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Total Ionizing Dose Test Report

No. 21T-RT3PE3000L-CG896-QQW05

September 1, 2021

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TOTAL IONIZING DOSE TEST REPORT

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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	QQW05
Quantity Tested	6
Total Dose: DUT Serial Number	25 krad(SiO ₂): 16177, 16178, 16206, 16207, 16208, 16224
Radiation Facility	Defense Microelectronics Activity
Radiation Source	Co-60
Dose Rate	10 krad(SiO ₂)/min(±5%)
Irradiation Temperature	Room
Irradiation and Measurement Bias (VCCI/VCCA)	Static at 3.3 V/1.5 V

B. Test Method

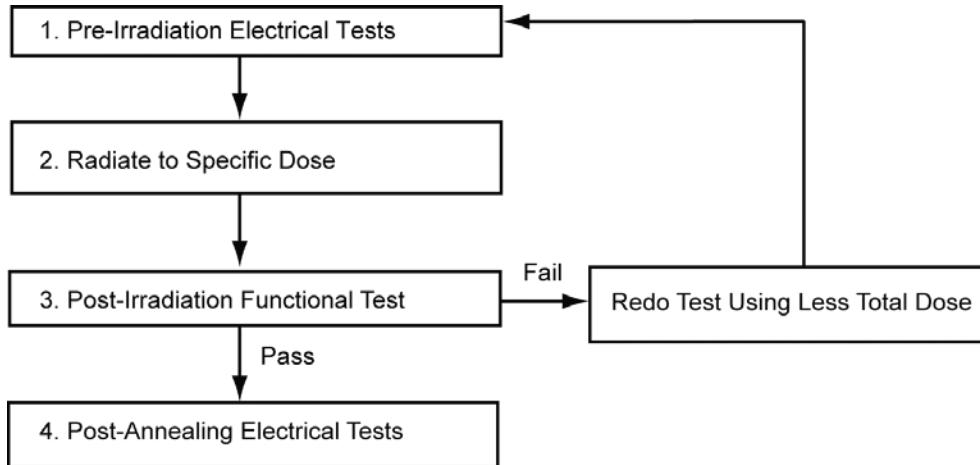


Figure 1 Parametric Test Flow Chart

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

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

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

Table 2 Logic Design for Parametric Measurements

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

III. Test Results

A. Functionality

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

B. Power Supply Current (ICCA and ICCI)

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

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

Table 3 Post Irradiation and Post Annealing ICC

DUT	Total Dose	ICCA at 1.5 V (mA)		ICCI at 3.3 V (mA)	
		Pre-rad	Post-ann	Pre-irrad	Post-ann
16177	25 krad	165.1	166.8	0.4	0.4
16178	25 krad	169.6	171.3	0.4	0.4
16206	25 krad	167.8	168.6	0.4	0.4
16207	25 krad	171.1	172.1	0.4	0.4
16208	25 krad	166.0	166.9	0.4	0.4
16224	25 krad	169.4	170.9	0.4	0.4

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.
16177	25 krad	-0.3397	-0.0311	0.3525	0.0949	-0.2991	-0.0429	0.2849	0.0876
16178	25 krad	-0.3576	-0.0599	0.3366	0.0955	-0.3883	-0.0622	0.2348	0.0871
16206	25 krad	-0.3576	-0.0363	0.2661	0.0979	-0.3387	-0.0462	0.2589	0.0867
16207	25 krad	-0.3464	-0.0569	0.2864	0.0964	-0.3136	-0.0604	0.2338	0.0879
16208	25 krad	-0.4841	-0.0481	0.2864	0.0995	-0.3799	-0.0505	0.2599	0.0890
16224	25 krad	-0.3828	-0.0606	0.2613	0.0969	-0.3369	-0.0604	0.2438	0.0879

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.
16177	25 krad	-0.3274	0.0207	0.8136	0.1117	-0.2699	0.0124	0.7673	0.0979
16178	25 krad	-0.3775	0.0233	0.3574	0.1017	-0.2949	0.0108	0.3030	0.0925
16206	25 krad	-0.3274	0.0267	0.5794	0.1062	-0.2870	0.0113	0.5423	0.0953
16207	25 krad	-0.3325	0.0233	0.3324	0.1018	-0.2949	0.0079	0.4250	0.0927
16208	25 krad	-0.3325	0.0265	0.3394	0.0996	-0.2991	0.0107	0.2941	0.0895
16224	25 krad	-0.3325	0.0228	0.5330	0.1069	-0.2372	0.0148	0.4968	0.0928

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.
16177	25 krad	153.9475	163.2382	194.2834	5.3035	155.6265	166.1743	196.2864	5.8804
16178	25 krad	152.8802	161.5634	191.7084	5.2928	154.2465	164.4481	203.5776	5.9063
16206	25 krad	153.0686	161.6137	191.7084	5.2489	154.5787	164.3110	198.854	6.0509
16207	25 krad	153.4749	162.3412	192.7761	5.3277	154.6228	164.9273	194.4651	5.8017
16208	25 krad	152.6919	161.3870	192.0224	5.1867	154.1289	163.8636	192.9578	5.7941
16224	25 krad	152.9733	161.6635	192.8389	5.2351	154.5601	164.4771	200.6726	6.0821

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.
16177	25 krad	83.4781	85.5990	90.4671	0.9418	83.9283	86.4915	91.1534	1.0367
16178	25 krad	82.6	84.5655	89.1482	0.8901	83.1128	85.3191	91.9672	1.0119
16206	25 krad	82.7881	84.4322	89.1482	0.8559	83.1128	85.1183	90.5489	1.0165
16207	25 krad	82.7881	85.1362	89.8459	0.9780	83.1128	85.7180	90.0229	1.0640
16208	25 krad	82.6627	84.3838	88.9597	0.8506	82.9873	85.0647	89.5833	0.9755
16224	25 krad	82.9865	84.5203	89.525	0.8582	83.4892	85.2612	90.9879	1.0220

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.
16177	25 krad	89.1237	92.5448	102.4	1.7762	89.762	93.8380	103.4629	1.9654
16178	25 krad	88.7158	91.5383	101.3951	1.7375	89.072	92.7030	105.4157	1.9519
16206	25 krad	88.5679	91.4110	101.0811	1.7162	88.9465	92.4708	103.9694	2.0172
16207	25 krad	88.6846	92.1045	101.7719	1.7901	89.3229	93.0375	102.6464	1.9593
16208	25 krad	88.4883	91.3315	101.2695	1.6962	88.8977	92.3906	101.6416	1.9119
16224	25 krad	88.5051	91.5198	101.5835	1.6976	89.42	92.6584	104.5338	2.0030

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.
16177	25 krad	118.418	123.3933	138.6384	2.6642	119.4324	125.2653	139.8889	2.9424
16178	25 krad	117.728	121.9644	136.9426	2.6197	118.5542	123.6290	143.0591	2.9245
16206	25 krad	117.6026	121.8061	136.503	2.5851	118.5815	123.4195	140.7191	3.0303
16207	25 krad	117.8544	122.7214	137.6335	2.6849	118.6169	124.1630	138.6956	2.9158
16208	25 krad	117.4705	121.6499	136.7542	2.5583	118.4056	123.2168	137.5023	2.8743
16224	25 krad	117.7844	121.9308	137.131	2.5675	118.6169	123.6166	141.5344	3.0129

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.
16177	25 krad	178.4494	188.0135	218.6517	5.3144	180.2786	191.2923	220.7798	5.8613
16178	25 krad	177.3203	185.7871	215.9511	5.2587	178.8359	188.8708	228.7779	5.8763
16206	25 krad	177.431	185.6293	215.4486	5.2068	178.9613	188.6778	223.2493	6.0490
16207	25 krad	177.87	186.8351	217.0816	5.3242	179.0868	189.6517	218.8329	5.7967
16208	25 krad	176.8634	185.4157	215.5742	5.1530	178.4886	188.2768	217.0744	5.7679
16224	25 krad	177.4937	185.8379	216.5791	5.1905	179.0868	188.8730	224.9425	6.0440

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.
16177	25 krad	106.6878	109.5581	113.9561	1.0584	107.514	110.6238	115.2201	1.1357
16178	25 krad	105.6094	107.8205	112.6372	0.9875	106.3222	108.7452	115.345	1.0958
16206	25 krad	105.8723	107.6935	111.6951	0.8860	106.4477	108.5267	113.9408	1.0458
16207	25 krad	105.8723	108.7998	113.7035	1.1152	106.5731	109.4291	113.7626	1.1830
16208	25 krad	105.5735	107.7884	112.1975	0.8974	106.134	108.6431	113.0835	1.0226
16224	25 krad	105.4374	107.7578	112.0719	0.8840	106.4152	108.6751	114.317	1.0640

