183.0200	203.8033	5.6078
9416	25 krad	171.1459	180.3055	207.7413	5.6728	171.1358	181.2064	202.7865	5.8125
9434	25 krad	169.7626	180.0749	200.1307	5.4925	170.5425	180.8838	201.4665	5.6294
9440	25 krad	166.2558	181.6249	210.5089	5.8235	171.5126	180.9984	202.1579	5.6090

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.
9398	25 krad	101.5229	104.4004	108.8032	1.0483	102.0335	104.6235	109.1972	1.0402
9400	25 krad	100.8781	103.1080	108.0484	1.1282	101.0276	103.4147	106.8717	1.0596
9403	25 krad	102.8279	105.3104	108.6351	1.0377	103.2909	105.6171	108.5713	1.0016
9416	25 krad	101.7263	103.7854	108.4887	1.0371	101.7972	103.9175	107.6259	1.0507
9434	25 krad	100.8152	103.4711	106.2328	1.0408	101.152	103.7907	106.9374	1.0447
9440	25 krad	101.3972	104.6154	109.0548	1.1094	101.9078	104.2079	108.1916	1.0223

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.
9398	25 krad	52.2582	53.8306	58.1077	0.9593	52.1147	54.0117	58.4114	0.9765
9400	25 krad	51.6108	53.2699	57.3529	1.0127	51.6746	53.4460	56.8401	0.9571
9403	25 krad	52.2396	54.1889	57.29	0.9403	52.7434	54.4060	57.718	0.9248
9416	25 krad	51.8623	53.5840	58.1077	0.9594	51.9287	53.6950	57.4686	0.9680
9434	25 krad	51.3593	53.4583	56.8497	0.9422	51.4949	53.6245	56.7772	0.9391
9440	25 krad	51.8734	54.0003	58.0875	0.9968	52.1776	53.8129	57.4686	0.9347

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.
9398	25 krad	2.5015	2.9152	3.2598	0.1393	2.5275	2.9478	3.2258	0.1353
9400	25 krad	2.4725	2.9116	3.2294	0.1479	2.4018	2.9041	3.2887	0.1489
9403	25 krad	2.5015	2.8835	3.2431	0.1499	2.4646	2.9116	3.3515	0.1516
9416	25 krad	2.5015	2.8835	3.198	0.1377	2.5272	2.9478	3.3515	0.1457
9434	25 krad	2.3757	2.8524	3.2294	0.1573	2.5272	2.8418	3.262	0.1440
9440	25 krad	2.4386	2.9152	3.418	0.1501	2.5275	2.9116	3.2887	0.1373

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.
9398	25 krad	1.9984	2.4725	2.9291	0.1448	2.0246	2.4998	2.7859	0.1283
9400	25 krad	2.0613	2.4432	2.8663	0.1500	1.8989	2.4473	2.8221	0.1430
9403	25 krad	1.9355	2.4725	2.8828	0.1446	1.9617	2.4473	2.8139	0.1454
9416	25 krad	1.9984	2.4432	2.8524	0.1443	2.0875	2.4716	2.8139	0.1391
9434	25 krad	1.9355	2.4266	2.8206	0.1449	1.9617	2.4370	2.8246	0.1427
9440	25 krad	2.0962	2.4430	2.8035	0.1407	2.0875	2.4646	2.8221	0.1328

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.
9398	25 krad	201.3364	205.7994	214.0793	1.9863	201.9328	206.0743	214.8395	2.0012
9400	25 krad	201.3364	204.5411	212.9855	2.0476	201.1458	204.8314	211.9466	1.9620
9403	25 krad	202.2771	206.4806	212.9874	1.9035	202.6359	206.8542	213.7011	1.9284
9416	25 krad	200.95	204.6382	213.6105	1.9553	201.1565	204.6292	211.8684	1.9573
9434	25 krad	200.5596	205.2525	212.3518	1.9764	201.0318	205.5262	211.9466	1.9710
9440	25 krad	202.2739	205.6990	214.3918	1.9780	201.1458	204.7444	212.0247	1.9279

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.
9398	25 krad	201.8833	205.8776	214.1574	1.9826	201.6204	206.0743	214.6832	1.9937
9400	25 krad	200.7896	204.4712	213.0636	2.0490	201.3023	204.7938	212.1029	1.9547
9403	25 krad	202.2771	206.4230	212.9093	1.9260	202.7921	206.9043	213.8575	1.9280
9416	25 krad	201.028	204.6275	213.5324	1.9473	200.9894	204.5888	211.712	1.9690
9434	25 krad	200.6377	205.2426	212.5862	1.9568	200.7971	205.4191	211.8242	1.9714
9440	25 krad	201.3364	205.6332	214.3136	1.9756	201.3079	204.7532	211.9806	1.9108

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.
9398	25 krad	4.375	4.9964	5.7084	0.2447	4.5783	5.1811	5.7287	0.2082
9400	25 krad	4.375	4.9664	5.7084	0.2403	4.4219	5.1557	5.7287	0.1944
9403	25 krad	4.4531	5.0129	5.6302	0.2340	4.6565	5.1557	5.7287	0.1969
9416	25 krad	4.375	4.9664	5.6302	0.2397	4.6565	5.1557	5.7287	0.1932
9434	25 krad	4.3719	4.9398	5.7084	0.2512	4.5777	5.1247	5.6504	0.2054
9440	25 krad	4.3719	5.0002	5.6302	0.2332	4.5783	5.1376	5.6504	0.2023

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.
9398	25 krad	4.528	5.1691	5.9428	0.2496	4.8249	5.3121	5.8851	0.1986
9400	25 krad	4.6061	5.1228	5.7865	0.2461	4.6565	5.3120	5.8069	0.2032
9403	25 krad	4.3719	5.1741	5.9428	0.2375	4.7347	5.3120	5.8851	0.1917
9416	25 krad	4.5442	5.1228	5.7865	0.2326	4.734	5.3120	5.8069	0.1911
9434	25 krad	4.4531	5.0960	5.8646	0.2459	4.6565	5.2809	5.8069	0.2130
9440	25 krad	4.4971	5.1228	5.8646	0.2162	4.7347	5.2940	5.8069	0.1923

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.
9398	25 krad	212.2737	218.7497	235.4073	3.8367	211.907	218.9624	235.6377	3.9226
9400	25 krad	211.177	217.5787	234.1573	3.9424	211.1592	217.6913	231.7667	3.8728
9403	25 krad	212.1138	219.1072	231.8916	3.6614	213.1149	219.5666	233.5654	3.7588
9416	25 krad	210.3183	217.5784	235.4073	3.8111	211.081	217.6913	231.7283	3.8670
9434	25 krad	210.1621	218.1252	233.4451	3.7192	210.8519	218.3948	231.4539	3.7948
9440	25 krad	196.1803	218.5155	235.4854	4.9168	211.2035	217.4568	231.5719	3.7507

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.
9398	25 krad	174.7746	183.2689	208.0637	5.6952	173.6091	183.5173	208.3499	5.9020
9400	25 krad	172.9231	182.5046	206.8918	5.8115	172.6703	182.6726	203.5343	5.7802
9403	25 krad	173.6257	183.2982	202.5949	5.4924	173.8438	183.9828	204.942	5.6209
9416	25 krad	172.5328	182.0482	209.0011	5.6729	172.5921	182.7316	204.2059	5.7934
9434	25 krad	172.4547	182.7218	203.3676	5.5024	172.6703	183.0285	204.5968	5.6296
9440	25 krad	173.7589	183.2689	207.673	5.6117	172.8268	182.3254	203.2676	5.6328

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.
9398	25 krad	206.3589	217.8909	250.5634	7.6036	205.1355	217.9469	251.7446	7.8847
9400	25 krad	204.7753	216.8829	249.9384	7.7446	203.4145	217.2611	245.724	7.7252
9403	25 krad	205.2438	217.5971	243.2197	7.3282	204.6662	218.7063	246.313	7.5216
9416	25 krad	203.9946	216.3449	252.5947	7.5895	203.4145	217.0264	245.8804	7.7447
9434	25 krad	203.214	217.0313	243.2197	7.3084	203.6514	217.5350	246.2714	7.5038
9440	25 krad	202.4301	217.6212	250.0166	7.5360	203.4145	216.6751	244.5512	7.5215

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.
9398	25 krad	233.9919	251.4971	300.5632	11.4095	232.2812	251.6551	301.8635	11.8365
9400	25 krad	232.0215	250.8024	299.7819	11.6187	230.4036	250.7955	296.3121	11.6263
9403	25 krad	232.4118	251.1736	289.2351	10.9652	231.1859	252.4131	294.2533	11.3201
9416	25 krad	231.3188	250.0554	304.235	11.3770	231.1077	251.0562	293.9664	11.6437
9434	25 krad	230.5381	250.4117	290.407	10.9109	230.5237	250.9904	295.2956	11.3053
9440	25 krad	219.3048	251.0282	299.7038	11.7383	230.5601	249.8579	291.6208	11.2864

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.
9398	25 krad	9.4639	9.7996	10.3027	0.1379	9.4709	9.8351	10.2668	0.1266
9400	25 krad	9.4831	9.8835	10.17	0.1244	9.5008	9.9058	10.2958	0.1128
9403	25 krad	9.5142	9.8417	10.8694	0.1350	9.5562	9.8827	10.8674	0.1302
9416	25 krad	9.549	10.0091	10.4533	0.1298	9.6664	10.0758	10.4964	0.1169
9434	25 krad	9.658	10.0992	10.4444	0.1297	9.7503	10.1278	10.4713	0.1121
9440	25 krad	9.3635	9.7287	10.1006	0.1312	9.5061	9.8372	10.2958	0.1176

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.
9398	25 krad	11.9254	12.2776	12.7376	0.1573	11.9109	12.3305	12.7536	0.1471
9400	25 krad	11.9318	12.3817	12.7056	0.1385	11.9516	12.4105	12.8033	0.1274
9403	25 krad	11.9986	12.3490	13.3488	0.1468	12.0189	12.3847	13.3854	0.1438
9416	25 krad	12.0229	12.5342	13.089	0.1414	12.1355	12.6219	13.0791	0.1365
9434	25 krad	12.2066	12.6463	13.0071	0.1421	12.2204	12.6738	13.0791	0.1306
9440	25 krad	11.7747	12.2026	12.6353	0.1490	11.9569	12.3367	12.8284	0.1349

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.
9398	25 krad	5.8102	6.1177	6.5122	0.1123	5.845	6.1438	6.4737	0.0960
9400	25 krad	5.7852	6.1754	6.4846	0.1049	5.8599	6.1917	6.5596	0.0916
9403	25 krad	5.8471	6.1379	6.9625	0.1125	5.87	6.1671	7.0148	0.1036
9416	25 krad	5.8641	6.2534	6.6126	0.1035	5.9945	6.2924	6.6348	0.0913
9434	25 krad	5.9851	6.3154	6.6351	0.1086	5.9348	6.3426	6.6599	0.0881
9440	25 krad	5.7717	6.0751	6.3903	0.1047	5.8848	6.1458	6.5345	0.0928

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.
9398	25 krad	8.1703	8.4617	8.922	0.1268	8.1705	8.5178	8.9103	0.1170
9400	25 krad	8.0839	8.5347	8.8663	0.1178	8.1962	8.5771	8.9417	0.1028
9403	25 krad	8.1811	8.5057	9.4669	0.1243	8.2268	8.5430	9.4573	0.1191
9416	25 krad	8.2245	8.6389	9.0475	0.1164	8.3738	8.7263	9.1674	0.1087
9434	25 krad	8.3588	8.7239	9.0374	0.1214	8.4064	8.7871	9.1173	0.1048
9440	25 krad	8.0825	8.4030	8.7493	0.1191	8.2109	8.5225	8.9417	0.1073

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.
9398	25 krad	3.2608	3.5592	3.8538	0.0968	3.288	3.5770	3.9115	0.0845
9400	25 krad	3.2117	3.5885	3.9023	0.0986	3.3358	3.6141	3.9267	0.0789
9403	25 krad	3.2851	3.5613	4.2578	0.0986	3.3108	3.5883	4.2449	0.0868
9416	25 krad	3.2472	3.6451	3.9581	0.0935	3.4111	3.6800	4.027	0.0772
9434	25 krad	3.3866	3.6854	3.9776	0.0954	3.4132	3.7047	4.027	0.0756
9440	25 krad	3.2349	3.5356	3.9439	0.0963	3.3133	3.5789	3.9267	0.0799

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.
9398	25 krad	3.2608	3.5592	3.8538	0.0968	3.288	3.5770	3.9115	0.0845
9400	25 krad	3.2117	3.5885	3.9023	0.0986	3.3358	3.6141	3.9267	0.0789
9403	25 krad	3.2851	3.5613	4.2578	0.0986	3.3108	3.5883	4.2449	0.0868
9416	25 krad	3.2472	3.6451	3.9581	0.0935	3.4111	3.6800	4.027	0.0772
9434	25 krad	3.3866	3.6854	3.9776	0.0954	3.4132	3.7047	4.027	0.0756
9440	25 krad	3.2349	3.5356	3.9439	0.0963	3.3133	3.5789	3.9267	0.0799

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.
9398	25 krad	16.5874	17.0633	17.6326	0.1885	16.5476	17.1125	17.5514	0.1799
9400	25 krad	16.679	17.1911	17.5486	0.1654	16.6702	17.1909	17.5425	0.1477
9403	25 krad	16.6826	17.1591	18.2074	0.1745	16.7544	17.1987	18.1194	0.1684
9416	25 krad	16.7959	17.3925	17.9338	0.1737	16.9242	17.4828	17.9688	0.1679
9434	25 krad	16.9639	17.4989	17.9567	0.1745	17.036	17.5547	17.9437	0.1588
9440	25 krad	16.4967	16.9800	17.4667	0.1768	16.6808	17.1351	17.6428	0.1669

