

TOTAL IONIZING DOSE TEST REPORT

No. 05T-RTSX72SU-D1JW01

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I. SUMMARY TABLE

Parameter	Tolerance
1. Gross Functionality	Passed 100 krad (Si)
2. Power Supply Current (I_{CCA}/I_{CCI})	Passed 97 krad (Si) per 25-mA spec. Post 100 krad (Si) and after 10 days room temperature annealing: average $I_{CCA} = 121$ mA; average $I_{CCI} = 56.7$ mA.
3. Input Threshold (V_{TIL}/V_{IH})	Passed 100 krad (Si)
4. Output Drive (V_{OL}/V_{OH})	Passed 100 krad (Si)
5. Propagation Delay	Passed 100 krad (Si) per 10% degradation criterion
6. Transition Time	Passed 100 krad (Si)

II. TOTAL IONIZING DOSE (TID) TESTING

This testing is designed on the base of an extensive database (see, for example, TID data of antifuse-based FPGA in <http://www.klabs.org/>) accumulated from the TID testing of many generations of antifuse-based FPGAs. One distinctive quality about this testing is the bench measurement of electrical parameters. Compared to the automatic-tester measurement, the bench measurement provides lower noise, better accuracy and more flexibility. The bench measurement samples pins for some measurements. However, since the tolerance is usually determined by the most degraded parameter, which is often either I_{CC} or propagation delay, sampling the pins for measuring non-critical parameters is appropriate.

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

Table 1 lists the DUT and irradiation parameters. There are two groups: DUT 66744, 66745 and 66746 are irradiated to 60 krad; DUT 66758, 66851 and 66861 are irradiated to 100 krad. During irradiation each input or output is grounded through a 1-M ohm resistor; during annealing each input or output is grounded through a 1-k ohm resistor. Appendix A contains the schematics of the bias circuit.

Table 1 DUT and Irradiation Parameters

Part Number	RTSX72SU
Package	CQFP256
Foundry	United Microelectronics Corp.
Technology	0.25 μ m CMOS
DUT Design	TDSX72CQFP256_2Strings
Die Lot Number	D1JW01
Quantity Tested	6
Serial Number/Total Dose	60 krad: 66744, 66745, 66746 100 krad: 66758, 66851, 66861
Radiation Facility	Defense Microelectronics Activity
Radiation Source	Co-60
Dose Rate	1 krad (Si)/min ($\pm 5\%$)
Irradiation Temperature	Room
Irradiation and Measurement Bias (V_{CCI}/V_{CCA})	Static at 5.0 V/2.5 V

B. Test Method

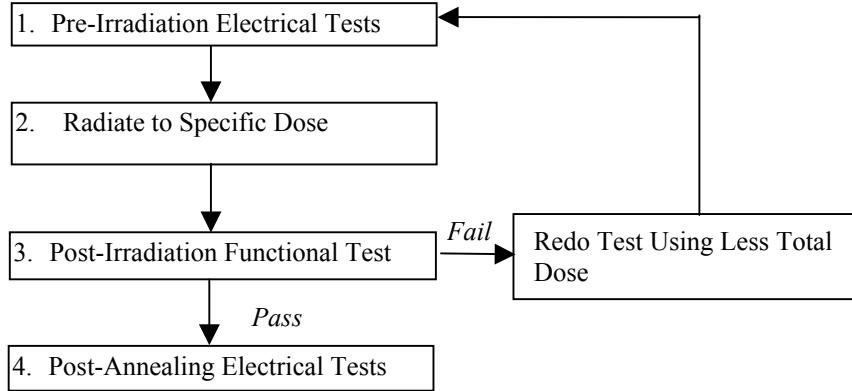


Figure 1 Parametric test flow chart

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 products manufactured by sub-micron CMOS technology. To prove this point, test data using a high dose rate (1 krad (Si)/min) are compared with test data using a low dose rate (1 krad (Si)/hr) for devices manufactured by several generations of sub-micron CMOS technologies. Since the results always show the low-dose-rate degradation less than the high-dose-rate degradation, the elevated rebound annealing would artificially improve the electrical parameters. Therefore, only room temperature annealing is performed in this report. Both 60 krad-irradiated and 100 krad-irradiated group are annealed for approximately 10 days.

C. Design and Parametric Measurements

DUTs use a high utilization generic design (TDSX72CQ256_2Strings) to test total dose effects in typical space applications. Appendix B contains the schematics illustrating the logic design.

Table 2 lists each electrical parameter and the corresponding logic design. The functionality is measured on the output pins (O_AND3 and O_AND4) of two combinational buffer-strings with 1400 buffers each and output pins (O_OR4 and O_NAND4) of a shift register with 1536 bits. I_{CC} is measured on the power supply of the logic-array (I_{CCA}) and I/O (I_{CCI}) respectively. The input logic thresholds (V_{TH}/V_{IH}) are measured on twelve combinational nets listed in Table 2. The output-drive voltages (V_{OL}/V_{OH}) are measured on a combinational net, the input pin DA to the output pin QA0. The propagation delays are measured on the O_AND4 output of one buffer string. The delay is defined as the time delay from the time of triggering edge at the CLOCK input to the time of switching state at the output O_AND4. 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 O_AND4, are displayed 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 (pins O_AND3, O_AND4, O_OR3, O_OR4, and O_NAND4)
2. I_{CC} (I_{CCA}/I_{CCI})	DUT power supply
3. Input Threshold (V_{TH}/V_{IH})	Input buffers (DA/QA0, DAH/QA0H, ENCCTR/YO0, ENCCTRH/YO0H, IDII0/IDIO0, IDII1/IDIO1, IDII2/IDIO2, IDII3/IDIO3, IDII4/IDIO4, IDII5/IDIO5, IDII6/IDIO6, IDII7/IDIO7)
4. Output Drive (V_{OL}/V_{OH})	Output buffer (DA/QA0)
5. Propagation Delay	String of buffers (pin LOADIN to O_AND4)
6. Transition Characteristic	D flip-flop output (O_AND4)

III. TEST RESULTS

A. Functionality

Every DUT passes the pre-irradiation, post-irradiation, and post-annealing functional tests.

B. Power Supply Current (I_{CCA} and I_{CCI})

Since the pre-irradiation I_{CCA} and I_{CCI} of every DUT are below 1 mA, the in-flux I_{CC} -plots of Figure 2 to Figure 7 basically show the radiation-induced leakage current. The room temperature annealing effect on I_{CC} is shown by Table 3, where the post-annealing data compares with the post-irradiation data.

Table 3 Post Irradiation and Post-Annealing I_{CC}

DUT	Total Dose	I_{CCA} (mA)		I_{CCI} (mA)	
		Post-rad	Post-ann	Post-rad	Post-ann
66744	60 krad	18.9	12	22.4	9
66745	60 krad	15.7	12	22.7	9
66746	60 krad	17.5	14	23.5	10
66758	100 krad	NA	99	NA	50
66851	100 krad	244	157	190	61
66861	100 krad	266	107	206	59

The 60 krad group shows the post-annealed I_{CC} passing the 25 mA spec. For the 100 krad group, a semi-log empirical equation is used to extrapolate the room temperature annealing for 10 years. Using the worst case, DUT 66861, the tolerance is extracted as 97 krad for 10 years mission.

