Total Ionizing Dose Test Report

No. 16T-RT3PE3000L-CG896-QMLPK

December 1, 2016

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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	CG896
Foundry	United Microelectronics Corp.
Technology	0.13 µm CMOS and Embedded Flash
DUT Design	RTA3PE3KL_CG896_TID
Die Lot Number	QMLPK
Quantity Tested	5
Total Dose: DUT Serial Number	25 krad(SiO2): 3435, 3436, 3437, 3439, 3556
Radiation Facility	Defense Microelectronics Activity
Radiation Source	Co-60
Dose Rate	7.5 krad(SiO2)/min(±5%)
Irradiation Temperature	Room
Irradiation and Measurement Bias (VCCI/VCCA)	Static at 3.3 V/1.5 V

B. Test Method

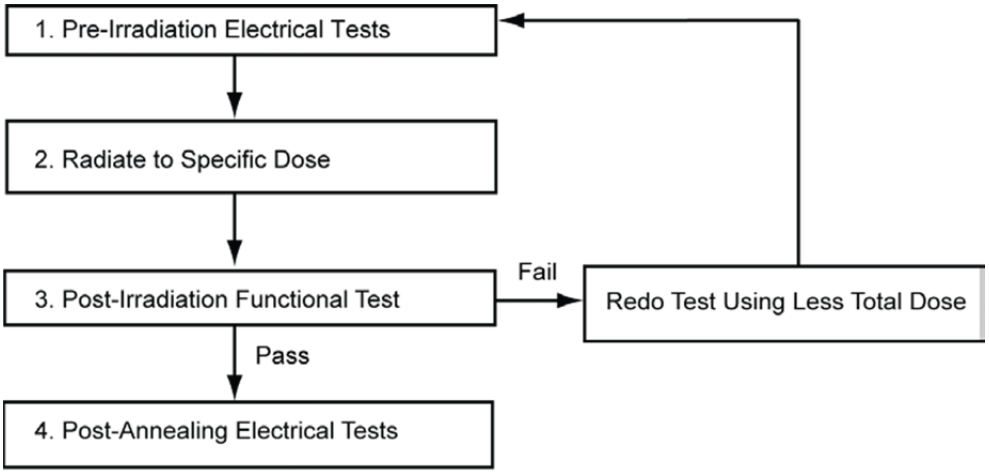


Figure Parametric Test Flow Chart

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_CG896_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 30 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 30 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
3435	25 krad	2.8	3	0.1	0.1
3436	25 krad	3.8	3.8	0.1	0.1
3437	25 krad	2.8	2.8	0.1	0.1
3439	25 krad	3.2	3.5	0.1	0.1
3556	25 krad	2.9	3.2	0.1	0.1

Figures 1a-e on the following page shows the influx standby ICCA and ICCI versus total dose for each DUT.