Table 6h Pre-Irradiation and Post-Annealing Ipd

Test name		lvttl_ipd_weak_ (lvttle_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.
9398	25 krad	18.2936	18.8263	19.44	0.1981	18.2981	18.8769	19.3349	0.1862
9400	25 krad	18.4031	18.9640	19.3386	0.1701	18.4179	18.9750	19.3479	0.1571
9403	25 krad	18.4441	18.9526	19.9605	0.1787	18.4618	18.9831	19.9324	0.1724
9416	25 krad	18.4952	19.1942	19.8165	0.1830	18.6855	19.2788	19.7742	0.1791
9434	25 krad	18.721	19.2904	19.7405	0.1867	18.7825	19.3309	19.7742	0.1690
9440	25 krad	18.2434	18.7638	19.2671	0.1835	18.4594	18.9049	19.4232	0.1694

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.
9398	25 krad	1.4452	1.4704	1.4805	0.0058	1.4433	1.4688	1.4794	0.0060
9400	25 krad	1.4457	1.4701	1.4794	0.0058	1.4465	1.4688	1.4789	0.0060
9403	25 krad	1.4484	1.4679	1.4766	0.0055	1.4441	1.4659	1.4758	0.0057
9416	25 krad	1.4409	1.4682	1.476	0.0057	1.4444	1.4666	1.4763	0.0058
9434	25 krad	1.4485	1.4687	1.4787	0.0055	1.4457	1.4665	1.4771	0.0055
9440	25 krad	1.4451	1.4695	1.4865	0.0057	1.4474	1.4691	1.4783	0.0057

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.
9398	25 krad	1.2237	1.2381	1.2452	0.0025	1.2217	1.2364	1.2439	0.0026
9400	25 krad	1.2238	1.2383	1.2456	0.0025	1.2214	1.2366	1.2435	0.0026
9403	25 krad	1.2218	1.2349	1.2421	0.0024	1.2192	1.2330	1.2405	0.0025
9416	25 krad	1.2232	1.2357	1.2424	0.0022	1.2213	1.2343	1.241	0.0023
9434	25 krad	1.2221	1.2357	1.2423	0.0023	1.2204	1.2339	1.2408	0.0023
9440	25 krad	1.2238	1.2372	1.2441	0.0025	1.2226	1.2366	1.2435	0.0026

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.
9398	25 krad	1.2156	1.2308	1.2388	0.0030	1.2128	1.2290	1.2372	0.0031
9400	25 krad	1.2157	1.2309	1.2387	0.0030	1.2136	1.2294	1.2371	0.0031
9403	25 krad	1.2135	1.2277	1.2352	0.0029	1.2107	1.2260	1.2336	0.0030
9416	25 krad	1.2151	1.2286	1.2354	0.0028	1.2128	1.2271	1.2341	0.0028
9434	25 krad	1.2138	1.2286	1.2352	0.0028	1.212	1.2268	1.2342	0.0028
9440	25 krad	1.2157	1.2299	1.2457	0.0034	1.2147	1.2293	1.2371	0.0030

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.
9398	25 krad	1.1785	1.1949	1.2041	0.0037	1.1759	1.1930	1.2025	0.0039
9400	25 krad	1.1782	1.1949	1.204	0.0038	1.176	1.1936	1.2024	0.0039
9403	25 krad	1.1757	1.1913	1.2002	0.0037	1.1731	1.1892	1.1983	0.0037
9416	25 krad	1.1768	1.1921	1.2001	0.0035	1.1752	1.1905	1.1988	0.0035
9434	25 krad	1.1763	1.1923	1.2004	0.0035	1.1741	1.1903	1.1984	0.0034
9440	25 krad	1.1787	1.1938	1.2112	0.0038	1.1774	1.1932	1.2022	0.0037

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.
9398	25 krad	1.1527	1.1787	1.1885	0.0059	1.1504	1.1765	1.1869	0.0061
9400	25 krad	1.1532	1.1782	1.189	0.0060	1.1544	1.1767	1.1872	0.0061
9403	25 krad	1.1556	1.1749	1.1851	0.0056	1.1512	1.1729	1.183	0.0058
9416	25 krad	1.1484	1.1755	1.1846	0.0057	1.1515	1.1736	1.1832	0.0059
9434	25 krad	1.1565	1.1760	1.186	0.0055	1.153	1.1737	1.1847	0.0056
9440	25 krad	1.1506	1.1774	1.1908	0.0059	1.1553	1.1768	1.1872	0.0058

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.
9398	25 krad	893.8916	924.9631	938.5031	4.9326	891.0432	922.7948	936.5026	5.0118
9400	25 krad	894.1537	925.4315	938.9719	5.0360	891.0148	923.2249	936.3462	5.0893
9403	25 krad	889.935	919.5956	933.034	4.8963	886.4799	917.2861	930.8701	4.9664
9416	25 krad	893.3724	921.3609	933.3465	4.4386	891.6403	919.6292	931.8088	4.4942
9434	25 krad	890.8729	920.8723	933.659	4.7684	888.6691	918.6577	931.183	4.7357
9440	25 krad	894.7787	923.7140	938.3504	4.9122	893.0477	923.0322	936.0333	4.9093

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.
9398	25 krad	1.0268	1.0380	1.044	0.0020	1.0245	1.0365	1.0421	0.0021
9400	25 krad	1.0265	1.0381	1.044	0.0021	1.0245	1.0367	1.0421	0.0021
9403	25 krad	1.0252	1.0360	1.0418	0.0020	1.0232	1.0344	1.0399	0.0020
9416	25 krad	1.026	1.0366	1.0416	0.0018	1.0244	1.0352	1.0402	0.0019
9434	25 krad	1.0256	1.0365	1.0416	0.0019	1.0237	1.0349	1.0401	0.0019
9440	25 krad	1.0262	1.0375	1.0448	0.0020	1.0252	1.0366	1.0424	0.0020

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.
9398	25 krad	1.1338	1.1346	1.1357	0.0003	1.1327	1.1334	1.1343	0.0003
9400	25 krad	1.1336	1.1346	1.1355	0.0003	1.1325	1.1334	1.1343	0.0003
9403	25 krad	1.1336	1.1344	1.1354	0.0003	1.1325	1.1333	1.1341	0.0003
9416	25 krad	1.1337	1.1345	1.1355	0.0003	1.1326	1.1333	1.1341	0.0003
9434	25 krad	1.1333	1.1345	1.1352	0.0003	1.1325	1.1333	1.1343	0.0003
9440	25 krad	1.1336	1.1345	1.1354	0.0003	1.1325	1.1333	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.
9398	25 krad	1.3929	1.3938	1.3946	0.0003	1.3917	1.3926	1.3934	0.0003
9400	25 krad	1.3929	1.3939	1.3948	0.0003	1.3917	1.3926	1.3934	0.0003
9403	25 krad	1.3931	1.3938	1.3948	0.0003	1.3916	1.3925	1.3937	0.0003
9416	25 krad	1.3929	1.3938	1.3946	0.0003	1.3917	1.3926	1.3934	0.0003
9434	25 krad	1.3932	1.3938	1.3948	0.0003	1.3917	1.3925	1.3932	0.0003
9440	25 krad	1.3931	1.3938	1.3948	0.0003	1.3917	1.3926	1.3932	0.0003

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.
9398	25 krad	2.6297	2.6443	2.6536	0.0036	2.6304	2.6456	2.6553	0.0037
9400	25 krad	2.6296	2.6444	2.6528	0.0036	2.6304	2.6458	2.654	0.0037
9403	25 krad	2.6249	2.6380	2.6474	0.0035	2.6251	2.6391	2.6484	0.0036
9416	25 krad	2.6266	2.6396	2.648	0.0031	2.6284	2.6415	2.6504	0.0032
9434	25 krad	2.627	2.6396	2.6476	0.0031	2.6278	2.6409	2.6492	0.0031
9440	25 krad	2.6284	2.6427	2.6528	0.0037	2.6311	2.6457	2.655	0.0038

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.
9398	25 krad	2.6295	2.6443	2.6532	0.0036	2.6305	2.6457	2.6558	0.0037
9400	25 krad	2.6298	2.6444	2.6529	0.0036	2.6303	2.6459	2.6546	0.0037
9403	25 krad	2.6249	2.6381	2.6471	0.0035	2.6249	2.6392	2.6486	0.0036
9416	25 krad	2.6268	2.6396	2.6476	0.0031	2.6284	2.6415	2.6501	0.0032
9434	25 krad	2.6269	2.6396	2.6478	0.0031	2.6278	2.6410	2.6491	0.0031
9440	25 krad	2.6288	2.6428	2.6519	0.0036	2.6313	2.6458	2.6552	0.0038

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.
9398	25 krad	2.9885	2.9893	2.99	0.0003	2.9901	2.9909	2.9917	0.0003
9400	25 krad	2.9885	2.9893	2.9901	0.0003	2.9902	2.9908	2.9918	0.0003
9403	25 krad	2.9884	2.9891	2.99	0.0003	2.99	2.9907	2.9914	0.0003
9416	25 krad	2.9884	2.9892	2.99	0.0003	2.9901	2.9908	2.9917	0.0003
9434	25 krad	2.9885	2.9892	2.9901	0.0003	2.99	2.9907	2.9916	0.0003
9440	25 krad	2.9886	2.9892	2.9899	0.0002	2.9902	2.9908	2.9917	0.0003

Table 7mPre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_1xE2 (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
9398	25 krad	2.6883	2.6892	2.69	0.0003	2.6876	2.6883	2.6892	0.0003
9400	25 krad	2.6883	2.6892	2.6901	0.0003	2.6875	2.6882	2.6892	0.0003
9403	25 krad	2.6882	2.6891	2.69	0.0003	2.6875	2.6881	2.689	0.0003
9416	25 krad	2.6883	2.6891	2.6899	0.0003	2.6874	2.6881	2.6891	0.0003
9434	25 krad	2.6883	2.6891	2.6899	0.0003	2.6874	2.6882	2.6891	0.0003
9440	25 krad	2.6885	2.6891	2.6898	0.0003	2.6875	2.6883	2.6892	0.0003

Table 7n Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_2x (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
9398	25 krad	2.612	2.6300	2.6411	0.0050	2.6119	2.6310	2.6432	0.0052
9400	25 krad	2.6126	2.6301	2.6418	0.0050	2.6132	2.6315	2.6417	0.0051
9403	25 krad	2.6084	2.6242	2.6354	0.0049	2.6078	2.6247	2.6355	0.0049
9416	25 krad	2.6076	2.6256	2.6351	0.0046	2.6113	2.6268	2.6371	0.0046
9434	25 krad	2.6099	2.6257	2.6353	0.0045	2.6104	2.6264	2.6368	0.0044
9440	25 krad	2.6107	2.6276	2.6463	0.0052	2.6138	2.6311	2.6426	0.0052

Table 7o Pre-Irradiation and Post-Annealing VOH

Test name		lvttl_voh_3x (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
9398	25 krad	2.6786	2.7045	2.7162	0.0060	2.6794	2.7057	2.7174	0.0062
9400	25 krad	2.679	2.7041	2.7157	0.0060	2.6827	2.7059	2.7165	0.0061
9403	25 krad	2.681	2.7004	2.7108	0.0057	2.6793	2.7013	2.7125	0.0058
9416	25 krad	2.6743	2.7012	2.711	0.0058	2.6809	2.7024	2.7129	0.0059
9434	25 krad	2.6803	2.7018	2.7116	0.0056	2.6816	2.7025	2.7141	0.0056
9440	25 krad	2.6778	2.7032	2.7197	0.0059	2.6841	2.7061	2.7165	0.0060

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.
9398	25 krad	2.646	2.6796	2.6928	0.0077	2.6463	2.6807	2.6951	0.0081
9400	25 krad	2.6463	2.6792	2.6924	0.0078	2.6509	2.6809	2.6943	0.0080
9403	25 krad	2.6495	2.6755	2.6878	0.0074	2.6471	2.6762	2.6899	0.0076
9416	25 krad	2.6404	2.6763	2.688	0.0075	2.6481	2.6773	2.6902	0.0077
9434	25 krad	2.6486	2.6769	2.6899	0.0072	2.6487	2.6773	2.6923	0.0074
9440	25 krad	2.645	2.6782	2.6911	0.0075	2.6522	2.6810	2.6942	0.0077

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.
9398	25 krad	2.6739	2.7231	2.7421	0.0113	2.6733	2.7240	2.7441	0.0118
9400	25 krad	2.6734	2.7222	2.7395	0.0115	2.6799	2.7238	2.7438	0.0116
9403	25 krad	2.6827	2.7204	2.7381	0.0109	2.6778	2.7207	2.7393	0.0111
9416	25 krad	2.6669	2.7203	2.7355	0.0111	2.6766	2.7211	2.7403	0.0115
9434	25 krad	2.6803	2.7211	2.7388	0.0107	2.6779	2.7209	2.7423	0.0110
9440	25 krad	2.6734	2.7216	2.7462	0.0113	2.682	2.7244	2.7426	0.0112

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.
9398	25 krad	-14.747	-14.2478	-13.7462	0.1819	-14.6951	-14.1467	-13.5895	0.1771
9400	25 krad	-14.9195	-14.3989	-13.7345	0.2235	-14.912	-14.2782	-13.7066	0.2163
9403	25 krad	-14.7971	-14.0118	-12.622	0.2344	-14.5838	-13.9185	-12.5505	0.2148
9416	25 krad	-14.6469	-14.1221	-13.4875	0.2102	-14.5223	-14.0431	-13.3117	0.1969
9434	25 krad	-14.5944	-14.0254	-13.3963	0.1933	-14.4041	-13.9553	-13.4094	0.1765
9440	25 krad	-14.5469	-13.9254	-13.3828	0.1979	-14.5253	-13.9034	-13.5267	0.1722