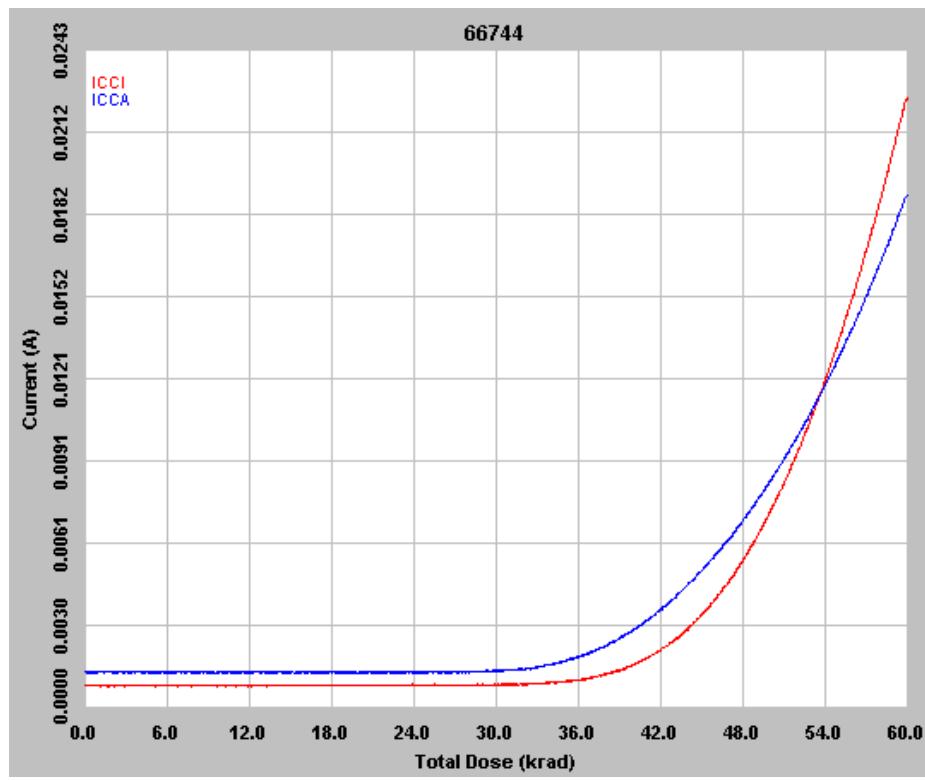


Figure 2 DUT 66744 in-flux I_{CCA} and I_{CCI}, 60-krad total dose

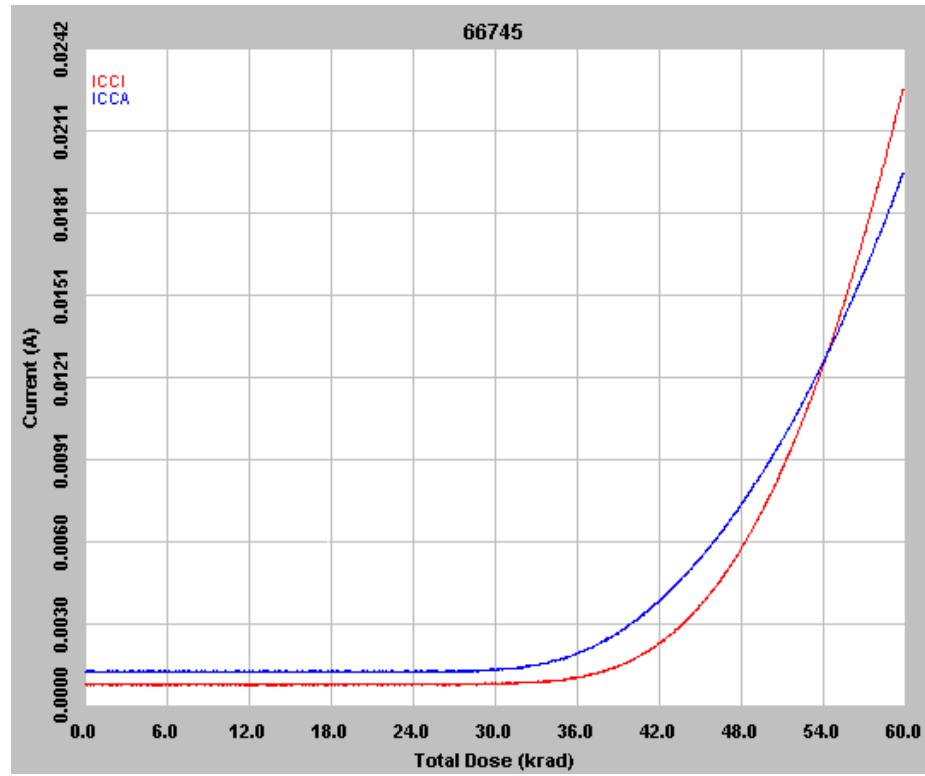


Figure 3 DUT 66745 in-flux I_{CCA} and I_{CCI}, 60-krad total dose

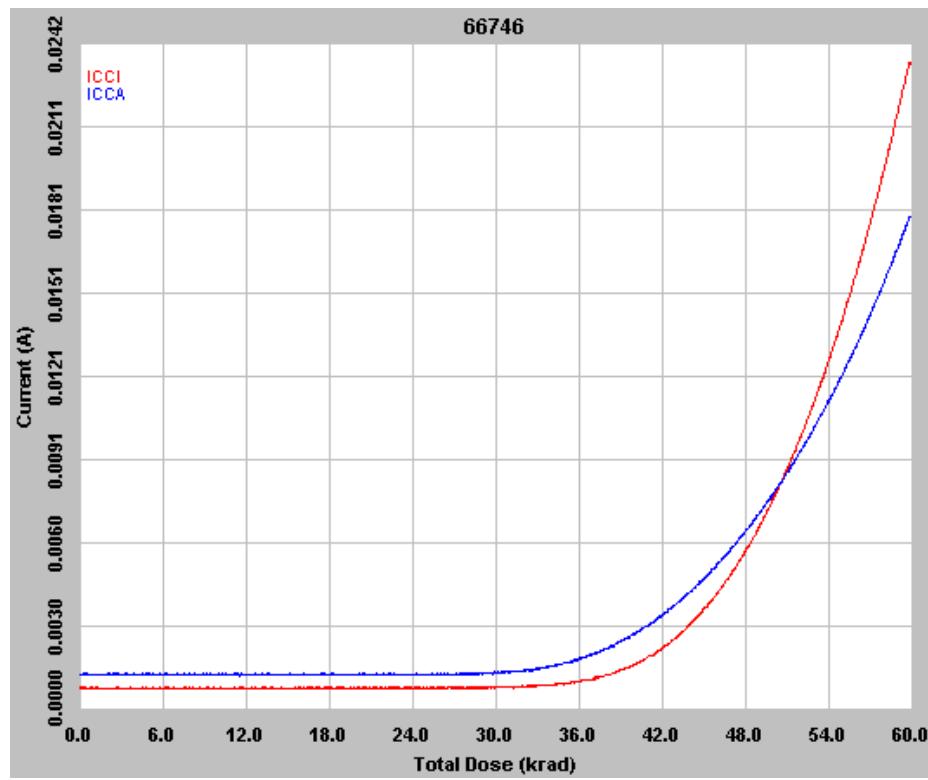


Figure 4 DUT 66746 in-flux I_{CCA} and I_{CCI} , 60-krad total dose

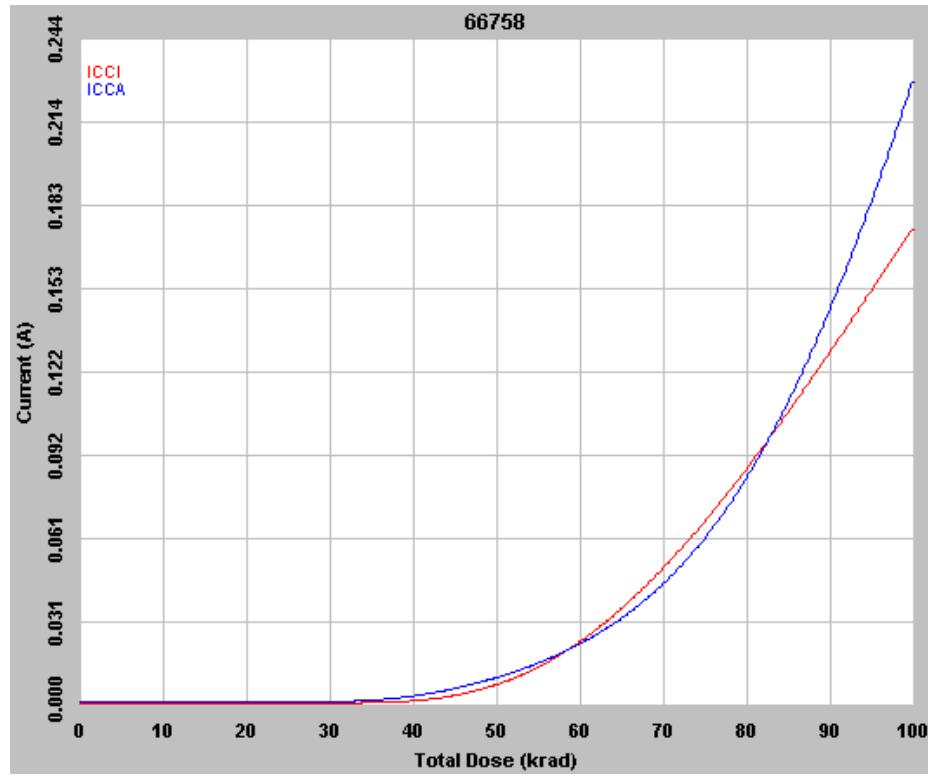


Figure 5 DUT 66758 in-flux I_{CCA} and I_{CCI} , 100-krad total dose

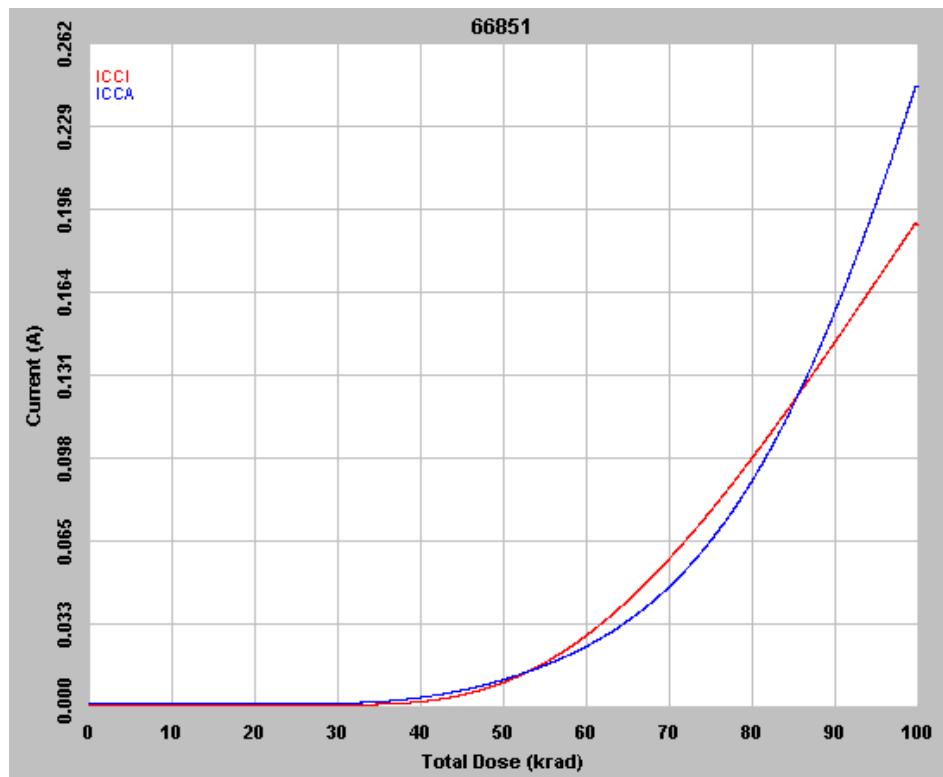


Figure 6 DUT 66851 in-flux I_{CCA} and I_{CCI} , 100-krad total dose

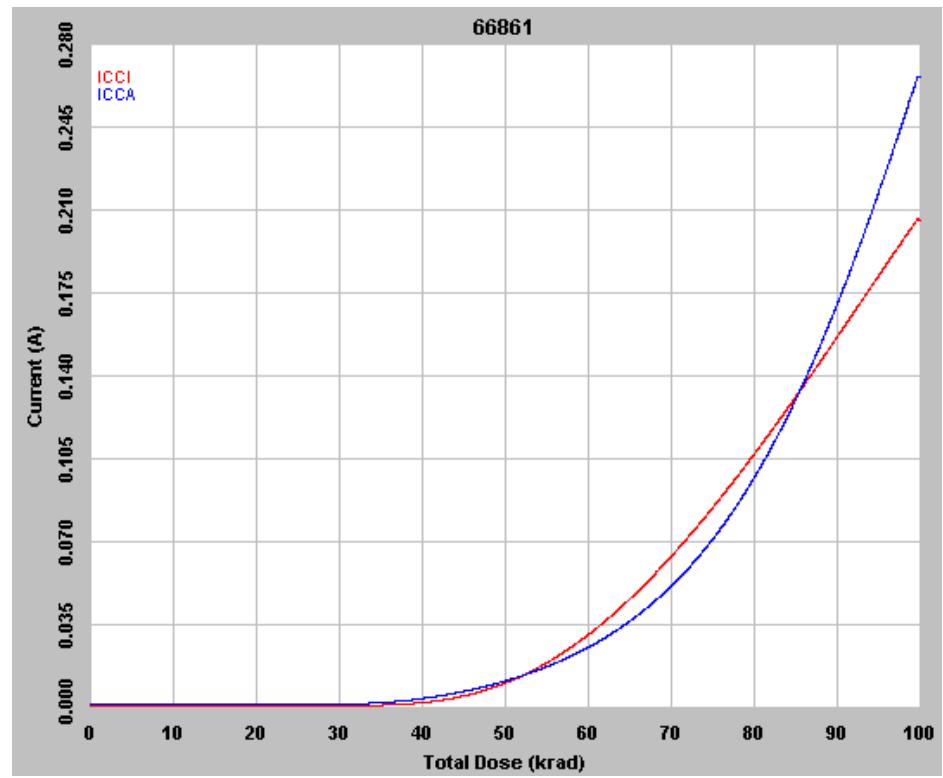


Figure 7 DUT 66861 in-flux I_{CCA} and I_{CCI} , 100-krad total dose

C. Input Logic Threshold (V_{IL}/V_{IH})

Table 4 lists the pre-irradiation and post-annealing input logic threshold. All data are within the spec limits.

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

In/Out Pin:		DA / QA0				DAH / QA0H			
DUT	Total Dose	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann
		V_{IL} (V)		V_{IH} (V)		V_{IL} (V)		V_{IH} (V)	
65838	60 krad	1.36	1.36	1.44	1.48	1.38	1.33	1.45	1.47
65878	60 krad	1.37	1.22	1.44	1.5	1.37	1.36	1.44	1.43
65891	60 krad	1.36	1.38	1.43	1.44	1.37	1.36	1.43	1.46
65907	100 krad	1.36	1.40	1.45	1.47	1.37	1.42	1.45	1.49
65981	100 krad	1.36	1.38	1.44	1.46	1.36	1.39	1.43	1.45
62926	100 krad	1.34	1.27	1.44	1.49	1.37	1.46	1.43	1.52

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

In/Out Pin:		ENCNTR/YO0				ENCNTRH/YO0H			
DUT	Total Dose	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann
		V_{IL} (V)		V_{IH} (V)		V_{IL} (V)		V_{IH} (V)	
65838	60 krad	1.36	1.39	1.44	1.46	1.38	1.38	1.44	1.47
65878	60 krad	1.36	1.36	1.44	1.44	1.36	1.34	1.43	1.44
65891	60 krad	1.39	1.37	1.44	1.45	1.37	1.37	1.44	1.44
65907	100 krad	1.38	1.42	1.44	1.48	1.36	1.40	1.43	1.47
65981	100 krad	1.36	1.37	1.43	1.47	1.36	1.37	1.44	1.43
62926	100 krad	1.39	1.41	1.44	1.46	1.36	1.43	1.43	1.49

Table 4c Pre-Irradiation and Post-Annealing Input Thresholds

In/Out Pin:		IDII0/IDIO0				IDII1/IDIO1			
DUT	Total Dose	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann
		V_{IL} (V)		V_{IH} (V)		V_{IL} (V)		V_{IH} (V)	
65838	60 krad	1.38	1.38	1.45	1.45	1.38	1.37	1.44	1.45
65878	60 krad	1.36	1.33	1.43	1.44	1.36	1.29	1.44	1.46
65891	60 krad	1.36	1.37	1.44	1.43	1.36	1.36	1.45	1.45
65907	100 krad	1.37	1.42	1.44	1.47	1.36	1.43	1.44	1.51
65981	100 krad	1.35	1.37	1.43	1.43	1.36	1.38	1.44	1.44
62926	100 krad	1.36	1.41	1.42	1.47	1.37	1.17	1.44	1.56

Table 4d Pre-Irradiation and Post-Annealing Input Thresholds

In/Out Pin:		IDII2 / IDIO2				IDII3 / IDIO3			
DUT	Total Dose	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann
		V_{IL} (V)		V_{IH} (V)		V_{IL} (V)		V_{IH} (V)	
65838	60 krad	1.36	1.29	1.44	1.44	1.37	1.39	1.45	1.45
65878	60 krad	1.36	1.37	1.44	1.43	1.37	1.32	1.43	1.44
65891	60 krad	1.37	1.38	1.44	1.43	1.37	1.38	1.45	1.43
65907	100 krad	1.36	1.41	1.44	1.47	1.37	1.44	1.45	1.49
65981	100 krad	1.37	1.39	1.44	1.45	1.37	1.39	1.43	1.48
62926	100 krad	1.37	1.41	1.44	1.48	1.38	1.40	1.45	1.47

Table 4e Pre-Irradiation and Post-Annealing Input Thresholds

In/Out Pin:		IDII4/IDIO4				IDII5/IDIO5			
DUT	Total Dose	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann
		V _{IL} (V)	V _{IH} (V)						
65838	60 krad	1.38	1.32	1.45	1.47	1.38	1.18	1.45	1.46
65878	60 krad	1.37	1.31	1.45	1.47	1.37	1.17	1.44	1.45
65891	60 krad	1.36	1.40	1.44	1.43	1.36	1.36	1.44	1.44
65907	100 krad	1.38	n/a	1.45	n/a	1.37	1.39	1.45	1.44
65981	100 krad	1.36	1.40	1.43	1.53	1.36	1.38	1.44	1.43
62926	100 krad	1.37	1.39	1.44	1.46	1.37	1.25	1.43	1.47

Table 4f Pre-Irradiation and Post-Annealing Input Thresholds

In/Out Pin:		IDII6/IDIO6				IDII7/IDIO7			
DUT	Total Dose	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann	Pre-Irrad	Post-Ann
		V _{IL} (V)	V _{IH} (V)						
65838	60 krad	1.37	1.29	1.45	1.45	1.37	1.22	1.42	1.43
65878	60 krad	1.36	1.30	1.44	1.44	1.36	1.19	1.42	1.45
65891	60 krad	1.38	1.36	1.44	1.44	1.37	1.37	1.42	1.42
65907	100 krad	1.37	1.41	1.44	1.49	1.36	1.37	1.44	1.44
65981	100 krad	1.35	1.37	1.43	1.44	1.37	1.38	1.43	1.42
62926	100 krad	1.36	1.17	1.44	1.46	1.37	1.34	1.43	1.45

D. Output-Drive Voltage (V_{OL}/V_{OH})

The pre-irradiation and post-annealing V_{OL}/V_{OH} are listed in Tables 5 and 6. The post-annealing data are within the spec limits; in each case, the post-annealing data varies minutely with respect to the pre-irradiation data.

Table 5 Pre-Irradiation and Post-Annealing V_{OL} (V) at Various Sinking Current

DUT	Total Dose	1 mA		12 mA		20 mA		50 mA		100 mA	
		Pre-rad	Pos-an								
66744	60 krad	0.009	0.010	0.104	0.107	0.174	0.179	0.439	0.450	0.902	0.926
66745	60 krad	0.009	0.009	0.106	0.107	0.177	0.178	0.447	0.449	0.918	0.923
66746	60 krad	0.009	0.009	0.104	0.105	0.174	0.174	0.440	0.440	0.904	0.904
66758	100 krad	0.009	0.009	0.106	0.107	0.176	0.178	0.445	0.448	0.916	0.921
66851	100 krad	0.009	0.009	0.104	0.105	0.173	0.176	0.437	0.442	0.899	0.908
66861	100 krad	0.009	0.009	0.104	0.106	0.174	0.176	0.439	0.444	0.903	0.912

Table 6 Pre-Irradiation and Post-Annealing V_{OH} (V) at Various Sourcing Current

DUT	Total Dose	1 mA		8 mA		20 mA		50 mA		100 mA	
		Pre-rad	Pos-an								
66744	60 krad	4.98	4.98	4.86	4.85	4.64	4.63	4.04	4.02	2.68	2.59
66745	60 krad	4.98	4.98	4.86	4.86	4.64	4.64	4.03	4.03	2.64	2.63
66746	60 krad	4.98	4.98	4.86	4.86	4.63	4.64	4.03	4.03	2.64	2.63
66758	100 krad	4.98	4.98	4.86	4.86	4.63	4.64	4.03	4.03	2.64	2.60
66851	100 krad	4.98	4.98	4.86	4.85	4.63	4.63	4.03	4.02	2.63	2.56
66861	100 krad	4.98	4.98	4.86	0.49	4.64	4.63	4.04	4.03	2.66	2.60

E. Propagation Delay

Table 7 lists the pre-irradiation and post-annealing propagation delays, and also lists the radiation-induced degradations in percentage. The 60 krad group shows negative degradation, indicating that the radiation effect is negligible. In the 100 krad group, DUT 66861 has the worst degradation of 3.48%.

Table 7 Radiation-Induced Propagation Delay Degradations

DUT	Total Dose	Pre-Irradiation	Post-Annealing	Degradation
66744	60 krad	1331.6	1336.7	0.37%
66745	60 krad	1340.0	1343.1	0.22%
66746	60 krad	1333.3	1336.7	0.26%
66758	100 krad	1308.1	1339.6	2.43%
66851	100 krad	1336.7	1377.4	3.08%
66861	100 krad	1330.8	1376.6	3.48%

F. Transition Time

Figures 8 to 19 show the pre-irradiation and post-annealing transition edges. In each case, the radiation effect is negligible.

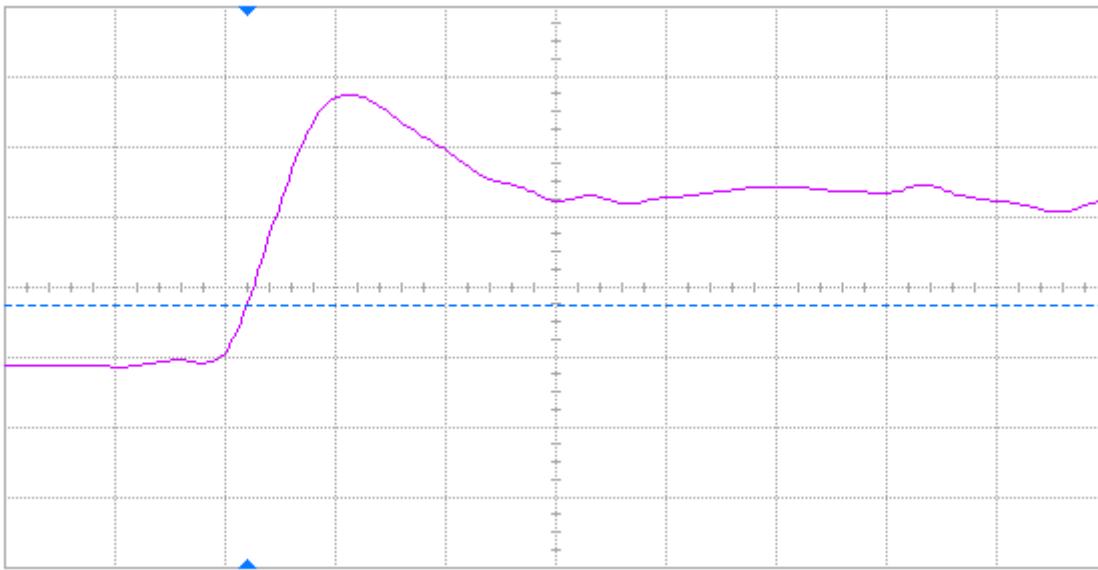


Figure 8(a) DUT 66744 pre-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

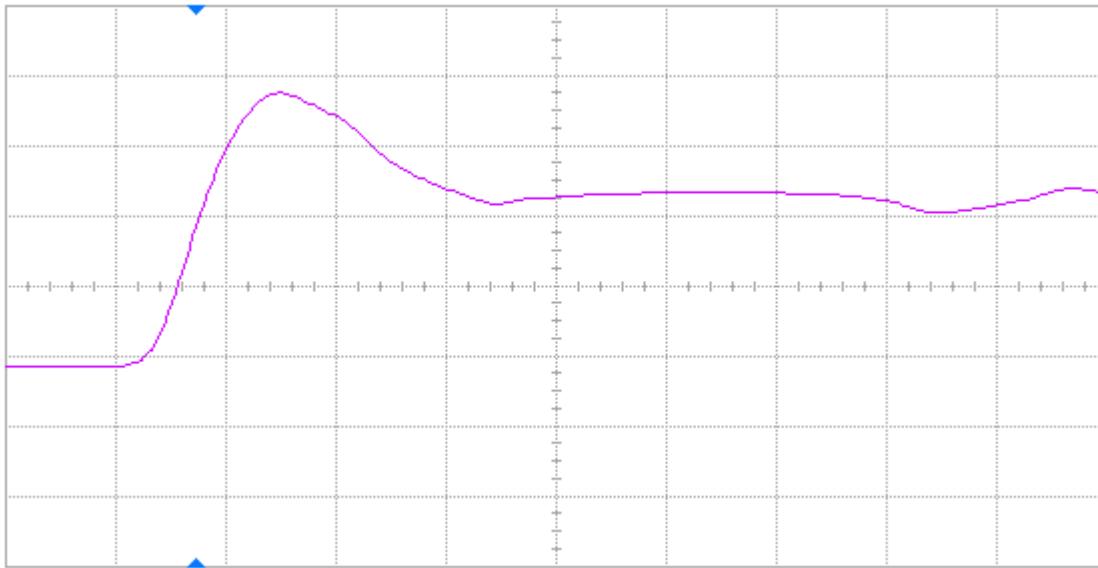


Figure 8(b) DUT 66744 post-annealing rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