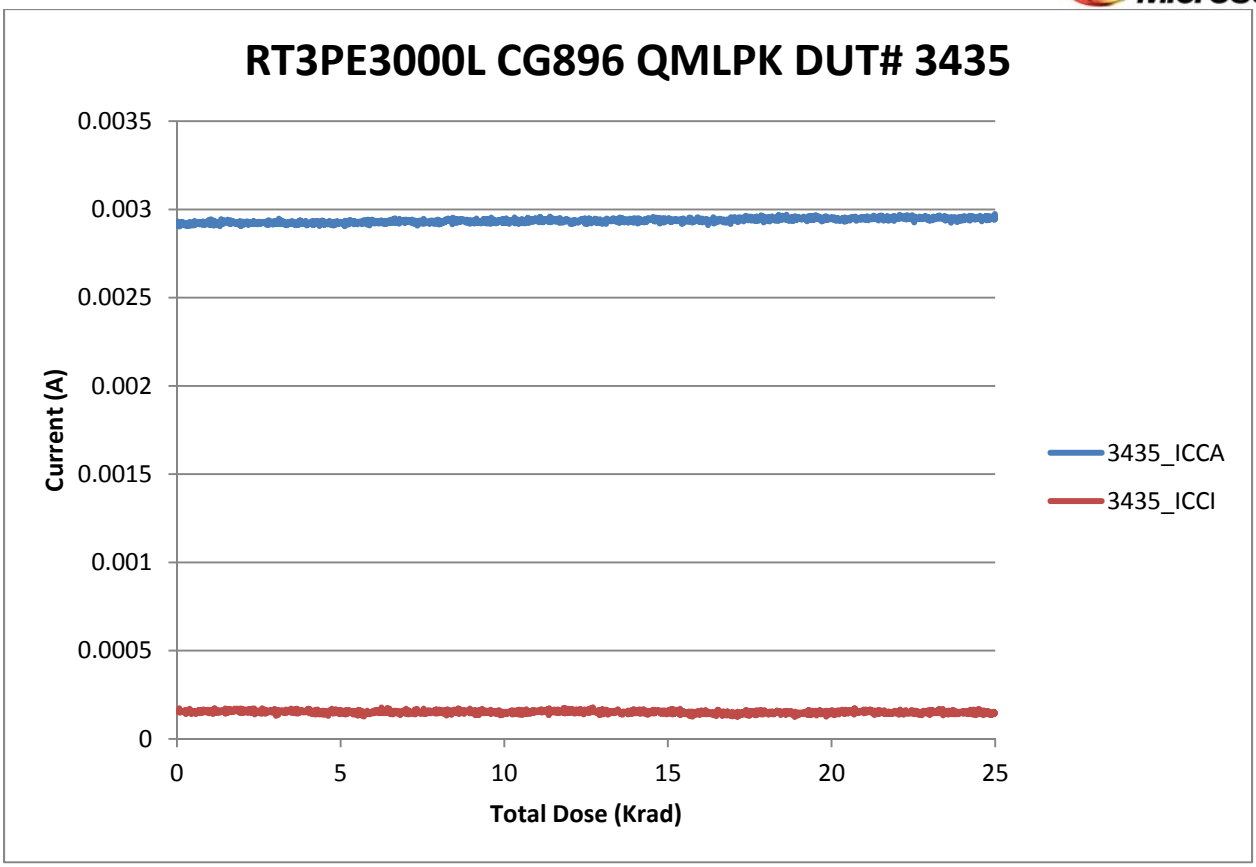


Figure 1a DUT 3435 Influx ICCI and ICCA

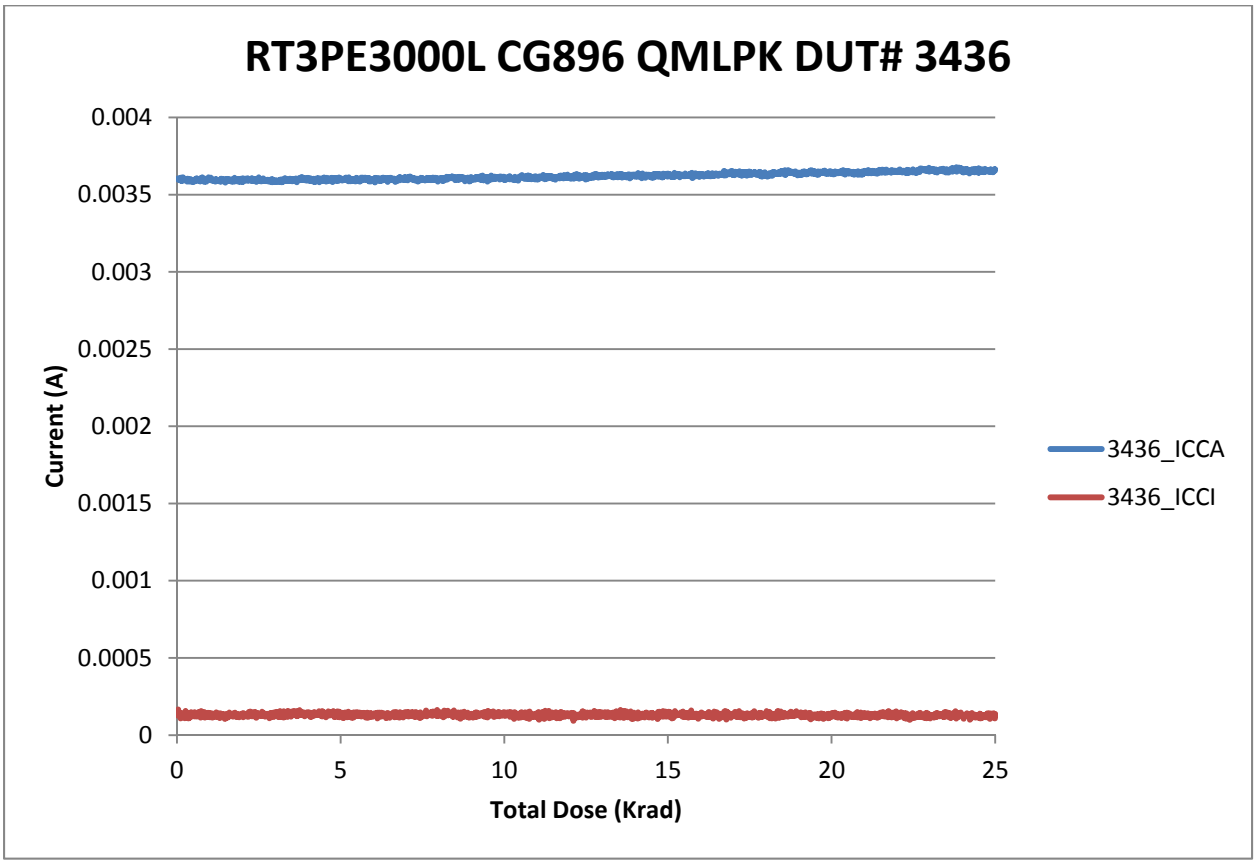


Figure 1b DUT 3436 Influx ICCI and ICCA

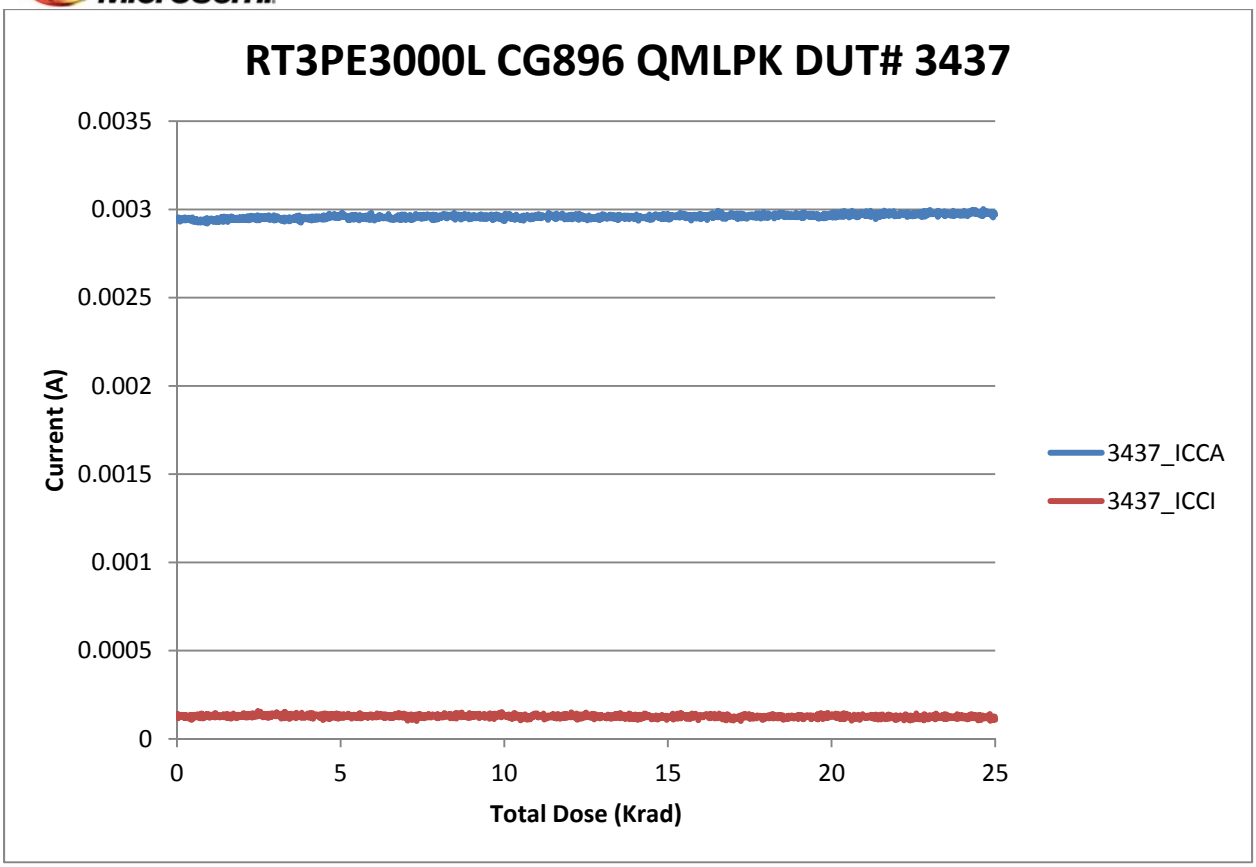


Figure 1c DUT 3437 Influx ICCI and ICCA

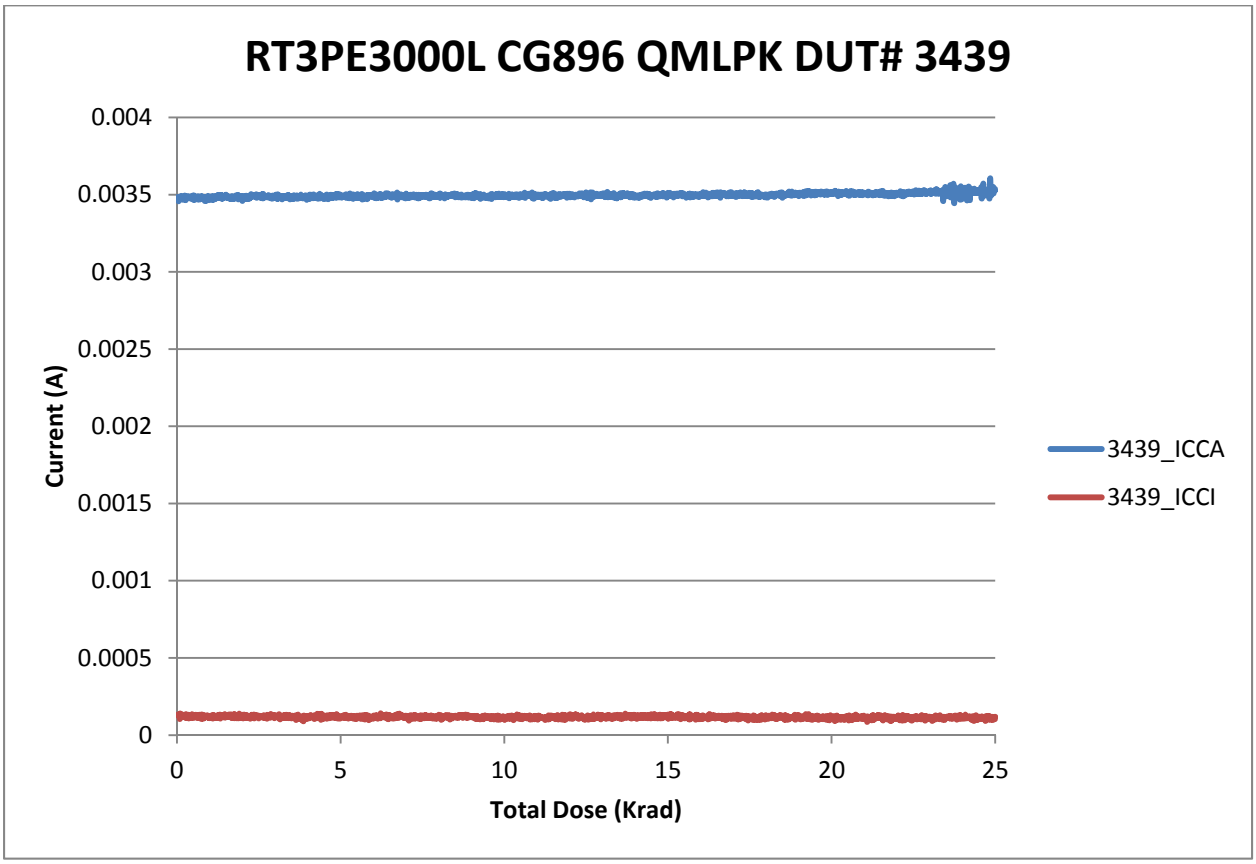


Figure 1d DUT 3439 Influx ICCI and ICCA

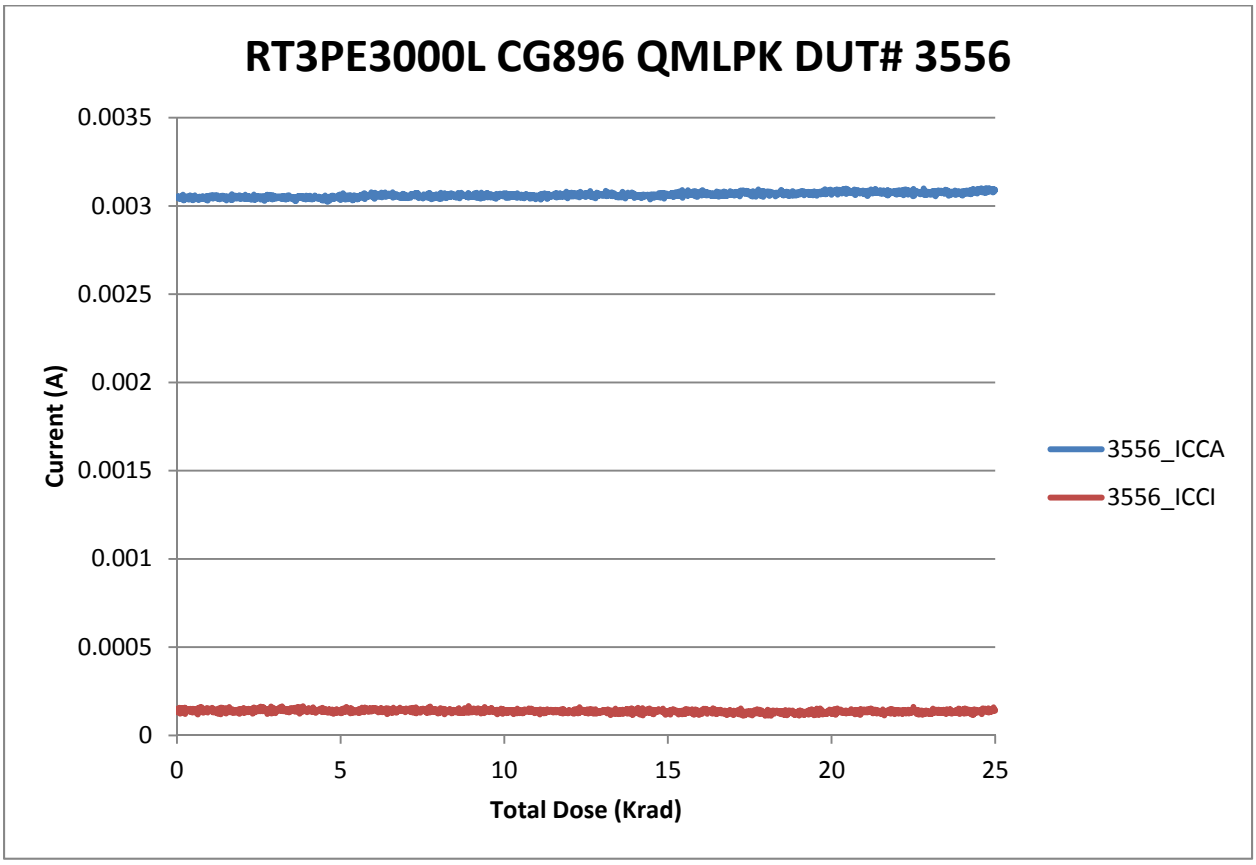


Figure 1e DUT 3556 Influx ICCI and ICCA

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.
3435	25 krad	-0.4629	-0.1235	0.1736	0.1003	-0.3841	-0.0957	0.1993	0.0751
3436	25 krad	-0.4023	-0.0813	0.1912	0.0959	-0.3878	-0.0752	0.2210	0.0959
3437	25 krad	-0.4260	-0.0835	0.1912	0.0930	-0.3110	-0.0676	0.2741	0.0720
3439	25 krad	-0.4023	-0.1029	0.1912	0.0946	-0.3362	-0.0809	0.2242	0.0710
3556	25 krad	-0.4023	-0.1008	0.2163	0.0945	-0.3012	-0.0773	0.1993	0.0704

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.
3435	25 krad	-0.2501	0.0282	0.3166	0.0938	-0.1856	0.0353	0.2815	0.0769
3436	25 krad	-0.3273	0.0256	0.3166	0.0944	-0.3023	0.0257	0.3166	0.0967
3437	25 krad	-0.3023	0.0254	0.3166	0.0968	-0.1949	0.0369	0.3092	0.0776
3439	25 krad	-0.3273	0.0316	0.3166	0.0960	-0.2231	0.0358	0.3241	0.0780
3556	25 krad	-0.2501	0.0269	0.2915	0.0917	-0.1731	0.0399	0.2591	0.0777

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.
3435	25 krad	152.8947	163.1157	192.2125	6.1625	152.2978	164.1755	193.9292	6.5285
3436	25 krad	149.6326	160.3591	190.8305	6.3797	150.8872	161.7415	192.5894	6.6077
3437	25 krad	151.8277	162.5813	197.175	6.4699	152.172	163.6798	198.2126	7.1306
3439	25 krad	149.7567	160.7639	190.9562	6.4558	149.0287	161.9366	200.0394	7.1125
3556	25 krad	150.5735	161.7506	189.9511	6.3377	149.7831	162.8813	198.7795	7.0997

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.
3435	25 krad	81.9484	84.0605	88.5022	1.0310	82.3525	84.3281	89.1117	1.0935
3436	25 krad	79.7107	82.0519	86.5548	1.1329	80.0665	82.5605	87.183	1.1529
3437	25 krad	81.5093	83.6852	89.6329	1.1143	81.5359	83.9150	89.4896	1.2016
3439	25 krad	79.6902	82.2099	86.9946	1.1287	79.8399	82.4370	88.4188	1.2163
3556	25 krad	80.1293	83.0080	87.2004	1.1547	80.4053	83.2575	89.3637	1.2741

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.
3435	25 krad	88.0331	91.5503	100.7514	2.0252	88.0057	91.8826	101.7729	2.1541
3436	25 krad	84.8783	89.5535	99.4951	2.1498	86.214	90.2122	100.1232	2.1962
3437	25 krad	87.1549	91.1598	102.8244	2.1595	87.6288	91.4895	102.7808	2.3556
3439	25 krad	85.8376	89.7162	99.6207	2.1618	85.7217	90.1056	102.4658	2.3734
3556	25 krad	86.0885	90.4128	99.4323	2.1414	86.1841	90.7936	102.4658	2.3844

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.
3435	25 krad	117.1846	122.1325	136.18	3.0468	116.9665	122.6251	137.363	3.2358
3436	25 krad	113.8773	119.4906	134.5468	3.1980	114.5673	120.5044	135.175	3.3094
3437	25 krad	116.01	121.6330	138.944	3.2345	116.2718	122.0937	139.1898	3.5441
3439	25 krad	113.94	119.6184	134.6724	3.2353	113.6975	120.2812	139.0638	3.5490
3556	25 krad	114.5046	120.5690	134.3583	3.1970	114.4519	121.1531	139.0638	3.5615

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.
3435	25 krad	176.8059	186.7630	215.4547	6.1229	176.1243	187.7416	217.173	6.4999
3436	25 krad	172.0894	182.8570	213.1305	6.3775	173.2813	184.3445	214.7009	6.5949
3437	25 krad	175.1631	185.9720	220.6056	6.4637	175.5585	186.9438	221.4564	7.1111
3439	25 krad	172.0267	183.1520	213.2561	6.4534	171.2207	184.2656	221.9603	7.1117
3556	25 krad	172.9049	184.5151	212.1882	6.3529	172.4152	185.5464	221.1414	7.1082

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.
3435	25 krad	104.7596	106.8645	110.8857	1.0570	104.8961	107.1462	111.7886	1.1273
3436	25 krad	99.6476	103.6371	108.3726	1.2005	101.457	104.2355	108.8124	1.2177
3437	25 krad	103.5898	106.3919	112.1841	1.1898	104.0231	106.5762	111.9775	1.2409
3439	25 krad	100.8924	103.8584	108.415	1.1959	101.0709	104.0640	109.3319	1.2681
3556	25 krad	101.457	104.9192	109.315	1.2719	101.5734	105.1587	111.4736	1.3795

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.
3435	25 krad	53.3442	55.2615	59.6693	1.0085	53.3326	55.4227	60.2617	1.0843
3436	25 krad	51.8971	53.8294	58.6642	1.0788	51.9641	54.1617	59.0411	1.1105
3437	25 krad	52.7796	55.0209	60.7372	1.0895	53.207	55.2181	60.8916	1.1854
3439	25 krad	51.6505	53.9080	58.6642	1.0926	51.7623	54.1534	60.0097	1.1800
3556	25 krad	51.9641	54.3607	58.6642	1.0939	52.0764	54.5795	60.3877	1.2095

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.
3435	25 krad	2.4037	2.9585	3.685	0.1587	2.6713	2.9757	3.3975	0.1256
3436	25 krad	2.4665	2.8546	3.2871	0.1526	2.5117	2.8566	3.3711	0.1440
3437	25 krad	2.5293	2.9269	3.3711	0.1555	2.6652	2.9792	3.4497	0.1245
3439	25 krad	2.3458	2.8830	3.3083	0.1537	2.5165	2.9259	3.3241	0.1325
3556	25 krad	2.4037	2.9103	3.3711	0.1524	2.6024	2.9485	3.3529	0.1338

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.
3435	25 krad	2.1576	2.4845	2.9317	0.1487	2.1945	2.5165	2.9577	0.1229
3436	25 krad	2.0321	2.4077	2.8689	0.1514	2.0267	2.4216	2.8061	0.1358
3437	25 krad	2.0841	2.4712	3.12	0.1519	2.0768	2.5078	2.8949	0.1352
3439	25 krad	2.0895	2.4294	2.9944	0.1422	2.0768	2.4827	2.8949	0.1274
3556	25 krad	2.0321	2.4560	2.9317	0.1526	2.1715	2.5008	2.8949	0.1243

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.
3435	25 krad	203.417	207.4133	217.3022	2.1036	204.0018	208.2507	218.2077	2.2476
3436	25 krad	199.751	204.3632	214.8015	2.3312	200.7291	205.3955	215.583	2.4145
3437	25 krad	202.4088	206.9214	219.7248	2.3030	203.3231	207.5332	219.5827	2.4722
3439	25 krad	199.8972	204.4461	215.1923	2.2793	200.3277	205.2397	217.6591	2.4936
3556	25 krad	201.4615	206.1758	215.2704	2.3023	201.3439	206.9177	219.6185	2.6068

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.
3435	25 krad	203.3388	207.4117	217.1459	2.1020	203.7919	208.2425	218.2861	2.2575
3436	25 krad	199.1415	204.4175	214.4108	2.3321	200.7576	205.4695	215.7393	2.4043
3437	25 krad	202.4784	206.8910	219.334	2.3028	202.9073	207.5532	219.3484	2.4861
3439	25 krad	199.8189	204.4346	214.8015	2.2844	200.0931	205.2039	217.5023	2.5016
3556	25 krad	201.3833	206.2507	215.2704	2.3030	201.1875	206.9684	219.6969	2.5955

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.
3435	25 krad	4.3509	5.0549	5.8699	0.1836	4.6022	5.2385	5.8972	0.2229
3436	25 krad	4.3509	4.9767	5.4948	0.1812	4.2727	4.9422	5.7769	0.2127
3437	25 krad	4.5073	5.0549	5.6356	0.1833	4.6022	5.2383	5.8972	0.2228
3439	25 krad	4.4227	4.9988	5.6356	0.1880	4.5241	5.1762	5.8972	0.2211
3556	25 krad	4.3446	5.0480	5.5575	0.1829	4.5241	5.2373	5.7409	0.2412

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.
3435	25 krad	4.7354	5.2114	5.64	0.1786	4.7584	5.3986	6.0384	0.2146
3436	25 krad	4.5856	5.1262	5.6511	0.1899	4.579	5.0888	5.6986	0.2073
3437	25 krad	4.6638	5.1821	5.7095	0.1793	4.8174	5.3936	6.0161	0.2364
3439	25 krad	4.5073	5.1333	5.6314	0.1825	4.6611	5.3298	5.9379	0.2205
3556	25 krad	4.6638	5.1712	5.7588	0.1825	4.7584	5.3906	5.96	0.2241