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.
16177	25 krad	54.2466	56.2010	60.886	0.9049	54.5555	56.8340	61.4473	1.0086
16178	25 krad	53.8702	55.4627	60.2579	0.8795	54.3206	56.0439	62.682	0.9912
16206	25 krad	53.6999	55.3807	59.9439	0.8529	54.1951	55.9181	61.5755	1.0045
16207	25 krad	53.9026	55.8834	60.6976	0.9386	54.1324	56.3385	60.8821	1.0177
16208	25 krad	53.682	55.3790	60.3836	0.8477	53.9905	55.9024	60.4425	0.9592
16224	25 krad	53.9654	55.4432	60.2579	0.8523	54.1951	55.9941	61.7637	1.0057

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.
16177	25 krad	2.3754	2.9730	3.5025	0.1850	2.2264	2.9390	3.514	0.1792
16178	25 krad	2.2497	2.9172	3.5653	0.1916	2.2264	2.9336	3.5653	0.1812
16206	25 krad	2.1869	2.9172	3.4397	0.1894	2.2892	2.9336	3.6281	0.1814
16207	25 krad	2.3754	2.9280	3.5025	0.1825	2.2892	2.9463	3.4512	0.1780
16208	25 krad	2.3126	2.9227	3.5025	0.1862	2.1007	2.9145	3.5653	0.1806
16224	25 krad	2.2497	2.9172	3.4397	0.1952	2.2892	2.9161	3.5653	0.1851

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.
16177	25 krad	1.8099	2.4775	3.0628	0.1906	1.7865	2.4700	2.9492	0.1789
16178	25 krad	1.747	2.4364	3	0.1884	1.7236	2.4373	2.9372	0.1781
16206	25 krad	1.747	2.4588	3	0.1895	1.8493	2.4459	3.0628	0.1684
16207	25 krad	1.8099	2.4382	3.0628	0.1941	1.7236	2.4459	2.9372	0.1801
16208	25 krad	1.747	2.4518	3	0.1852	1.6608	2.4135	2.8743	0.1743
16224	25 krad	1.6842	2.4364	3	0.1891	1.8493	2.4444	2.9372	0.1754

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.
16177	25 krad	204.6255	209.0048	219.5409	1.8608	206.1061	210.8627	221.1454	2.0823
16178	25 krad	204.1563	207.3375	217.1196	1.7615	205.2459	209.1187	222.6243	2.0034
16206	25 krad	204.19	207.4171	218.135	1.7863	205.1014	208.9514	219.6448	2.0900
16207	25 krad	204.3909	208.3091	218.0569	1.8669	205.4023	209.6527	219.1146	2.0852
16208	25 krad	204.2682	207.4953	217.7445	1.7115	205.5587	209.0429	218.8022	1.9634
16224	25 krad	204.2682	207.3708	217.9007	1.7308	205.336	209.0779	220.6613	2.0685

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.
16177	25 krad	204.7037	208.9568	219.5409	1.8606	206.1061	210.9118	221.0672	2.0796
16178	25 krad	204.1563	207.2520	217.0415	1.7466	205.1677	209.0455	222.8588	2.0058
16206	25 krad	204.2682	207.4255	217.7445	1.7824	204.945	208.9215	219.8794	2.0837
16207	25 krad	204.2345	208.2909	218.4474	1.8606	205.0113	209.6684	219.0365	2.0691
16208	25 krad	204.5028	207.4572	217.6664	1.7188	205.4023	208.9861	218.9584	1.9539
16224	25 krad	204.19	207.3626	217.7445	1.7235	205.4924	209.0159	220.2704	2.0727

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.
16177	25 krad	4.4358	5.0841	5.7219	0.2209	4.2657	5.0735	5.7446	0.2312
16178	25 krad	4.4595	5.0400	5.7524	0.2211	4.3439	5.0426	5.6453	0.2323
16206	25 krad	4.3815	5.0400	5.6743	0.2151	4.1876	5.0735	5.6742	0.2351
16207	25 krad	4.2578	5.0669	5.6743	0.2238	4.0312	5.0484	5.5961	0.2388
16208	25 krad	4.3815	5.0400	5.5961	0.2166	3.953	5.0248	5.51	0.2399
16224	25 krad	4.5139	5.0400	5.8001	0.2298	4.1876	5.0426	5.6742	0.2330

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.
16177	25 krad	4.5705	5.2637	5.9868	0.2209	4.3439	5.2537	5.7524	0.2362
16178	25 krad	4.592	5.1962	5.9778	0.2167	4.1094	5.1971	5.7524	0.2391
16206	25 krad	4.6157	5.1964	5.9778	0.2143	4.3439	5.2299	5.7524	0.2244
16207	25 krad	4.6487	5.2233	6.0344	0.2200	4.3439	5.2299	5.9086	0.2427
16208	25 krad	4.6937	5.2135	5.8996	0.2164	4.4221	5.1687	5.6664	0.2341
16224	25 krad	4.5709	5.2169	6.0344	0.2220	4.4221	5.1971	5.8019	0.2273

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.
16177	25 krad	215.3392	222.5081	244.6131	3.7466	216.5855	224.5700	246.6862	4.2444
16178	25 krad	214.4329	220.8642	242.4261	3.7034	215.4907	222.8175	249.2057	4.2042
16206	25 krad	214.1983	220.8915	242.7385	3.6488	215.188	222.8345	244.4992	4.2657
16207	25 krad	214.6675	221.8610	243.2853	3.8020	215.2662	223.3111	244.7335	4.2171
16208	25 krad	214.7457	220.9230	242.8166	3.5646	215.7187	222.5478	243.9524	4.1132
16224	25 krad	213.8856	220.8915	242.9729	3.6379	214.9534	222.8806	245.8386	4.3042

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.
16177	25 krad	176.8725	186.1912	217.5883	5.3252	178.2654	188.9033	219.6613	5.9167
16178	25 krad	175.7008	185.0077	215.4013	5.3458	177.4833	187.7883	225.6733	5.9659
16206	25 krad	176.5889	185.2311	216.2605	5.2871	177.8912	187.8811	222.1469	6.1080
16207	25 krad	176.4326	185.7502	216.4948	5.3480	177.9525	188.1341	217.943	5.8296
16208	25 krad	176.2476	184.9906	216.5729	5.2163	177.6397	187.4153	217.1619	5.8309
16224	25 krad	176.4038	185.0612	216.9634	5.2822	177.7961	187.8766	223.8671	6.1053

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.
16177	25 krad	209.2122	221.3772	263.5148	7.1092	211.1112	224.9892	266.0565	7.8758
16178	25 krad	207.8843	219.9641	260.6249	7.1508	209.9381	223.4595	273.5199	7.9384
16206	25 krad	208.3341	220.1657	261.1717	7.0746	210.1056	223.6499	269.843	8.1507
16207	25 krad	208.725	220.8476	261.6403	7.1538	210.3292	224.0364	263.2447	7.7653
16208	25 krad	208.0405	219.8123	261.6403	6.9703	209.86	223.0568	262.9323	7.7707
16224	25 krad	208.4311	220.0052	262.3432	7.0653	210.3292	223.6777	272.0323	8.1519

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.
16177	25 krad	237.6462	255.8217	320.0639	10.7113	239.8565	260.5505	323.0742	11.8797
16178	25 krad	236.3182	254.5202	315.8462	10.8122	238.952	259.3514	334.5008	11.9992
16206	25 krad	237.1775	254.7404	317.0959	10.6749	239.5052	259.4185	328.173	12.2832
16207	25 krad	237.499	255.3718	317.3302	10.7813	239.1866	259.5466	320.1843	11.6940
16208	25 krad	236.6307	254.3300	318.0331	10.5302	238.5285	258.4935	318.9346	11.7583
16224	25 krad	236.9431	254.6359	318.7361	10.6921	239.0302	259.6909	331.6134	12.3038

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.
16177	25 krad	8.6835	9.0637	9.4992	0.1328	8.6561	9.0460	9.4443	0.1331
16178	25 krad	9.4377	9.8160	10.1466	0.1208	9.3287	9.8087	10.2798	0.1208
16206	25 krad	9.2364	9.6017	10.0588	0.1319	9.254	9.6088	10.1059	0.1237
16207	25 krad	9.0986	9.5185	9.9588	0.1349	9.2166	9.5262	10.0468	0.1263
16208	25 krad	9.201	9.5323	10.0827	0.1105	9.0895	9.5197	9.9303	0.1110
16224	25 krad	9.3872	9.7938	10.2582	0.1339	9.4073	9.7757	10.2724	0.1307