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.
9398	25 krad	-18.0811	-17.4050	-16.8459	0.2074	-18.0034	-17.3050	-16.7393	0.2024
9400	25 krad	-18.1625	-17.5961	-16.817	0.2544	-18.1577	-17.4517	-16.7892	0.2487
9403	25 krad	-18.0244	-17.1326	-15.6023	0.2630	-17.828	-17.0324	-15.5218	0.2501
9416	25 krad	-17.7523	-17.2640	-16.5471	0.2416	-17.7207	-17.1753	-16.4137	0.2262
9434	25 krad	-17.7116	-17.1643	-16.5367	0.2166	-17.6334	-17.0772	-16.465	0.1997
9440	25 krad	-17.7742	-17.0431	-16.516	0.2218	-17.7796	-17.0241	-16.5392	0.2013

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.
9398	25 krad	-9.5932	-9.1870	-8.7219	0.1364	-9.482	-9.1036	-8.7005	0.1271
9400	25 krad	-9.6905	-9.2843	-8.7472	0.1623	-9.7191	-9.1824	-8.7606	0.1543
9403	25 krad	-9.6433	-9.0227	-7.6132	0.1814	-9.443	-8.9537	-7.59	0.1674
9416	25 krad	-9.4932	-9.1007	-8.6719	0.1548	-9.4809	-9.0388	-8.5087	0.1421
9434	25 krad	-9.447	-9.0319	-8.5219	0.1482	-9.2946	-8.9672	-8.5844	0.1263
9440	25 krad	-9.4682	-8.9710	-8.5451	0.1495	-9.3435	-8.9431	-8.6402	0.1258

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.
9398	25 krad	-12.8129	-12.3269	-11.7965	0.1653	-12.7903	-12.3393	-11.8813	0.1588
9400	25 krad	-12.9291	-12.4656	-11.8047	0.1977	-13.0146	-12.4536	-11.9066	0.1941
9403	25 krad	-12.8453	-12.1279	-10.7187	0.2132	-12.7122	-12.1398	-10.7124	0.2011
9416	25 krad	-12.7205	-12.2216	-11.6568	0.1889	-12.7415	-12.2396	-11.5856	0.1777
9434	25 krad	-12.6704	-12.1456	-11.5965	0.1743	-12.5513	-12.1522	-11.6813	0.1575
9440	25 krad	-12.6455	-12.0625	-11.6282	0.1768	-12.6979	-12.1255	-11.7543	0.1552

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.
9398	25 krad	-5.9799	-5.6412	-5.2223	0.1105	-5.9131	-5.5997	-5.2453	0.1032
9400	25 krad	-6.0453	-5.7172	-5.2887	0.1266	-6.074	-5.6556	-5.2508	0.1167
9403	25 krad	-6.0488	-5.5349	-4.2823	0.1471	-5.8245	-5.4992	-4.241	0.1314
9416	25 krad	-6.0406	-5.5945	-5.2284	0.1264	-5.9193	-5.5526	-5.1565	0.1050
9434	25 krad	-5.8988	-5.5514	-5.0973	0.1187	-5.8011	-5.4986	-5.1615	0.1003
9440	25 krad	-5.9906	-5.5110	-5.1612	0.1208	-5.7638	-5.4931	-5.1981	0.0942

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.
9398	25 krad	-7.498	-7.1515	-6.7721	0.1210	-7.5166	-7.1558	-6.7738	0.1146
9400	25 krad	-7.6039	-7.2365	-6.7674	0.1420	-7.6968	-7.2237	-6.8055	0.1314
9403	25 krad	-7.5918	-7.0142	-5.6597	0.1595	-7.3991	-7.0280	-5.7518	0.1438
9416	25 krad	-7.4917	-7.0865	-6.6721	0.1363	-7.4744	-7.0919	-6.6325	0.1219
9434	25 krad	-7.4231	-7.0268	-6.5471	0.1320	-7.4222	-7.0310	-6.6716	0.1129
9440	25 krad	-7.4417	-6.9832	-6.5899	0.1327	-7.3909	-7.0222	-6.7197	0.1119

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.
9398	25 krad	-36.2439	-34.9933	-34.0579	0.3466	-36.2492	-34.9616	-33.9729	0.3419
9400	25 krad	-36.2004	-35.2471	-34.0719	0.4188	-36.1324	-35.1806	-34.0112	0.4131
9403	25 krad	-35.8374	-34.4759	-32.7325	0.3999	-35.6087	-34.4469	-32.7957	0.3897
9416	25 krad	-35.4295	-34.5525	-33.3246	0.4031	-35.5838	-34.5847	-33.2994	0.3915
9434	25 krad	-35.4444	-34.6081	-33.6476	0.3335	-35.3895	-34.6219	-33.6211	0.3224
9440	25 krad	-35.5922	-34.3046	-33.5585	0.3657	-35.7032	-34.4805	-33.6746	0.3521

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.
9398	25 krad	-36.2439	-34.9933	-34.0579	0.3466	-36.2492	-34.9616	-33.9729	0.3419
9400	25 krad	-36.2004	-35.2471	-34.0719	0.4188	-36.1324	-35.1806	-34.0112	0.4131
9403	25 krad	-35.8374	-34.4759	-32.7325	0.3999	-35.6087	-34.4469	-32.7957	0.3897
9416	25 krad	-35.4295	-34.5525	-33.3246	0.4031	-35.5838	-34.5847	-33.2994	0.3915
9434	25 krad	-35.4444	-34.6081	-33.6476	0.3335	-35.3895	-34.6219	-33.6211	0.3224
9440	25 krad	-35.5922	-34.3046	-33.5585	0.3657	-35.7032	-34.4805	-33.6746	0.3521

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)
9398	699.500	1171.000	777.500
9400	701.500	1197.000	772.500
9403	720.000	1219.000	789.000
9416	720.000	1173.500	780.500
9434	724.000	1204.000	793.000
9440	700.500	1047.500	744.000

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

DUT	(Compared to Pre-irradiation)	Post-25 krad(%)	Post-Annealing (%)
9398	-	40.3%	10%
9400	-	41.4%	9.2%
9403	-	40.9%	8.7%
9416	-	38.6%	7.8%
9434	-	40.0%	8.7%
9440	-	33.1%	5.8%

Figure 8 below has the percentage of the degradation on propagation delay in Tables 9b plotted.

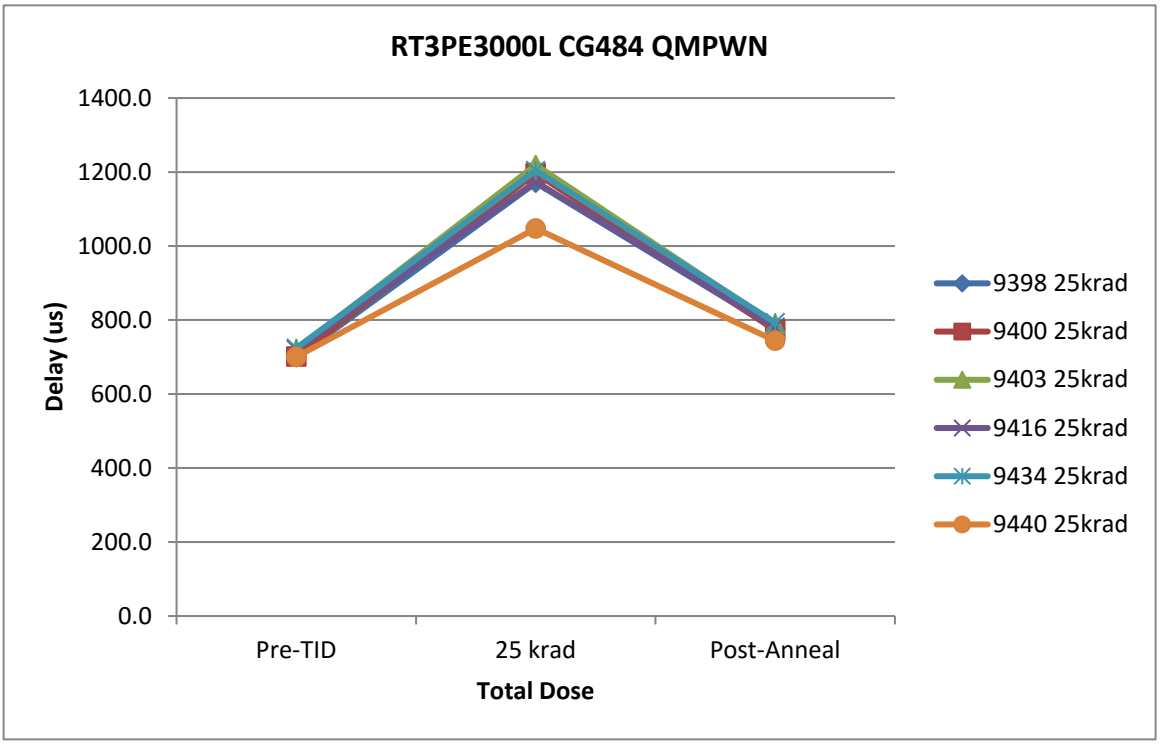


Figure 8 Degradation of Propagation Delay versus TID and Annealing

G. Transition Time

Figures 9a to Figure 20b show pre-irradiation and post-annealing transition edges. In each case, the radiation effect is not significant.