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.
3435	25 krad	214.1345	221.3922	240.5119	4.1635	214.2592	222.3709	242.5833	4.4869
3436	25 krad	209.9484	218.3236	238.1675	4.4283	210.3391	219.2165	239.1052	4.5529
3437	25 krad	213.2725	220.7838	243.7159	4.3873	213.617	221.8406	245.5616	4.9277
3439	25 krad	210.4953	218.6360	238.7145	4.3962	210.5878	219.5820	245.0914	4.9272
3556	25 krad	212.0992	220.1423	238.2456	4.3414	211.7409	221.2154	246.0319	4.9852

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.
3435	25 krad	176.6904	187.2326	217.1459	6.2340	176.2178	188.1810	218.3645	6.6043
3436	25 krad	173.9544	184.9903	216.0519	6.4356	175.2583	186.3231	217.3804	6.6608
3437	25 krad	176.065	186.7966	221.5222	6.5224	176.3741	187.8916	222.832	7.1879
3439	25 krad	174.3452	185.4093	216.4426	6.4985	173.6401	186.5695	225.0266	7.1840
3556	25 krad	175.2833	186.2787	215.1141	6.3686	174.3431	187.3773	223.6158	7.1787

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.
3435	25 krad	208.7407	223.0519	263.0963	8.3047	208.3225	224.2137	264.294	8.7892
3436	25 krad	205.6138	220.4352	261.6897	8.5686	207.719	222.0286	263.1745	8.8849
3437	25 krad	207.8026	222.4966	268.6448	8.6977	208.4007	223.9074	270.1723	9.5713
3439	25 krad	206.3956	220.9006	262.0023	8.6531	205.1199	222.3392	274.1696	9.5655
3556	25 krad	207.2497	221.9434	260.1268	8.4840	205.8229	223.3195	271.348	9.5387

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.
3435	25 krad	230.3125	259.0429	318.3462	12.4919	236.0529	260.5144	321.118	13.2267
3436	25 krad	233.203	256.2372	318.2681	12.8347	236.9727	258.2772	319.9873	13.2322
3437	25 krad	233.7499	258.4562	326.6298	13.0799	237.0684	260.5387	330.2099	14.3903
3439	25 krad	235.3972	256.8742	318.1118	12.9648	233.1627	259.0577	339.3018	14.3527
3556	25 krad	230.5468	257.7442	315.3766	12.7115	233.9438	259.8585	332.4829	14.2754

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.
3435	25 krad	9.4475	9.8242	10.2233	0.1120	9.5267	9.8514	10.1799	0.0943
3436	25 krad	9.5992	9.9401	10.3271	0.1202	9.5742	9.9497	10.3271	0.1179
3437	25 krad	9.6485	10.0203	10.3837	0.1169	9.7263	10.0633	10.3544	0.1014
3439	25 krad	9.8702	10.1839	10.5733	0.1206	9.8131	10.2181	10.5573	0.1074
3556	25 krad	9.8952	10.3089	10.6482	0.1257	10.0007	10.3444	10.6531	0.1114

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.
3435	25 krad	11.9348	12.3465	12.7979	0.1209	11.9962	12.3777	12.8228	0.1069
3436	25 krad	12.1125	12.4858	12.9444	0.1266	12.071	12.4770	12.8945	0.1296
3437	25 krad	12.1106	12.5945	13.0228	0.1253	12.2603	12.6358	12.9791	0.1125
3439	25 krad	12.4643	12.7946	13.2285	0.1329	12.3756	12.8248	13.1968	0.1207
3556	25 krad	12.4394	12.9243	13.3059	0.1410	12.5949	12.9565	13.2891	0.1262

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.
3435	25 krad	5.7544	6.1086	6.4296	0.1024	5.8807	6.1545	6.4649	0.0768
3436	25 krad	5.8486	6.1913	6.5158	0.1048	5.8856	6.2144	6.5311	0.1042
3437	25 krad	5.8812	6.2436	6.5594	0.1026	6.0096	6.2904	6.5646	0.0835
3439	25 krad	6.0236	6.3475	6.76	0.1037	6.0699	6.3953	6.7128	0.0872
3556	25 krad	6.081	6.4363	6.7586	0.1109	6.1956	6.4855	6.7391	0.0871

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.
3435	25 krad	8.024	8.4688	8.8308	0.1088	8.2066	8.5204	8.8184	0.0877
3436	25 krad	8.249	8.5838	8.9313	0.1104	8.1993	8.5873	9.006	0.1148
3437	25 krad	8.2667	8.6573	9.006	0.1094	8.3891	8.7089	9.008	0.0949
3439	25 krad	8.4734	8.7930	9.192	0.1136	8.4565	8.8415	9.1375	0.0976
3556	25 krad	8.4734	8.8998	9.2661	0.1206	8.6287	8.9588	9.2655	0.1027

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.
3435	25 krad	3.1918	3.5134	3.8244	0.0959	3.296	3.5537	3.8438	0.0730
3436	25 krad	3.2612	3.5808	3.8544	0.0980	3.2786	3.6021	3.8876	0.0993
3437	25 krad	3.242	3.5982	3.8768	0.0965	3.3937	3.6414	3.8937	0.0741
3439	25 krad	3.3732	3.6643	4.04	0.0961	3.407	3.7043	3.9864	0.0748
3556	25 krad	3.3928	3.7274	4.0243	0.0987	3.4964	3.7679	4.0451	0.0777

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.
3435	25 krad	3.1918	3.5134	3.8244	0.0959	3.296	3.5537	3.8438	0.0730
3436	25 krad	3.2612	3.5808	3.8544	0.0980	3.2786	3.6021	3.8876	0.0993
3437	25 krad	3.242	3.5982	3.8768	0.0965	3.3937	3.6414	3.8937	0.0741
3439	25 krad	3.3732	3.6643	4.04	0.0961	3.407	3.7043	3.9864	0.0748
3556	25 krad	3.3928	3.7274	4.0243	0.0987	3.4964	3.7679	4.0451	0.0777

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.
3435	25 krad	16.7419	17.2007	17.7146	0.1353	16.8251	17.2272	17.6848	0.1208
3436	25 krad	16.9417	17.4202	17.8556	0.1360	16.7329	17.3805	17.8556	0.1366
3437	25 krad	17.0124	17.4921	17.9985	0.1447	17.1668	17.5365	17.984	0.1343
3439	25 krad	17.3782	17.7467	18.247	0.1522	17.2995	17.7815	18.2587	0.1444
3556	25 krad	17.3532	17.8738	18.3085	0.1605	17.4502	17.9132	18.2832	0.1498

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.
3435	25 krad	17.741	18.2131	18.6923	0.1387	17.8774	18.2454	18.7826	0.1250
3436	25 krad	18.0754	18.4673	18.9267	0.1388	18.0158	18.4248	18.8768	0.1378
3437	25 krad	18.0583	18.5260	19.0005	0.1486	18.1781	18.5736	19.0312	0.1358
3439	25 krad	18.4009	18.7931	19.2959	0.1575	18.3295	18.8238	19.3553	0.1480
3556	25 krad	18.4009	18.8974	19.4707	0.1608	18.5053	18.9518	19.3213	0.1531

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.
3435	25 krad	1.435	1.4619	1.4745	0.0061	1.4321	1.4595	1.4727	0.0064
3436	25 krad	1.4367	1.4647	1.4772	0.0062	1.4348	1.4634	1.4753	0.0064
3437	25 krad	1.4255	1.4600	1.4726	0.0063	1.4248	1.4573	1.4707	0.0069
3439	25 krad	1.4345	1.4620	1.4754	0.0063	1.4221	1.4596	1.4731	0.0069
3556	25 krad	1.4366	1.4619	1.4748	0.0061	1.4246	1.4595	1.4742	0.0068

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.
3435	25 krad	1.222	1.2331	1.2395	0.0021	1.2227	1.2341	1.2404	0.0020
3436	25 krad	1.2219	1.2362	1.2434	0.0024	1.2206	1.2352	1.242	0.0024
3437	25 krad	1.2169	1.2306	1.2373	0.0022	1.2185	1.2317	1.2378	0.0022
3439	25 krad	1.2214	1.2337	1.2402	0.0021	1.2207	1.2348	1.2408	0.0021
3556	25 krad	1.2203	1.2331	1.2394	0.0021	1.2197	1.2342	1.2403	0.0021

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.
3435	25 krad	1.213	1.2252	1.2326	0.0026	1.2138	1.2260	1.2331	0.0026
3436	25 krad	1.2128	1.2283	1.2364	0.0029	1.2119	1.2272	1.2347	0.0029
3437	25 krad	1.2089	1.2228	1.2301	0.0028	1.2097	1.2237	1.2304	0.0029
3439	25 krad	1.2134	1.2258	1.2329	0.0027	1.2094	1.2267	1.2337	0.0028
3556	25 krad	1.2122	1.2252	1.2317	0.0026	1.2097	1.2262	1.2329	0.0028

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.
3435	25 krad	1.1741	1.1876	1.1965	0.0035	1.175	1.1882	1.197	0.0035
3436	25 krad	1.1753	1.1913	1.2004	0.0037	1.1737	1.1900	1.199	0.0038
3437	25 krad	1.1673	1.1847	1.1934	0.0037	1.17	1.1854	1.1945	0.0039
3439	25 krad	1.1752	1.1884	1.1981	0.0036	1.1688	1.1890	1.1987	0.0038
3556	25 krad	1.174	1.1876	1.1967	0.0035	1.1694	1.1883	1.1976	0.0038

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.
3435	25 krad	1.1426	1.1687	1.1823	0.0062	1.1421	1.1690	1.1831	0.0064
3436	25 krad	1.1449	1.1726	1.1853	0.0062	1.1432	1.1711	1.1836	0.0065
3437	25 krad	1.1315	1.1660	1.1793	0.0064	1.1348	1.1660	1.1806	0.0069
3439	25 krad	1.1424	1.1694	1.1839	0.0063	1.133	1.1695	1.1844	0.0069
3556	25 krad	1.1449	1.1689	1.1825	0.0062	1.1349	1.1690	1.1845	0.0069

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.
3435	25 krad	887.5695	914.4630	927.8403	3.8481	888.7005	915.3214	927.9031	3.8006
3436	25 krad	887.1936	919.2571	932.9487	4.4076	885.005	917.7675	931.3253	4.4630
3437	25 krad	879.3773	910.0199	922.5716	4.2199	880.6588	911.1244	923.7535	4.1502
3439	25 krad	888.6005	915.9583	929.4037	3.8966	888.0263	917.0575	928.998	3.8934
3556	25 krad	886.2556	914.5157	928.0773	3.9165	886.1453	915.6547	929.1544	3.9238

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.
3435	25 krad	1.0223	1.0319	1.0367	0.0016	1.0233	1.0331	1.0377	0.0017
3436	25 krad	1.0224	1.0338	1.0394	0.0018	1.021	1.0332	1.0384	0.0019
3437	25 krad	1.0198	1.0303	1.035	0.0017	1.0206	1.0314	1.0361	0.0018
3439	25 krad	1.0226	1.0325	1.0376	0.0017	1.0221	1.0336	1.038	0.0017
3556	25 krad	1.0219	1.0320	1.0368	0.0016	1.0211	1.0332	1.0378	0.0017

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.
3435	25 krad	1.1309	1.1320	1.1326	0.0002	1.1325	1.1332	1.134	0.0003
3436	25 krad	1.1309	1.1320	1.1327	0.0003	1.1309	1.1319	1.1329	0.0003
3437	25 krad	1.1309	1.1319	1.1326	0.0003	1.1323	1.1332	1.1341	0.0003
3439	25 krad	1.1312	1.1320	1.1329	0.0002	1.1322	1.1333	1.1339	0.0003
3556	25 krad	1.1312	1.1319	1.1326	0.0003	1.1325	1.1333	1.1342	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.
3435	25 krad	1.3929	1.3938	1.3947	0.0002	1.3943	1.3951	1.3961	0.0003
3436	25 krad	1.3929	1.3939	1.3947	0.0002	1.3931	1.3938	1.3946	0.0003
3437	25 krad	1.3929	1.3938	1.3946	0.0003	1.3943	1.3951	1.3961	0.0003
3439	25 krad	1.3931	1.3938	1.3945	0.0002	1.3943	1.3951	1.3961	0.0003
3556	25 krad	1.3931	1.3939	1.3947	0.0002	1.3943	1.3951	1.396	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.
3435	25 krad	2.6238	2.6341	2.6443	0.0035	2.6248	2.6348	2.6452	0.0034
3436	25 krad	2.6247	2.6397	2.6495	0.0039	2.6226	2.6379	2.6477	0.0039
3437	25 krad	2.6165	2.6292	2.6399	0.0038	2.6174	2.6302	2.6408	0.0037
3439	25 krad	2.6227	2.6338	2.646	0.0036	2.6192	2.6345	2.6465	0.0036
3556	25 krad	2.6212	2.6334	2.6449	0.0034	2.6184	2.6343	2.6446	0.0035

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.
3435	25 krad	2.6238	2.6341	2.6445	0.0035	2.6246	2.6349	2.6448	0.0034
3436	25 krad	2.6247	2.6398	2.6498	0.0039	2.6226	2.6380	2.6478	0.0040
3437	25 krad	2.6162	2.6292	2.6399	0.0038	2.6173	2.6302	2.6414	0.0037
3439	25 krad	2.6227	2.6338	2.6461	0.0036	2.6192	2.6346	2.6466	0.0036
3556	25 krad	2.6212	2.6333	2.6434	0.0034	2.6186	2.6344	2.6446	0.0035

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.
3435	25 krad	2.9884	2.9891	2.9899	0.0002	2.9898	2.9908	2.9915	0.0003
3436	25 krad	2.9885	2.9892	2.9898	0.0002	2.9881	2.9890	2.9898	0.0003
3437	25 krad	2.9882	2.9889	2.9896	0.0002	2.9899	2.9907	2.9914	0.0003
3439	25 krad	2.9884	2.9891	2.9899	0.0002	2.9899	2.9908	2.9914	0.0003
3556	25 krad	2.9882	2.9891	2.9899	0.0003	2.99	2.9908	2.9916	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.
3435	25 krad	2.6882	2.6889	2.6897	0.0003	2.6872	2.6881	2.6888	0.0003
3436	25 krad	2.6883	2.6890	2.6899	0.0003	2.6881	2.6889	2.6897	0.0003
3437	25 krad	2.688	2.6888	2.6896	0.0003	2.6873	2.6880	2.6888	0.0003
3439	25 krad	2.688	2.6889	2.6897	0.0003	2.6873	2.6881	2.689	0.0003
3556	25 krad	2.6881	2.6889	2.6897	0.0003	2.6873	2.6881	2.6889	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.
3435	25 krad	2.5992	2.6174	2.6315	0.0049	2.6007	2.6184	2.6327	0.0046
3436	25 krad	2.6069	2.6231	2.6352	0.0051	2.6037	2.6205	2.6332	0.0054
3437	25 krad	2.5887	2.6127	2.6268	0.0051	2.5945	2.6140	2.628	0.0050
3439	25 krad	2.6004	2.6171	2.6328	0.0050	2.5966	2.6183	2.6335	0.0049
3556	25 krad	2.6003	2.6168	2.6299	0.0048	2.5967	2.6180	2.6323	0.0049