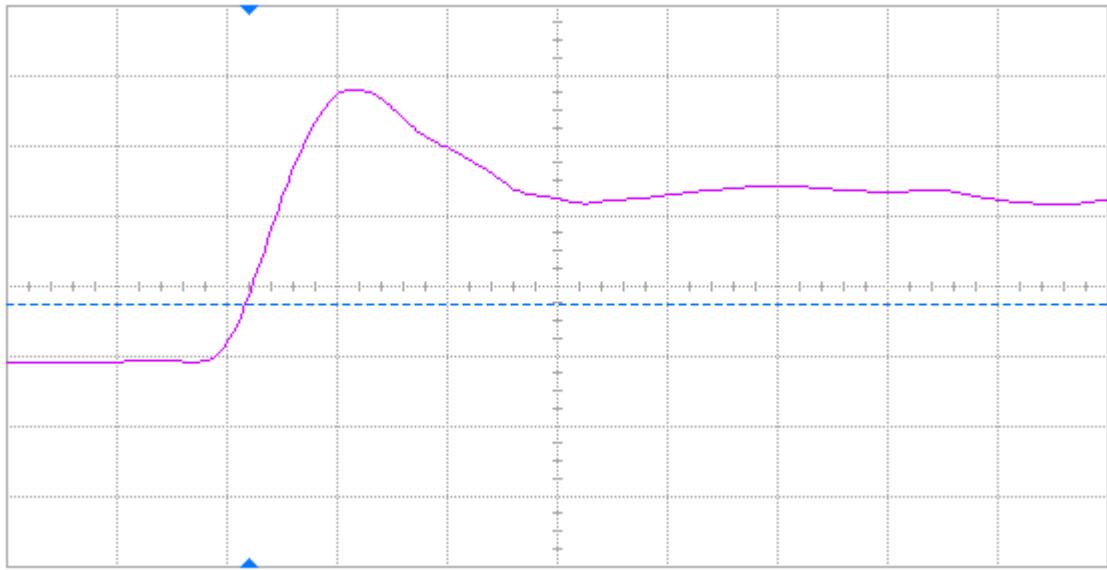


Figure 9(a) DUT 66745 pre-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

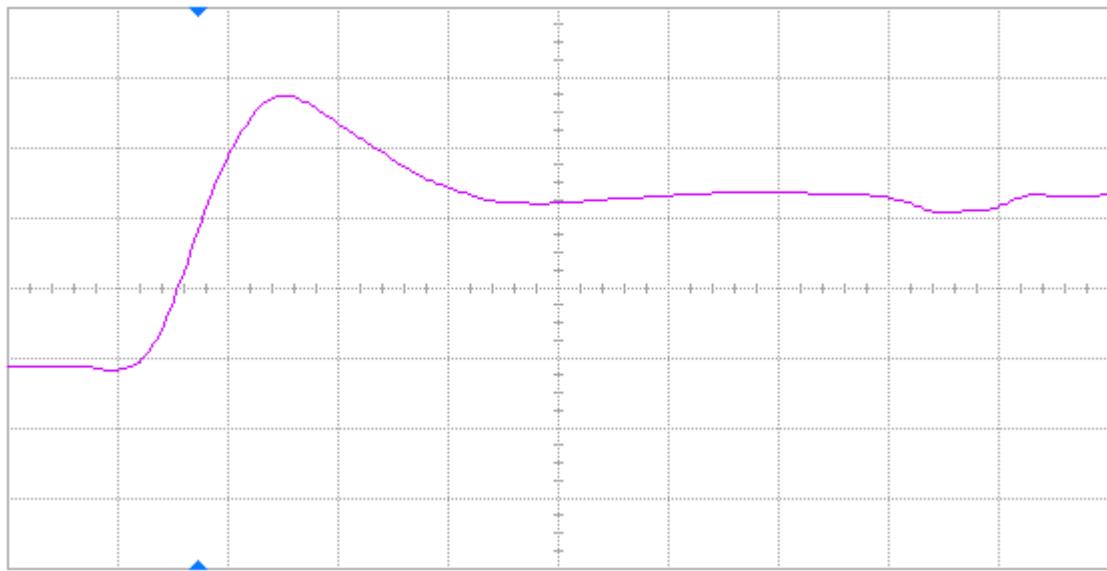


Figure 9(b) DUT 66745 post-annealing rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

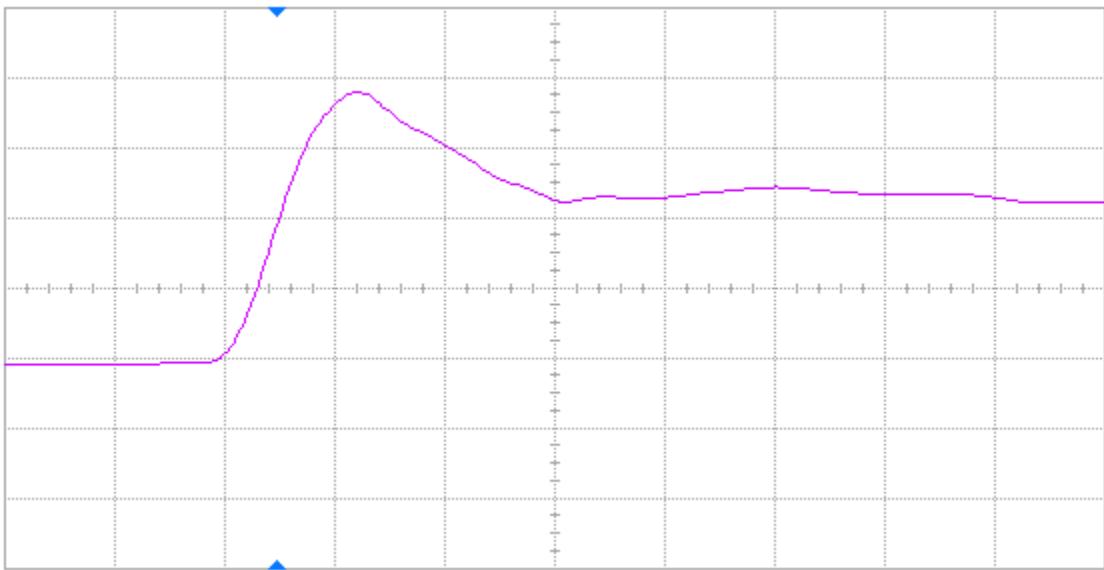


Figure 10(a) DUT 66746 pre-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

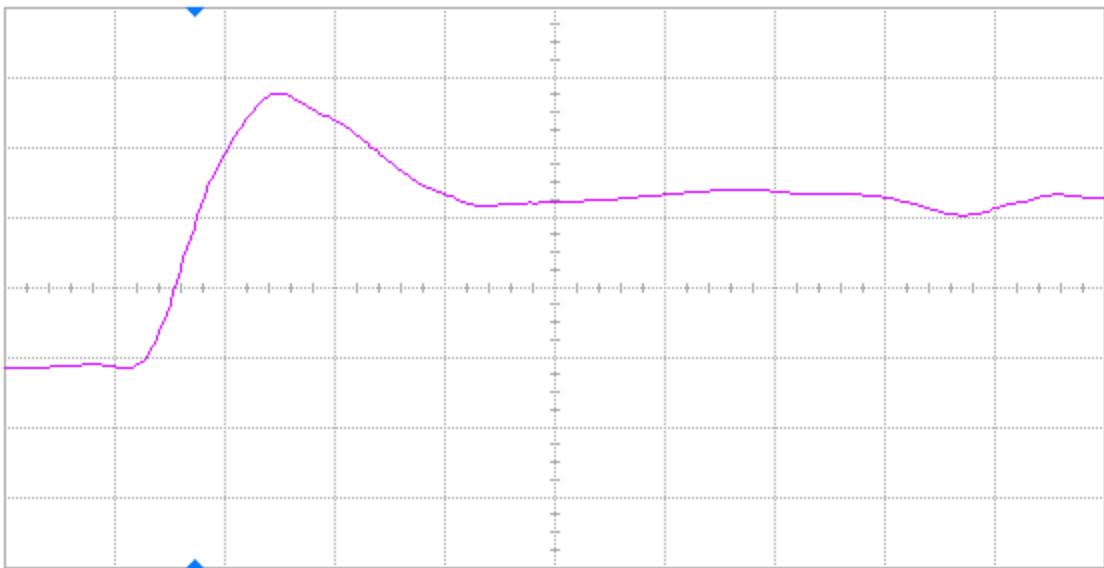


Figure 10(b) DUT 66746 post-annealing rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

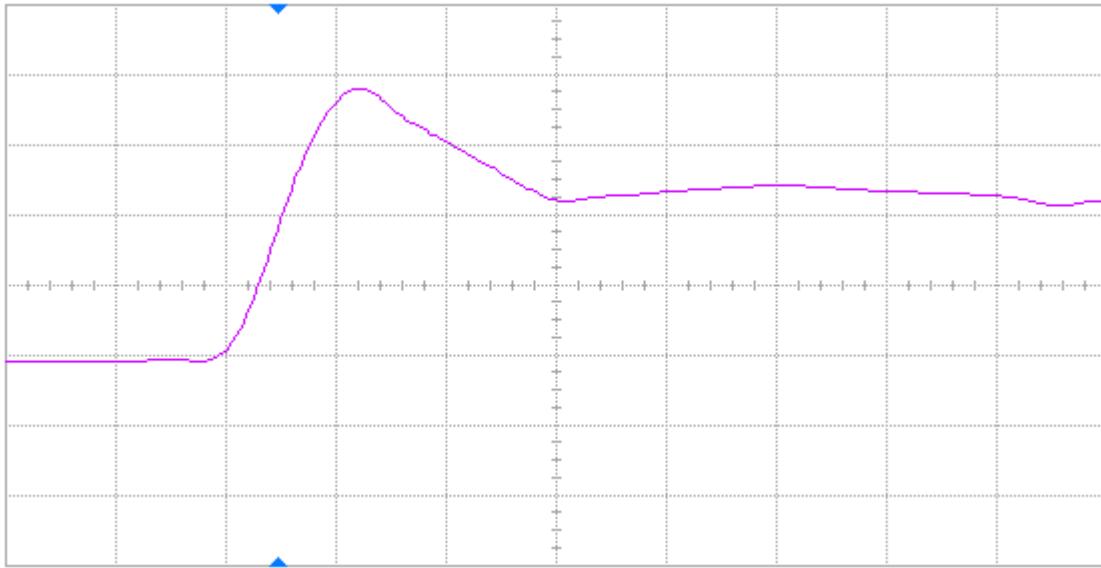


Figure 11(a) DUT 66758 pre-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

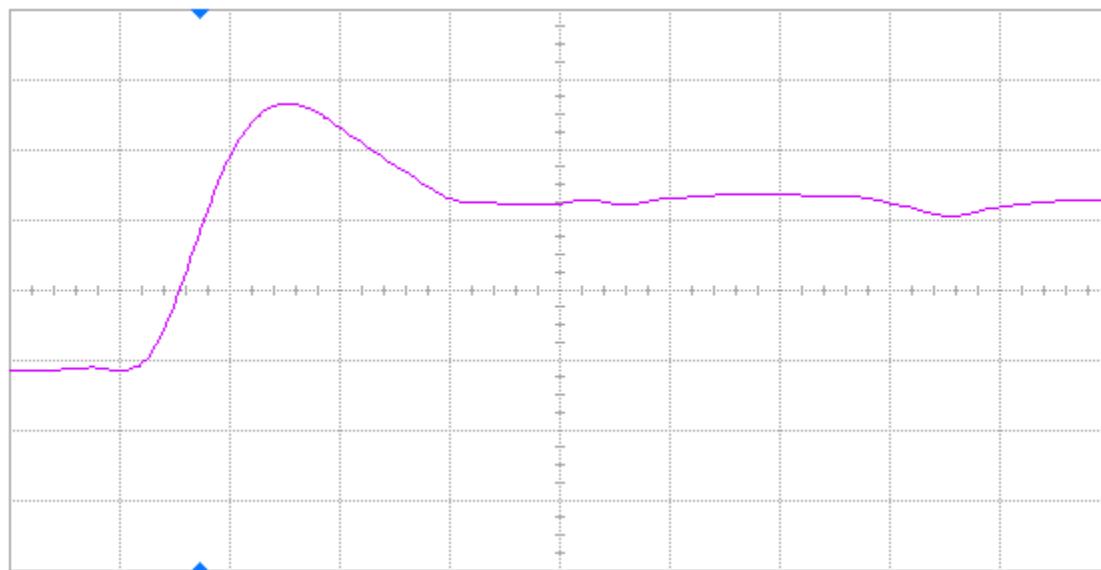


Figure 11(b) DUT 66758 post-annealing rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

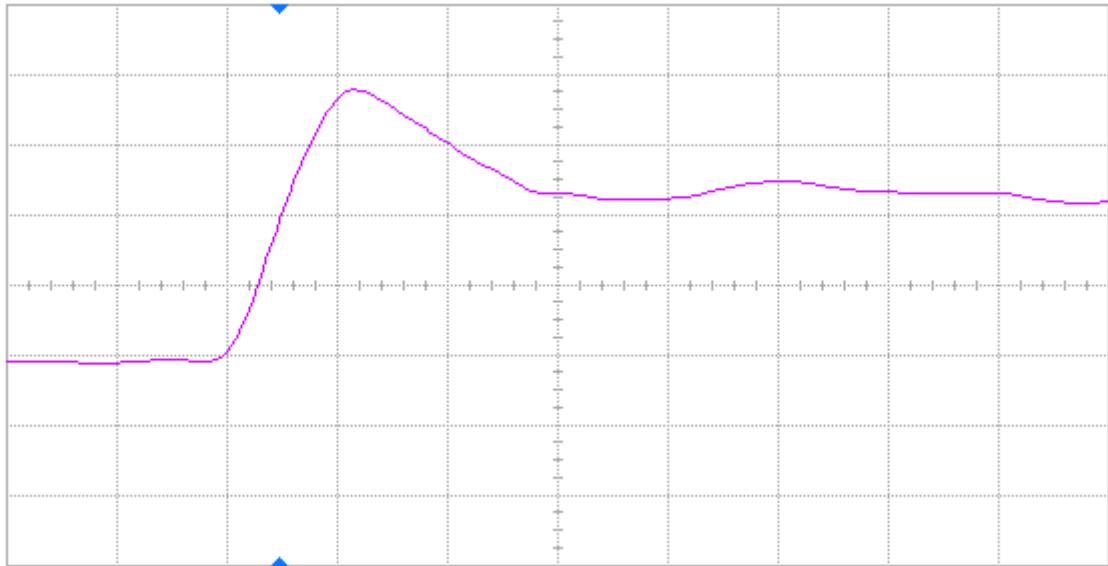


Figure 12(a) DUT 66851 pre-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

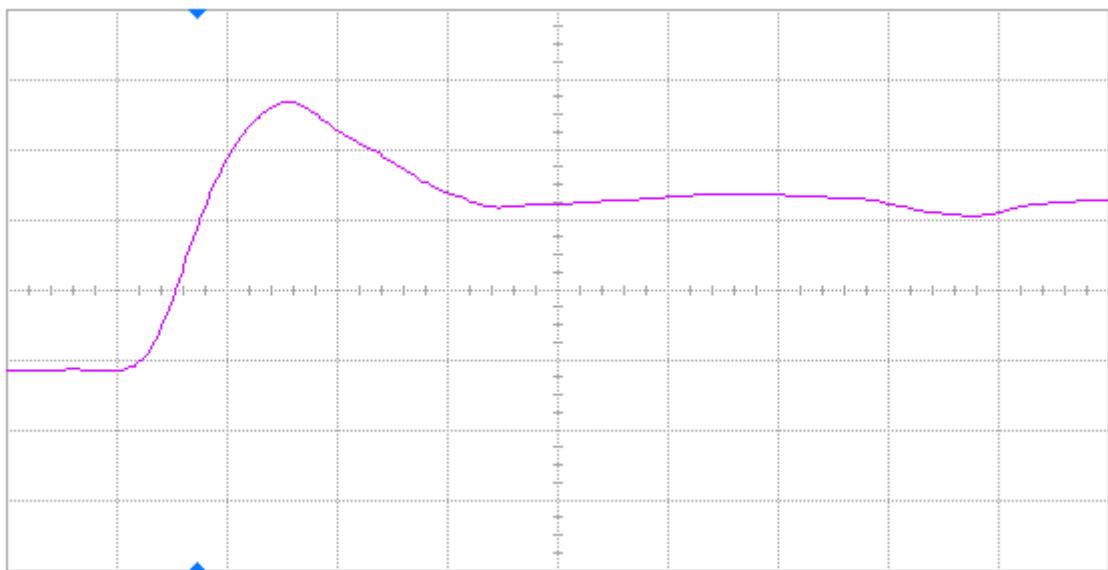


Figure 12(b) DUT 66851 post-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

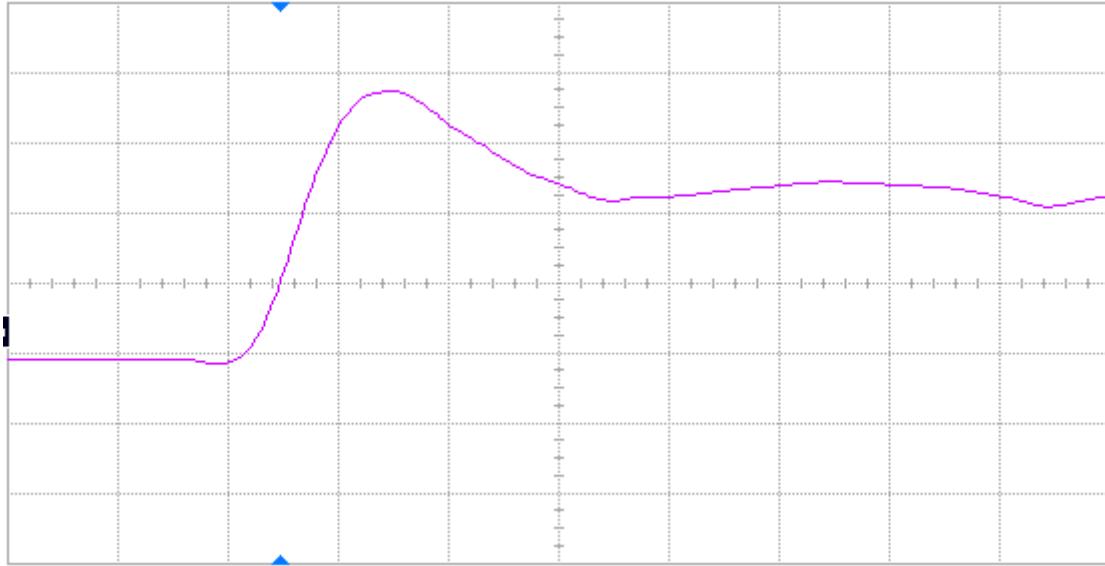


Figure 13(a) DUT 66861 pre-irradiation rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

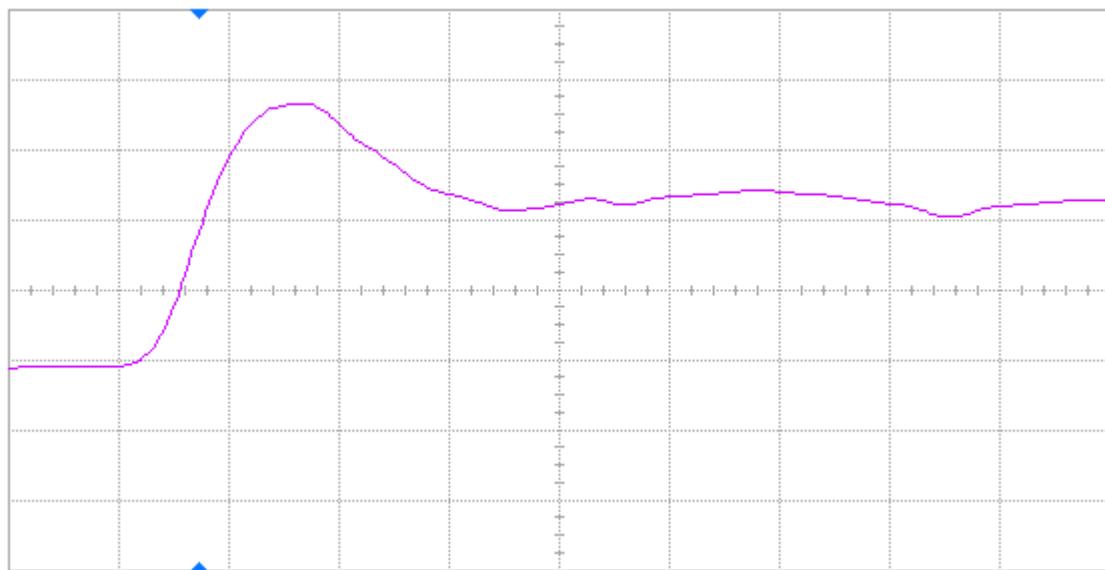


Figure 13(b) DUT 66861 post-annealing rising edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