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.
16177	25 krad	11.077	11.4344	11.9103	0.1491	10.9729	11.3849	11.8117	0.1495
16178	25 krad	12.0001	12.3572	12.8059	0.1330	11.8448	12.3320	12.8046	0.1321
16206	25 krad	11.6493	12.0953	12.5574	0.1448	11.6953	12.0793	12.643	0.1394
16207	25 krad	11.5488	11.9980	12.5247	0.1506	11.6318	11.9919	12.579	0.1427
16208	25 krad	11.6478	12.0087	12.5443	0.1149	11.5212	11.9772	12.3368	0.1162
16224	25 krad	11.9258	12.3222	12.8006	0.1478	11.8713	12.2801	12.9049	0.1462

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.
16177	25 krad	5.3155	5.6372	6.0075	0.1131	5.2682	5.6290	5.9944	0.1088
16178	25 krad	5.7679	6.1069	6.4154	0.1095	5.7415	6.1092	6.4919	0.1005
16206	25 krad	5.592	5.9757	6.3357	0.1127	5.6169	5.9802	6.363	0.1041
16207	25 krad	5.557	5.9182	6.2608	0.1127	5.6396	5.9283	6.3362	0.1044
16208	25 krad	5.5893	5.9282	6.3903	0.1011	5.5798	5.9274	6.2265	0.0956
16224	25 krad	5.7583	6.0928	6.4292	0.1136	5.7616	6.0888	6.5368	0.1105

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.
16177	25 krad	7.4746	7.8241	8.2521	0.1266	7.4604	7.8049	8.1507	0.1221
16178	25 krad	8.1236	8.4727	8.8307	0.1166	8.0583	8.4659	8.8499	0.1127
16206	25 krad	7.9043	8.2881	8.7205	0.1231	7.9337	8.2880	8.7431	0.1175
16207	25 krad	7.8038	8.2162	8.6364	0.1254	7.9355	8.2190	8.7494	0.1205
16208	25 krad	7.8725	8.2261	8.6258	0.1054	7.8611	8.2161	8.5267	0.1037
16224	25 krad	8.0802	8.4501	8.8727	0.1251	8.0747	8.4344	8.9436	0.1213

Table 6e Pre-Irradiation and Post-Annealing Ip_d

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.
16177	25 krad	2.8775	3.2414	3.6213	0.1016	2.9265	3.2489	3.5496	0.0972
16178	25 krad	3.1911	3.5178	3.824	0.1005	3.2006	3.5263	3.851	0.0944
16206	25 krad	3.1091	3.4417	3.7737	0.1037	3.0746	3.4475	3.8762	0.0954
16207	25 krad	3.0905	3.4053	3.7371	0.1026	3.1436	3.4187	3.8259	0.0925
16208	25 krad	3.0653	3.4102	3.8044	0.0969	3.1258	3.4160	3.7016	0.0909
16224	25 krad	3.166	3.5095	3.8533	0.1050	3.2504	3.5130	3.9043	0.0974

 Table 6f Pre-Irradiation and Post-Annealing Ip_d

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.
16177	25 krad	2.8775	3.2414	3.6213	0.1016	2.9265	3.2489	3.5496	0.0972
16178	25 krad	3.1911	3.5178	3.824	0.1005	3.2006	3.5263	3.851	0.0944
16206	25 krad	3.1091	3.4417	3.7737	0.1037	3.0746	3.4475	3.8762	0.0954
16207	25 krad	3.0905	3.4053	3.7371	0.1026	3.1436	3.4187	3.8259	0.0925
16208	25 krad	3.0653	3.4102	3.8044	0.0969	3.1258	3.4160	3.7016	0.0909
16224	25 krad	3.166	3.5095	3.8533	0.1050	3.2504	3.5130	3.9043	0.0974

 Table 6g Pre-Irradiation and Post-Annealing Ip_d

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.
16177	25 krad	15.655	16.1120	16.6823	0.1828	15.6064	16.0332	16.5188	0.1850
16178	25 krad	16.8633	17.2747	17.7376	0.1478	16.7025	17.2180	17.7437	0.1467
16206	25 krad	16.5	16.9291	17.4548	0.1661	16.4603	16.8871	17.4408	0.1651
16207	25 krad	16.4248	16.8608	17.4917	0.1717	16.4473	16.8348	17.4911	0.1639
16208	25 krad	16.4801	16.8676	17.3671	0.1246	16.3596	16.7974	17.1782	0.1256
16224	25 krad	16.7767	17.2183	17.7928	0.1694	16.6987	17.1565	17.8189	0.1661

Table 6h Pre-Irradiation and Post-Annealing IpD

Test name		Ivttl_ipd_weak_ (Ivttle_ipd_ipd_weak_max) (uA) [8.9, 29.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
16177	25 krad	16.7056	17.1255	17.712	0.1869	16.6484	17.0448	17.594	0.1912
16178	25 krad	17.9205	18.3054	18.791	0.1462	17.7737	18.2503	18.7716	0.1457
16206	25 krad	17.4817	17.9560	18.4793	0.1698	17.453	17.9160	18.5461	0.1711
16207	25 krad	17.4312	17.8948	18.4952	0.1722	17.4278	17.8639	18.5961	0.1672
16208	25 krad	17.4617	17.8935	18.3661	0.1266	17.3374	17.8295	18.2569	0.1262
16224	25 krad	17.828	18.2629	18.823	0.1741	17.7296	18.2056	18.8719	0.1688

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.
16177	25 krad	1.4421	1.4691	1.481	0.0054	1.4398	1.4659	1.4795	0.0059
16178	25 krad	1.439	1.4656	1.4779	0.0053	1.4219	1.4626	1.4746	0.0059
16206	25 krad	1.4384	1.4663	1.4773	0.0053	1.4279	1.4633	1.4745	0.0061
16207	25 krad	1.4409	1.4685	1.4798	0.0054	1.4391	1.4661	1.4776	0.0057
16208	25 krad	1.4389	1.4679	1.4781	0.0052	1.4376	1.4651	1.4766	0.0058
16224	25 krad	1.4389	1.4674	1.4785	0.0053	1.4271	1.4641	1.4749	0.0061

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.
16177	25 krad	1.2264	1.2379	1.2451	0.0022	1.2257	1.2363	1.2437	0.0022
16178	25 krad	1.2229	1.2348	1.2421	0.0019	1.2225	1.2335	1.2405	0.0019
16206	25 krad	1.2243	1.2356	1.2413	0.0018	1.2246	1.2343	1.2397	0.0018
16207	25 krad	1.2265	1.2379	1.2442	0.0019	1.2268	1.2368	1.2421	0.0018
16208	25 krad	1.225	1.2366	1.2435	0.0017	1.2248	1.2352	1.2415	0.0017
16224	25 krad	1.225	1.2369	1.2437	0.0019	1.2243	1.2355	1.2419	0.0019

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.
16177	25 krad	1.2181	1.2304	1.2388	0.0027	1.2173	1.2286	1.2372	0.0026
16178	25 krad	1.2154	1.2271	1.2352	0.0023	1.2129	1.2256	1.2324	0.0024
16206	25 krad	1.2142	1.2280	1.2346	0.0023	1.2137	1.2264	1.2334	0.0024
16207	25 krad	1.2193	1.2304	1.2371	0.0023	1.2189	1.2290	1.2358	0.0023
16208	25 krad	1.2178	1.2291	1.2371	0.0022	1.2167	1.2275	1.2342	0.0023
16224	25 krad	1.2171	1.2294	1.2368	0.0023	1.2138	1.2276	1.234	0.0025

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.
16177	25 krad	1.1813	1.1941	1.2048	0.0034	1.1791	1.1917	1.2023	0.0035
16178	25 krad	1.1774	1.1900	1.1996	0.0030	1.1677	1.1879	1.1971	0.0032
16206	25 krad	1.1749	1.1910	1.1992	0.0030	1.1699	1.1888	1.1973	0.0033
16207	25 krad	1.1812	1.1940	1.2023	0.0031	1.1793	1.1921	1.2008	0.0032
16208	25 krad	1.1794	1.1925	1.2013	0.0029	1.1782	1.1904	1.1986	0.0031
16224	25 krad	1.1796	1.1927	1.2016	0.0030	1.1704	1.1905	1.1986	0.0033

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.
16177	25 krad	1.1506	1.1765	1.1901	0.0056	1.1475	1.1730	1.1872	0.0059
16178	25 krad	1.1466	1.1723	1.1851	0.0053	1.128	1.1691	1.1821	0.0059
16206	25 krad	1.1466	1.1732	1.1854	0.0053	1.1339	1.1700	1.182	0.0062
16207	25 krad	1.15	1.1763	1.1879	0.0054	1.1484	1.1736	1.1859	0.0057
16208	25 krad	1.1472	1.1750	1.186	0.0052	1.1455	1.1719	1.1838	0.0057
16224	25 krad	1.1481	1.1748	1.1876	0.0053	1.1336	1.1715	1.183	0.0061