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.
3435	25 krad	2.6685	2.6934	2.7083	0.0062	2.6677	2.6941	2.7096	0.0064
3436	25 krad	2.672	2.6975	2.7139	0.0063	2.6699	2.6959	2.7097	0.0066
3437	25 krad	2.6557	2.6903	2.7053	0.0064	2.6596	2.6908	2.7067	0.0069
3439	25 krad	2.6683	2.6933	2.7094	0.0063	2.6584	2.6937	2.7096	0.0069
3556	25 krad	2.6695	2.6932	2.7084	0.0061	2.6598	2.6936	2.7098	0.0068

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.
3435	25 krad	2.632	2.6666	2.6853	0.0082	2.6309	2.6669	2.6865	0.0085
3436	25 krad	2.6352	2.6711	2.6892	0.0083	2.6333	2.6695	2.6866	0.0086
3437	25 krad	2.6175	2.6634	2.6817	0.0084	2.6212	2.6634	2.6831	0.0092
3439	25 krad	2.6315	2.6664	2.686	0.0083	2.6181	2.6666	2.6861	0.0091
3556	25 krad	2.6341	2.6666	2.6849	0.0081	2.621	2.6666	2.6869	0.0091

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.
3435	25 krad	2.6527	2.7088	2.7317	0.0123	2.6518	2.7089	2.7337	0.0128
3436	25 krad	2.6535	2.7118	2.747	0.0125	2.651	2.7097	2.7318	0.0128
3437	25 krad	2.6373	2.7066	2.7295	0.0127	2.6399	2.7058	2.7315	0.0138
3439	25 krad	2.6507	2.7081	2.7321	0.0126	2.6297	2.7078	2.732	0.0137
3556	25 krad	2.6547	2.7089	2.7321	0.0123	2.6391	2.7085	2.7344	0.0136

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.
3435	25 krad	-14.7712	-14.2374	-13.7988	0.1739	-14.6168	-14.1015	-13.5561	0.1584
3436	25 krad	-14.9826	-14.2870	-13.7485	0.2037	-14.7988	-14.1532	-13.5777	0.1985
3437	25 krad	-14.7319	-14.0644	-13.4835	0.1957	-14.5167	-13.9499	-13.4594	0.1789
3439	25 krad	-15.0048	-14.2514	-13.7753	0.2007	-14.7929	-14.1089	-13.6406	0.1844
3556	25 krad	-14.8795	-14.2517	-13.7488	0.1764	-14.6895	-14.1332	-13.6523	0.1577

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.
3435	25 krad	-18.0169	-17.3965	-16.9071	0.1945	-17.7832	-17.2334	-16.6209	0.1783
3436	25 krad	-18.1674	-17.4969	-16.8375	0.2291	-17.9873	-17.3261	-16.6807	0.2250
3437	25 krad	-17.9166	-17.1986	-16.4993	0.2223	-17.6875	-17.0613	-16.4981	0.2018
3439	25 krad	-18.3371	-17.4006	-16.8294	0.2261	-17.9998	-17.2582	-16.7204	0.2083
3556	25 krad	-18.0114	-17.4061	-16.8652	0.1982	-17.8661	-17.2670	-16.7062	0.1810

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.
3435	25 krad	-9.6413	-9.1806	-8.8095	0.1367	-9.5319	-9.1516	-8.7473	0.1187
3436	25 krad	-9.7416	-9.1966	-8.7986	0.1563	-9.6413	-9.1018	-8.6985	0.1520
3437	25 krad	-9.6162	-9.0605	-8.5985	0.1503	-9.5233	-9.0481	-8.6332	0.1333
3439	25 krad	-9.7934	-9.1908	-8.7451	0.1528	-9.6318	-9.1615	-8.8428	0.1330
3556	25 krad	-9.643	-9.1930	-8.8231	0.1369	-9.6118	-9.1800	-8.796	0.1177

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.
3435	25 krad	-12.8511	-12.3246	-11.8432	0.1604	-12.7824	-12.2752	-11.7622	0.1431
3436	25 krad	-12.9779	-12.3672	-11.8705	0.1835	-12.8511	-12.2424	-11.7457	0.1810
3437	25 krad	-12.7759	-12.1762	-11.6254	0.1791	-12.6691	-12.1463	-11.6684	0.1584
3439	25 krad	-13.0756	-12.3362	-11.9008	0.1811	-12.8888	-12.2991	-11.9129	0.1627
3556	25 krad	-12.8574	-12.3422	-11.8736	0.1615	-12.8135	-12.3126	-11.9	0.1423

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.
3435	25 krad	-5.9783	-5.5971	-5.1992	0.1164	-5.9219	-5.5870	-5.2839	0.0953
3436	25 krad	-6.0302	-5.5884	-5.277	0.1266	-5.96	-5.5355	-5.2445	0.1242
3437	25 krad	-5.955	-5.5116	-5.1185	0.1246	-5.8737	-5.5076	-5.2217	0.1039
3439	25 krad	-6.1103	-5.6029	-5.2698	0.1268	-6.0241	-5.5952	-5.3026	0.1063
3556	25 krad	-6.0101	-5.6124	-5.2226	0.1162	-5.9642	-5.6088	-5.2998	0.0950

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.
3435	25 krad	-7.5652	-7.1554	-6.7787	0.1248	-7.505	-7.1298	-6.7539	0.1044
3436	25 krad	-7.6151	-7.1448	-6.7965	0.1381	-7.5652	-7.0762	-6.7214	0.1368
3437	25 krad	-7.5348	-7.0528	-6.6672	0.1350	-7.4271	-7.0455	-6.7105	0.1160
3439	25 krad	-7.737	-7.1625	-6.7536	0.1368	-7.6275	-7.1450	-6.855	0.1157
3556	25 krad	-7.5635	-7.1617	-6.7978	0.1245	-7.5608	-7.1594	-6.8152	0.1055

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.
3435	25 krad	-35.7963	-34.7745	-34.0203	0.3117	-35.5599	-34.6711	-33.6887	0.2983
3436	25 krad	-36.1762	-35.1613	-34.0098	0.3755	-35.9257	-34.8274	-33.6604	0.3707
3437	25 krad	-35.5957	-34.4484	-33.4475	0.3441	-35.3408	-34.3668	-33.3927	0.3270
3439	25 krad	-36.3266	-34.8905	-34.0705	0.3553	-35.8596	-34.7896	-34.0726	0.3408
3556	25 krad	-35.8076	-34.8051	-33.9644	0.3091	-35.7039	-34.7194	-33.8532	0.2971

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.
3435	25 krad	-35.7963	-34.7745	-34.0203	0.3117	-35.5599	-34.6711	-33.6887	0.2983
3436	25 krad	-36.1762	-35.1613	-34.0098	0.3755	-35.9257	-34.8274	-33.6604	0.3707
3437	25 krad	-35.5957	-34.4484	-33.4475	0.3441	-35.3408	-34.3668	-33.3927	0.3270
3439	25 krad	-36.3266	-34.8905	-34.0705	0.3553	-35.8596	-34.7896	-34.0726	0.3408
3556	25 krad	-35.8076	-34.8051	-33.9644	0.3091	-35.7039	-34.7194	-33.8532	0.2971

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 9a Propagation Delay to Irradiation Dose, Vcc =1.5V

DUT	Pre-Irradiation (ns)	Post-25 krad(ns)	Post-Annealing (ns)
3435	158.3	175	172.9
3556	157.1	170.8	169.3
3437	158.5	174.35	173.6
3439	154.25	168.55	167.9
3436	150.8	162.5	163.9

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

DUT	(Compared to Pre-irradiation)	Post-25 krad(%)	Post-Annealing (%)
3435	-	10.5%	9.2%
3556	-	8.7%	7.8%
3437	-	10.8%	9.5%
3439	-	9.3%	8.8%
3436	-	7.8%	8.7%

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

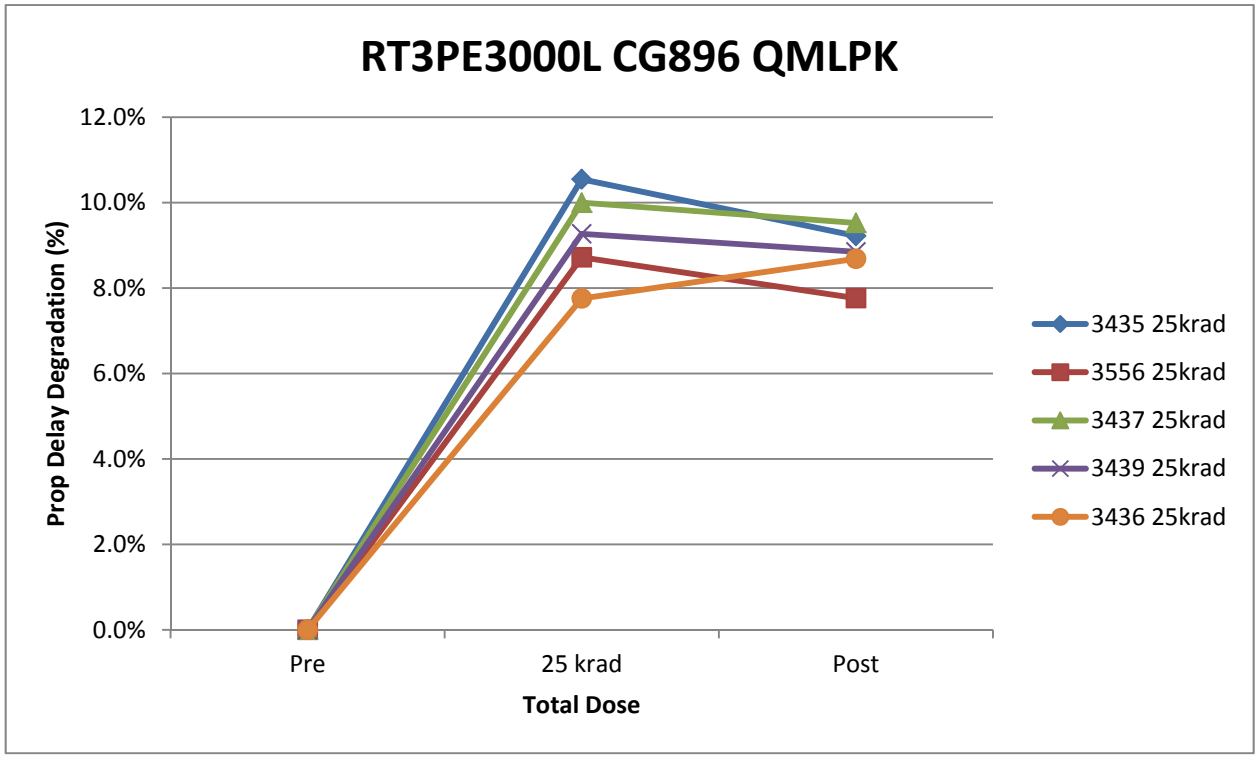


Figure 2 Degradation of Propagation Delay versus TID and Annealing

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.