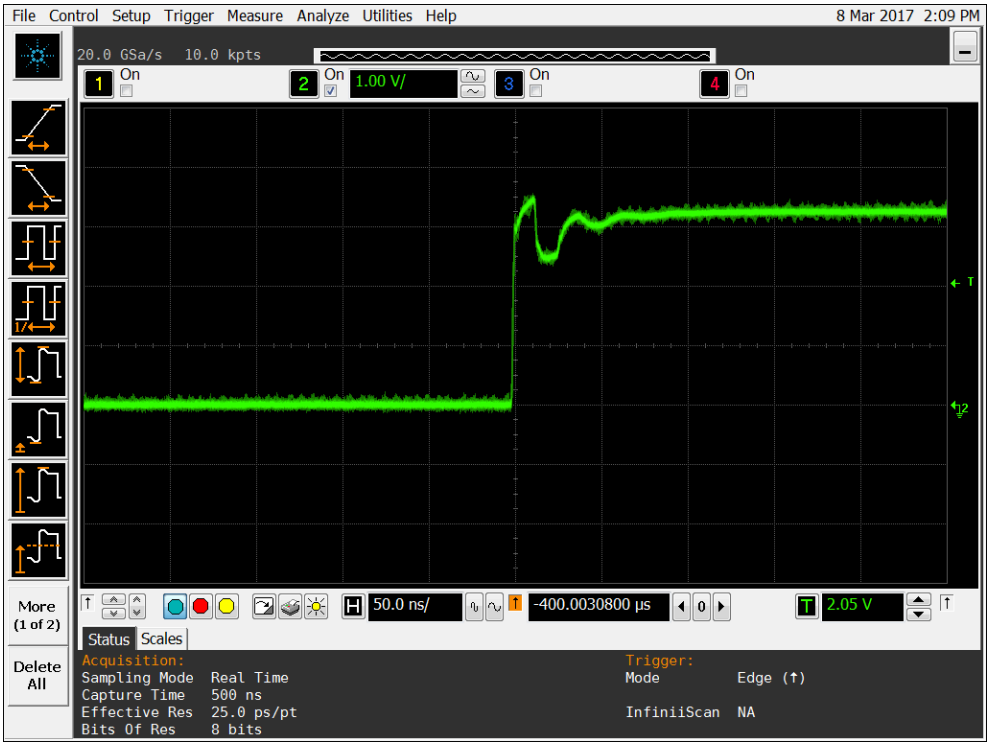


Figure 9a DUT 9398 Pre-Irradiation Rising Edge

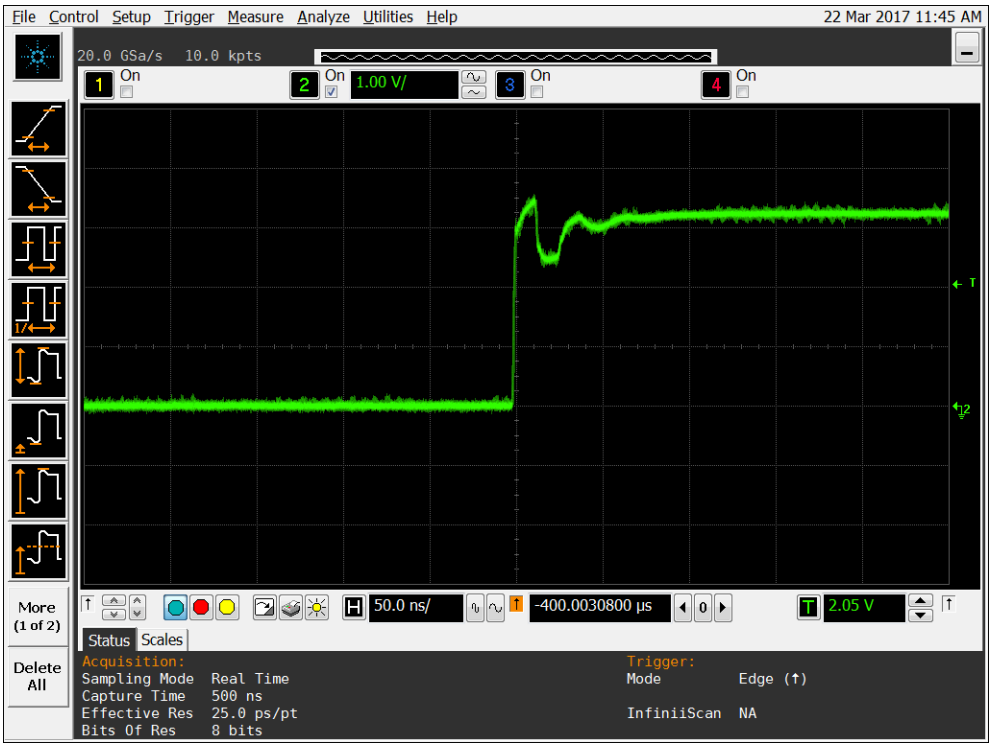


Figure 9b DUT 9398 Post-Annealing Rising Edge

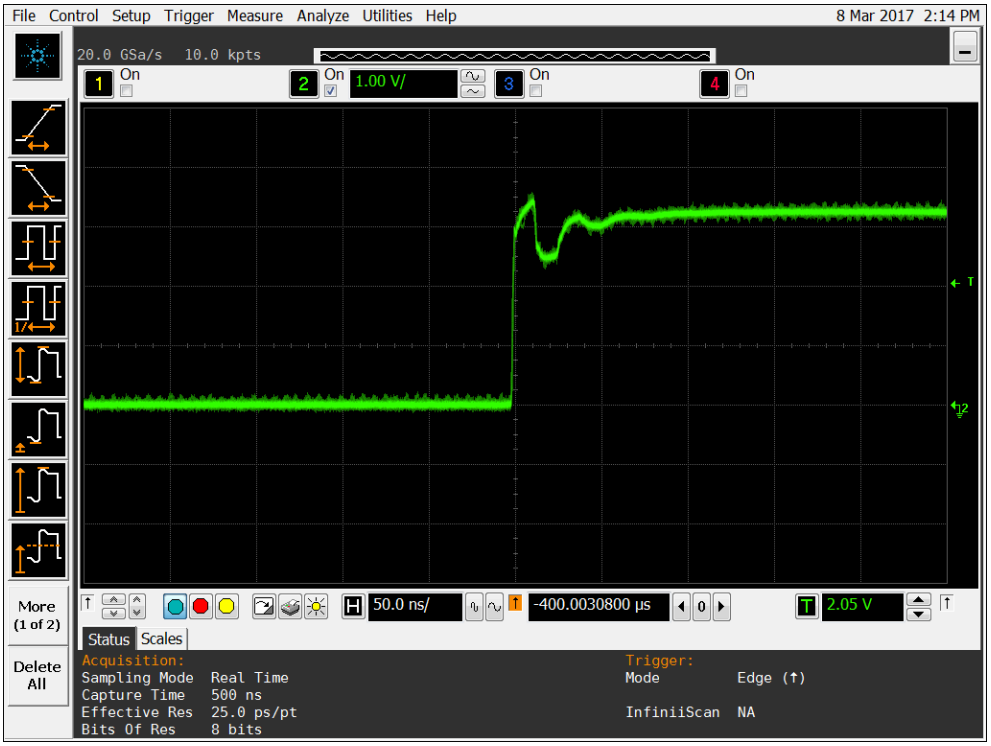


Figure 10a DUT 9400 Pre-Irradiation Rising Edge

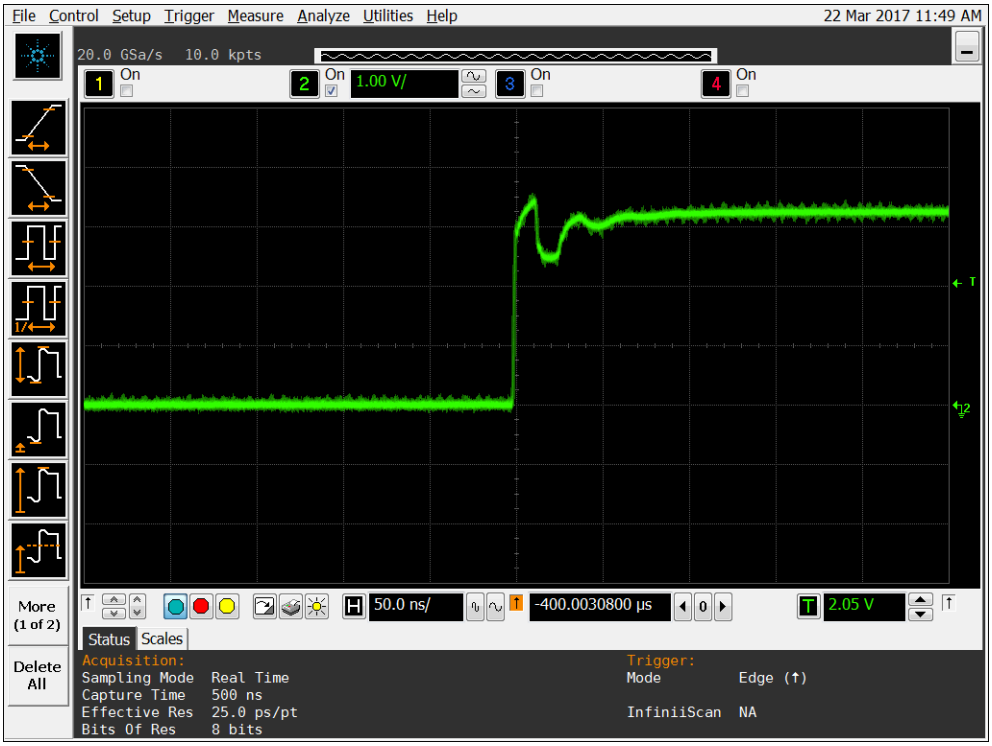


Figure 10b DUT 9400 Post-Annealing Rising Edge

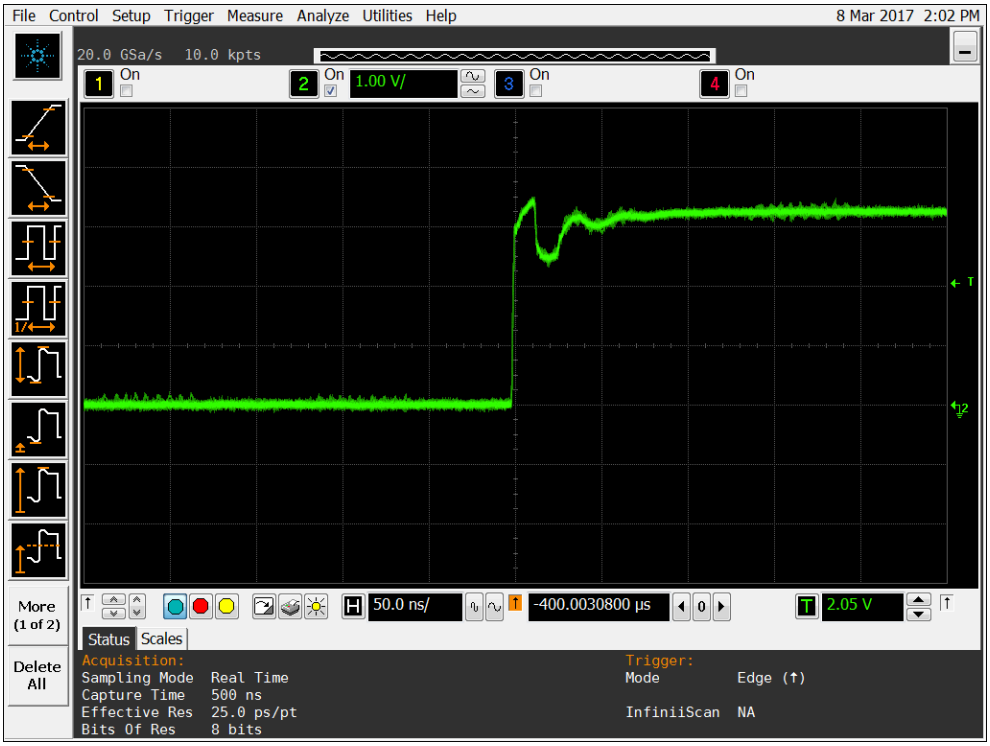


Figure 11a DUT 9403 Pre-Irradiation Rising Edge

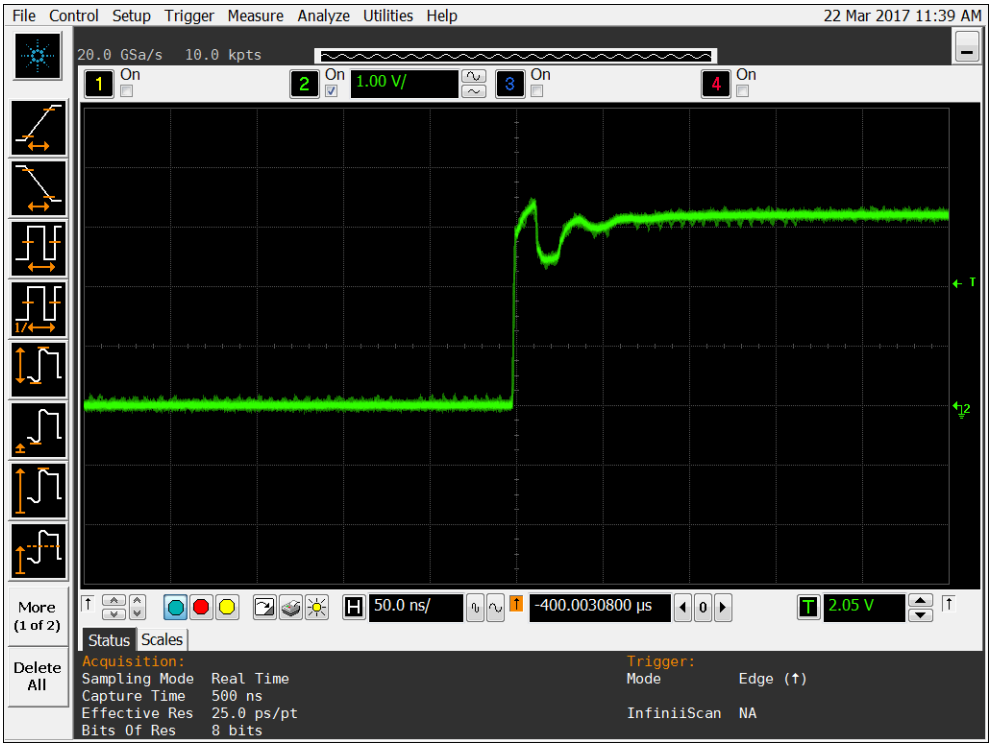


Figure 11b DUT 9403 Post-Annealing Rising Edge

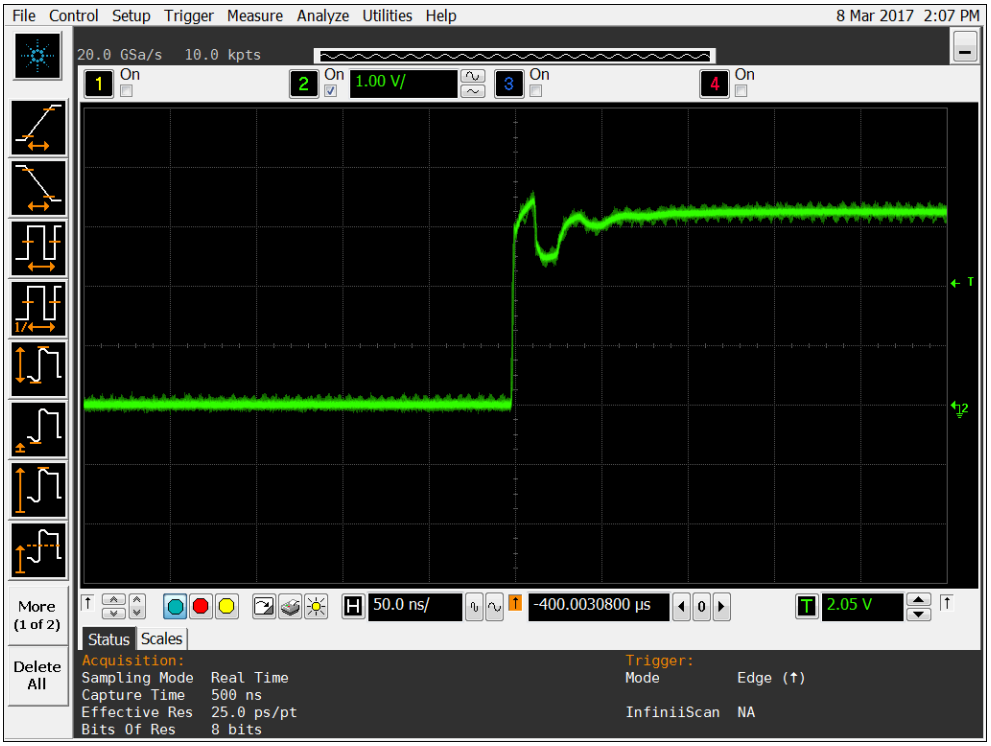


Figure 12a DUT 9416 Pre-Irradiation Rising Edge

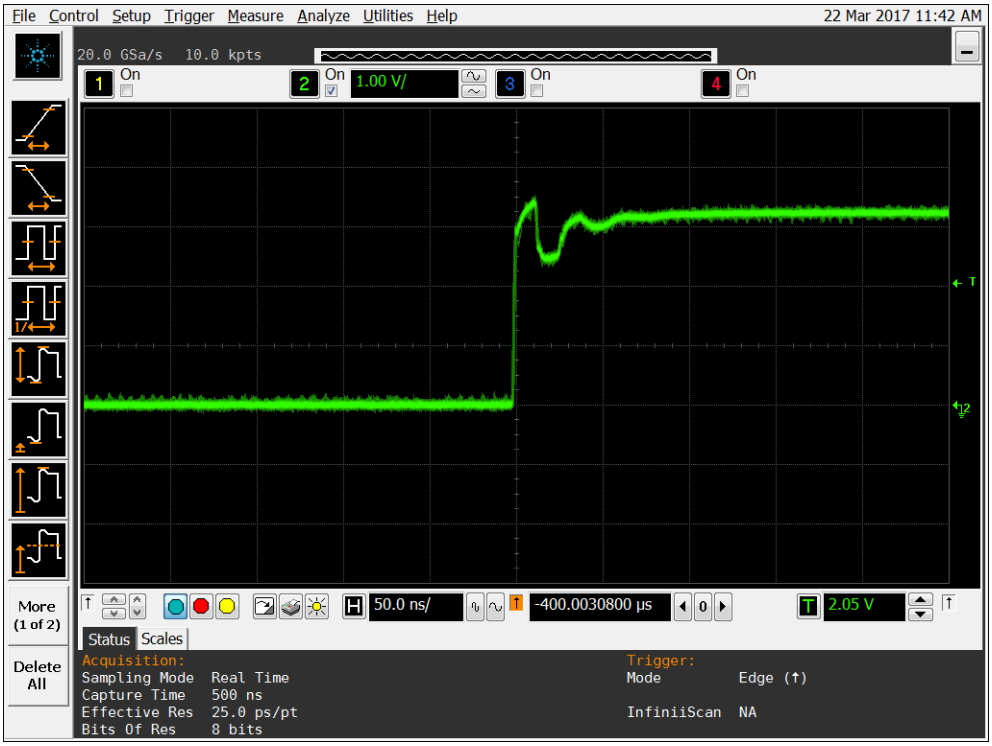


Figure 12b DUT 9416 Post-Annealing Rising Edge

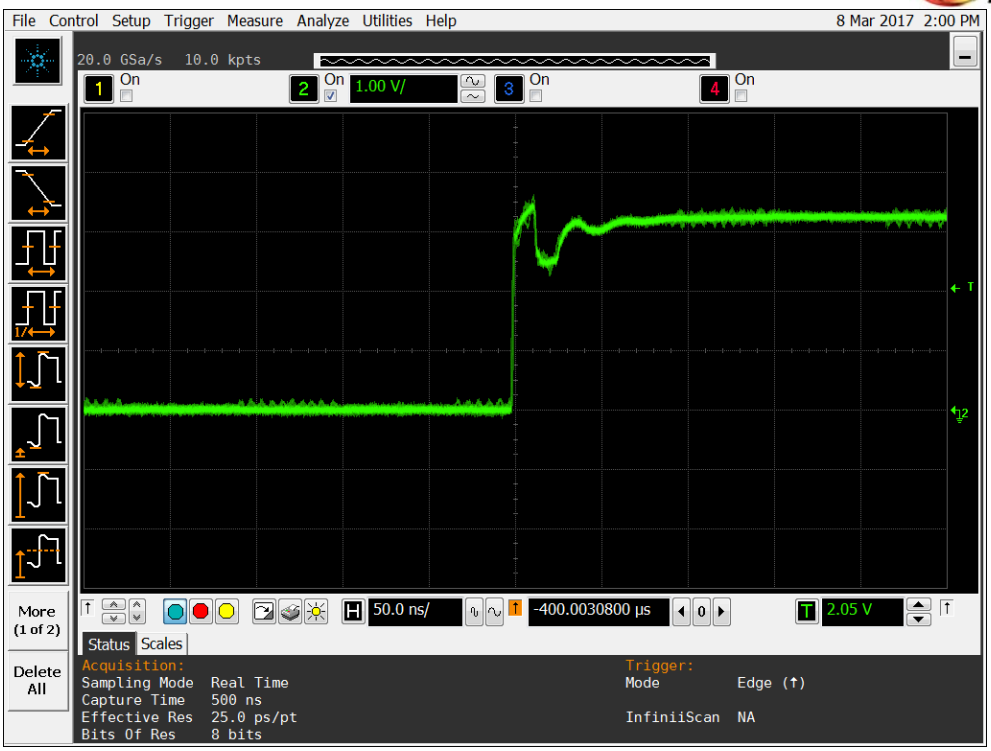


Figure 13a DUT 9434 Pre-Irradiation Rising Edge