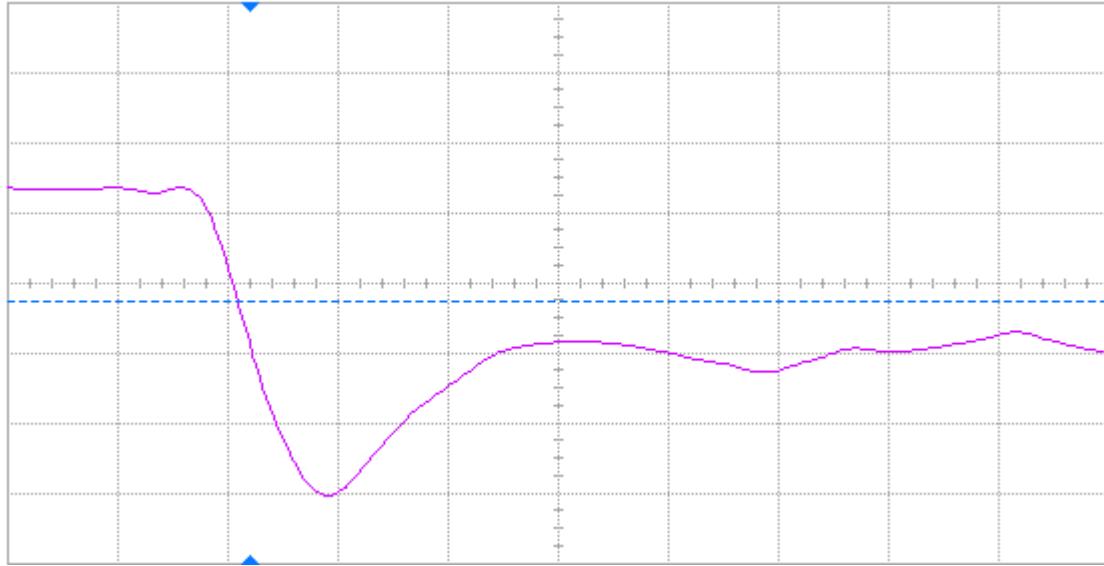


Figure 14(a) DUT 66744 pre-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

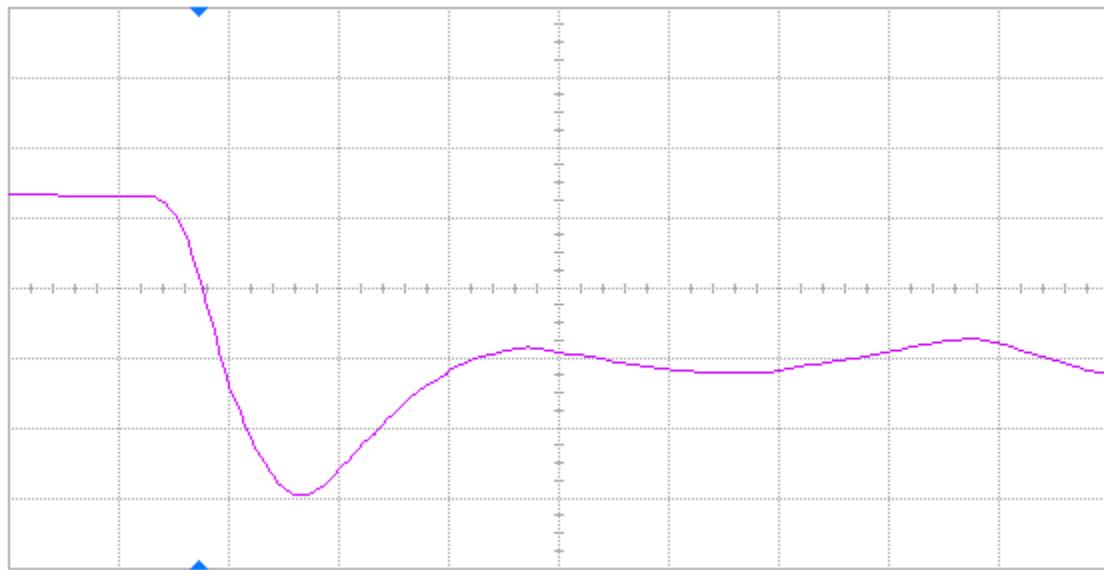


Figure 14(b) DUT 66744 post-annealing falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

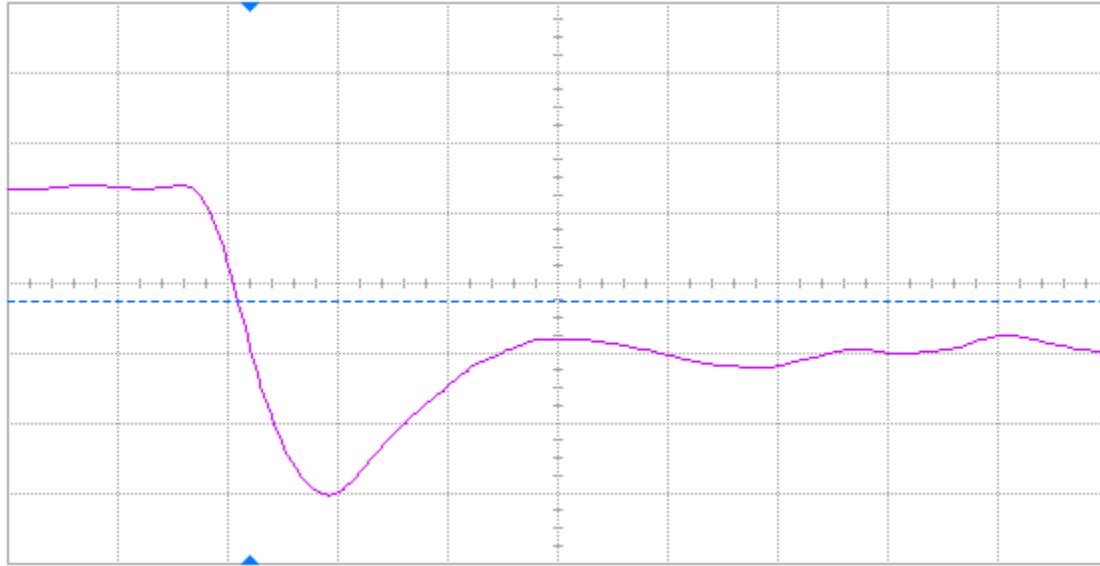


Figure 15(a) DUT 66745 pre-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

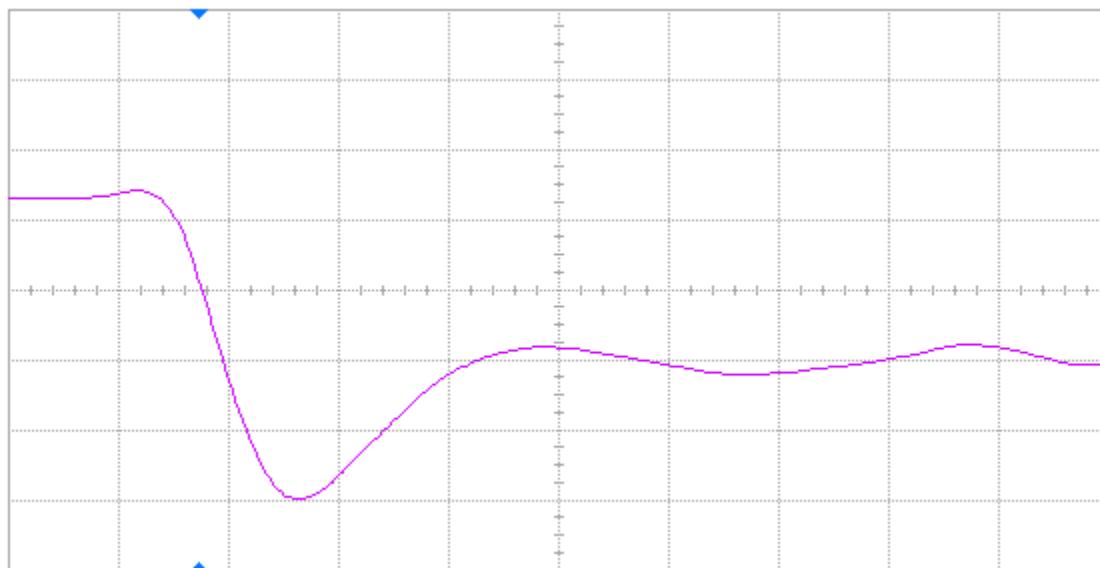


Figure 15(b) DUT 66745 post-annealing falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

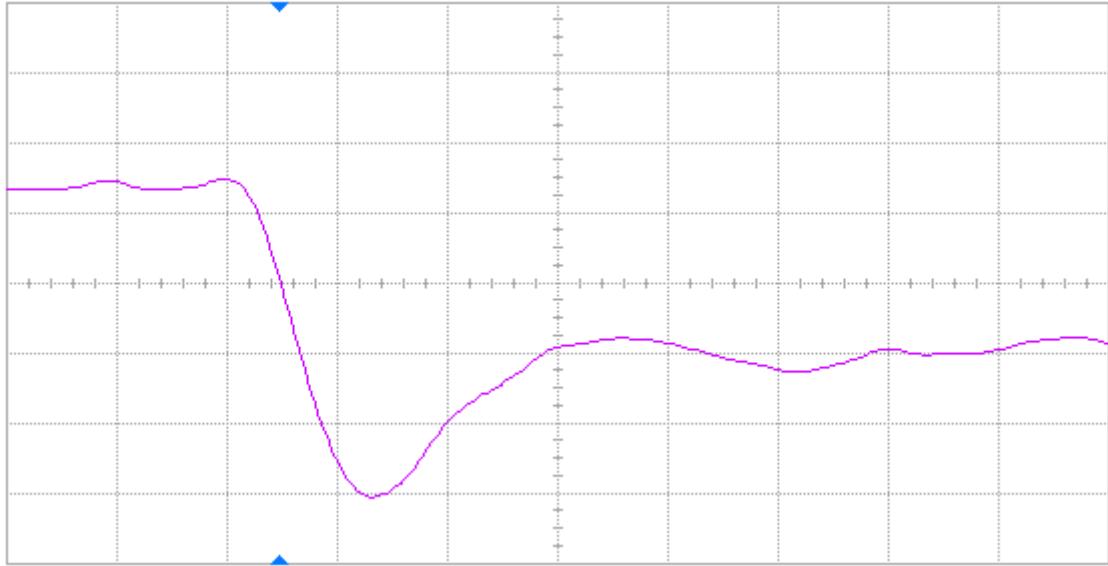


Figure 16(a) DUT 66746 pre-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

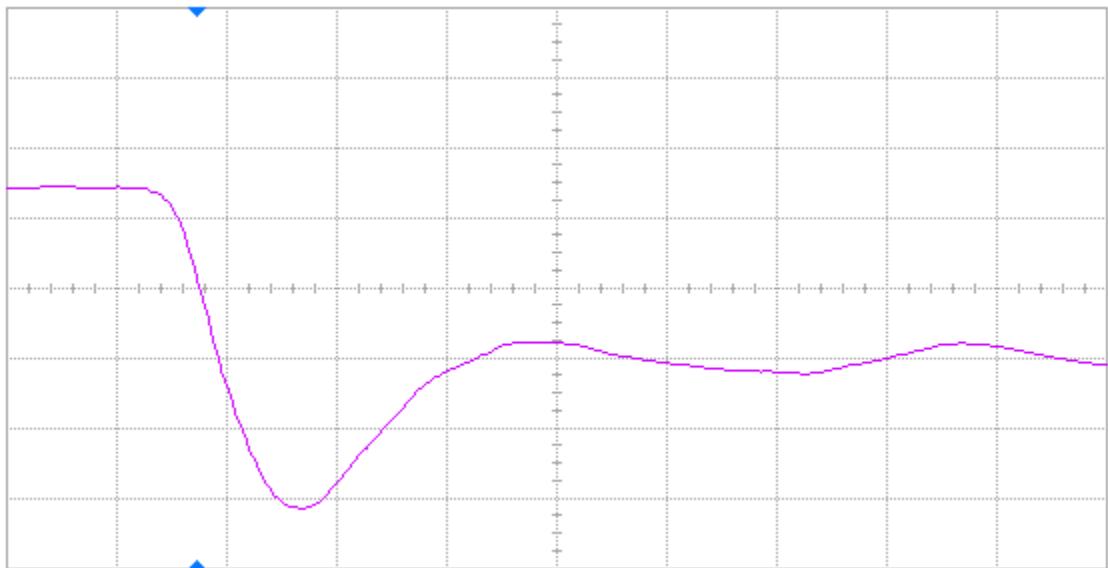


Figure 16(b) DUT 66746 post-annealing falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

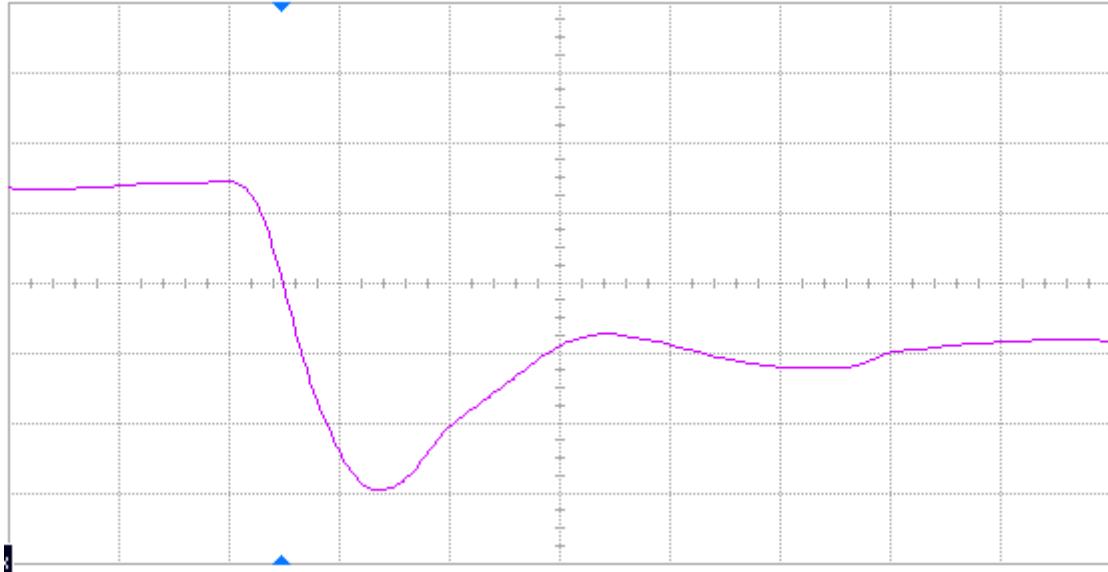


Figure 17(a) DUT 66758 pre-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

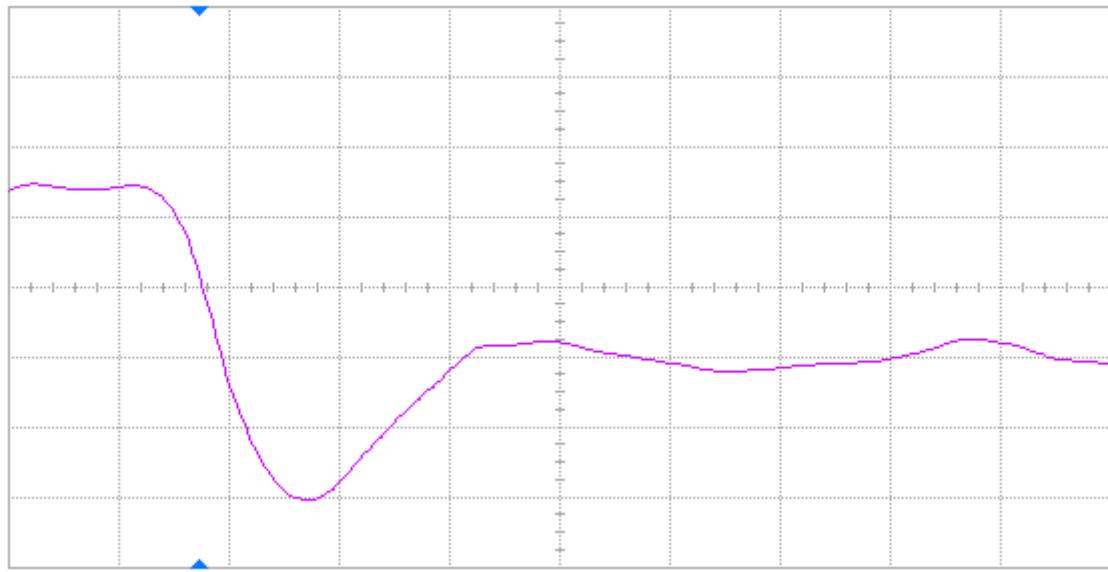


Figure 17(b) DUT 66758 post-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