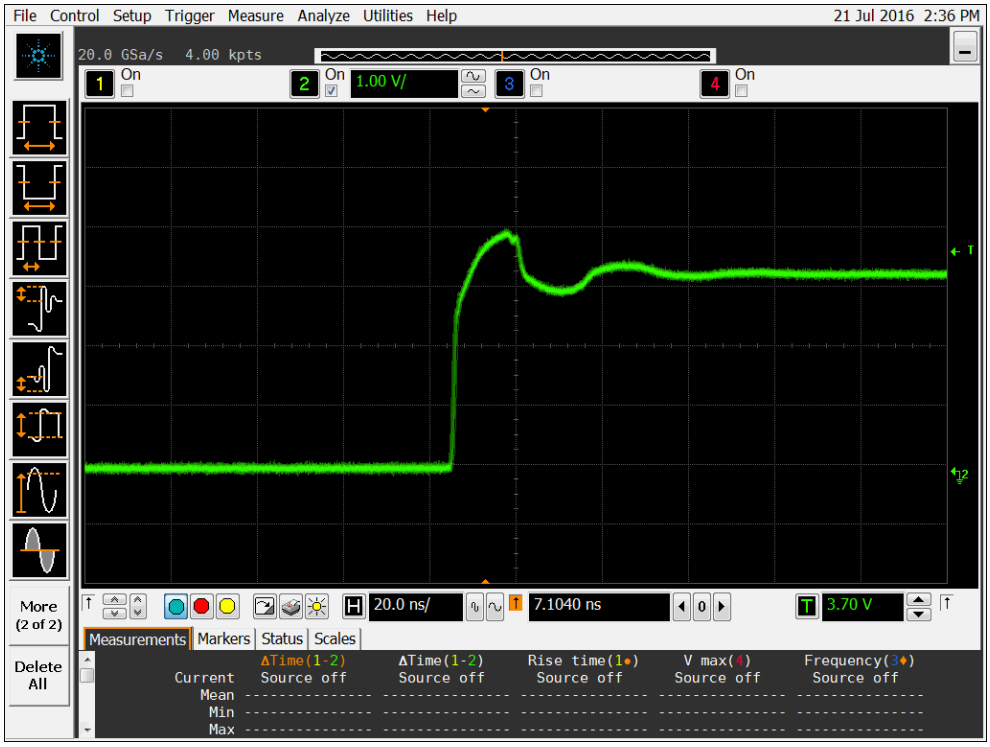


Figure 3a DUT 3435 Pre-Irradiation Rising Edge

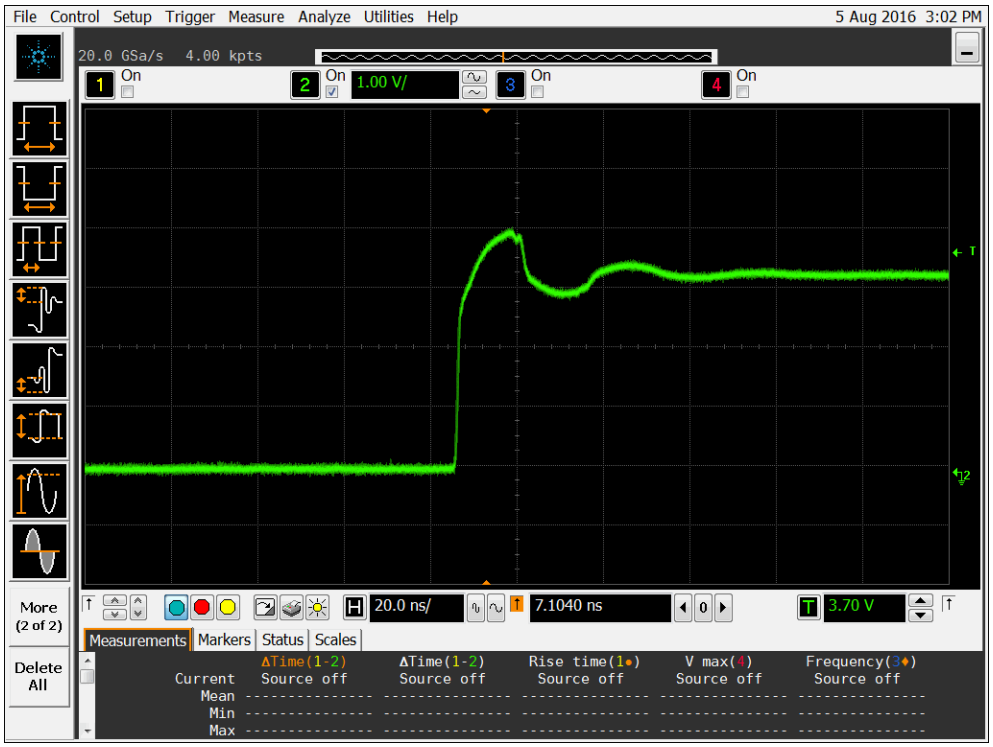


Figure 3b DUT 3435 Post-Annealing Rising Edge

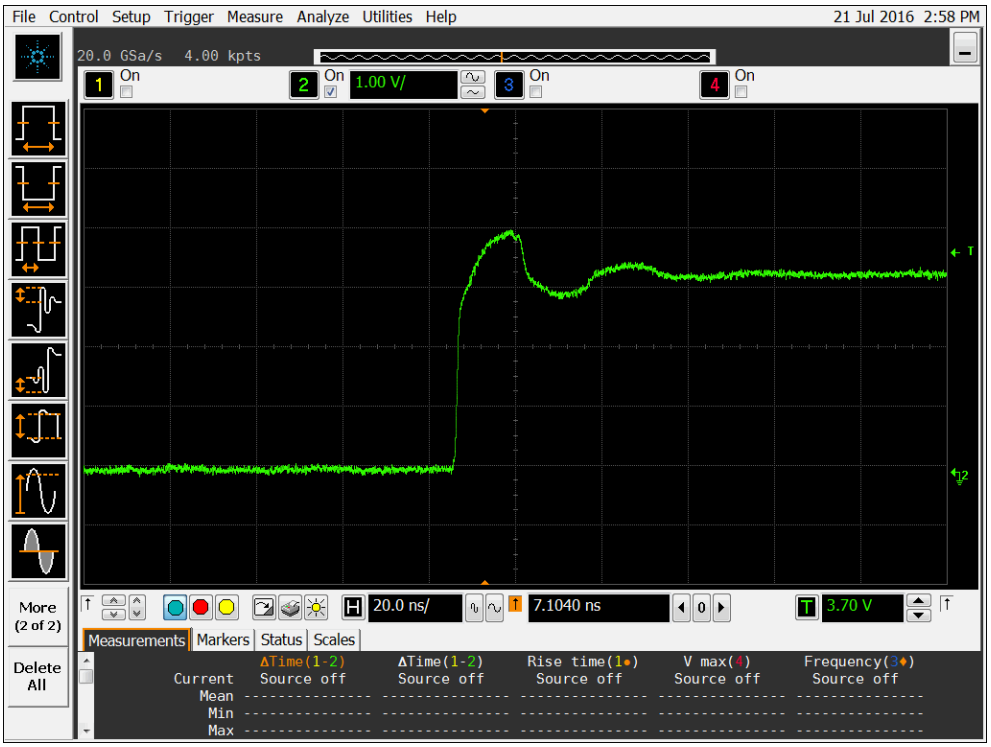


Figure 4a DUT 3436 Pre-Irradiation Rising Edge

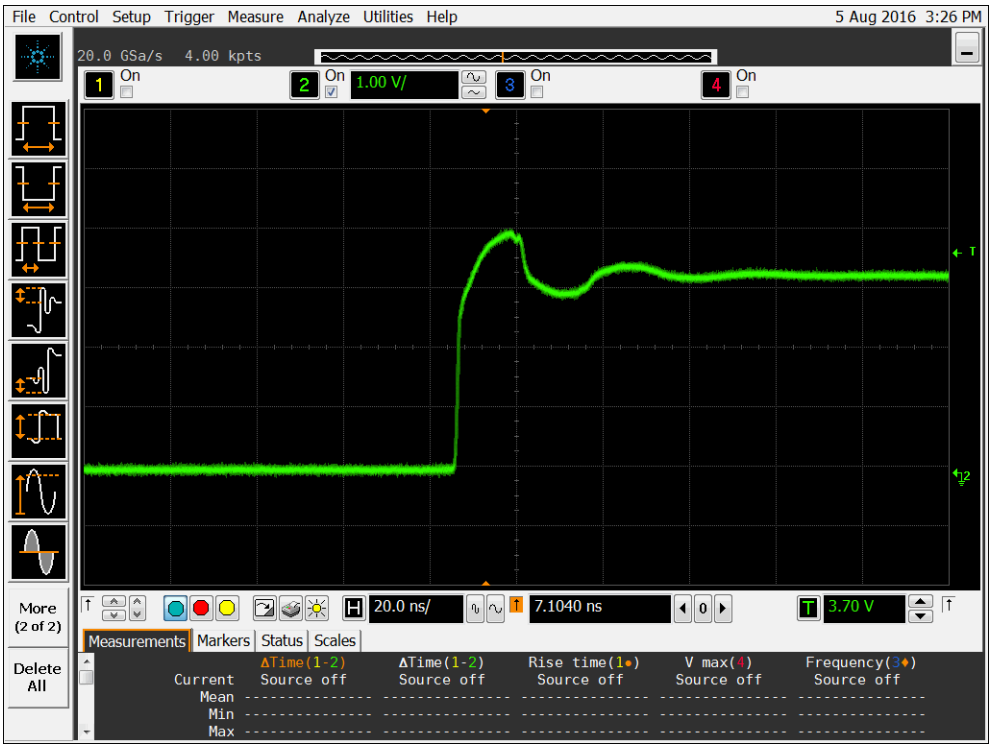


Figure 4b DUT 3436 Post-Annealing Rising Edge

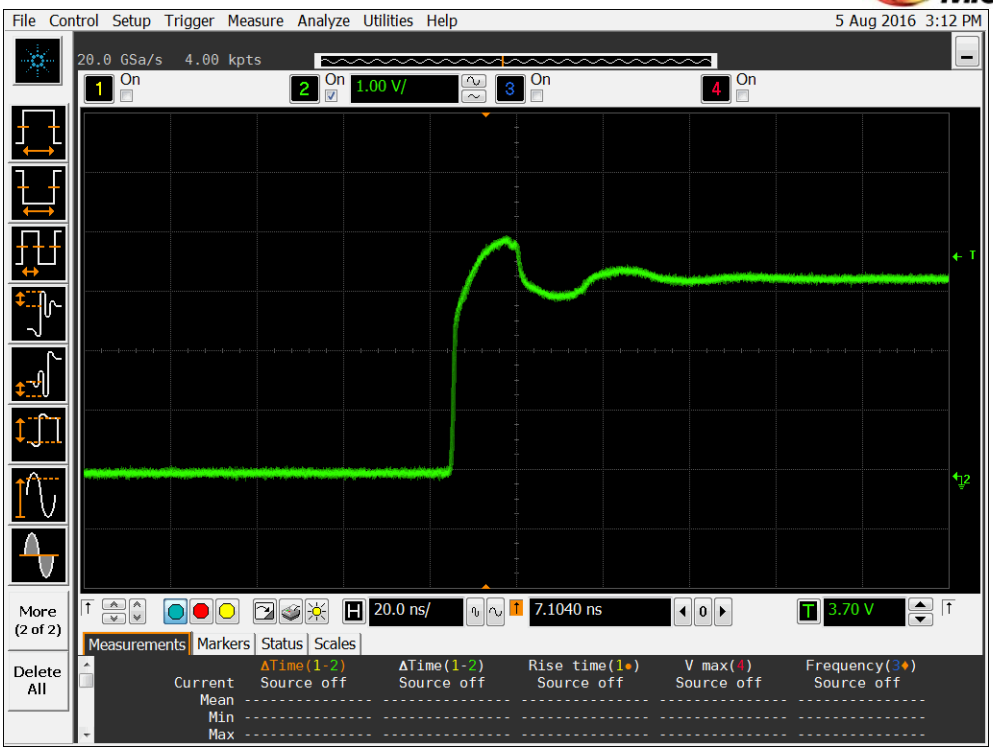


Figure 5a DUT 3437 Pre-Irradiation Rising Edge

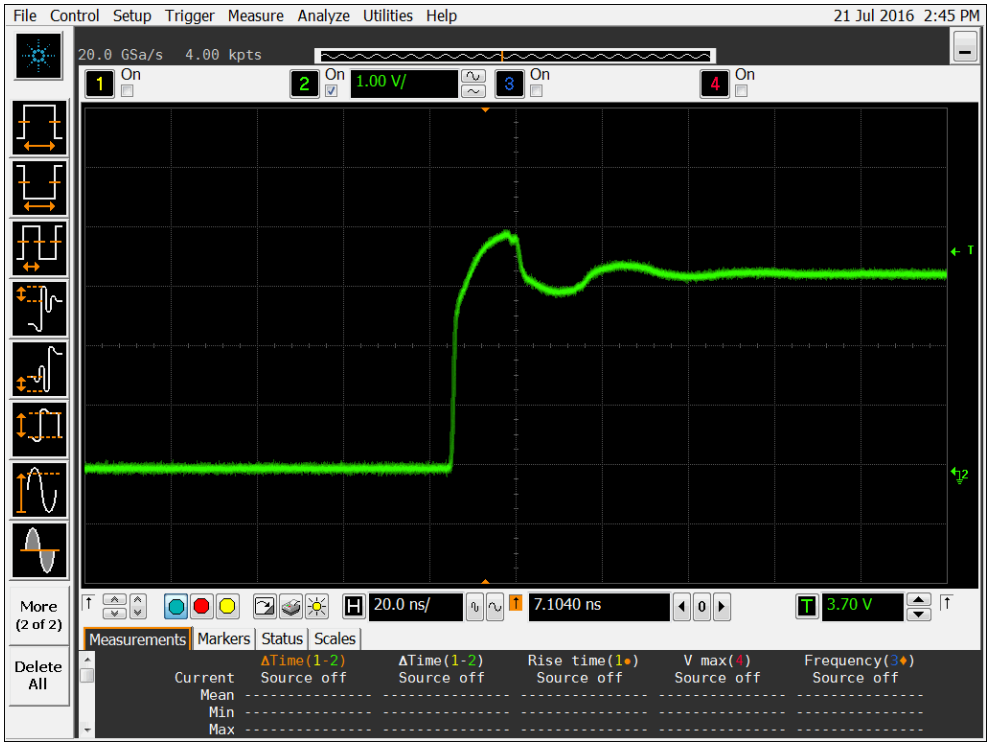


Figure 5b DUT 3437 Post-Annealing Rising Edge

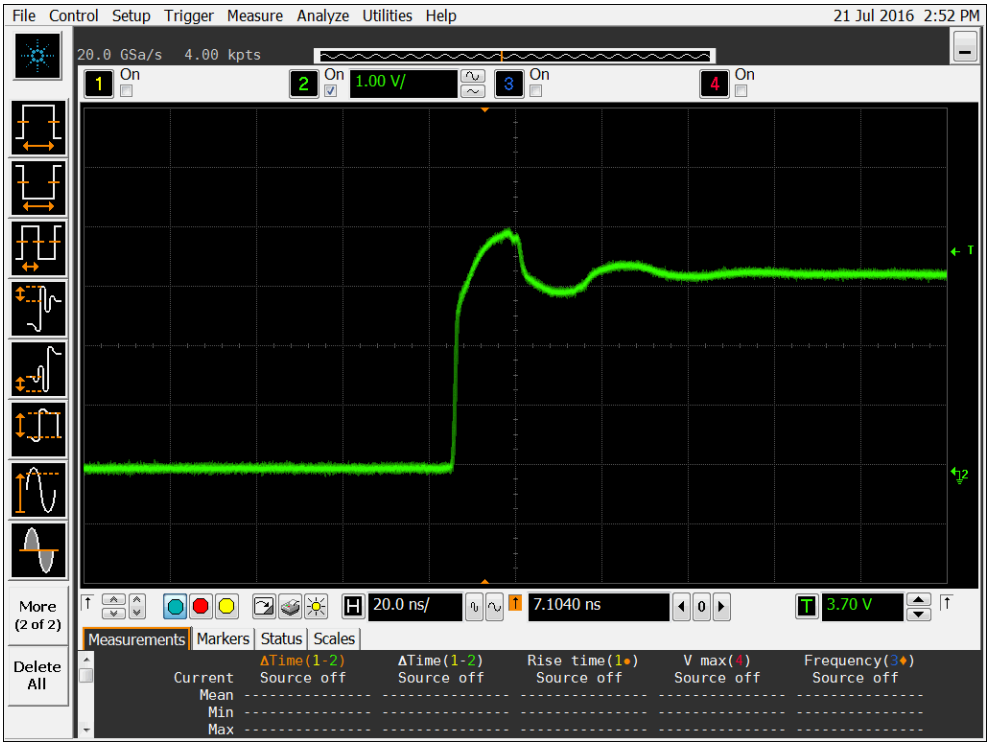


Figure 6a DUT 3439 Pre-Irradiation Rising Edge

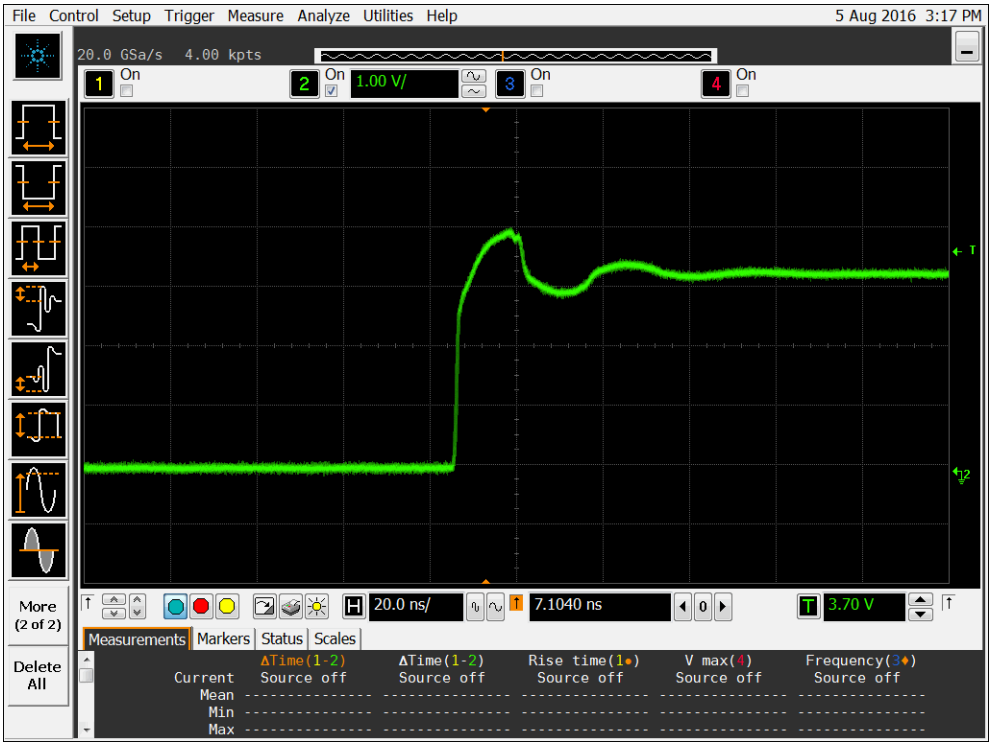


Figure 6b DUT 3439 Post-Annealing Rising Edge