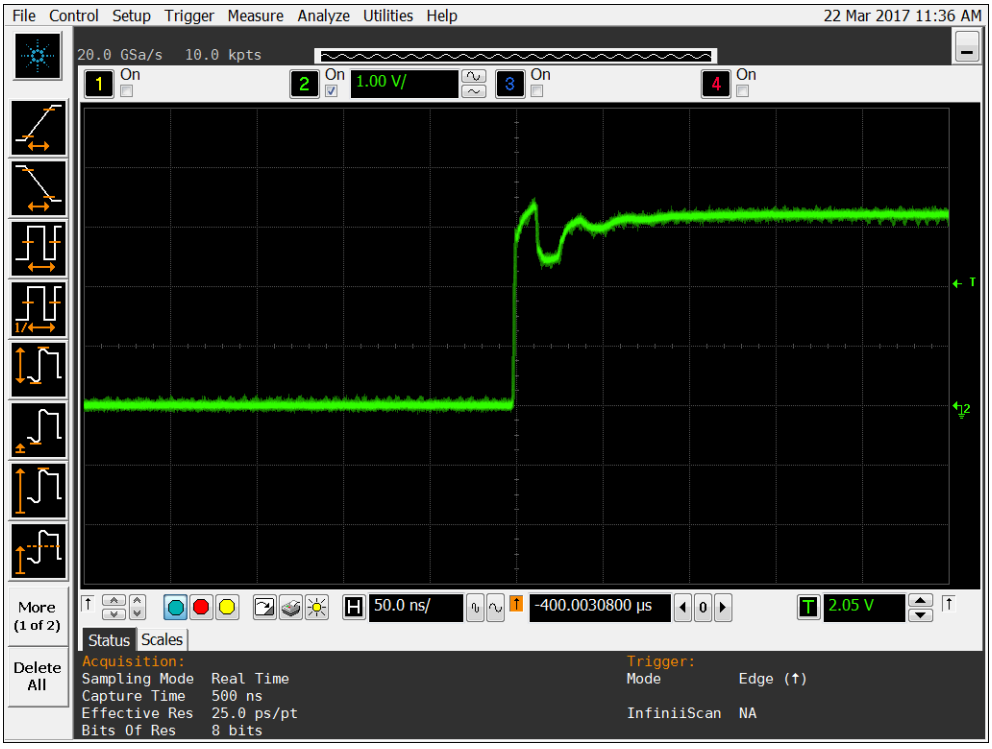


Figure 13b DUT 9434 Post-Annealing Rising Edge

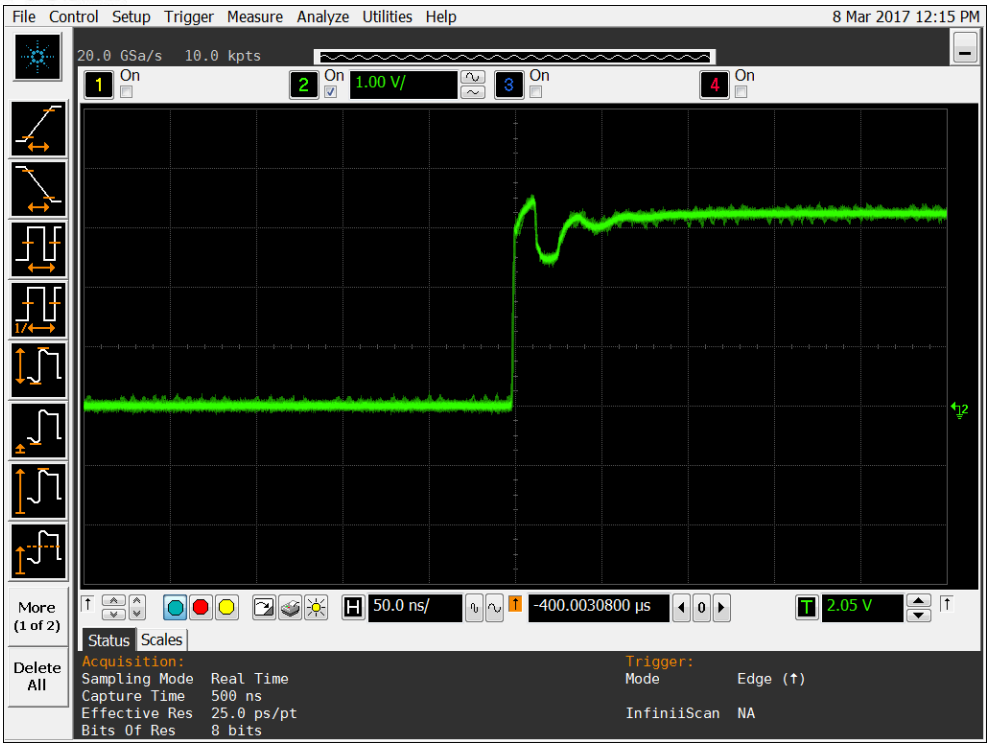


Figure 14a DUT 9440 Pre-Irradiation Rising Edge

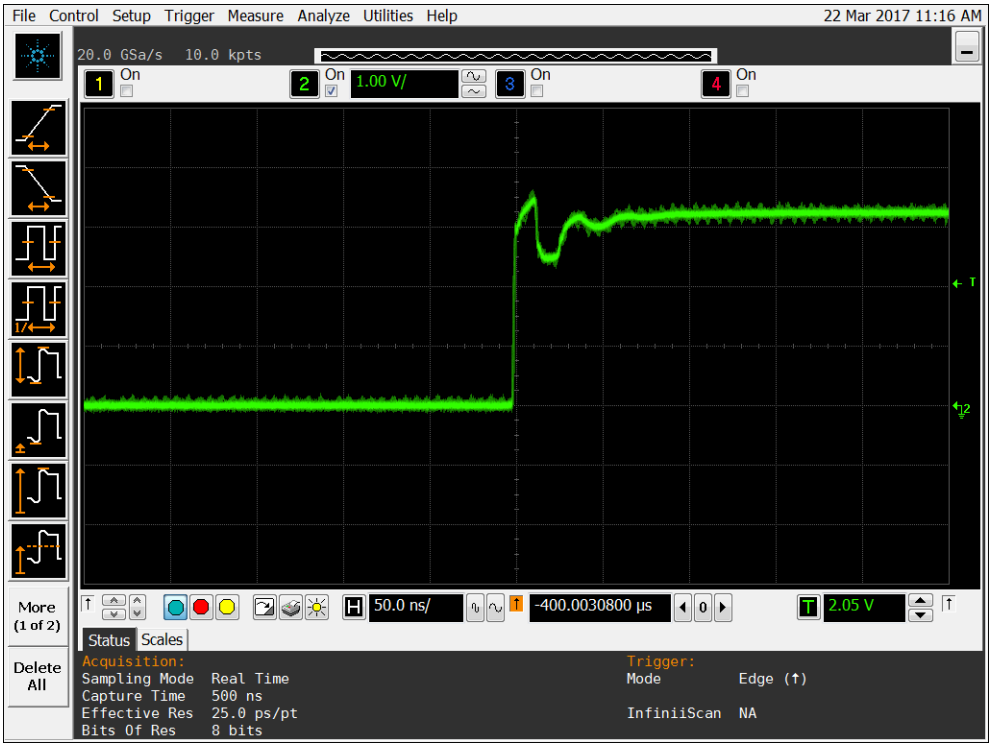


Figure 14b DUT 9440 Post-Annealing Rising Edge

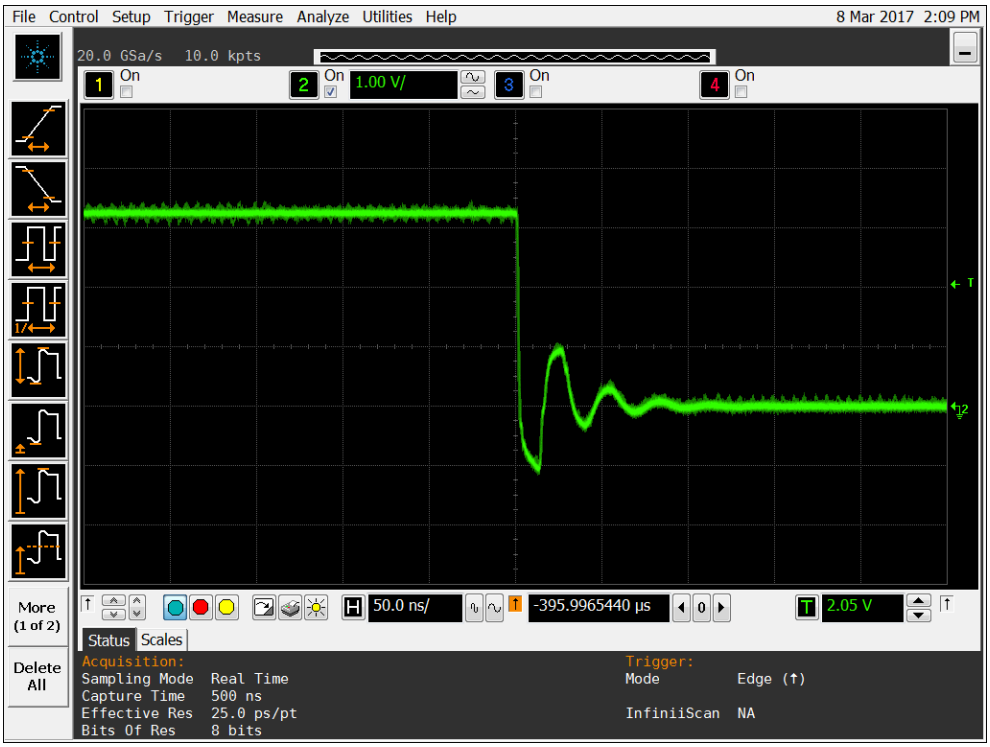


Figure 15a DUT 9398 Pre-Irradiation Falling Edge

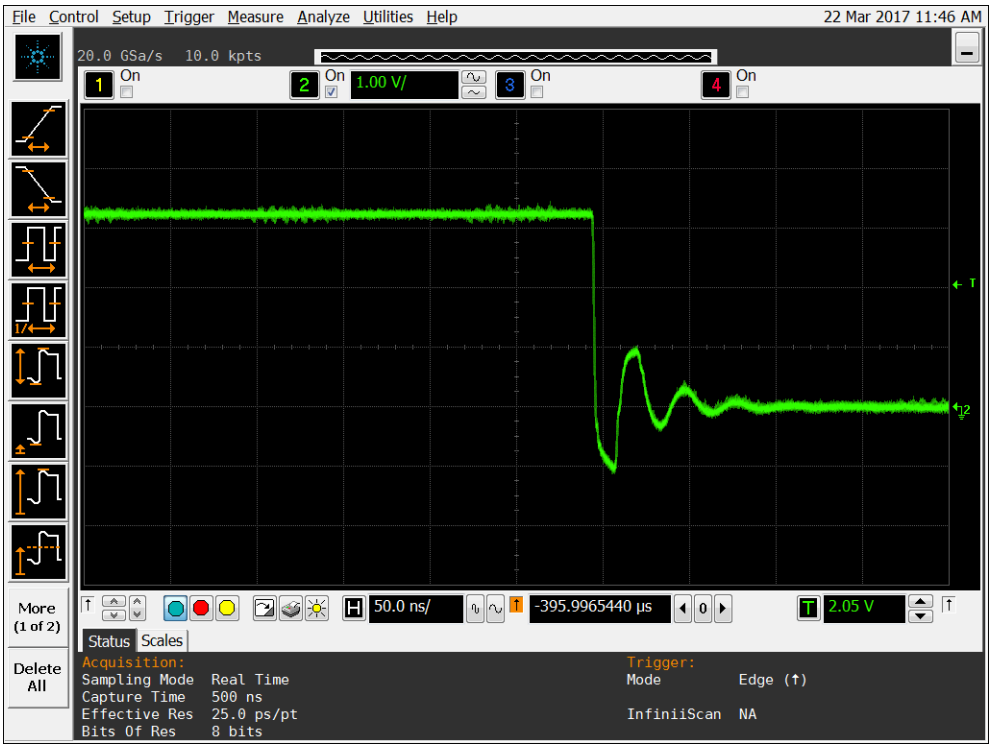


Figure 15b DUT 9398 Post-Annealing Falling Edge

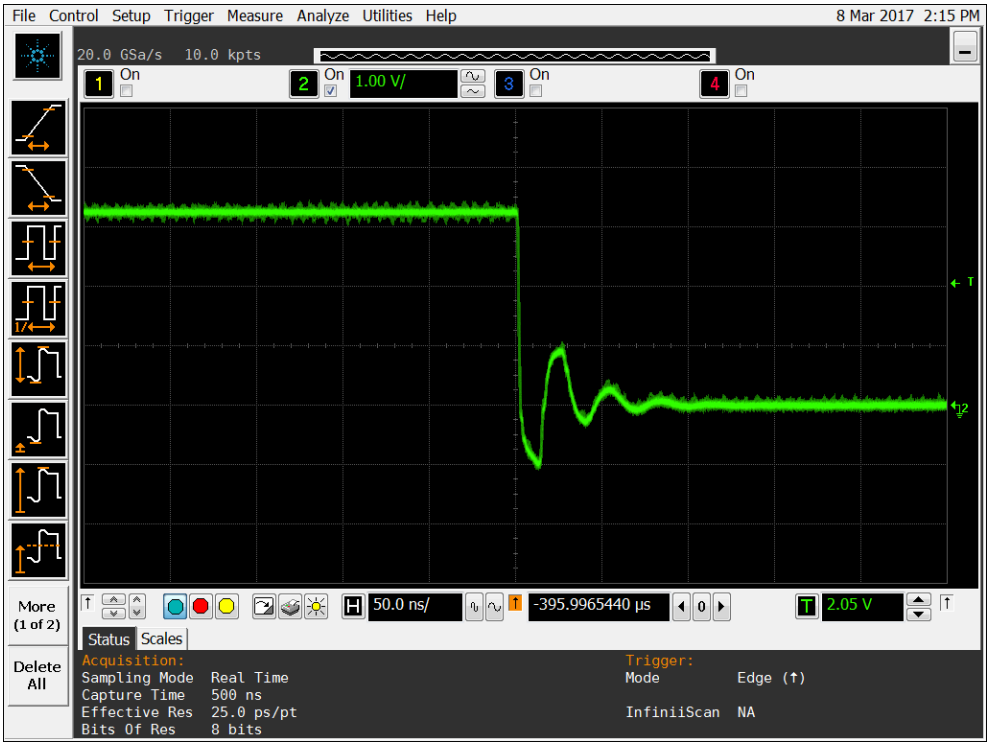


Figure 16a DUT 9400 Pre-Irradiation Falling Edge

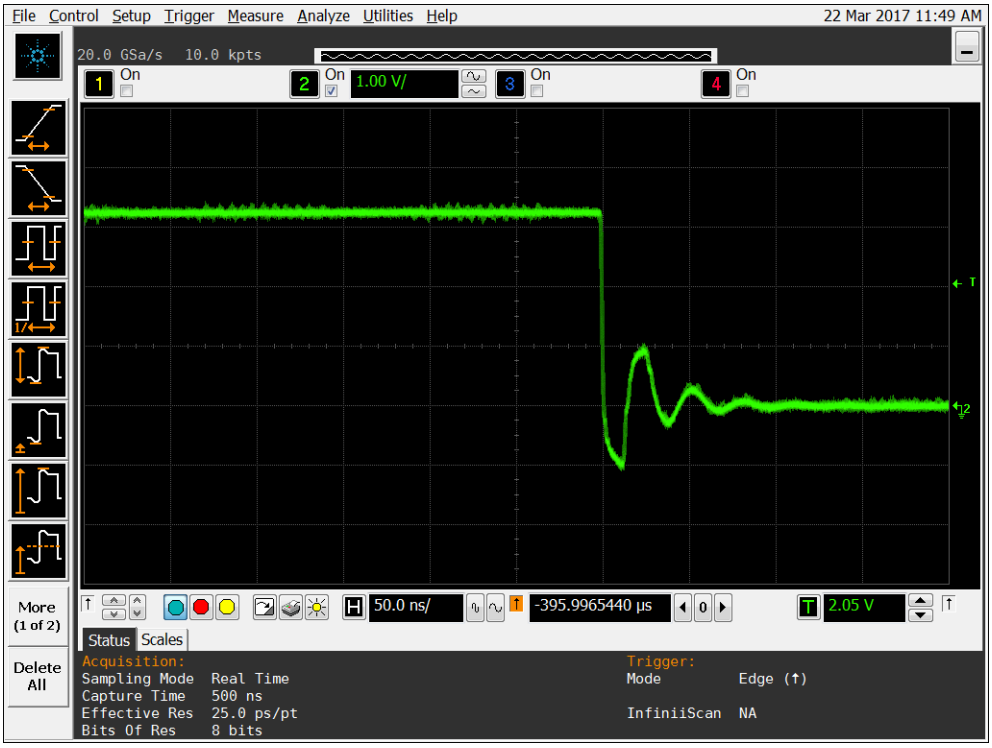


Figure 16b DUT 9400 Post-Annealing Falling Edge

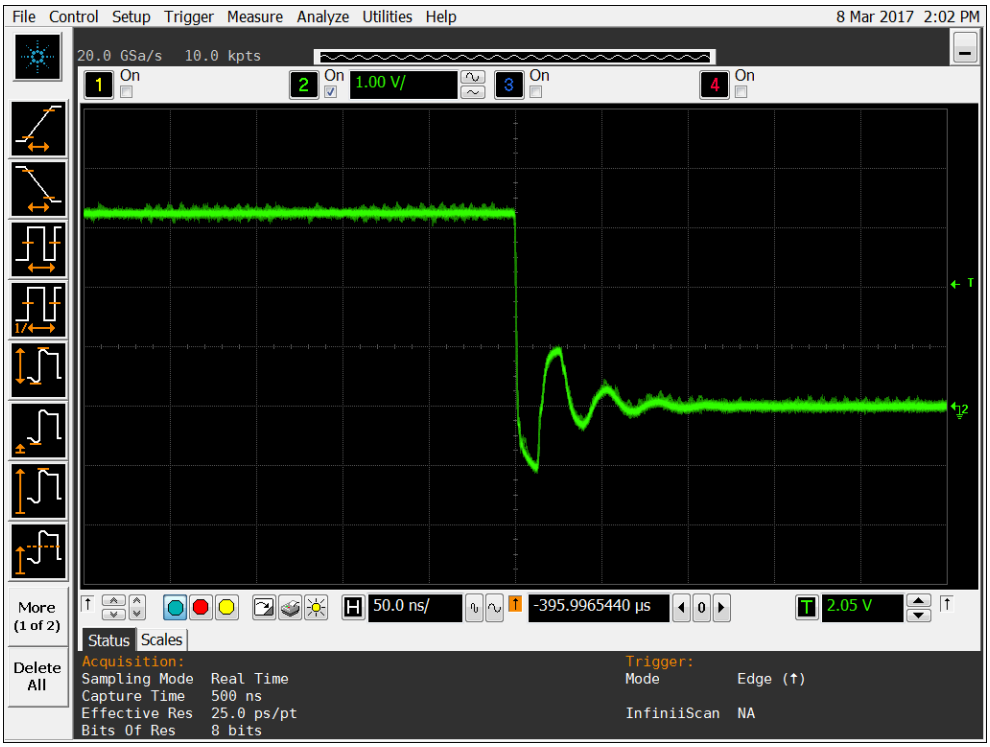


Figure 17a DUT 9403 Pre-Irradiation Falling Edge

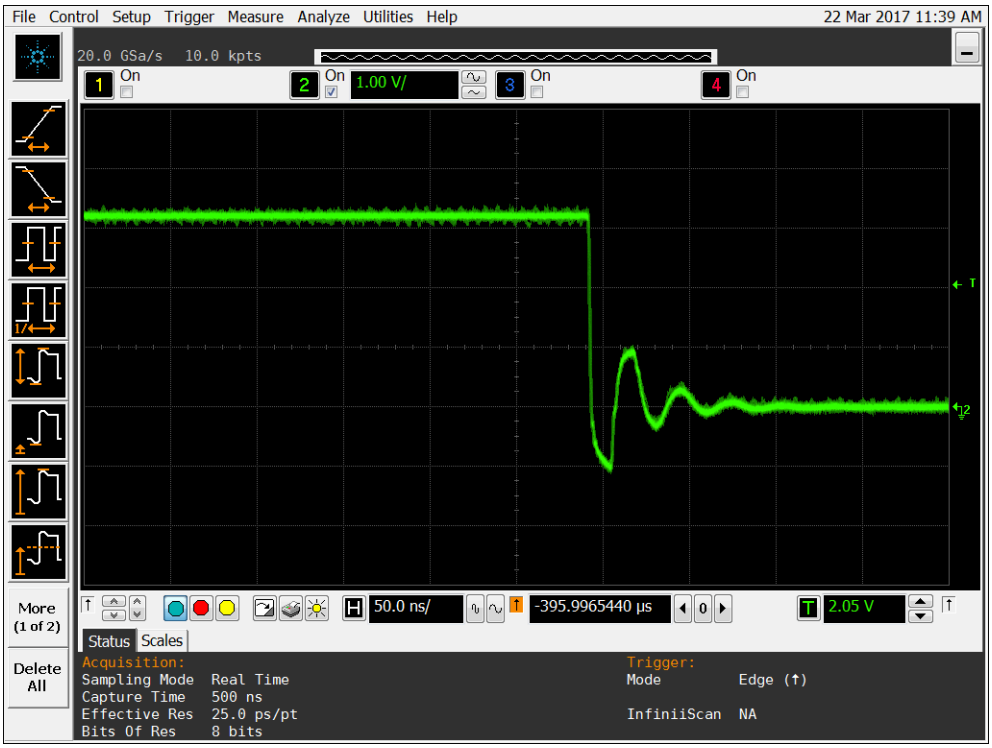


Figure 17b DUT 9403 Post-Annealing Falling Edge