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.
16177	25 krad	892.9534	919.7192	934.8783	4.1033	893.2546	917.6048	931.5664	3.9181
16178	25 krad	888.7291	916.1101	930.1973	3.5463	889.6843	914.4108	927.2247	3.4018
16206	25 krad	892.484	917.0464	928.0097	3.3366	892.8134	915.4809	925.3495	3.1985
16207	25 krad	897.96	921.2824	933.1583	3.3909	898.2891	919.8791	931.0974	3.2301
16208	25 krad	891.7017	918.3040	931.9162	3.3722	892.6292	916.5963	928.9435	3.2080
16224	25 krad	893.5792	919.9416	932.8538	3.5563	893.9085	918.2061	930.0374	3.4122

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.
16177	25 krad	1.0248	1.0346	1.0404	0.0017	1.0246	1.0334	1.0394	0.0017
16178	25 krad	1.0233	1.0329	1.0385	0.0015	1.0234	1.0319	1.0371	0.0015
16206	25 krad	1.0239	1.0333	1.0381	0.0014	1.0242	1.0324	1.0367	0.0015
16207	25 krad	1.0264	1.0349	1.0398	0.0015	1.0263	1.0342	1.0387	0.0014
16208	25 krad	1.0245	1.0339	1.0393	0.0014	1.0247	1.0330	1.0382	0.0014
16224	25 krad	1.0245	1.0343	1.0394	0.0015	1.0244	1.0333	1.038	0.0015

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.
16177	25 krad	1.1313	1.1321	1.1329	0.0003	1.1308	1.1319	1.1326	0.0003
16178	25 krad	1.1311	1.1319	1.1329	0.0003	1.1306	1.1318	1.1328	0.0003
16206	25 krad	1.1312	1.1320	1.133	0.0003	1.1306	1.1319	1.1329	0.0003
16207	25 krad	1.1313	1.1321	1.1329	0.0003	1.1309	1.1319	1.1328	0.0003
16208	25 krad	1.131	1.1320	1.1332	0.0003	1.1306	1.1319	1.1327	0.0003
16224	25 krad	1.1313	1.1320	1.1329	0.0003	1.1309	1.1319	1.1326	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.
16177	25 krad	1.3931	1.3939	1.3948	0.0003	1.3927	1.3938	1.3946	0.0003
16178	25 krad	1.3928	1.3938	1.3946	0.0003	1.3922	1.3937	1.3945	0.0003
16206	25 krad	1.3929	1.3939	1.3949	0.0003	1.3924	1.3937	1.3945	0.0003
16207	25 krad	1.3931	1.3939	1.3948	0.0003	1.3925	1.3938	1.3945	0.0003
16208	25 krad	1.393	1.3939	1.3951	0.0003	1.3925	1.3937	1.3946	0.0003
16224	25 krad	1.3929	1.3939	1.3951	0.0003	1.3925	1.3937	1.3945	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.
16177	25 krad	2.6372	2.6472	2.6599	0.0040	2.6353	2.6443	2.6569	0.0039
16178	25 krad	2.6269	2.6390	2.6503	0.0032	2.6242	2.6366	2.6473	0.0032
16206	25 krad	2.6298	2.6405	2.6502	0.0028	2.6235	2.6383	2.6473	0.0029
16207	25 krad	2.6336	2.6451	2.6556	0.0031	2.6317	2.6430	2.6531	0.0030
16208	25 krad	2.6327	2.6432	2.6538	0.0027	2.6316	2.6408	2.6501	0.0027
16224	25 krad	2.6305	2.6426	2.6538	0.0031	2.6243	2.6401	2.6512	0.0032

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.
16177	25 krad	2.6373	2.6474	2.6599	0.0040	2.6353	2.6444	2.6571	0.0039
16178	25 krad	2.627	2.6390	2.6505	0.0032	2.6238	2.6367	2.6469	0.0033
16206	25 krad	2.6301	2.6405	2.6501	0.0028	2.6235	2.6384	2.6474	0.0029
16207	25 krad	2.6335	2.6450	2.6554	0.0031	2.6318	2.6431	2.6532	0.0030
16208	25 krad	2.6328	2.6433	2.6535	0.0027	2.6318	2.6409	2.6502	0.0027
16224	25 krad	2.6309	2.6426	2.6538	0.0031	2.6245	2.6402	2.6513	0.0032

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.
16177	25 krad	2.9887	2.9894	2.9904	0.0003	2.9882	2.9892	2.9899	0.0003
16178	25 krad	2.9886	2.9892	2.9902	0.0003	2.9882	2.9890	2.9897	0.0003
16206	25 krad	2.9885	2.9892	2.9903	0.0003	2.9883	2.9891	2.9898	0.0003
16207	25 krad	2.9886	2.9893	2.9902	0.0003	2.9883	2.9892	2.9898	0.0003
16208	25 krad	2.9885	2.9893	2.9902	0.0003	2.9881	2.9891	2.9898	0.0003
16224	25 krad	2.9884	2.9893	2.9903	0.0003	2.9881	2.9891	2.9896	0.0003

Table 7m Pre-Irradiation and Post-Annealing VOH

Test name		I _{VTTL_VOH_1xE2} (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
16177	25 krad	2.6886	2.6893	2.6902	0.0003	2.6883	2.6891	2.6897	0.0003
16178	25 krad	2.6884	2.6891	2.6901	0.0003	2.6881	2.6889	2.6895	0.0003
16206	25 krad	2.6884	2.6891	2.69	0.0003	2.6878	2.6889	2.6896	0.0003
16207	25 krad	2.6885	2.6892	2.6904	0.0003	2.6881	2.6890	2.6897	0.0003
16208	25 krad	2.6884	2.6892	2.6902	0.0003	2.6882	2.6889	2.6896	0.0003
16224	25 krad	2.6885	2.6891	2.6902	0.0003	2.6881	2.6890	2.6896	0.0003

Table 7n Pre-Irradiation and Post-Annealing VOH

Test name		I _{VTTL_VOH_2x} (V) [2.5, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
16177	25 krad	2.6176	2.6330	2.648	0.0051	2.611	2.6287	2.6423	0.0049
16178	25 krad	2.6091	2.6245	2.6388	0.0045	2.5939	2.6205	2.6335	0.0045
16206	25 krad	2.6093	2.6260	2.6385	0.0044	2.5952	2.6224	2.634	0.0045
16207	25 krad	2.612	2.6306	2.6435	0.0045	2.6077	2.6271	2.6397	0.0042
16208	25 krad	2.6125	2.6290	2.6408	0.0040	2.6085	2.6249	2.6367	0.0039
16224	25 krad	2.6123	2.6280	2.642	0.0045	2.5952	2.6240	2.6369	0.0046

Table 7o Pre-Irradiation and Post-Annealing VOH

Test name		I _{VTTL_VOH_3x} (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
16177	25 krad	2.6807	2.7053	2.7198	0.0057	2.6762	2.7019	2.7163	0.0061
16178	25 krad	2.676	2.6992	2.7137	0.0054	2.6577	2.6959	2.71	0.0059
16206	25 krad	2.6747	2.7003	2.7135	0.0054	2.6607	2.6970	2.7092	0.0061
16207	25 krad	2.6786	2.7038	2.7172	0.0054	2.675	2.7009	2.7145	0.0058
16208	25 krad	2.6756	2.7026	2.7146	0.0052	2.674	2.6996	2.7124	0.0057
16224	25 krad	2.6761	2.7017	2.716	0.0053	2.6598	2.6982	2.7113	0.0061

Table 7p Pre-Irradiation and Post-Annealing VOH

Test name		Ivttl_voh_4x (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
16177	25 krad	2.6453	2.6801	2.6971	0.0074	2.6419	2.6758	2.6936	0.0079
16178	25 krad	2.6403	2.6735	2.691	0.0071	2.6178	2.6695	2.687	0.0078
16206	25 krad	2.6386	2.6746	2.6906	0.0071	2.623	2.6706	2.6858	0.0081
16207	25 krad	2.6434	2.6782	2.6946	0.0071	2.6408	2.6748	2.6912	0.0076
16208	25 krad	2.6399	2.6772	2.6921	0.0069	2.6383	2.6734	2.6895	0.0076
16224	25 krad	2.6404	2.6760	2.6928	0.0070	2.6218	2.6719	2.6874	0.0080