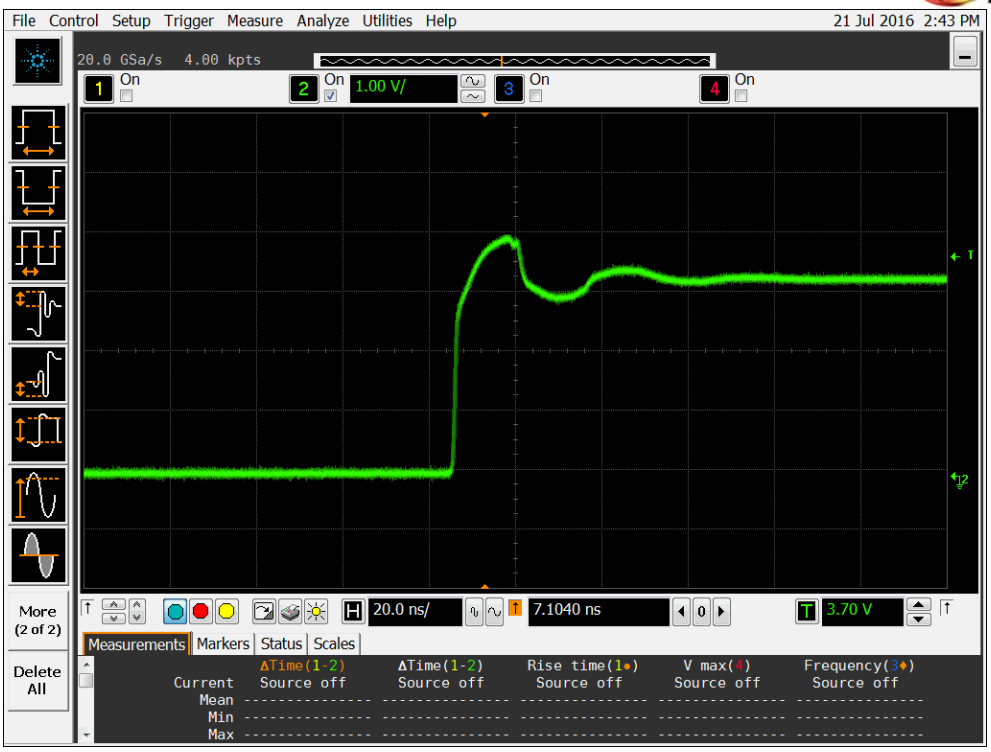


Figure 7a DUT 3556 Pre-Irradiation Rising Edge

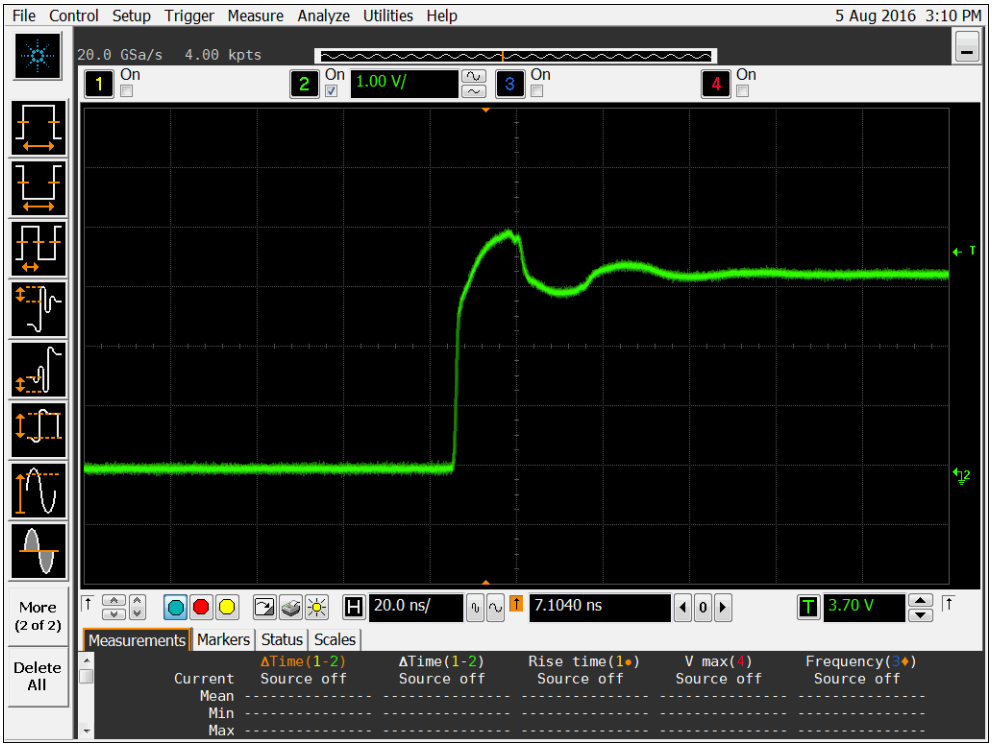


Figure 7b DUT 3556 Post-Annealing Rising Edge

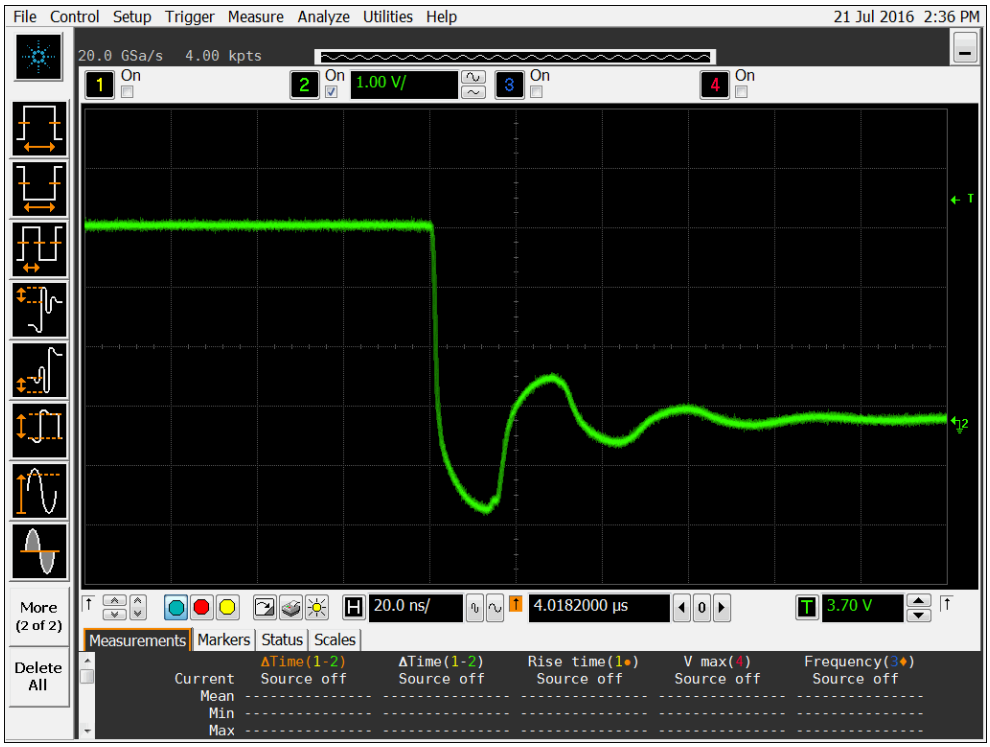


Figure 8a DUT 3435 Pre-Irradiation Falling Edge

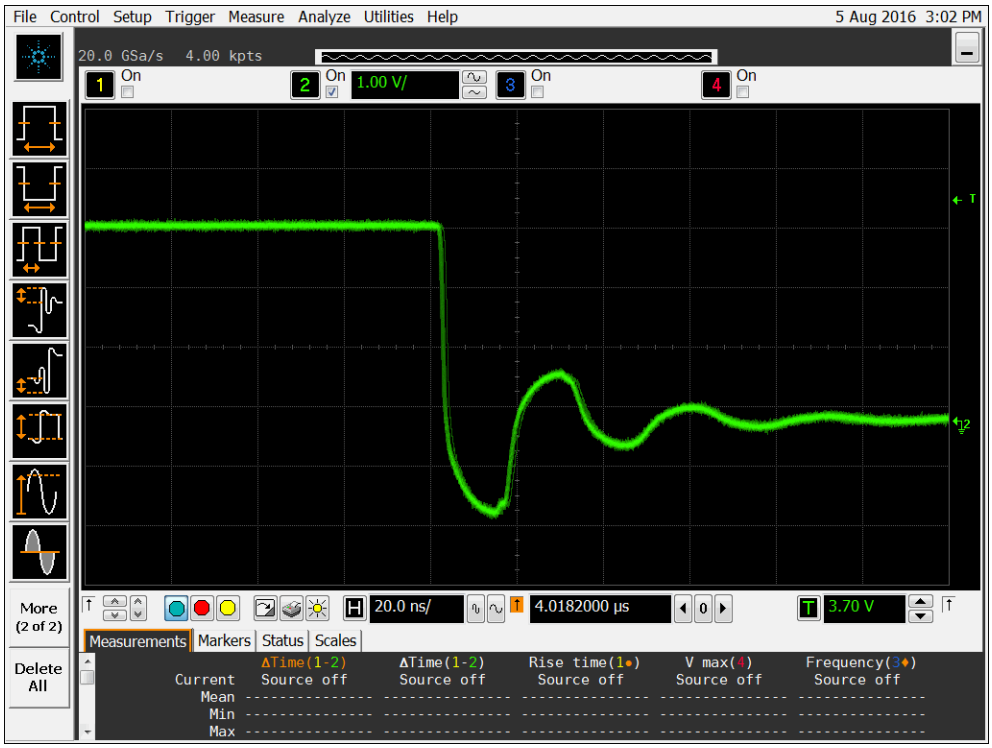


Figure 8b DUT 3435 Post-Annealing Falling Edge

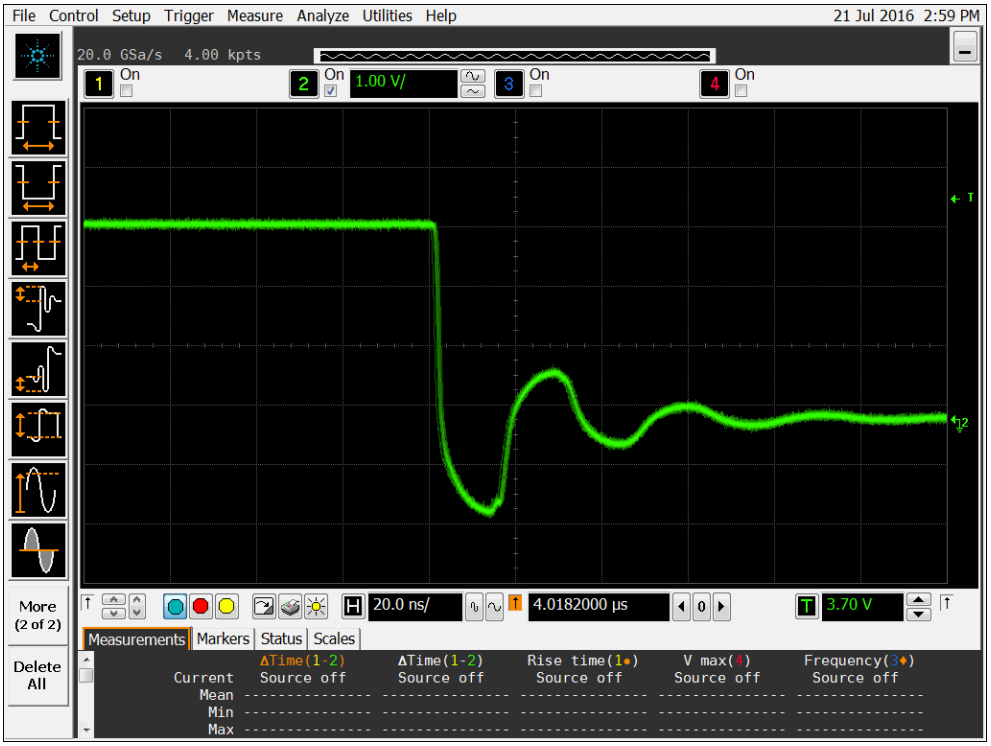


Figure 9a DUT 3436 Pre-Irradiation Falling Edge

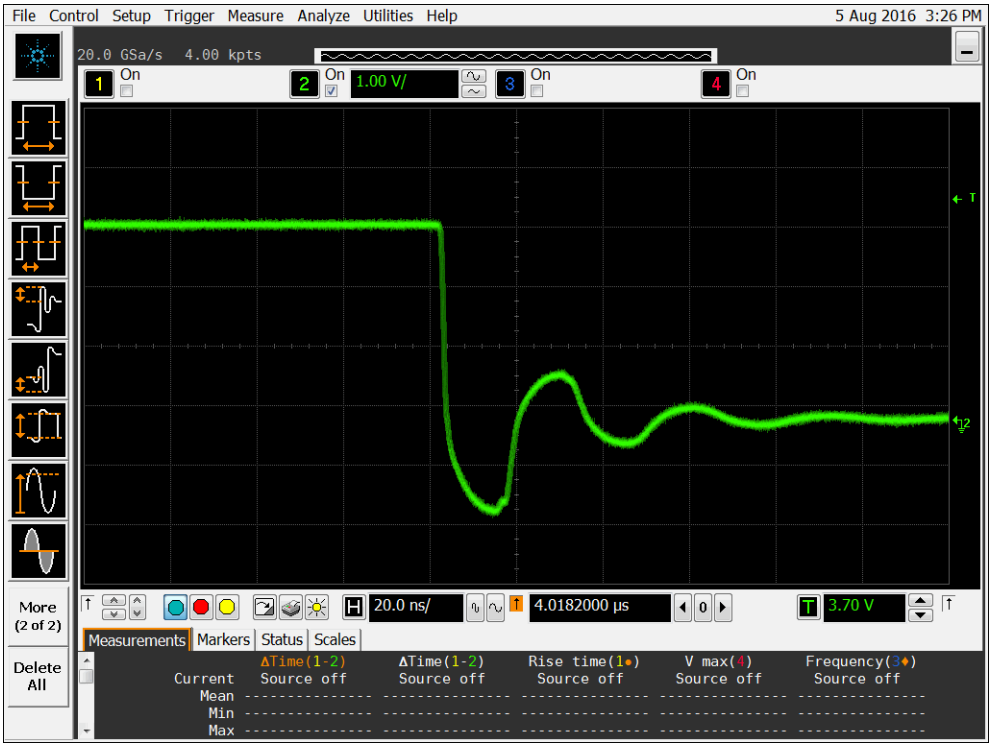


Figure 9b DUT 3436 Post-Annealing Falling Edge

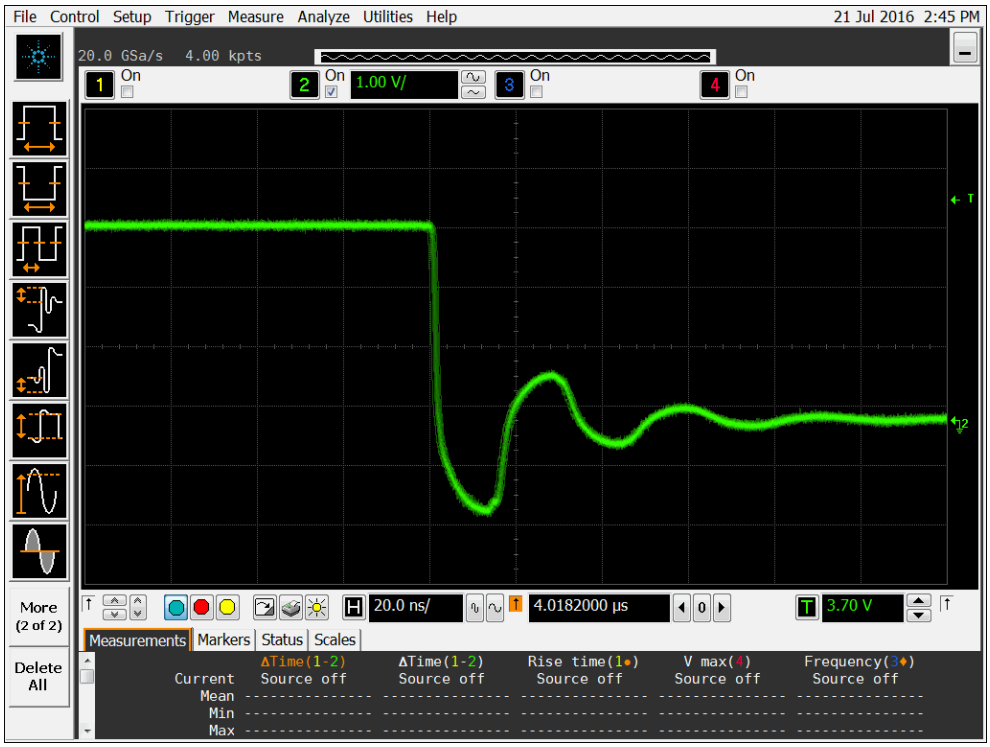


Figure 10a DUT 3437 Pre-Irradiation Falling Edge

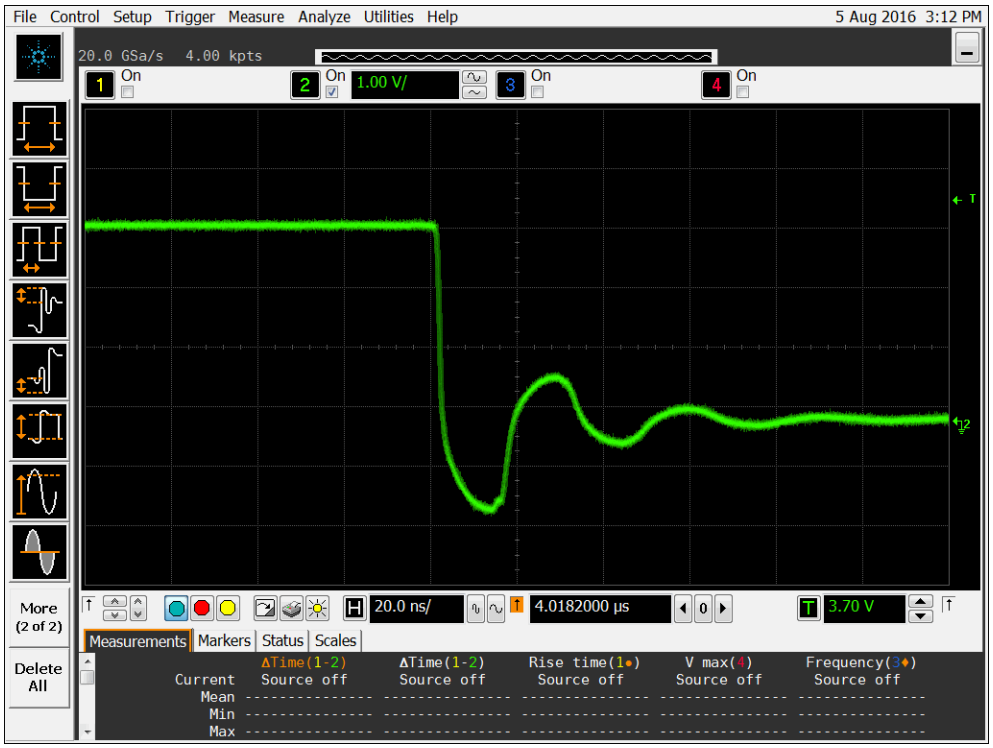


Figure 10b DUT 3437 Post-Annealing Falling Edge