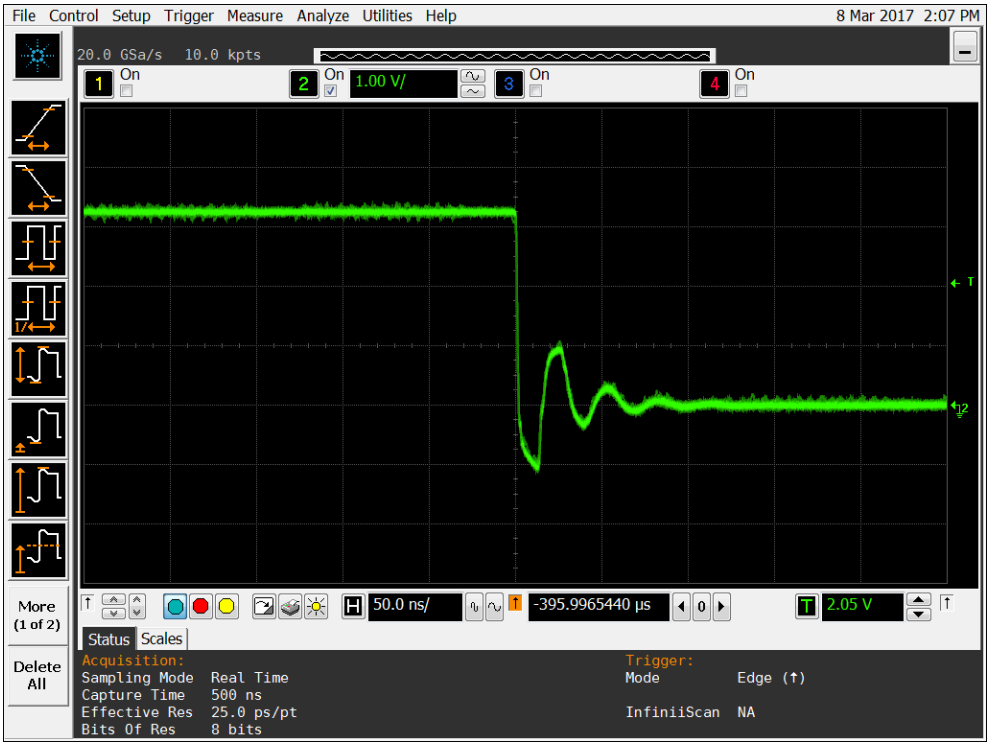


Figure 18a DUT 9416 Pre-Irradiation Falling Edge

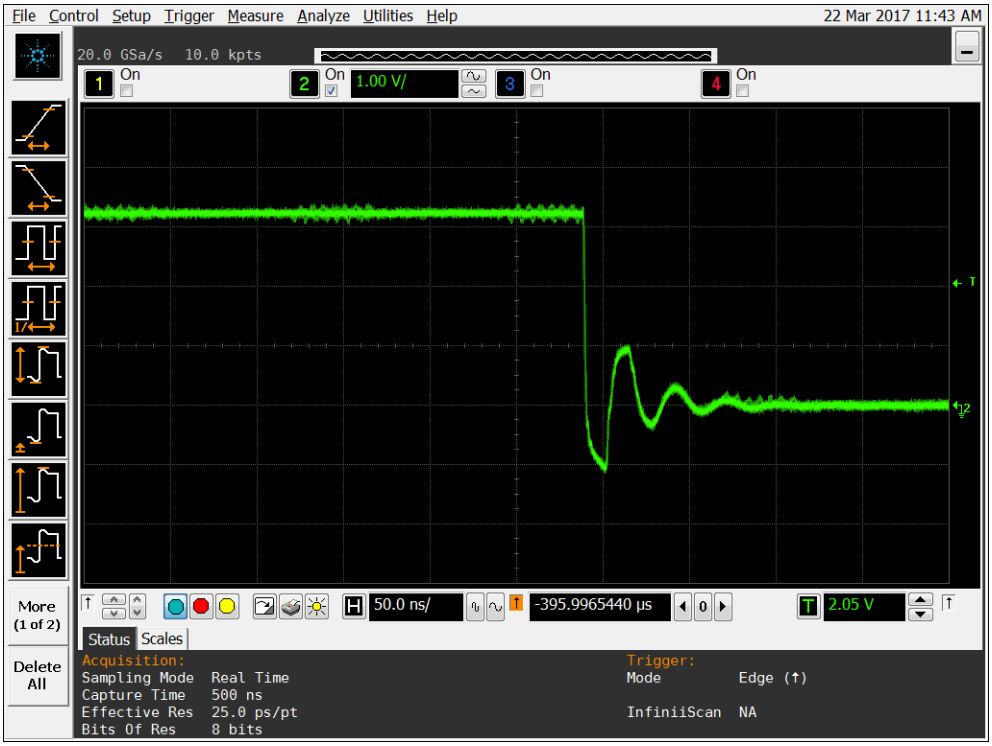


Figure 18b DUT 9416 Post-Annealing Falling Edge

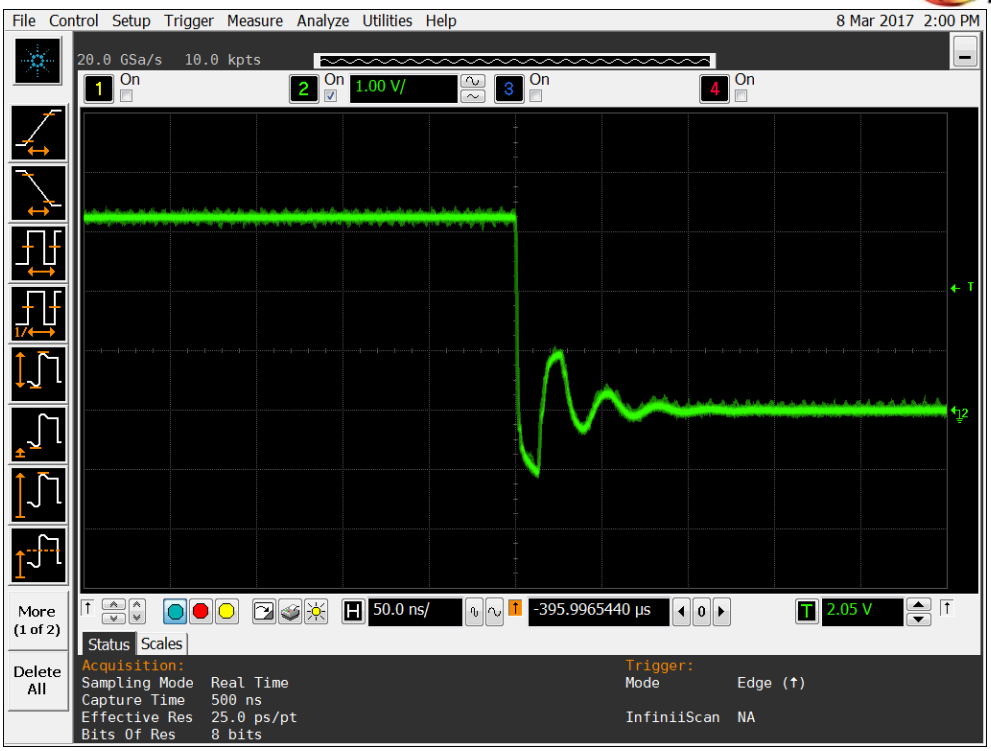


Figure 19a DUT 9434 Pre-Irradiation Falling Edge

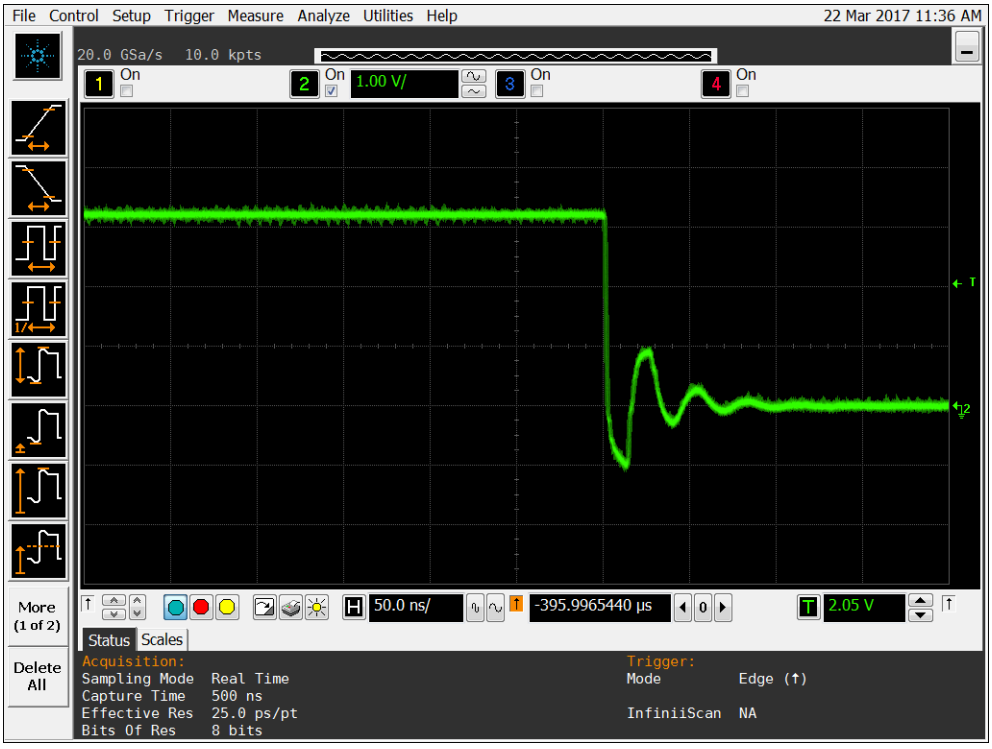


Figure 19b DUT 9434 Post-Annealing Falling Edge

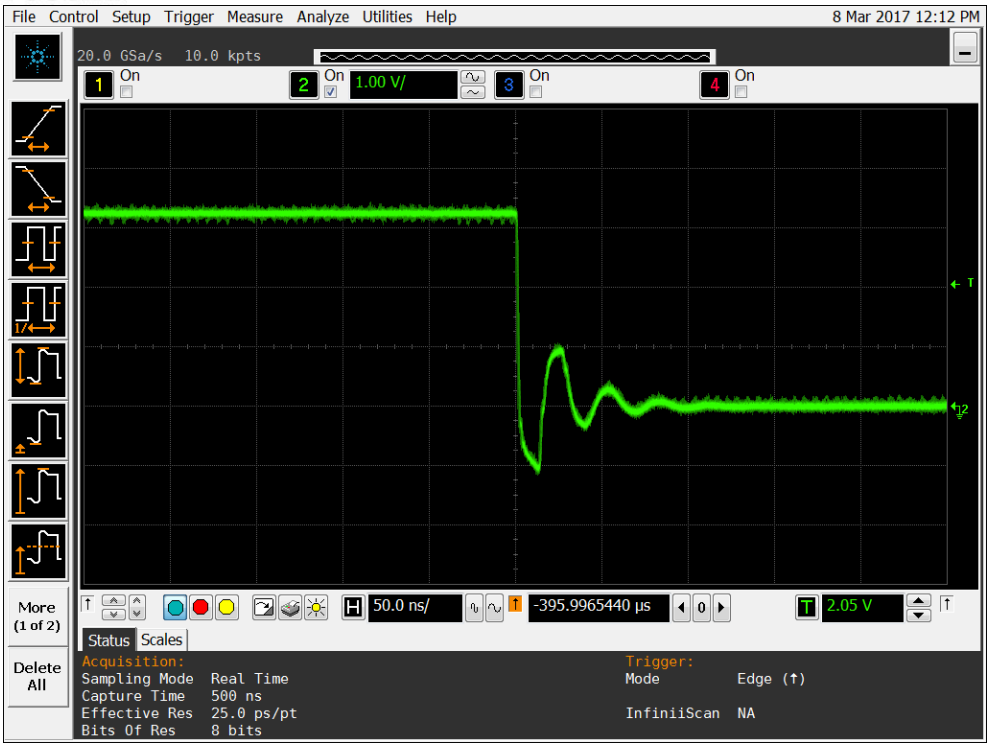


Figure 20a DUT 9440 Pre-Irradiation Falling Edge

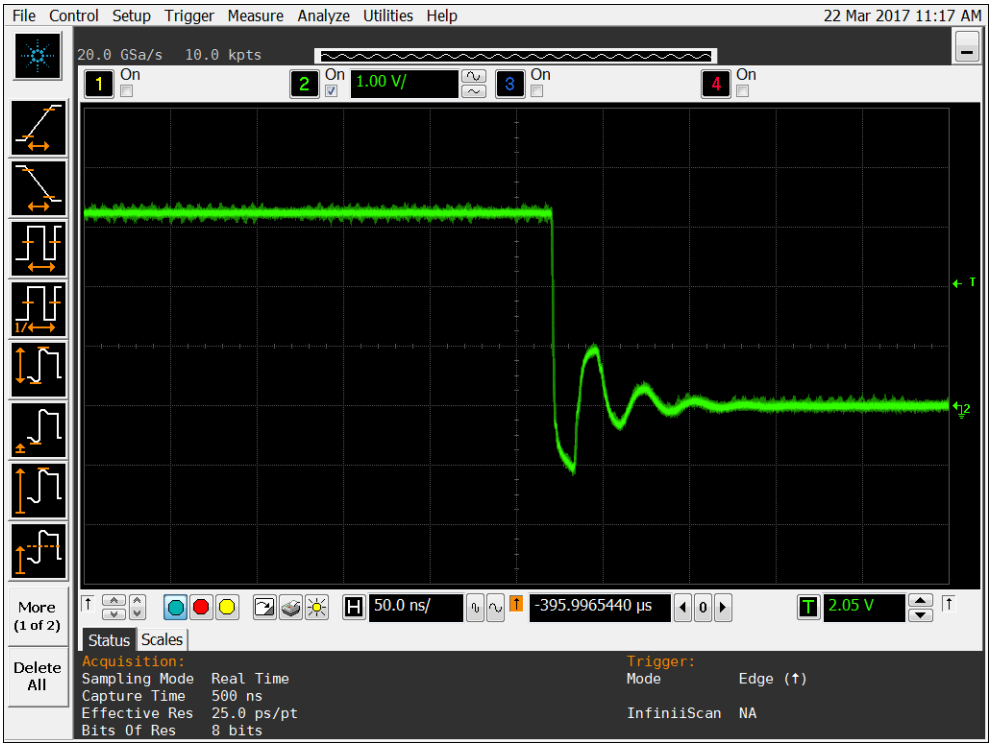


Figure 20b DUT 9440 Post-Annealing Falling Edge

Appendix A: DUT Design Block Diagrams and Schematics

A. PLL Block

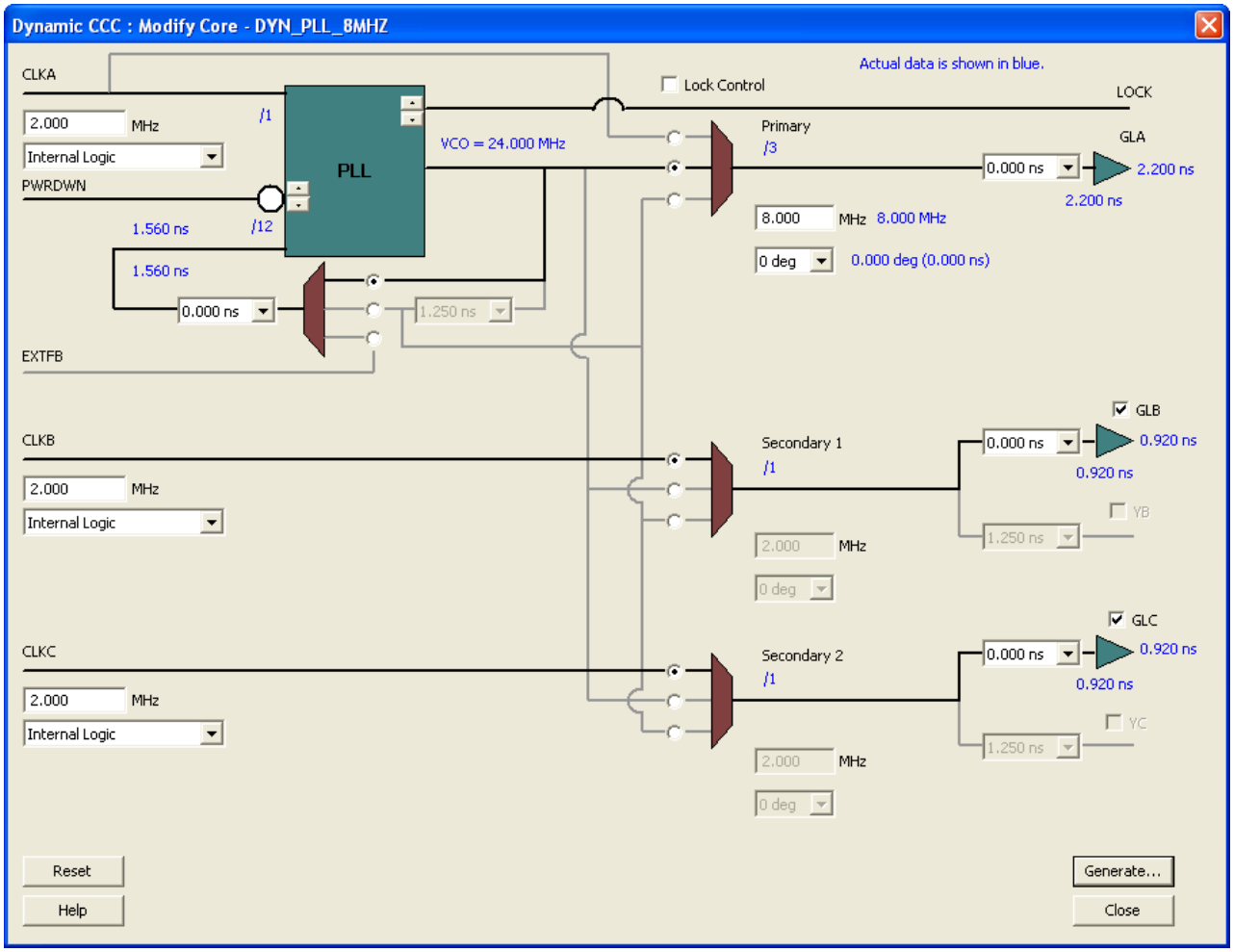
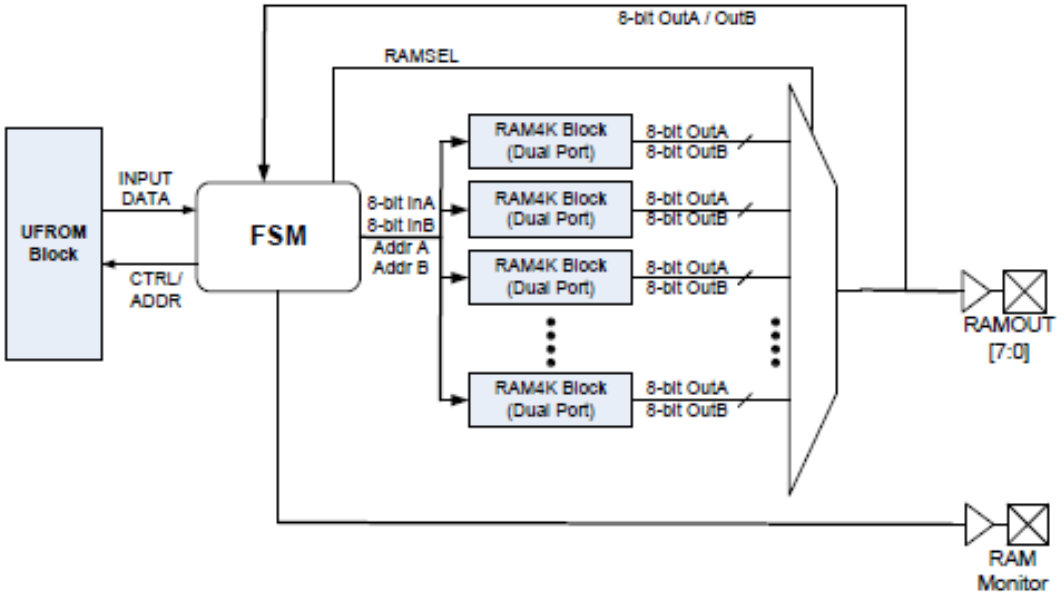


Table 10 lists the signals that go through each of the PLLS:

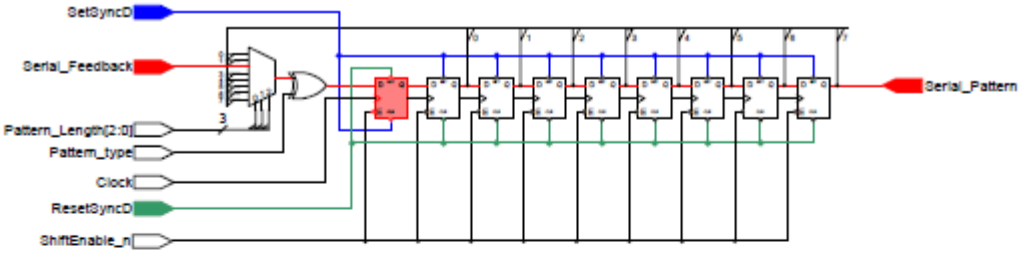