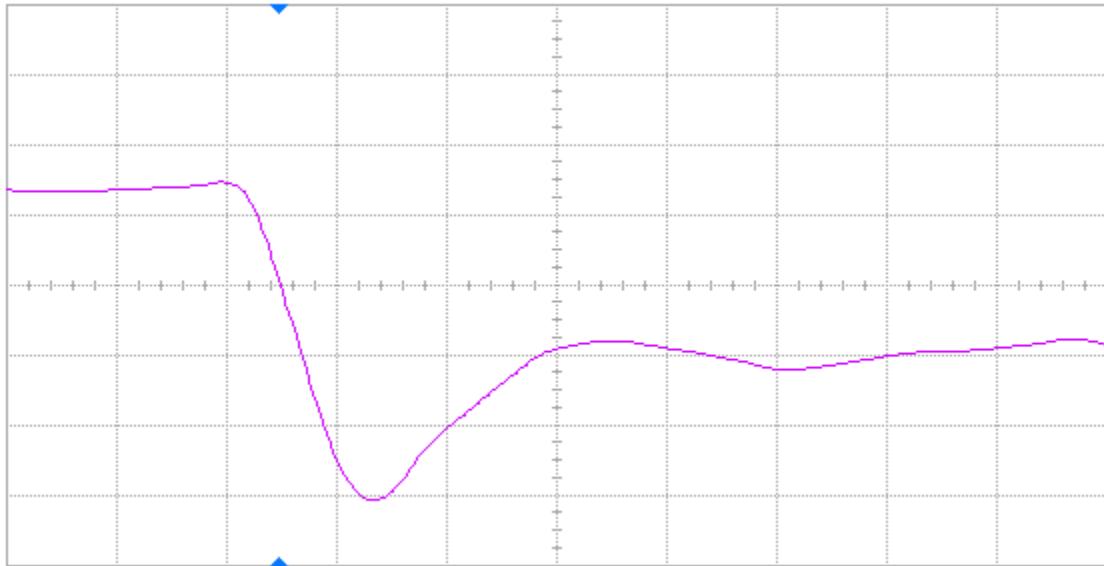


Figure 18(a) DUT 66851 pre-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

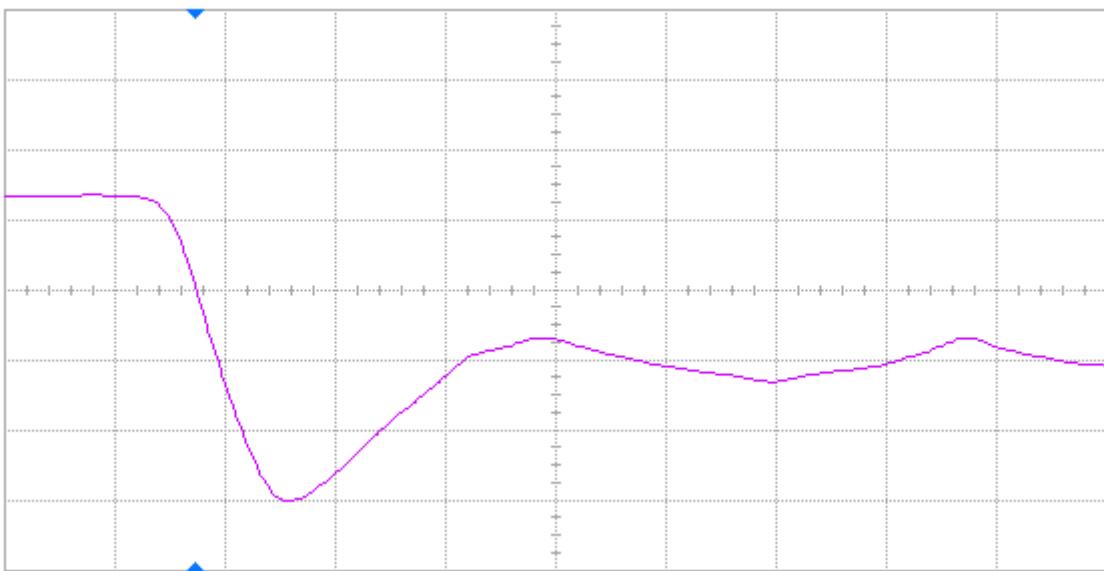


Figure 18(b) DUT 66851 post-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

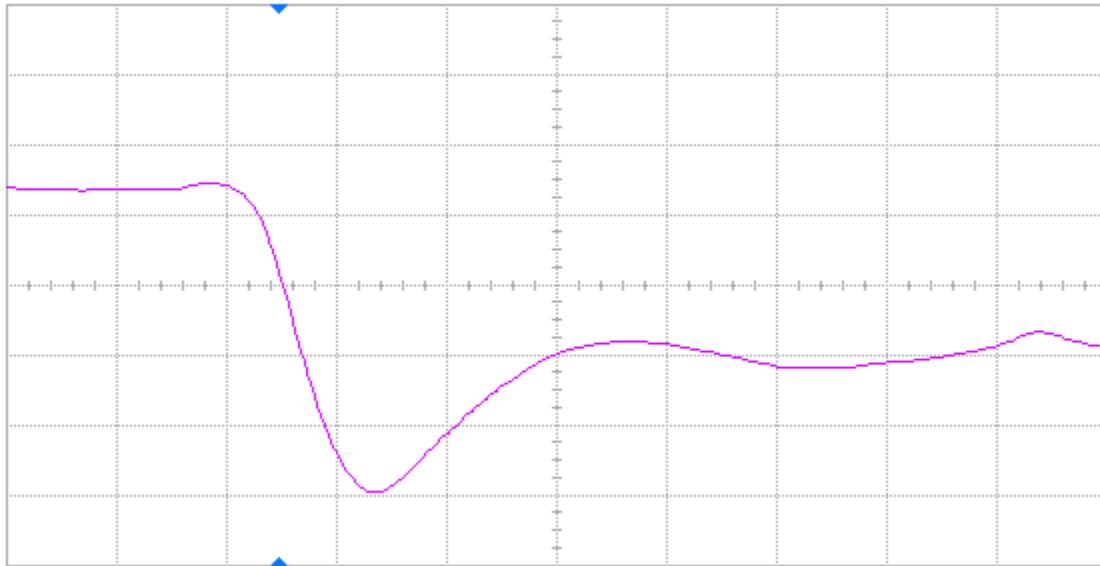


Figure 19(a) DUT 66861 pre-irradiation falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

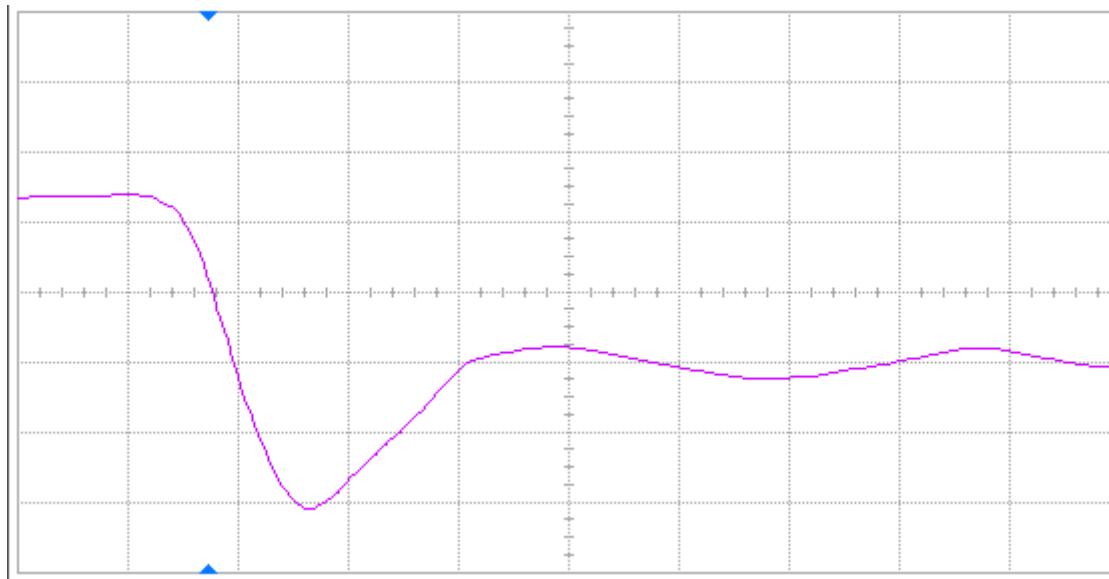
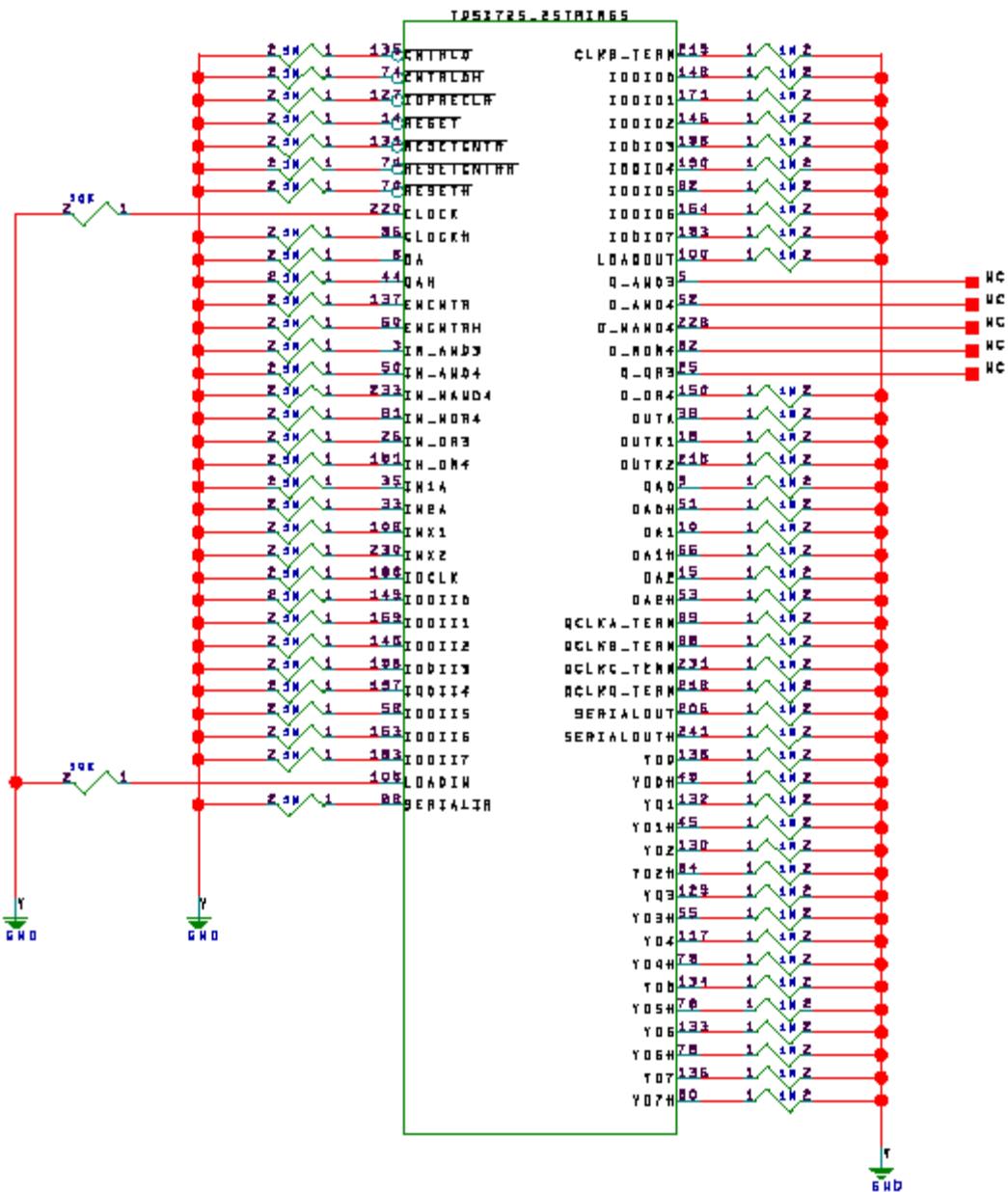
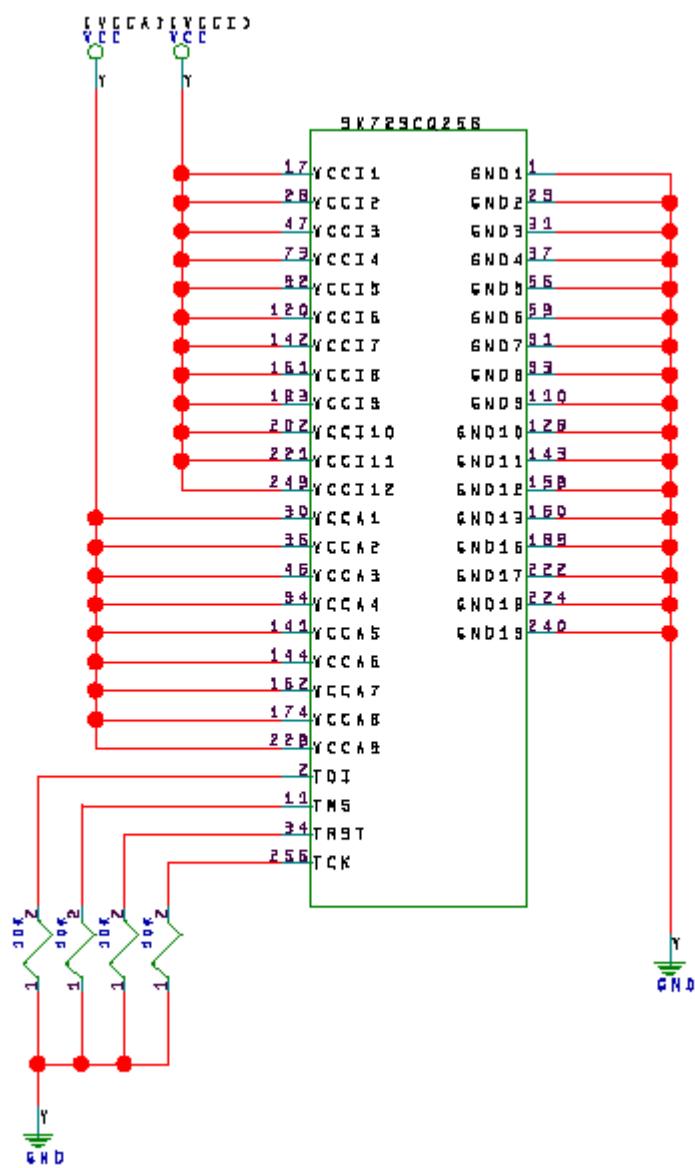


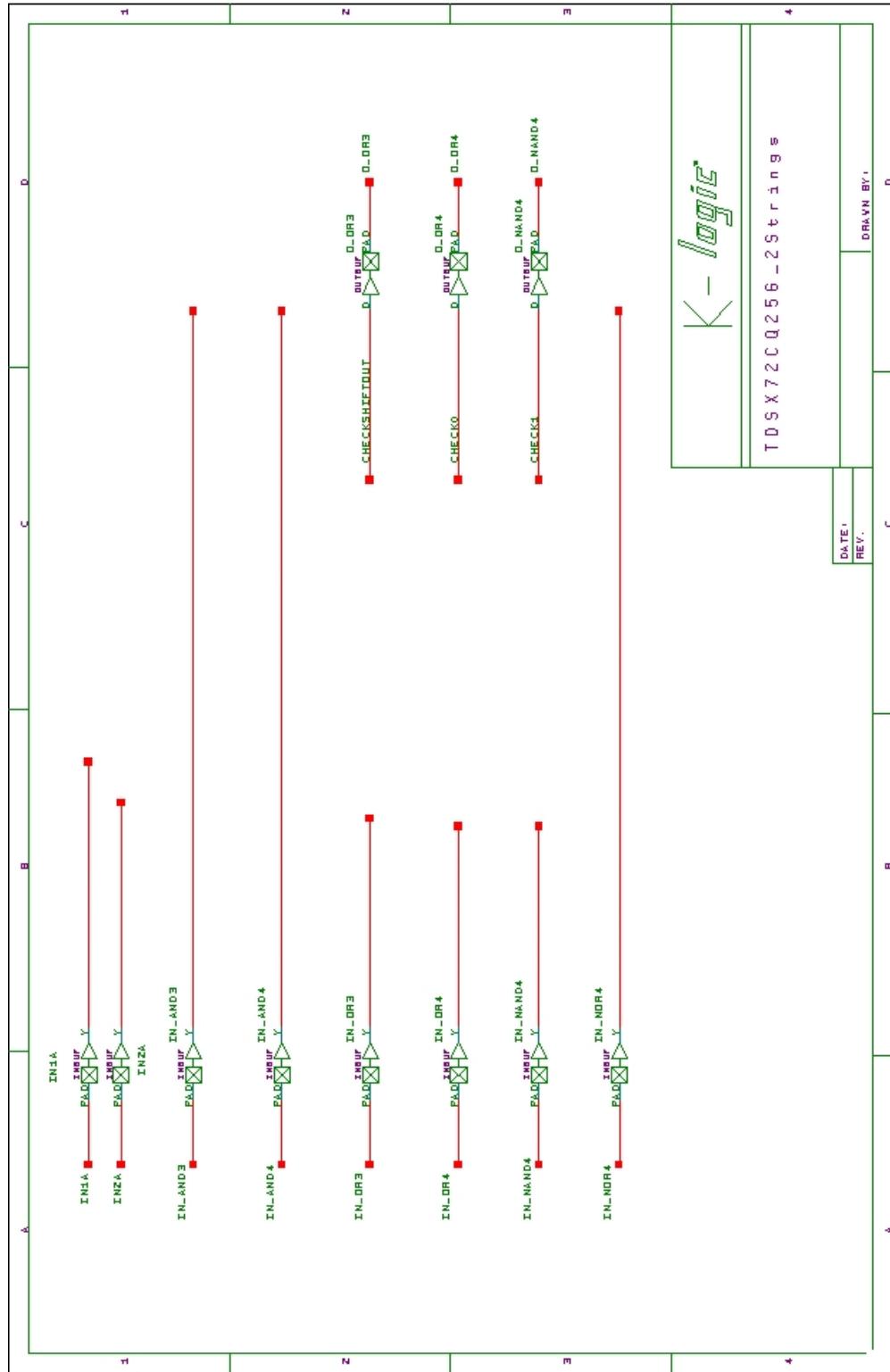
Figure 19(b) DUT 66861 post-annealing falling edge, abscissa scale is 2 V/div and ordinate scale is 2 ns/div.