Table 7q Pre-Irradiation and Post-Annealing VOH

Test name		Ivttl_voh_5x (V) [2.4, 3.0]							
DUT	Total Dose	Pre-Radiation				Post-Anneal			
		Min.	Median	Max.	Std.Dev.	Min.	Median	Max.	Std. Dev.
16177	25 krad	2.6637	2.7215	2.7427	0.0106	2.6603	2.7160	2.7387	0.0115
16178	25 krad	2.6612	2.7167	2.7378	0.0106	2.6329	2.7115	2.7332	0.0117
16206	25 krad	2.6597	2.7173	2.7373	0.0106	2.6419	2.7118	2.7331	0.0121
16207	25 krad	2.6638	2.7200	2.7402	0.0106	2.6609	2.7156	2.7369	0.0114
16208	25 krad	2.6604	2.7195	2.7389	0.0104	2.6589	2.7147	2.7354	0.0115
16224	25 krad	2.6601	2.7181	2.7384	0.0105	2.639	2.7128	2.7338	0.0120

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.
16177	25 krad	-14.3768	-13.3941	-12.8247	0.2695	-14.1319	-13.2467	-12.7154	0.2632
16178	25 krad	-13.9979	-13.3504	-11.8436	0.2060	-13.8379	-13.2488	-11.9237	0.1887
16206	25 krad	-13.9639	-13.5249	-13.0423	0.1645	-13.9159	-13.4293	-12.902	0.1560
16207	25 krad	-14.1824	-13.5889	-12.975	0.1733	-14.0531	-13.4800	-12.9541	0.1623
16208	25 krad	-13.9072	-13.3799	-12.8327	0.1869	-13.8813	-13.2731	-12.7372	0.1767
16224	25 krad	-14.0092	-13.4154	-12.8586	0.1810	-13.8984	-13.3125	-12.8293	0.1732

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.
16177	25 krad	-17.5904	-16.4497	-15.8356	0.3044	-17.3623	-16.2790	-15.7148	0.2973
16178	25 krad	-17.1082	-16.3705	-14.502	0.2276	-16.8569	-16.2583	-14.5332	0.2117
16206	25 krad	-17.1119	-16.5778	-16.0444	0.1799	-16.9599	-16.4654	-15.9518	0.1660
16207	25 krad	-17.2906	-16.6482	-15.9834	0.1939	-17.1367	-16.5269	-15.9685	0.1795
16208	25 krad	-17.0381	-16.4310	-15.8723	0.2012	-16.9718	-16.3007	-15.7376	0.1901
16224	25 krad	-17.1385	-16.4525	-15.837	0.1981	-16.9855	-16.3266	-15.8117	0.1869

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.
16177	25 krad	-9.2802	-8.5861	-8.0978	0.1952	-9.1645	-8.4927	-8.0314	0.1936
16178	25 krad	-9.0564	-8.5750	-7.4296	0.1585	-8.9346	-8.5181	-7.5077	0.1482
16206	25 krad	-9.0732	-8.6923	-8.254	0.1359	-9.0858	-8.6301	-8.1615	0.1252
16207	25 krad	-9.1735	-8.7326	-8.1867	0.1363	-9.1143	-8.6685	-8.2064	0.1257
16208	25 krad	-9.0228	-8.5910	-8.085	0.1483	-8.9871	-8.5175	-8.0865	0.1401
16224	25 krad	-9.1296	-8.6129	-8.1066	0.1425	-8.9446	-8.5520	-8.1428	0.1353

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.
16177	25 krad	-12.5189	-11.5805	-11.0272	0.2400	-12.223	-11.4580	-10.937	0.2326
16178	25 krad	-12.1169	-11.5504	-10.1382	0.1855	-11.9771	-11.4683	-10.2426	0.1703
16206	25 krad	-12.0828	-11.7027	-11.2409	0.1541	-12.0543	-11.6207	-11.1021	0.1424
16207	25 krad	-12.2774	-11.7533	-11.17	0.1590	-12.223	-11.6736	-11.1455	0.1479
16208	25 krad	-12.0598	-11.5815	-11.0241	0.1696	-12.0723	-11.4874	-10.9869	0.1626
16224	25 krad	-12.1925	-11.6019	-11.055	0.1637	-11.9505	-11.5188	-11.0499	0.1555

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.
16177	25 krad	-5.7402	-5.1712	-4.7927	0.1502	-5.618	-5.1357	-4.711	0.1455
16178	25 krad	-5.6011	-5.1814	-4.3698	0.1298	-5.4848	-5.1608	-4.4718	0.1197
16206	25 krad	-5.5869	-5.2627	-4.8881	0.1170	-5.589	-5.2327	-4.861	0.1077
16207	25 krad	-5.7151	-5.2979	-4.8022	0.1148	-5.6547	-5.2653	-4.8153	0.1073
16208	25 krad	-5.5164	-5.1931	-4.7876	0.1237	-5.526	-5.1496	-4.7399	0.1182
16224	25 krad	-5.6582	-5.2140	-4.8083	0.1192	-5.526	-5.1794	-4.7915	0.1120

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.
16177	25 krad	-7.2968	-6.6513	-6.2459	0.1707	-7.1487	-6.5889	-6.1466	0.1659
16178	25 krad	-7.125	-6.6539	-5.6991	0.1420	-6.9985	-6.6122	-5.8016	0.1300
16206	25 krad	-7.096	-6.7516	-6.345	0.1258	-7.1235	-6.7018	-6.1612	0.1159
16207	25 krad	-7.2215	-6.7846	-6.3064	0.1247	-7.1338	-6.7423	-6.3225	0.1148
16208	25 krad	-7.0153	-6.6657	-6.2261	0.1331	-7.0472	-6.6123	-6.2112	0.1254
16224	25 krad	-7.2215	-6.6935	-6.2326	0.1295	-6.9882	-6.6434	-6.1887	0.1216

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.
16177	25 krad	-35.1396	-33.4557	-32.546	0.4626	-34.6435	-33.1197	-32.1217	0.4515
16178	25 krad	-34.2799	-33.1509	-30.0013	0.3444	-33.8541	-32.9160	-29.9389	0.3240
16206	25 krad	-34.1885	-33.5112	-32.7802	0.2381	-33.969	-33.2927	-32.5568	0.2247
16207	25 krad	-34.6792	-33.6254	-32.784	0.2833	-34.2554	-33.3739	-32.5975	0.2660
16208	25 krad	-34.4118	-33.4714	-32.3569	0.2662	-33.9942	-33.1882	-32.1082	0.2571
16224	25 krad	-34.4618	-33.3807	-32.5421	0.2998	-34.0942	-33.1386	-32.331	0.2870

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.
16177	25 krad	-53.3166	-50.9852	-49.6687	0.6682	-52.6163	-50.4740	-49.0515	0.6480
16178	25 krad	-51.9806	-50.4848	-47.2562	0.4783	-51.5377	-50.1190	-47.0006	0.4562
16206	25 krad	-51.9421	-51.0271	-49.9318	0.3295	-51.6789	-50.6728	-49.5866	0.3188
16207	25 krad	-52.773	-51.1858	-49.909	0.4054	-52.192	-50.8257	-49.6173	0.3871
16208	25 krad	-52.3185	-50.9788	-49.7435	0.3725	-51.8395	-50.5632	-49.3495	0.3623
16224	25 krad	-52.2872	-50.8389	-49.6926	0.4314	-51.9044	-50.4804	-49.3541	0.4172

F. Propagation Delay

DUTs are irradiated to 25 krads. Table 9a and Table 9b lists the pre-irradiation, post-25-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)
16177	157.25	168.1	167.95
16178	159.95	170.65	170.3
16206	158.6	178.1	170.65
16207	158	168.35	170
16208	158.35	167.05	168.3
16224	157.1	169.75	169.4

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

DUT	(Compared to Pre-irradiation)	Post-25 krad(%)	Post-Annealing (%)
16177	-	6.90%	6.80%
16178	-	6.69%	6.47%
16206	-	12.30%	7.60%
16207	-	6.55%	7.59%
16208	-	5.49%	6.28%
16224	-	8.05%	7.83%