Table 10 Signals Through PLLs

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

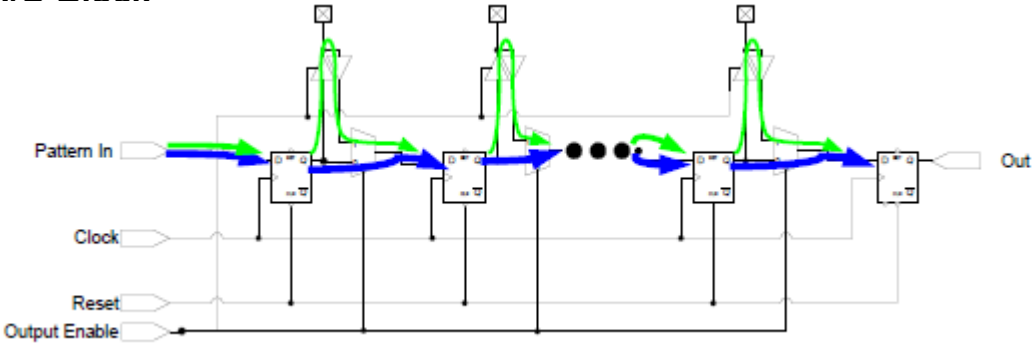


C. Pattern Generators Block

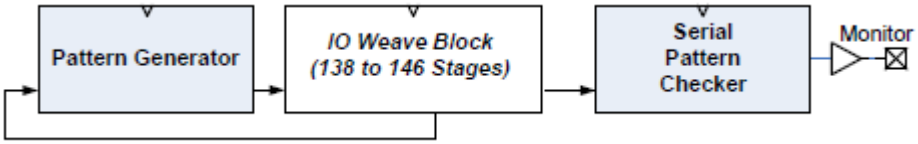


Pattern Type	Pattern Length		Code Length	Δ Bits	Switching Rate
0	000	1 0 ⇒ 0 1 ↻	2	2	100.00%
0	001	1 0 0 ⇒ 0 1 0 ⇒ 0 0 1 ↻	3	2	66.67%
0	010	One hot I/O at a time switching in entire I/O ring	#Bits+9	2	N/A
0	011	1 0 0 0 0 ⇒ 0 1 0 0 0 ⇒ 0 0 1 0 0 ⇒ 0 0 0 1 0 ⇒ 0 0 0 0 1 ↻	5	2	40.00%
0	100	1 0 0 0 0 0 ⇒ 0 1 0 0 0 0 ⇒ 0 0 1 0 0 0 ⇒ 0 0 0 1 0 0 ⇒ 0 0 0 0 1 0 ⇒ 0 0 0 0 0 1 ↻	6	2	33.33%
0	101	1 0 0 0 0 0 0 ⇒ 0 1 0 0 0 0 0 ⇒ 0 0 1 0 0 0 0 ⇒ 0 0 0 1 0 0 0 ⇒ 0 0 0 0 1 0 0 ⇒ 0 0	7	2	28.57%
0	110	1 0 0 0 0 0 0 0 ⇒ 0 1 0 0 0 0 0 0 ⇒ 0 0 1 0 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 1 0 0 0 0 0 0 0 ⇒ 0 0 1 0 0 0 0 0 0 ⇒ 0 0 0 1 0 0 0 0 0 ⇒ 0 0	9	2	22.22%