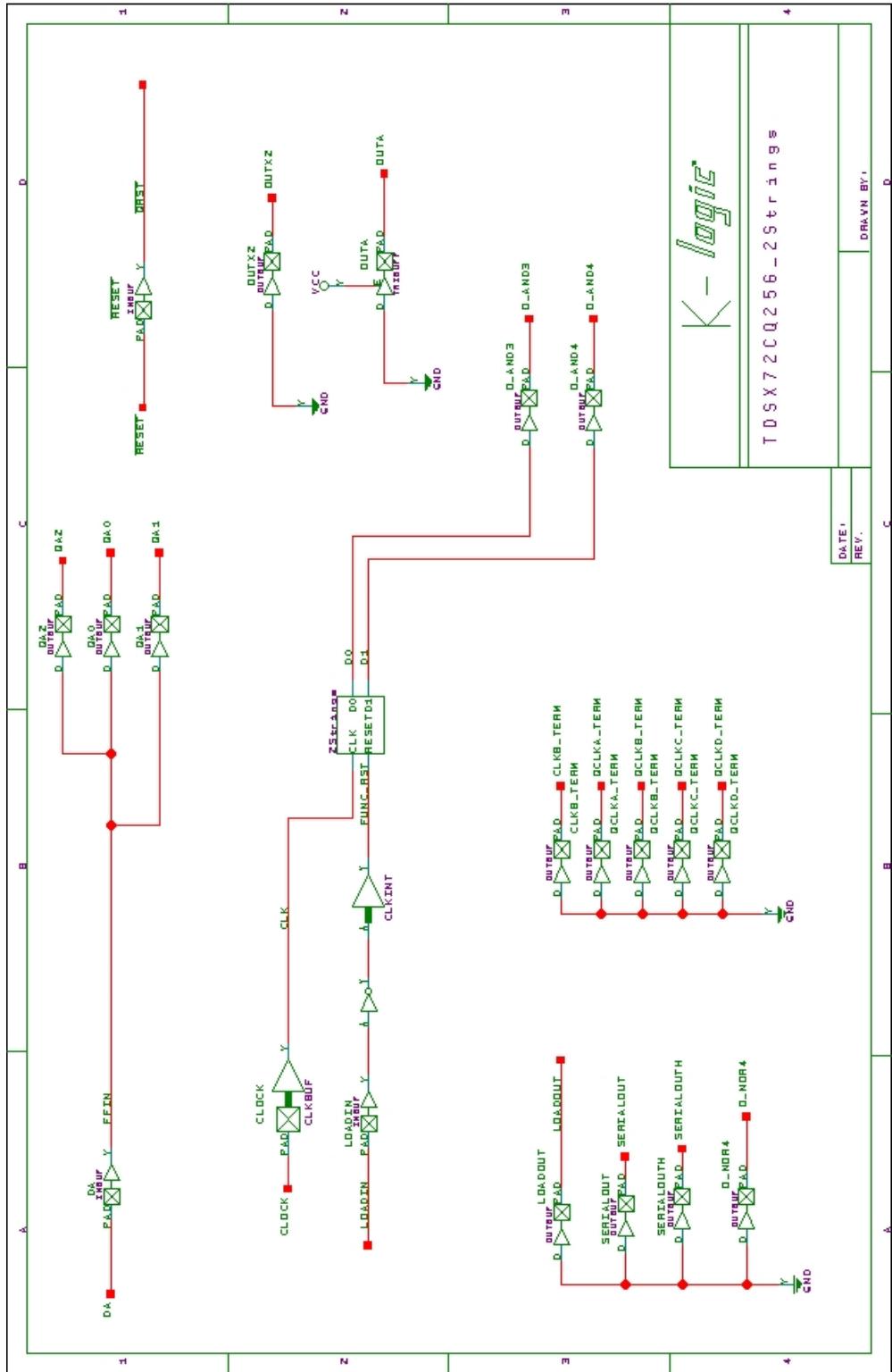
APPENDIX A DUT BIAS

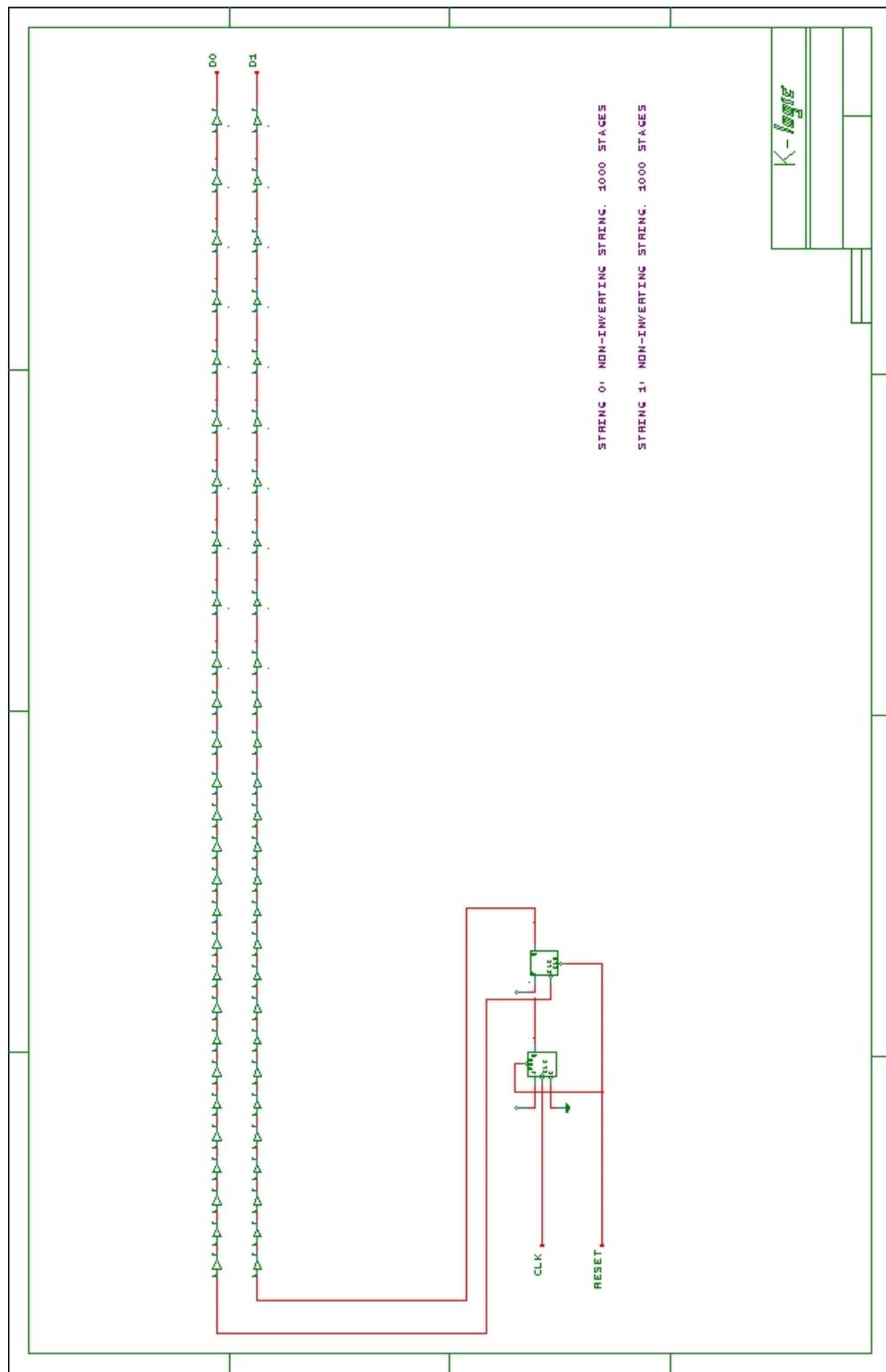


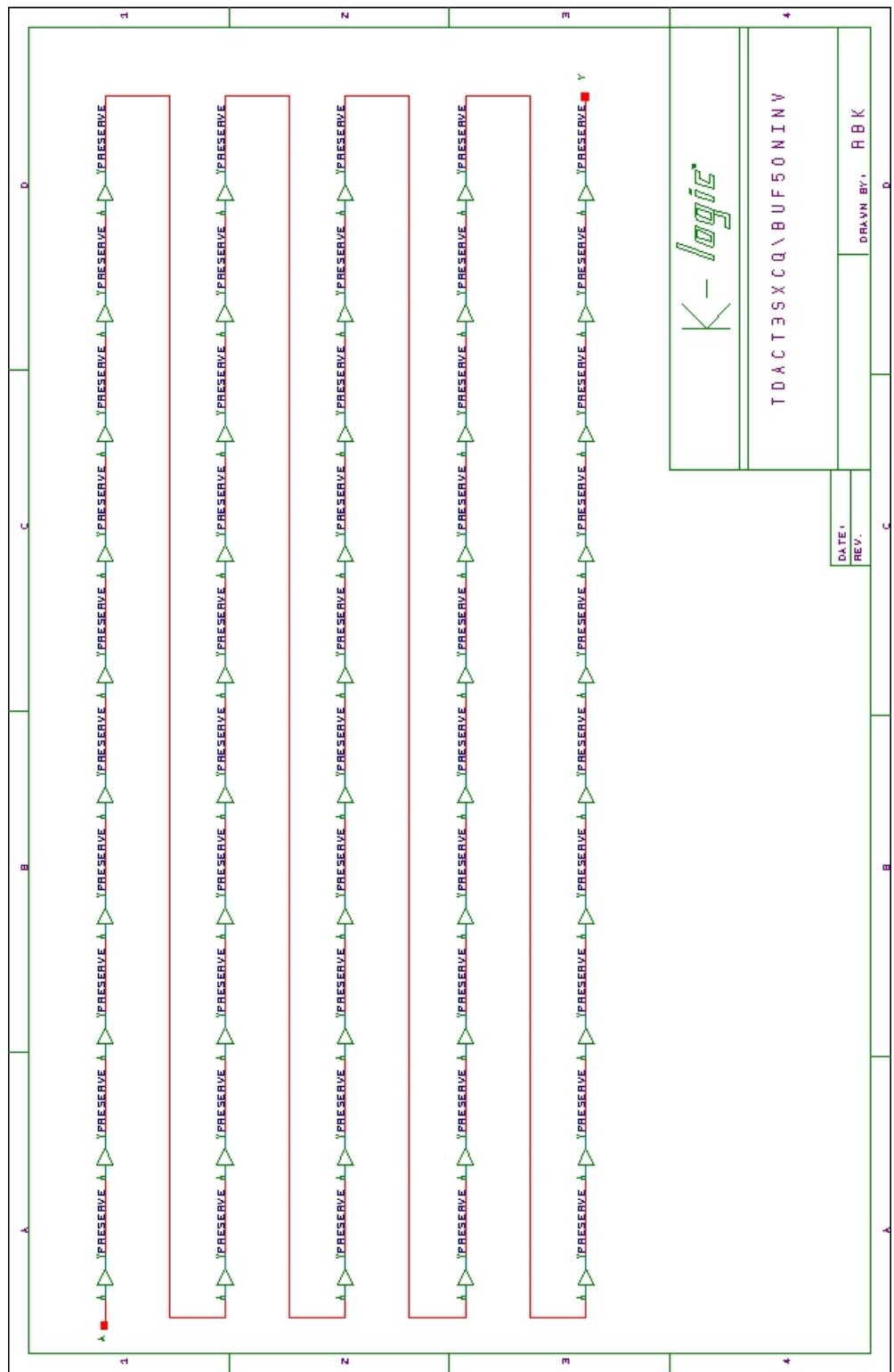


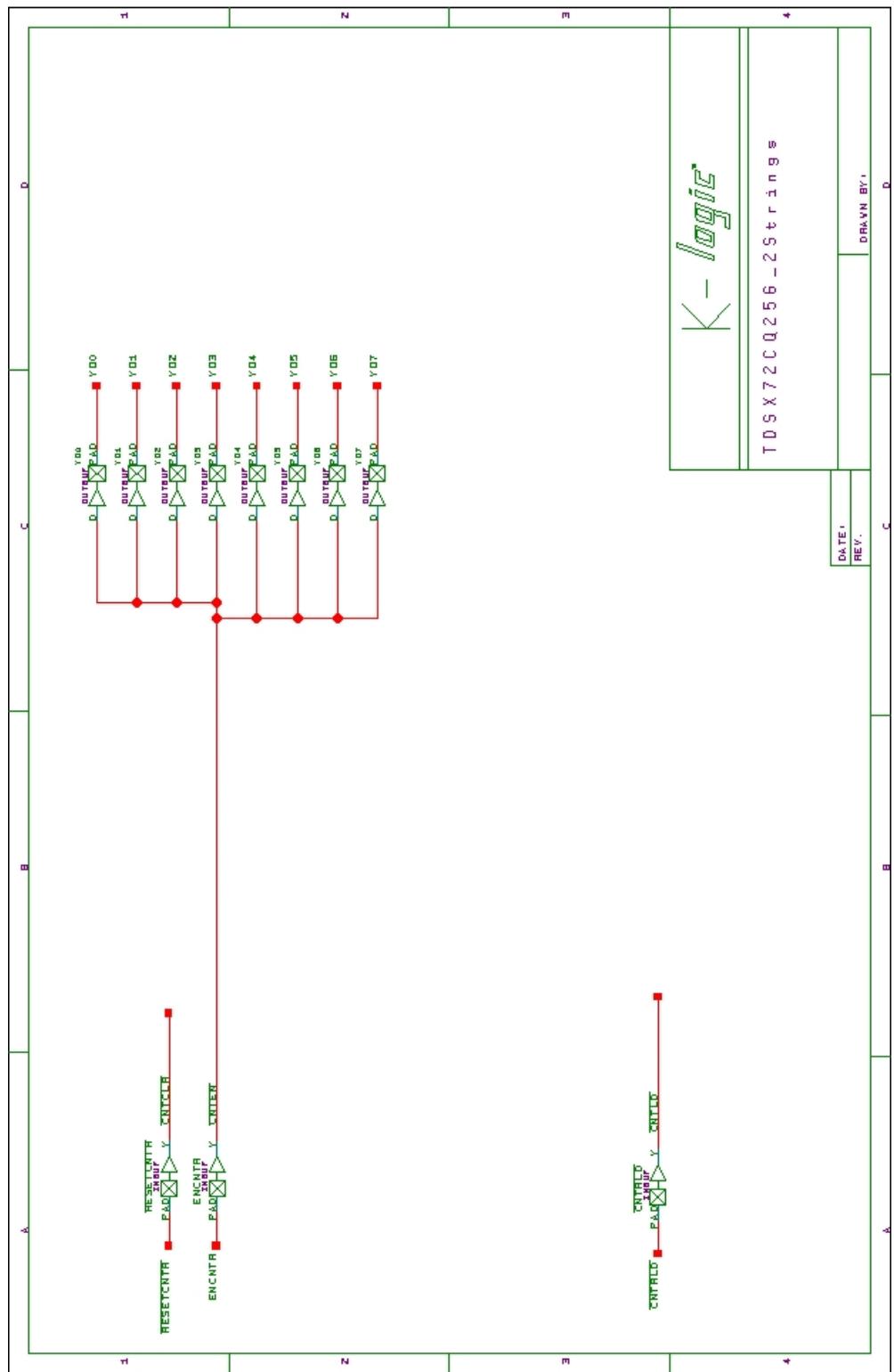
APPENDIX B DUT DESIGN SCHEMATICS