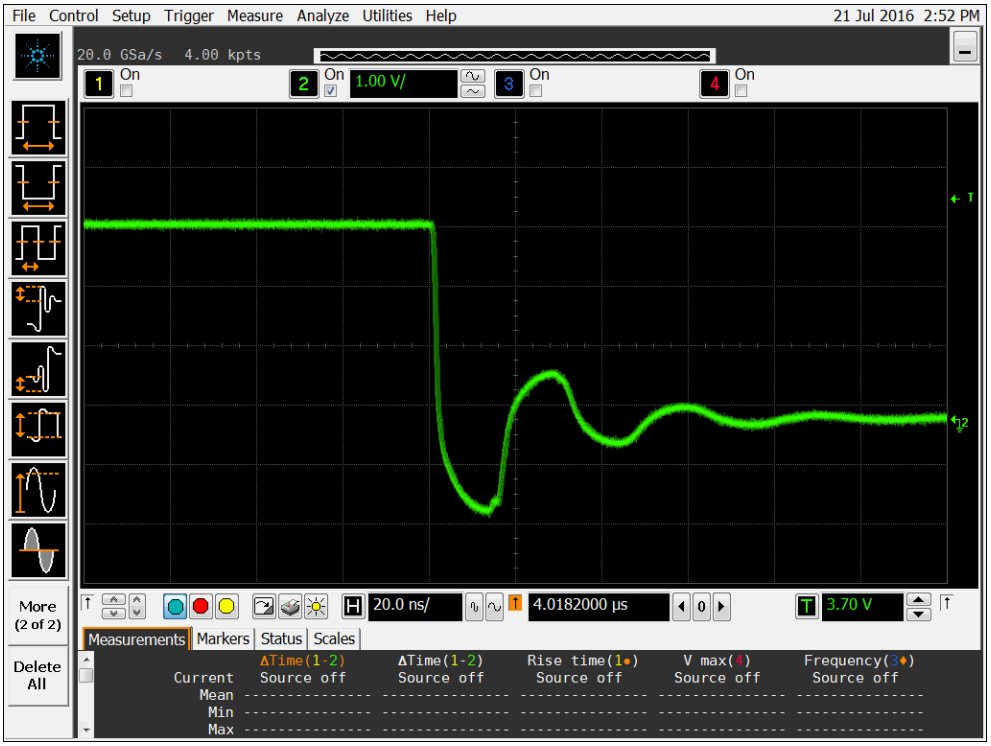


Figure 11a DUT 3439 Pre-Irradiation Falling Edge

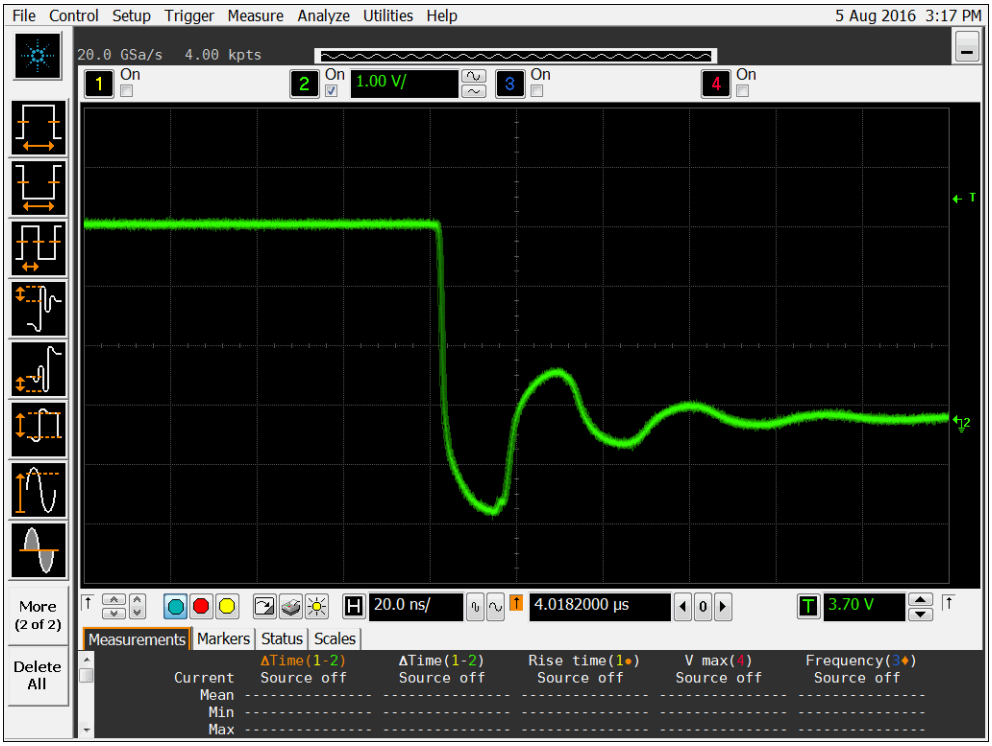


Figure 11b DUT 3439 Post-Annealing Falling Edge

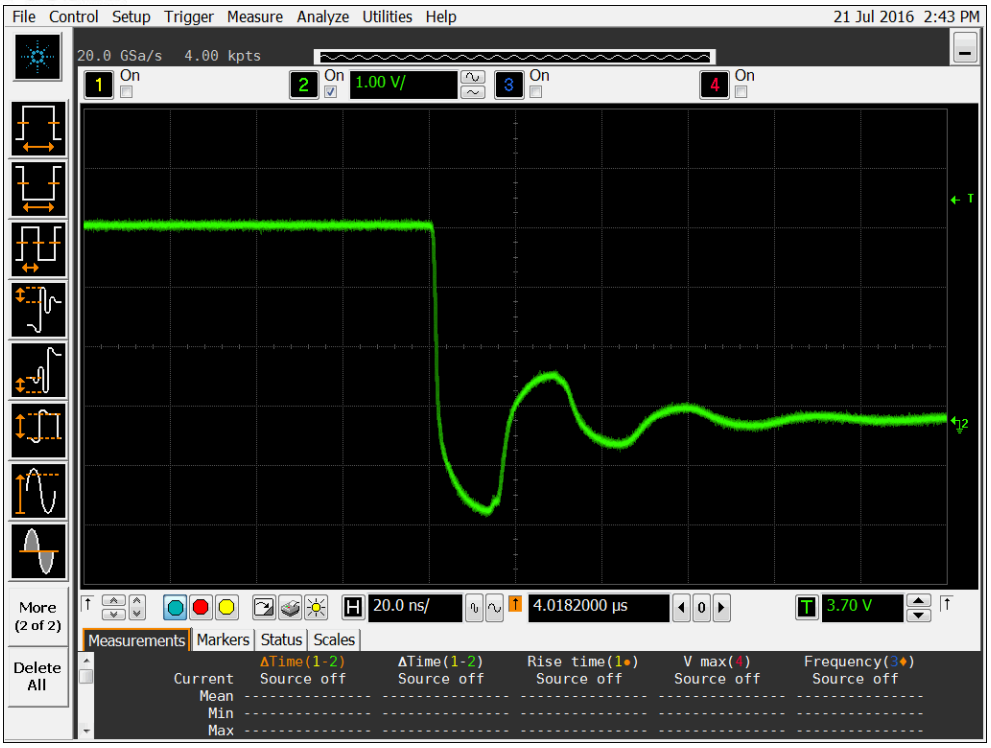


Figure 12a DUT 3556 Pre-Irradiation Falling Edge

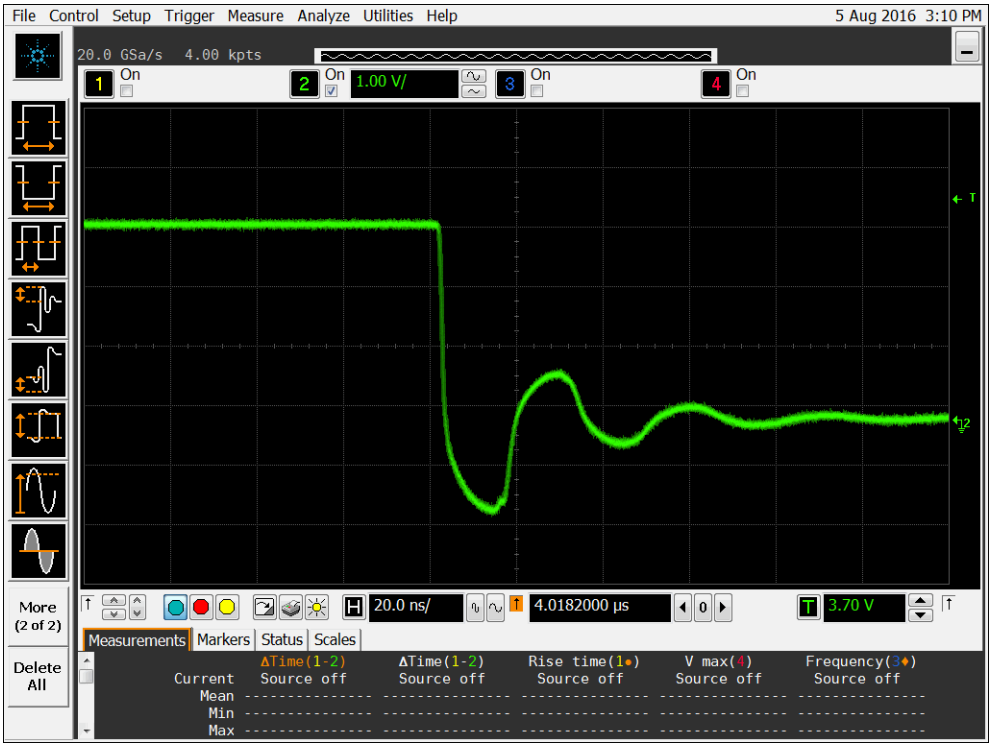


Figure 12b DUT 3556 Post-Annealing Falling Edge

Appendix A: DUT Design Block Diagrams and Schematics

A. PLL Block

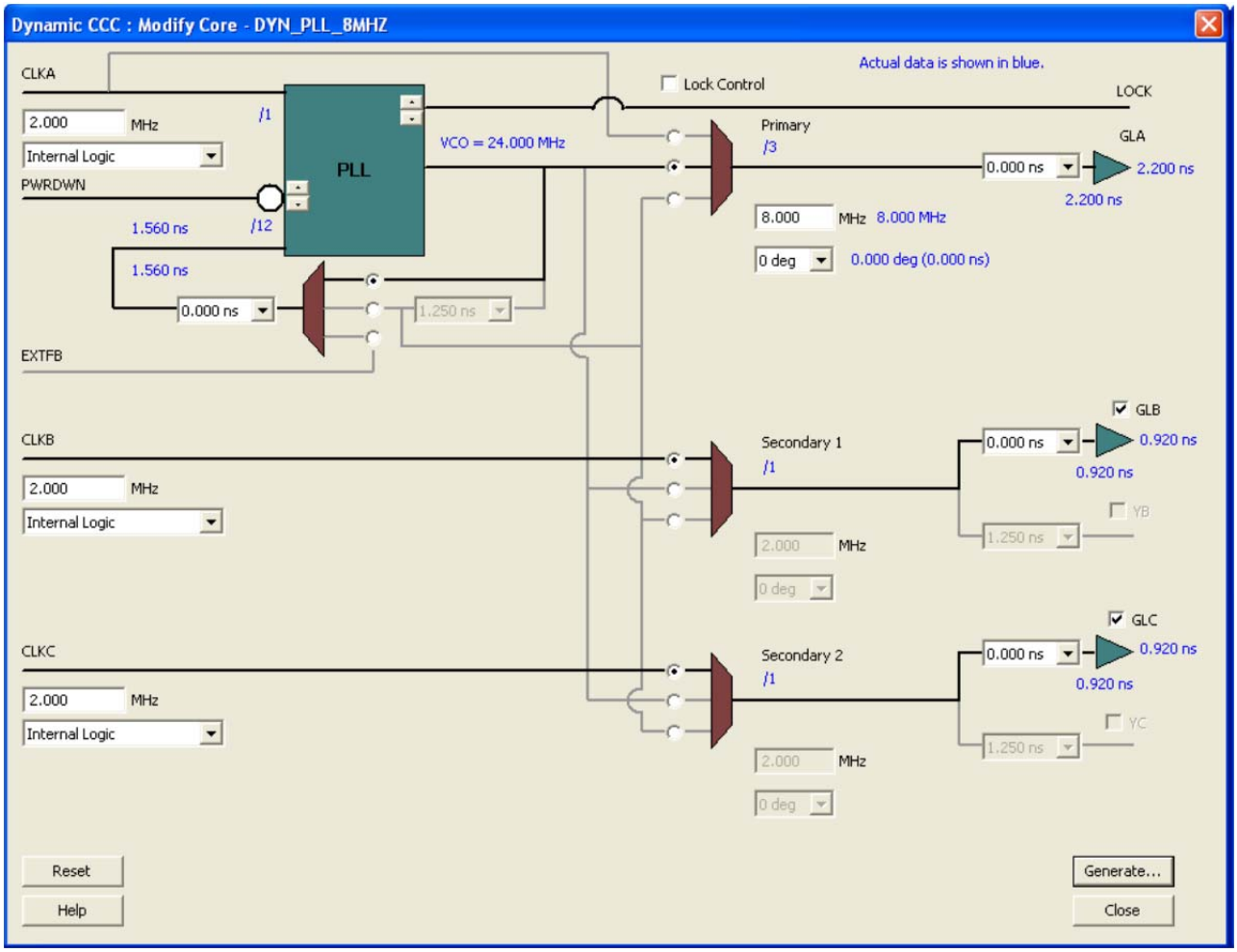
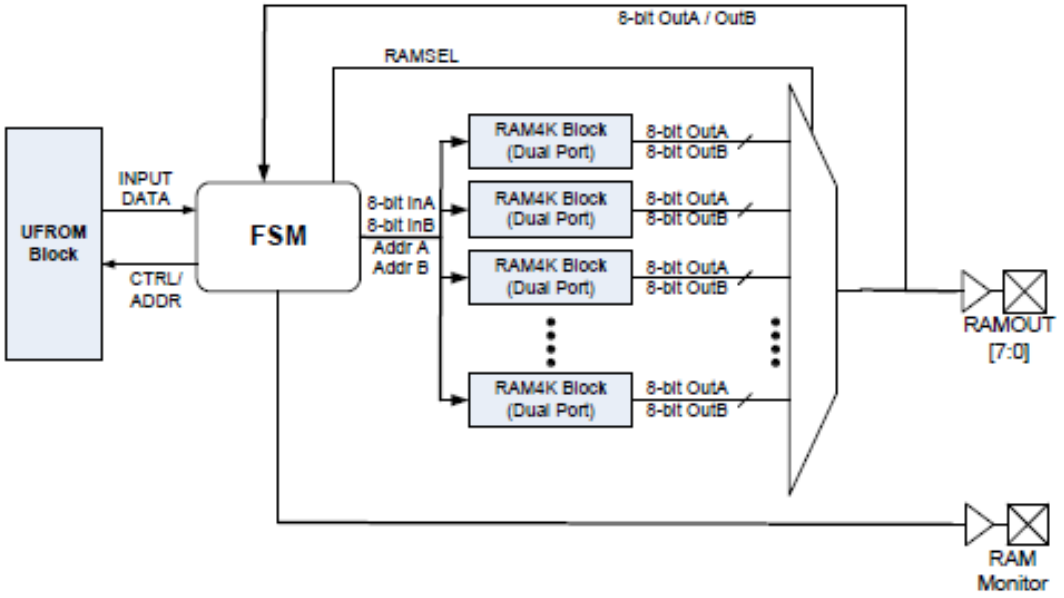


Table 10 lists the signals that go through each of the PLLS:

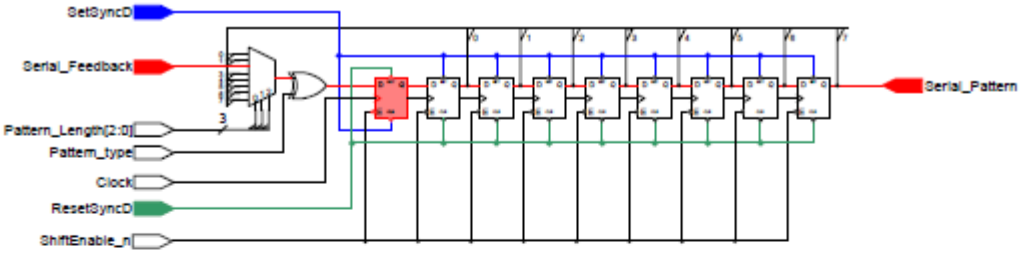
Table 10 Signals Through PLLs

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