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

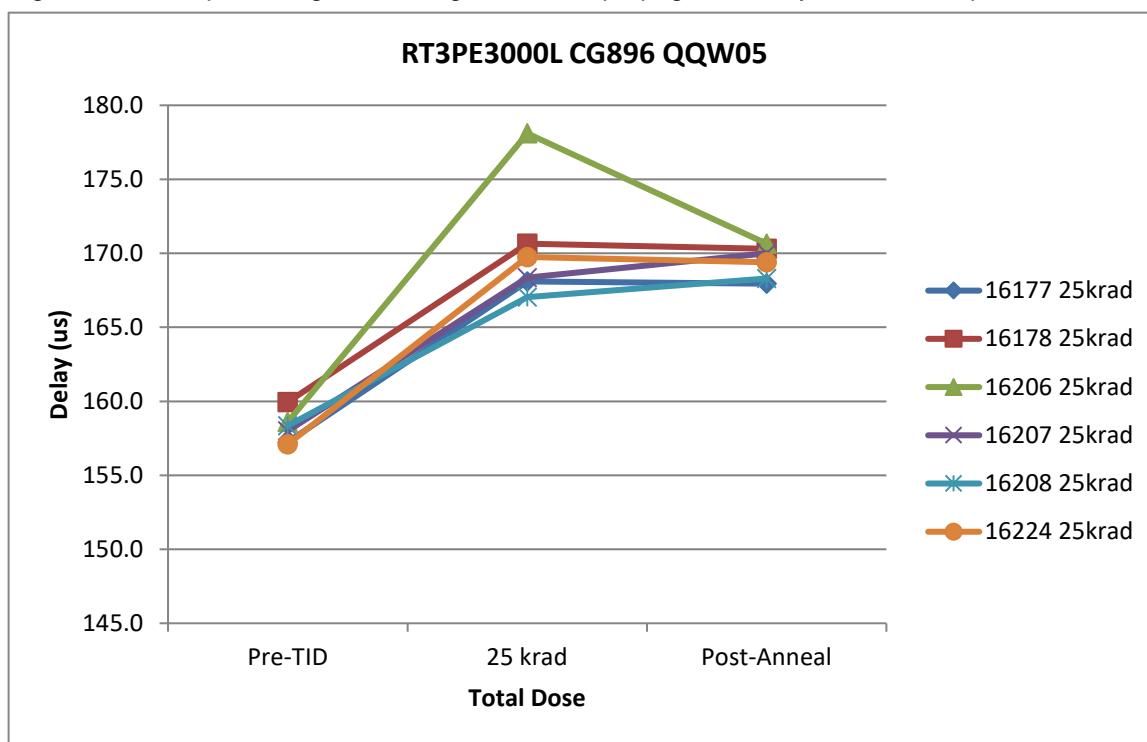


Figure 2 Degradation of Propagation Delay versus TID and Annealing

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 16177 Pre-Irradiation Rising Edge