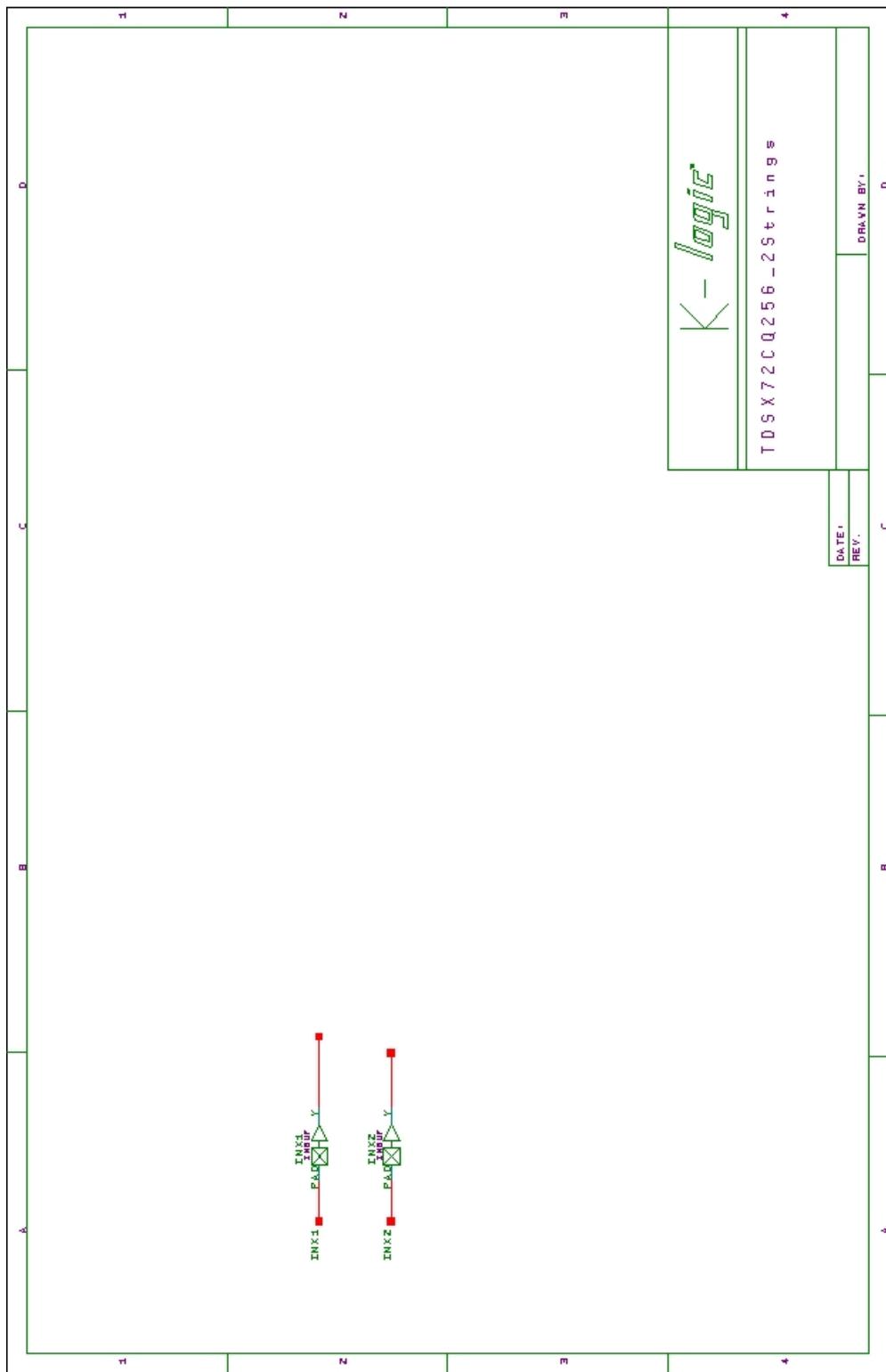


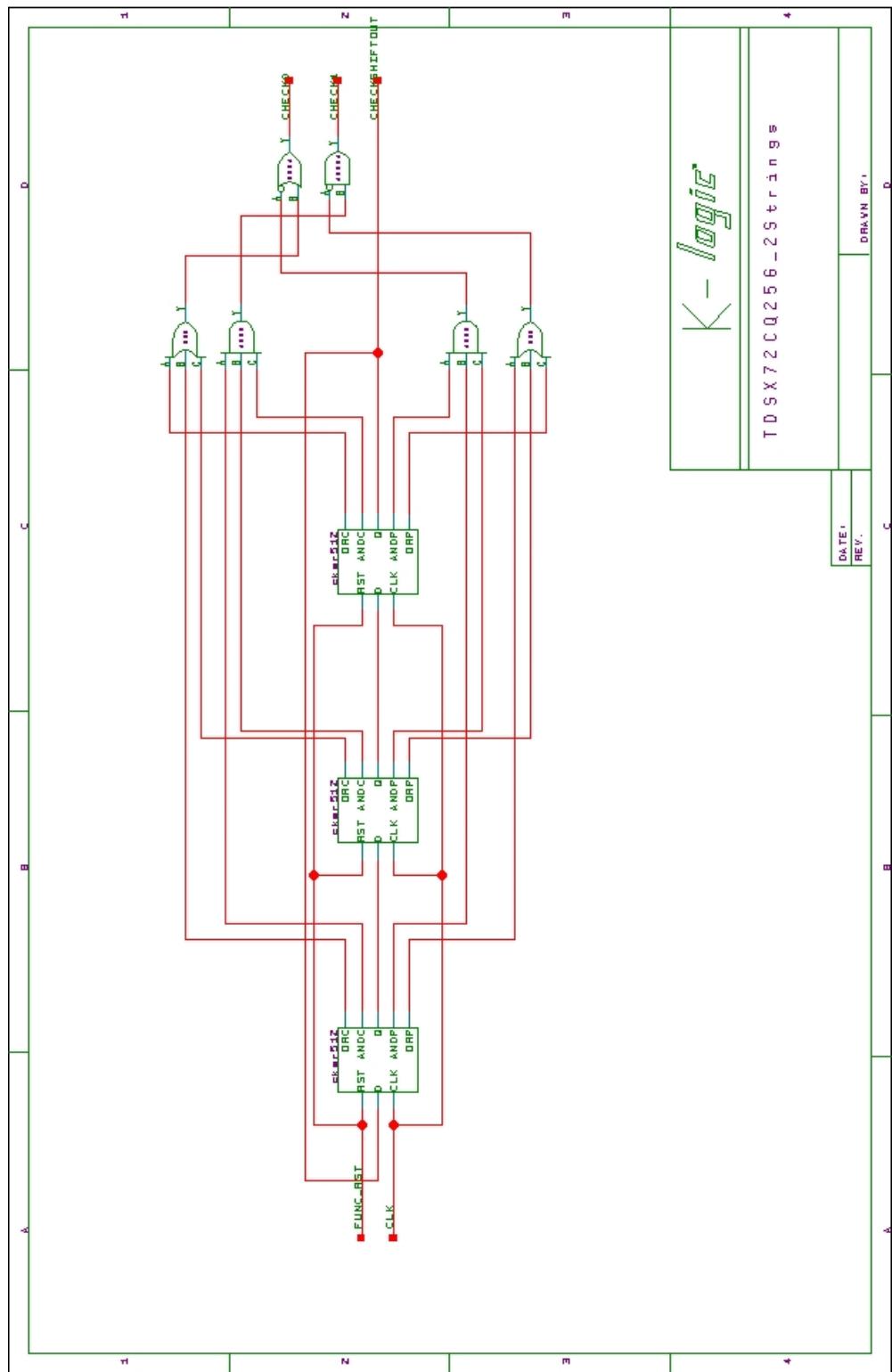


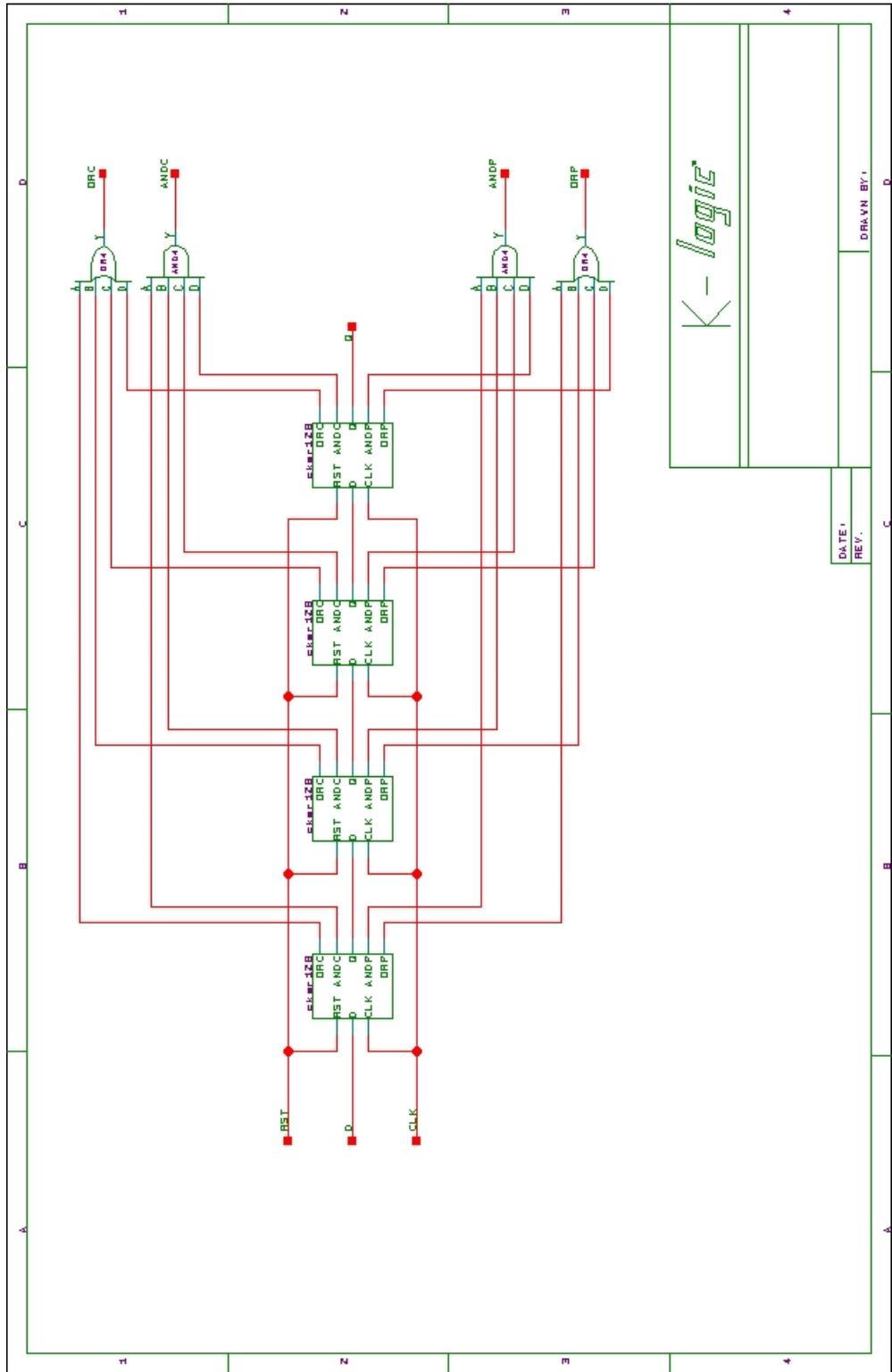


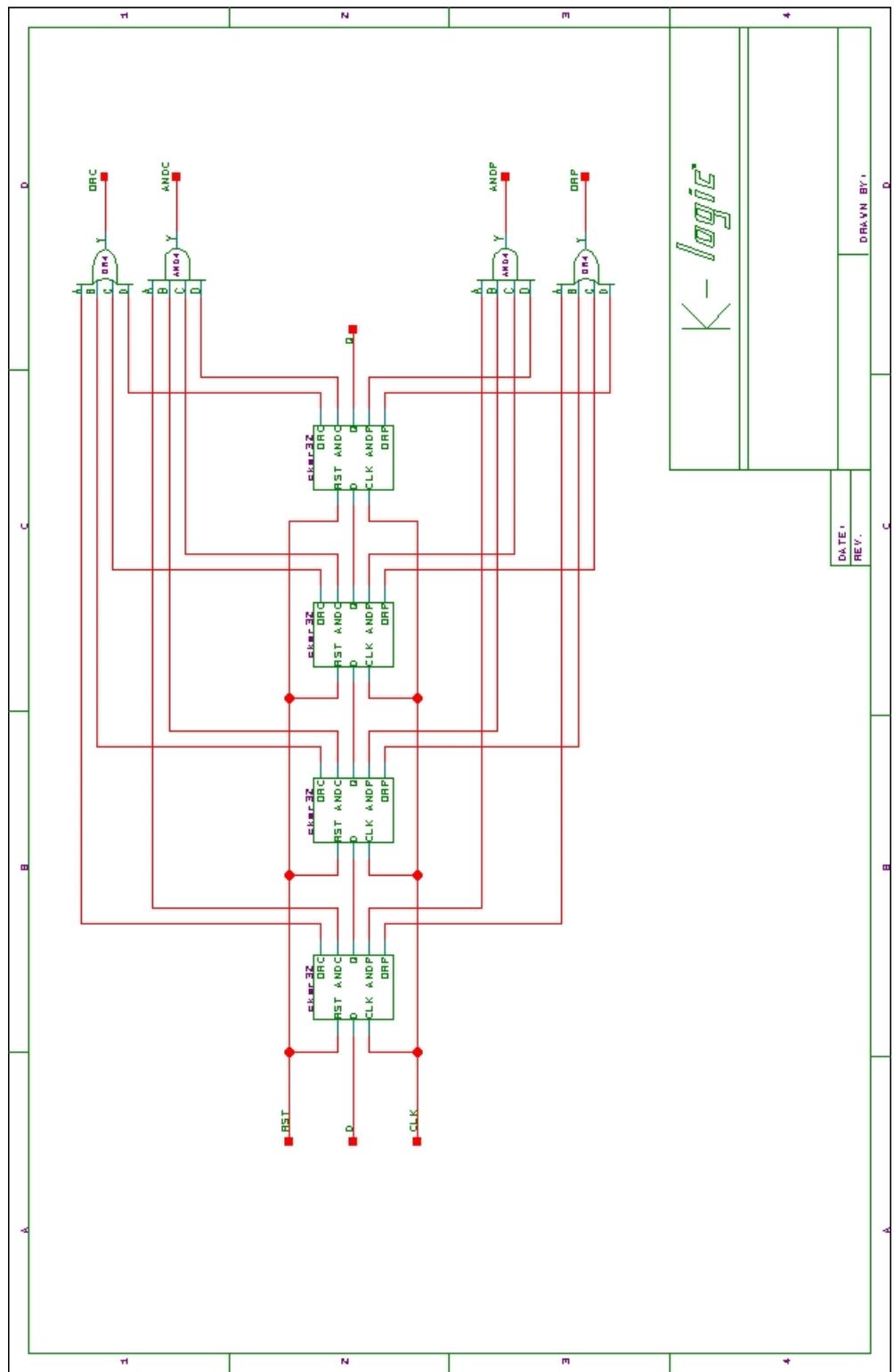


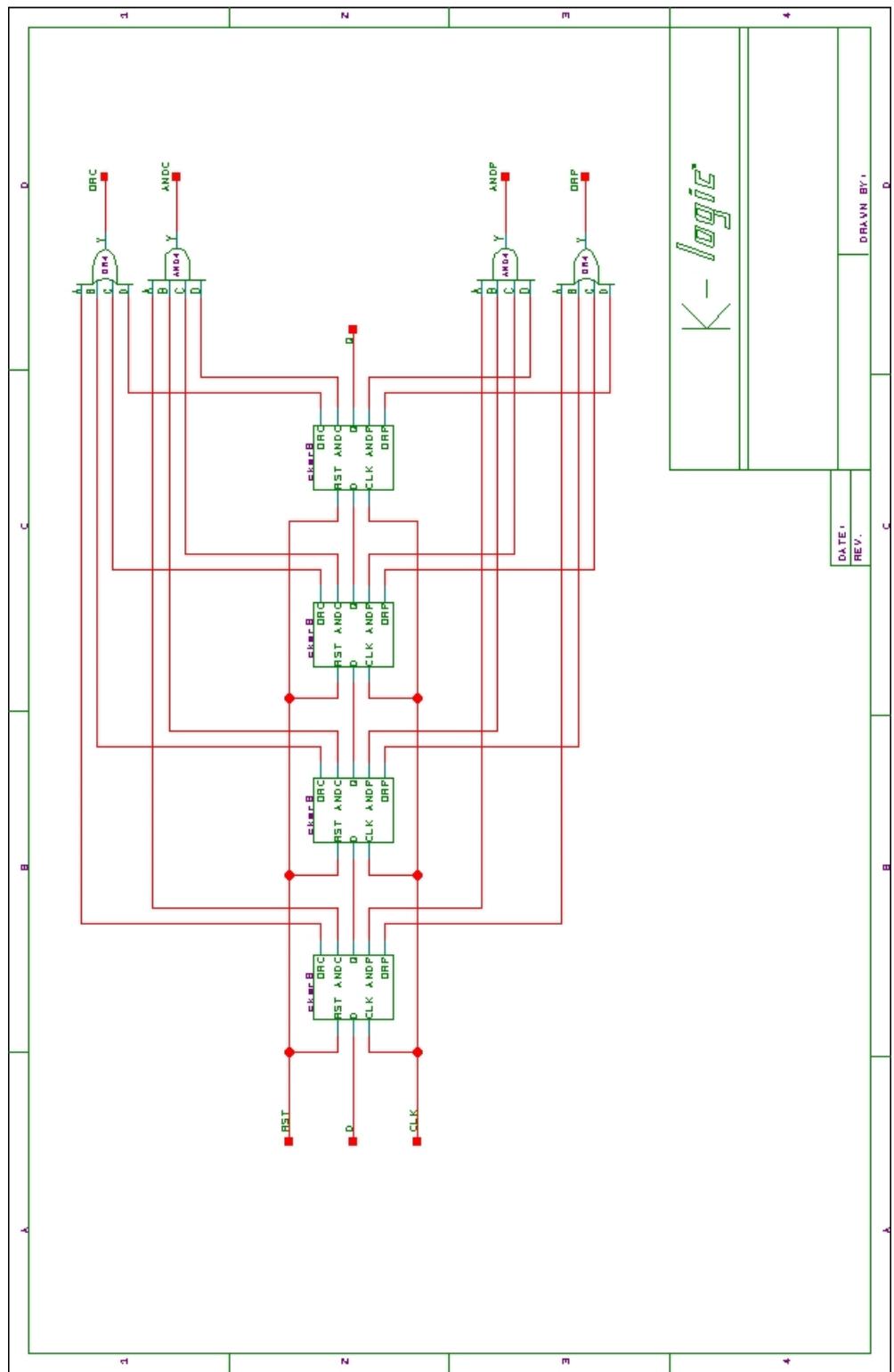


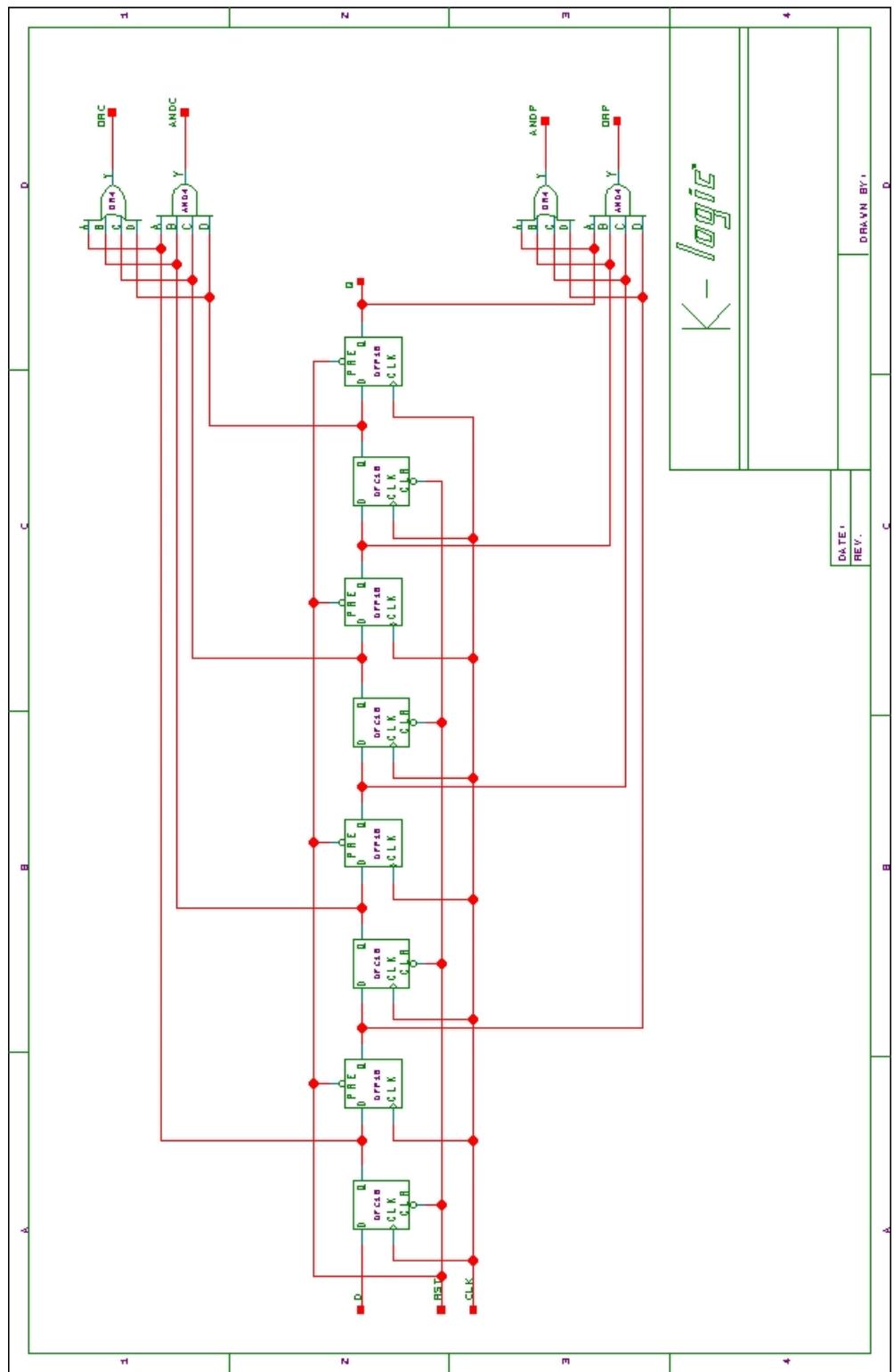