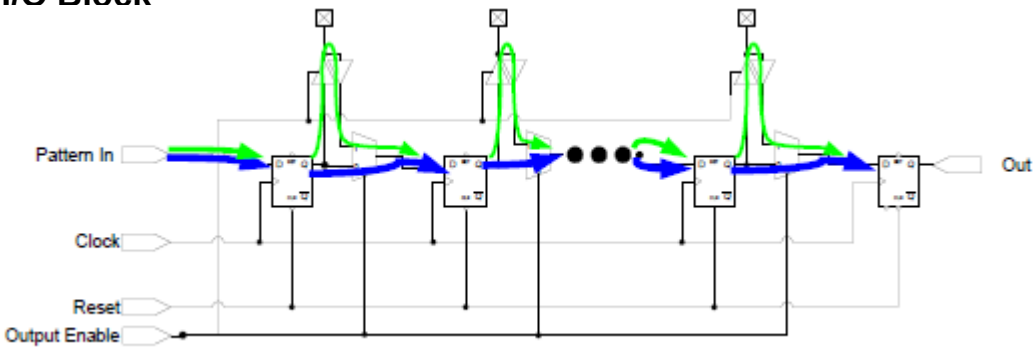


C. Pattern Generators Block

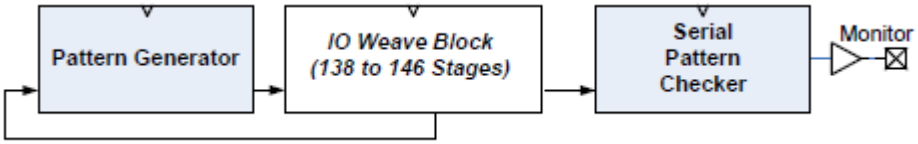


Pattern Type	Pattern Length		Code Length	Δ Bits	Switching Rate
0	000	1 0 ⇒ 0 1 ↻	2	2	100.00%
0	001	1 0 0 ⇒ 0 1 0 ⇒ 0 0 1 ↻	3	2	66.67%
0	010	One hot I/O at a time switching in entire I/O ring	#Bits+9	2	N/A
0	011	1 0 0 0 0 ⇒ 0 1 0 0 0 ⇒ 0 0 1 0 0 ⇒ 0 0 0 1 0 ⇒ 0 0 0 0 1 ↻	5	2	40.00%
0	100	1 0 0 0 0 0 ⇒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

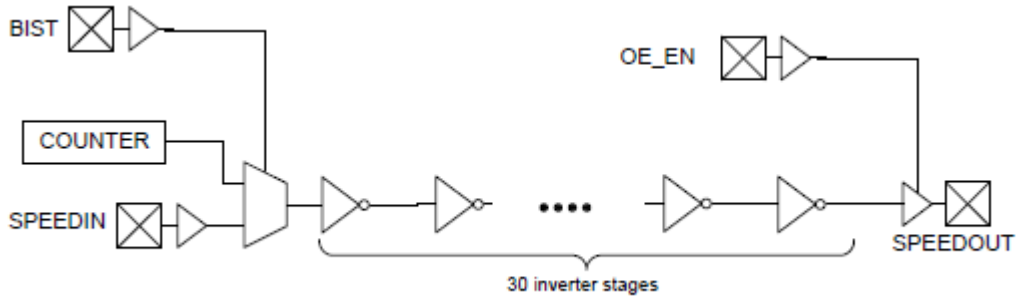
D. I/O Block



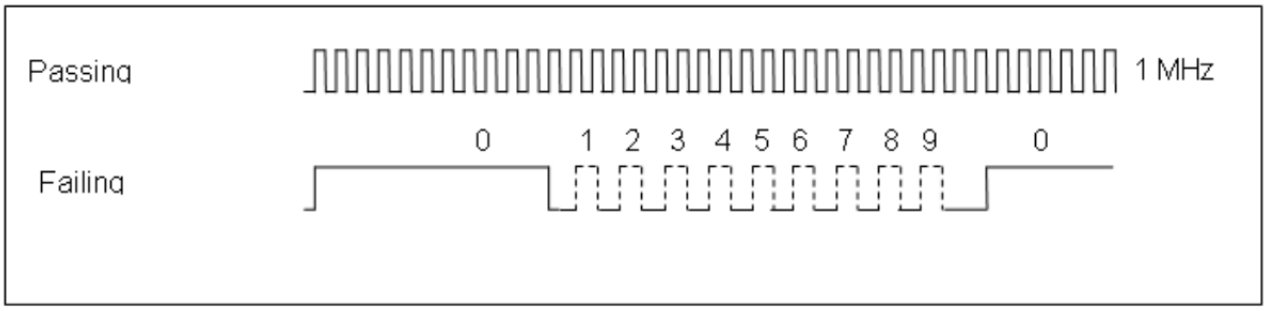
E. Array Shift Registers Block



F. Delay Path Block



G. Monitor Block



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