Figure 3b DUT 16177 Post-Annealing Rising Edge

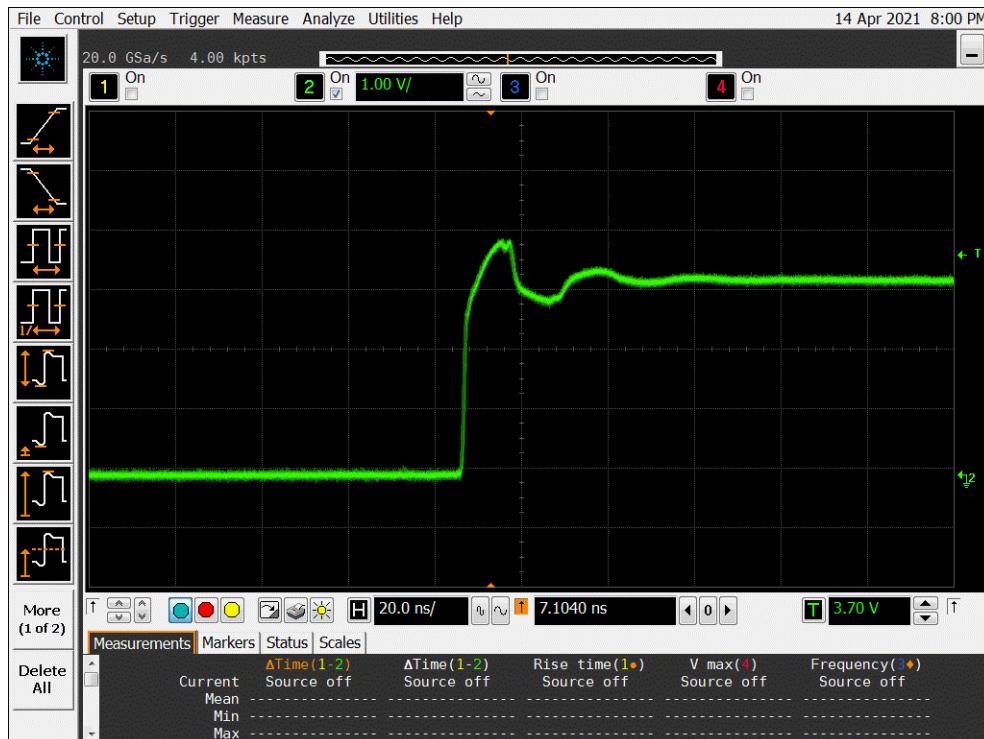

Figure 4a DUT 16178 Pre-Irradiation Rising Edge

Figure 4b DUT 16178 Post-Annealing Rising Edge

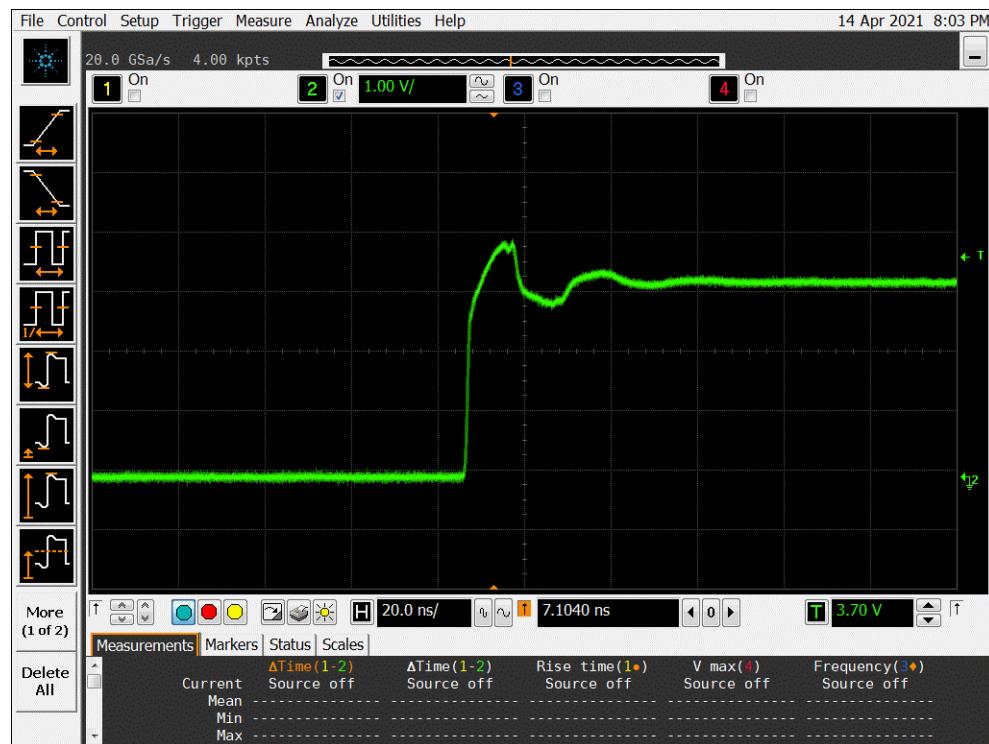

Figure 5a DUT 16206 Pre-Irradiation Rising Edge

Figure 5b DUT 16206 Post-Annealing Rising Edge



Figure 6a DUT 16207 Pre-Irradiation Rising Edge



Figure 6b DUT 16207 Post-Annealing Rising Edge

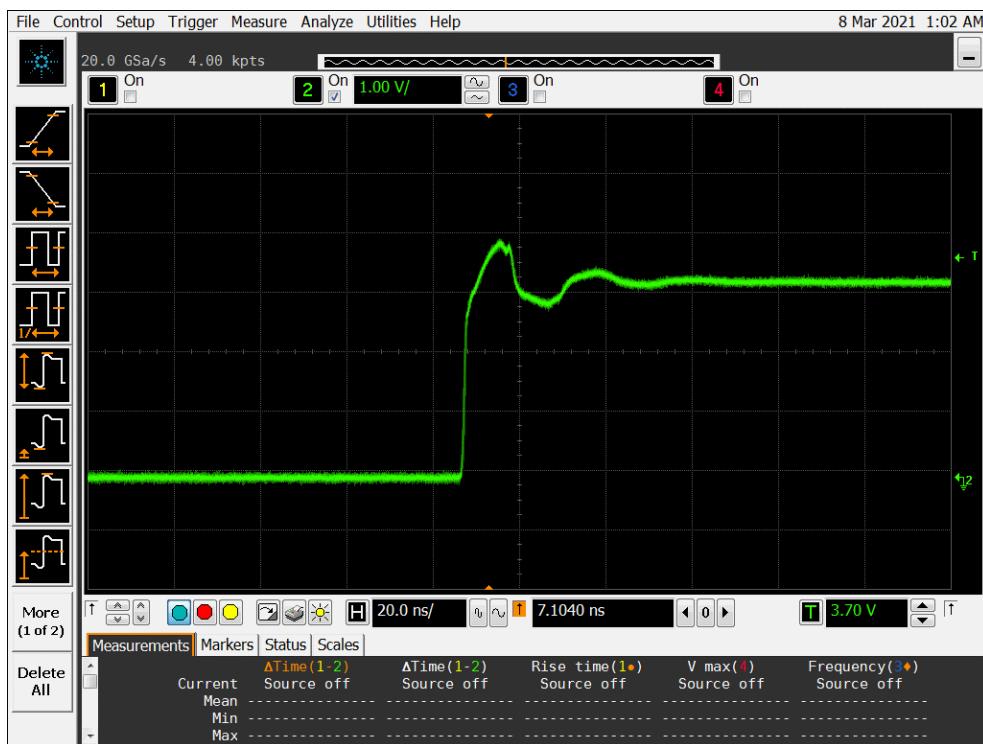


Figure 7a DUT 16208 Pre-Irradiation Rising Edge



Figure 7b DUT 16208 Post-Annealing Rising Edge

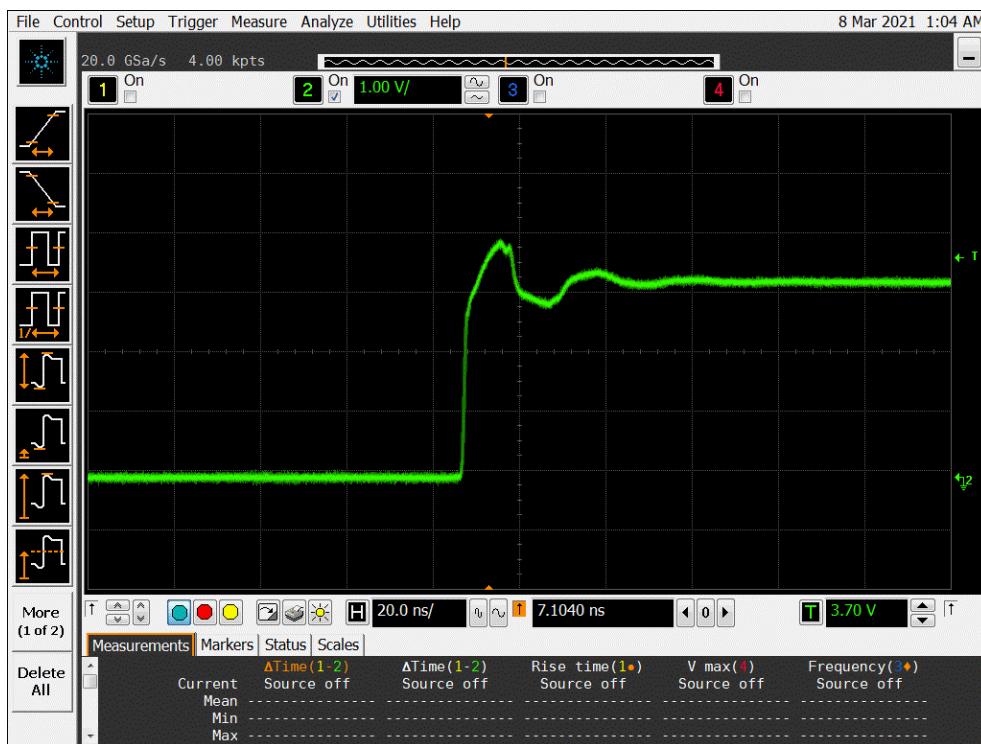


Figure 8a DUT 16224 Pre-Irradiation Rising Edge



Figure 8b DUT 16224 Post-Annealing Rising Edge


Figure 9a DUT 16177 Pre-Irradiation Falling Edge

Figure 9b DUT 16177 Post-Annealing Falling Edge


Figure 10a DUT 16178 Pre-Irradiation Falling Edge

Figure 10b DUT 16178 Post-Annealing Falling Edge


Figure 11a DUT 16206 Pre-Irradiation Falling Edge

Figure 11b DUT 16206 Post-Annealing Falling Edge


Figure 12a DUT 16207 Pre-Irradiation Falling Edge

Figure 12b DUT 16207 Post-Annealing Falling Edge



Figure 13a DUT 16208 Pre-Irradiation Falling Edge



Figure 13b DUT 16208 Post-Annealing Falling Edge



Figure 14a DUT 16224 Pre-Irradiation Falling Edge



Figure 14b DUT 16224 Post-Annealing Falling Edge

Appendix A: DUT Design Block Diagrams and Schematics

A. PLL Block

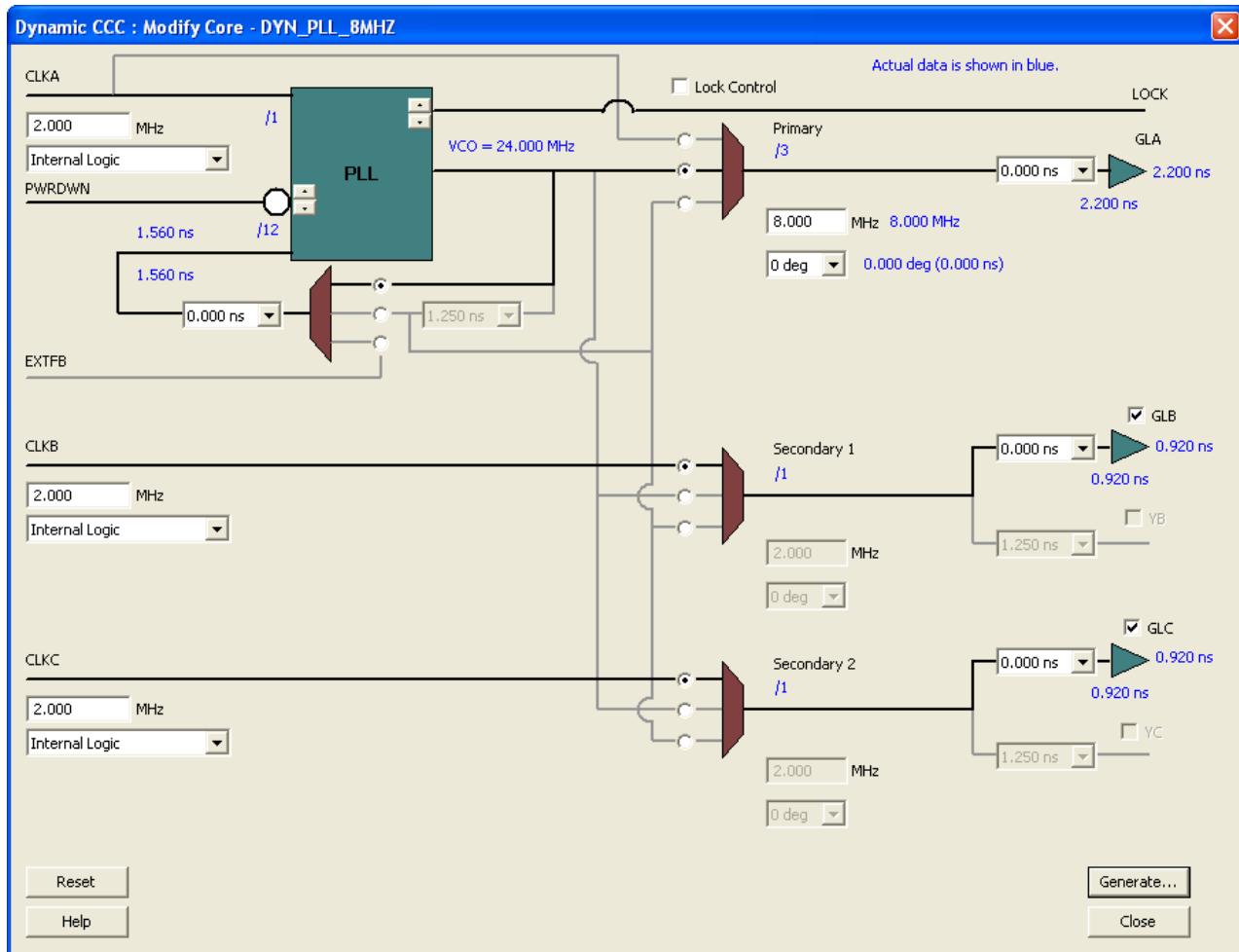
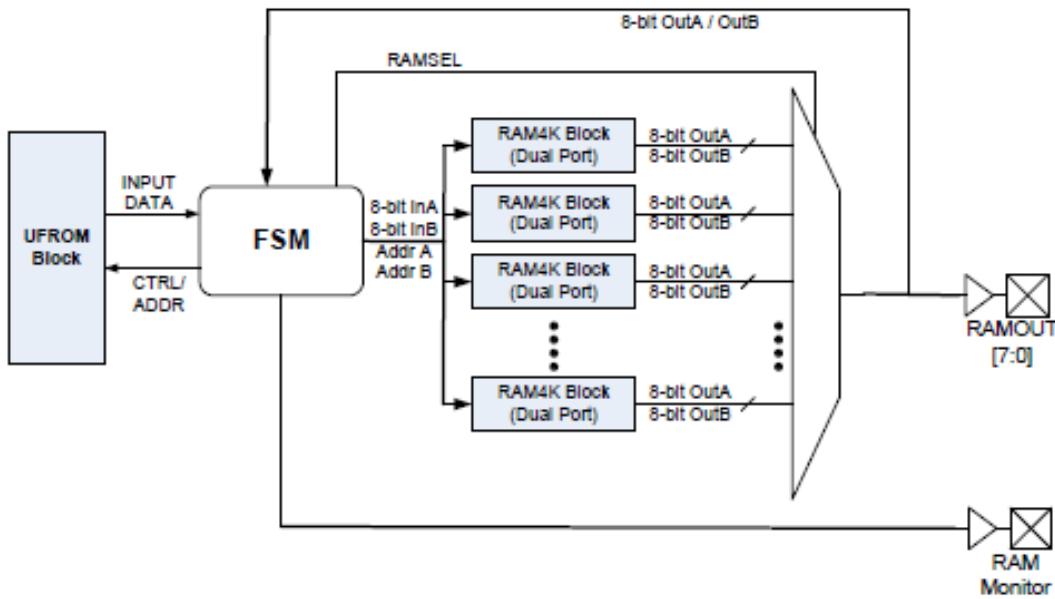