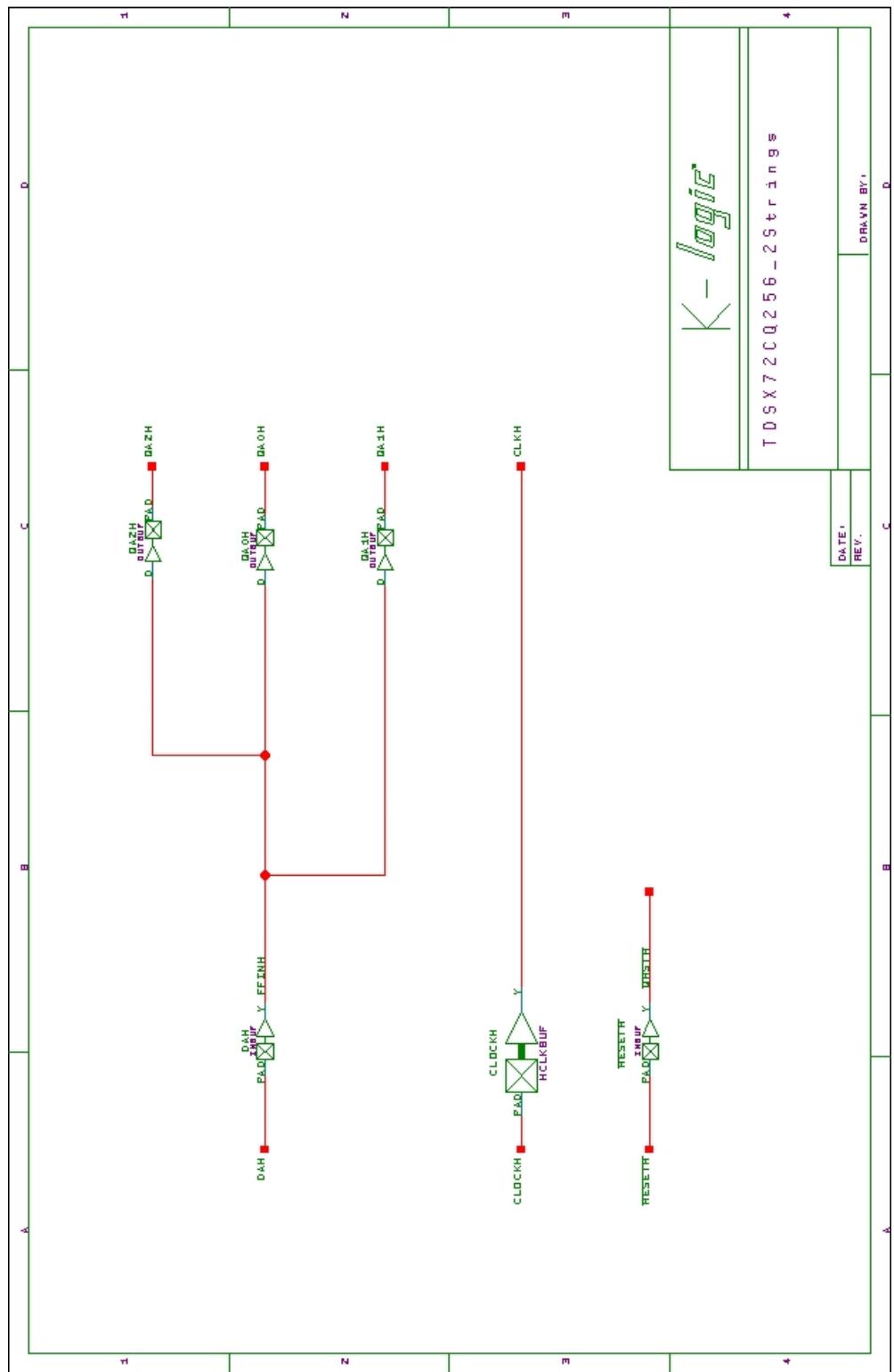


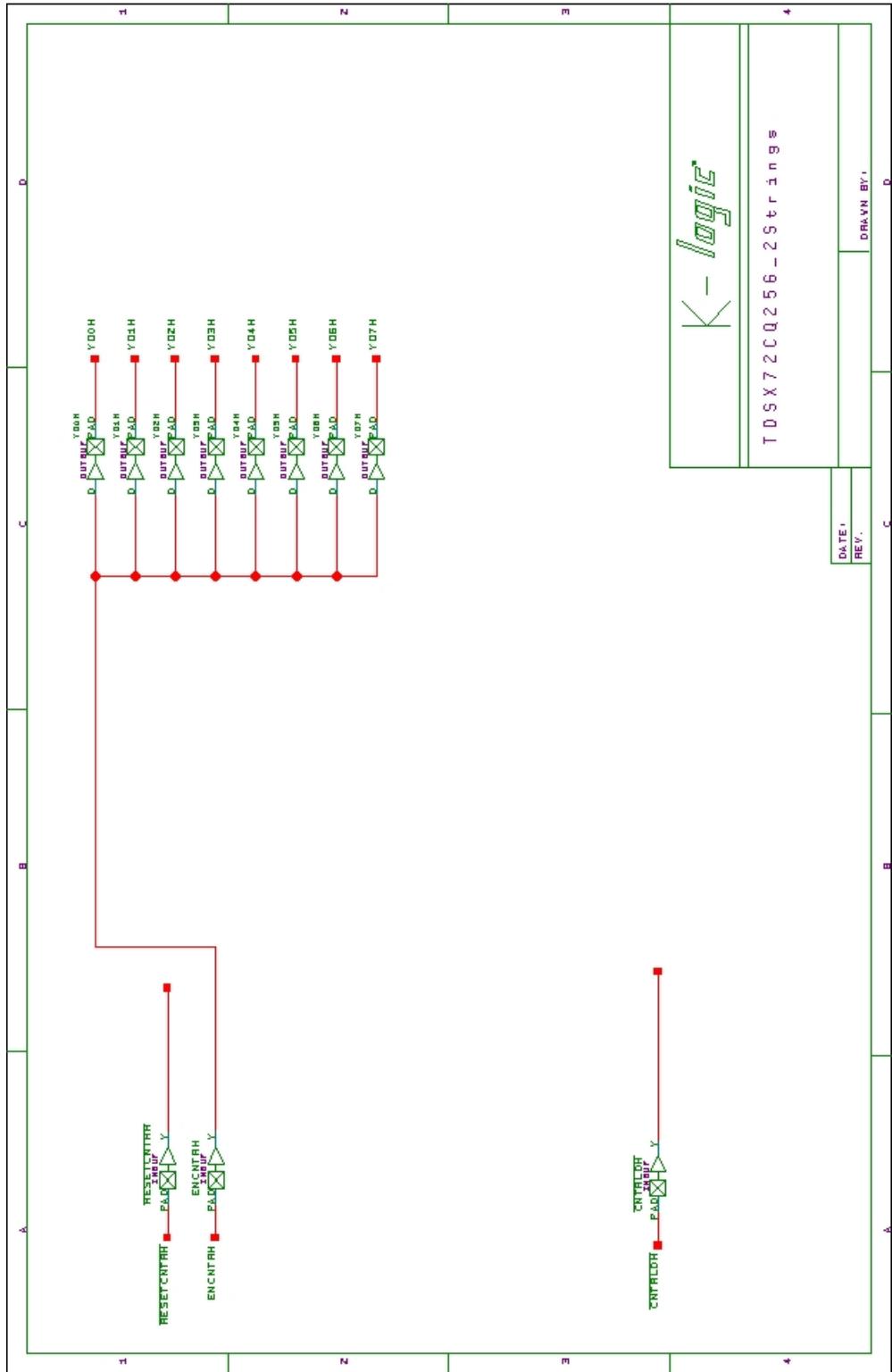




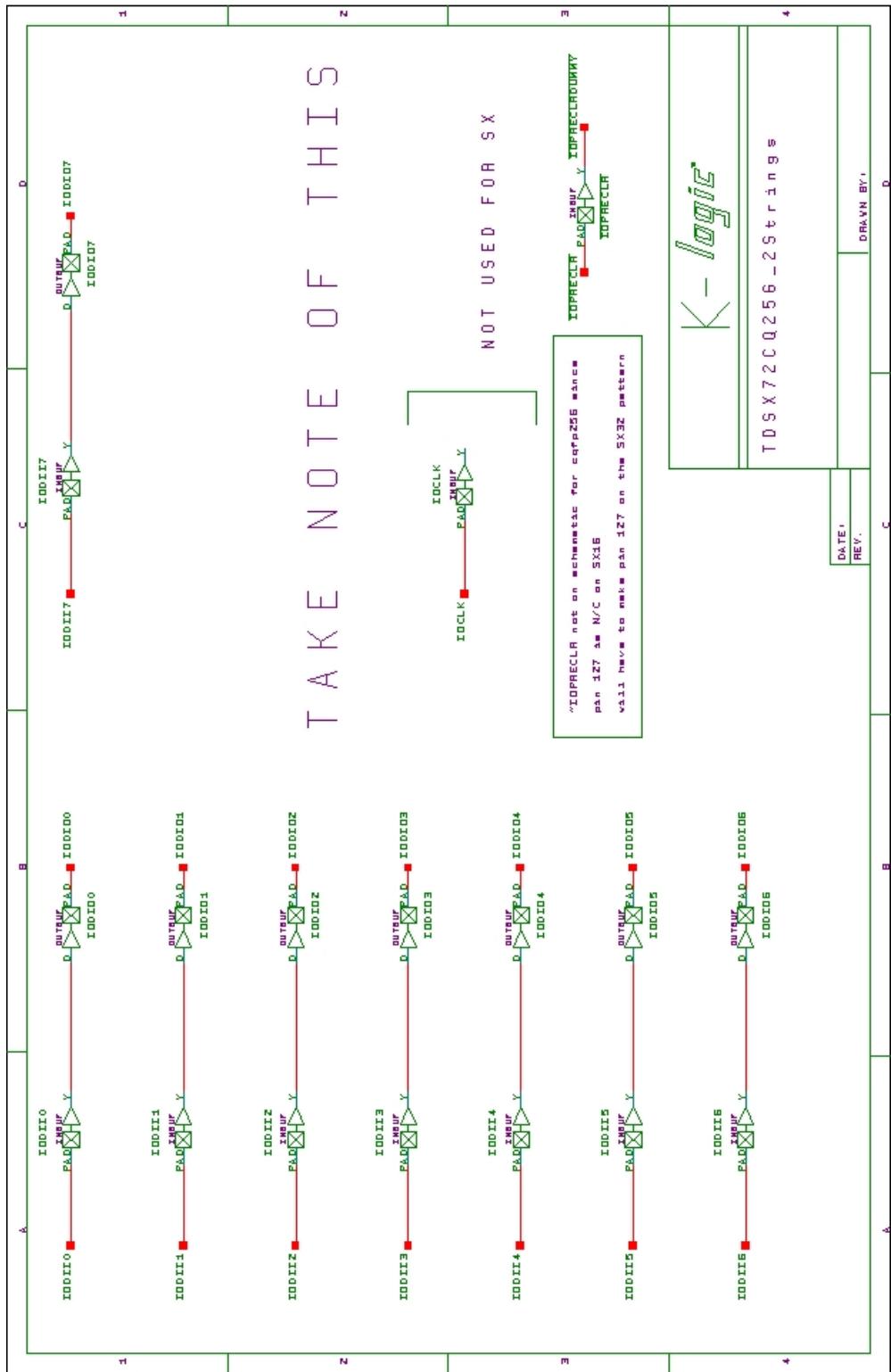


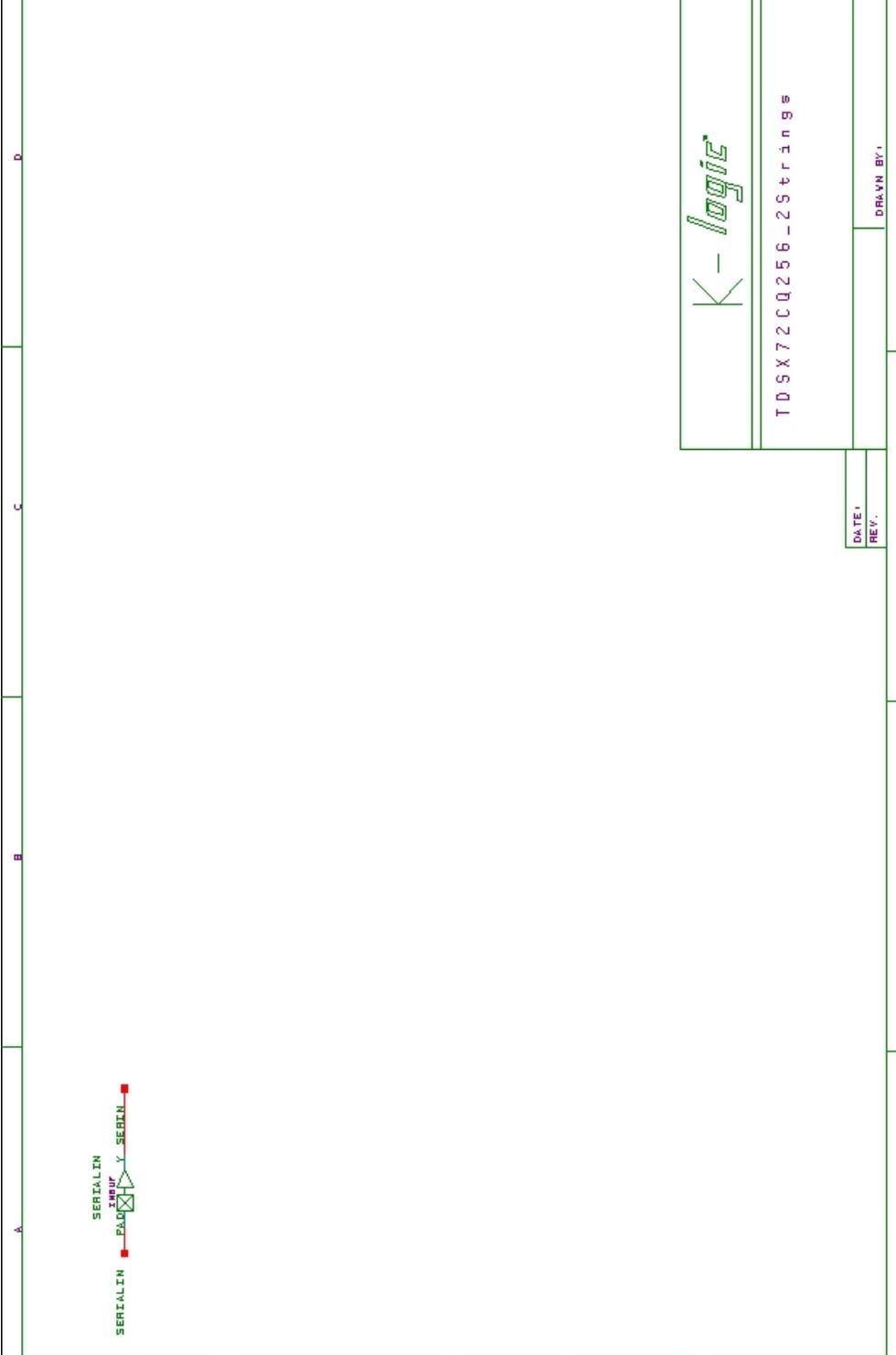






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