1	000	1 0 ⇒ 1 1 ⇒ 0 1 ⇒ 0 0 ↻	2	1	50.00%
1	001	1 0 0 ⇒ 1 1 0 ⇒ 1 1 1 ⇒ 0 1 1 ⇒ 0 0 1 ⇒ 0 0 0 ↻	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 0 ⇒ 1 1 1 1 1 ⇒ 0 1 1 1 1 ⇒ 0 0 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 ⇒	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	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	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 ⇒ 1 1 1	9	1	11.11%

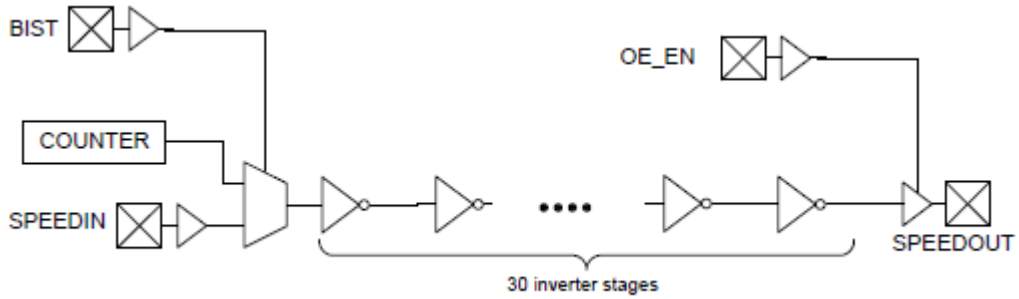
D. I/O Block



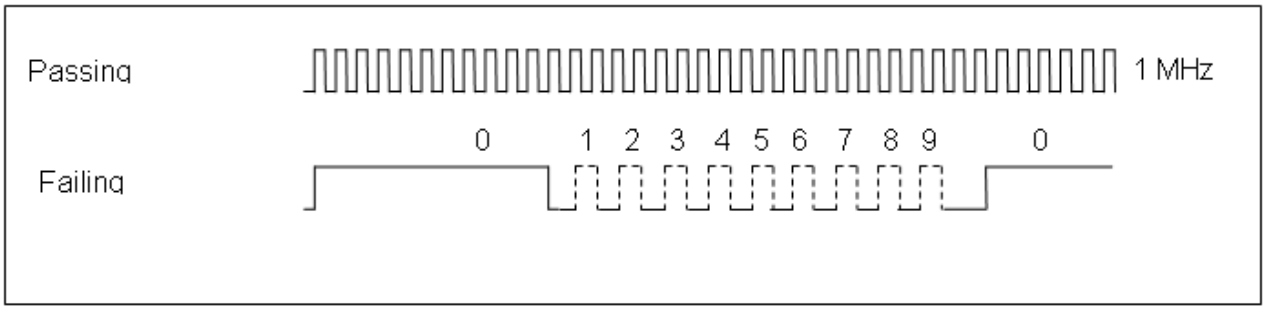
E. Array Shift Registers Block



F. Delay Path Block



G. Monitor Block



Microsemi Corporate Headquarters
One Enterprise, Aliso Viejo CA 92656 USA
Within the USA: +1 (949) 380-6100
Sales: +1 (949) 380-6136
Fax: +1 (949) 215-4996

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