Table 10 lists the signals that go through each of the PLLs:

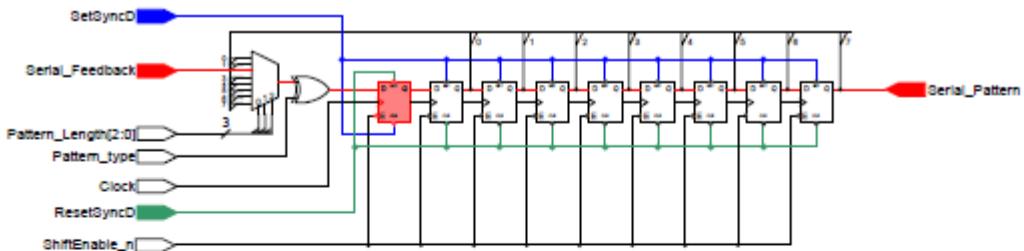
Table 10 Signals Through PLLs

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

B. UFROM/SRAM Block

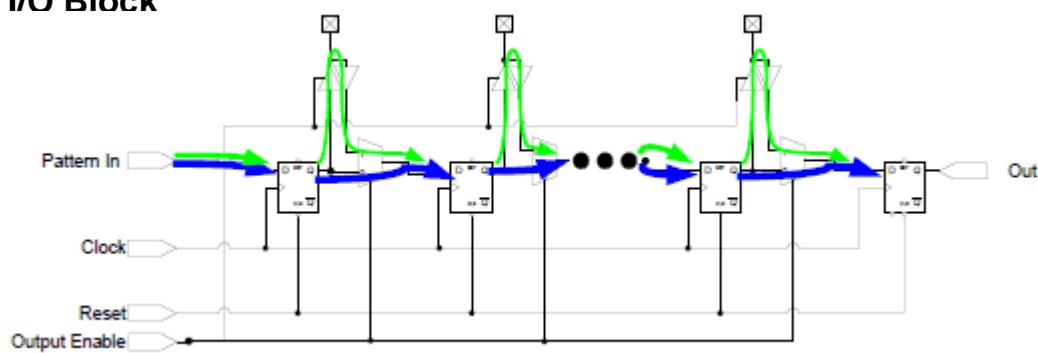


C. Pattern Generators Block

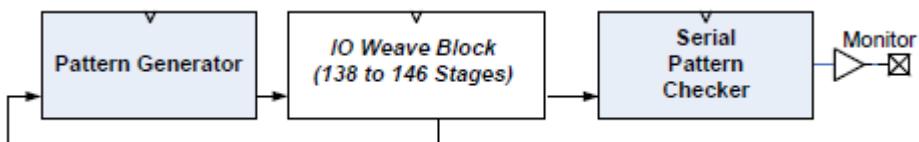


Type	Patter	n	n	Code Length	Δ Bits	Switching Rate
0	000 1 0 < 0 1 &			2	2	100.00%
0	001 1 0 < 0 1 0 < 0 0 1 &			3	2	66.67%
0	010 One hot I/O at a time switching in entire I/O ring			#Bits+9	2	N/A
0	011 1 0 0 0 0 < 0 1 0 0 0 < 0 0 1 0 0 < 0 0 0 1 0 < 0 0 0 0 1 &			5	2	40.00%
0	100 1 0 0 0 0 < 0 1 0 0 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 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 0 &			7	2	28.57%
0	110 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 0 0 0 &			8	2	25.00%
0	111 1 0 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 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 1 < 0 1 1 1 1 1 < 0 0 1 1 1 1 &			5	1	20.00%
1	100 1 0 0 0 0 0 < 1 1 0 0 0 0 < 1 1 1 0 0 0 < 1 1 1 1 0 0 < 1 1 1 1 1 0 < 1 1 1 1 1 1 < 1 1 1 1 1 1 &			6	1	16.67%
1	101 1 0 0 0 0 0 < 1 1 0 0 0 0 0 < 1 1 1 0 0 0 0 < 1 1 1 1 0 0 0 < 1 1 1 1 1 0 0 < 1 1 1 1 1 1 0 < 1 1 &			7	1	14.29%
1	110 1 0 0 0 0 0 0 < 1 1 0 0 0 0 0 < 1 1 1 0 0 0 0 < 1 1 1 1 0 0 0 < 1 1 1 1 1 0 0 < 1 1 1 1 1 1 0 < 1 1 &			8	1	12.50%
1	111 1 0 0 0 0 0 0 0 < 1 1 0 0 0 0 0 < 1 1 1 0 0 0 0 0 < 1 1 1 1 0 0 0 0 < 1 1 1 1 1 0 0 0 < 1 1 1 &			9	1	11.11%

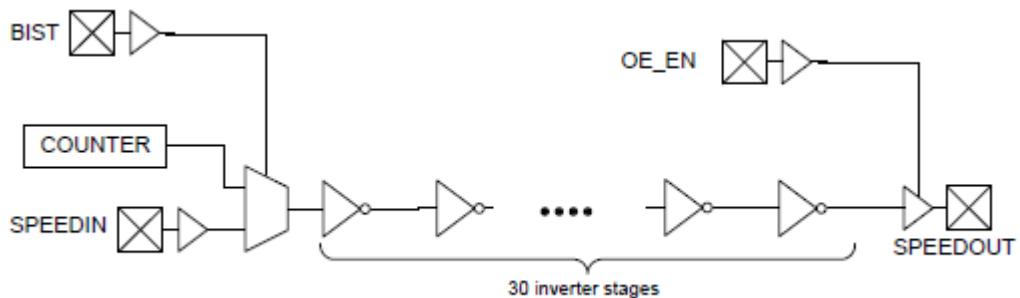
D. I/O Block



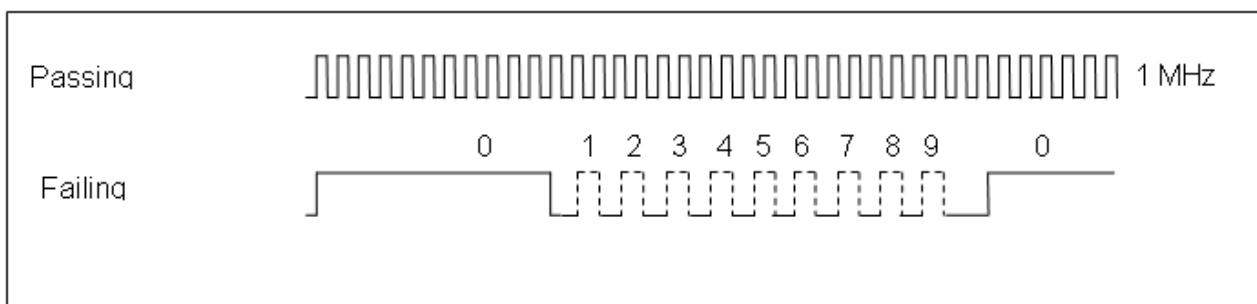
E. Array Shift Registers Block



F. Delay Path Block



G. Monitor Block





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