

AD/A-005 590

NUCLEAR RADIATION TESTING OF DIODES,
SILICON CONTROLLED RECTIFIERS, TRANSI-
TORS AND INTEGRATED CIRCUITS

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Dover, New Jersey

December 1974

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report 4692	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-005590
4. TITLE (and Subtitle) NUCLEAR RADIATION TESTING OF DIODES, SILICON CONTROLLED RECTIFIERS, TRANSISTORS AND INTEGRATED CIRCUITS		5. TYPE OF REPORT & PERIOD COVERED
7. AUTHOR(s) E. T. Cassidy		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Nuclear Weapons Development Division, NDED Picatinny Arsenal Dover, New Jersey 07801		8. CONTRACT OR GRANT NUMBER(s) AMCMS Code: 6636.04.1244.600
11. CONTROLLING OFFICE NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE DECEMBER 1974
		13. NUMBER OF PAGES 75
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Reproduced by NATIONAL TECHNICAL INFORMATION SERVICE US Department of Commerce Springfield, VA. 22151		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Radiation effects Silicon controlled rectifiers Bipolar integrated circuits Neutron dose CMOS integrated circuits Gamma dose Diodes Gamma dose rate Transistors Radiation hardening		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Extensive nuclear radiation tests have been conducted on various types of diodes, transistors, silicon controlled rectifiers, DTL and CMOS integrated circuits for use in digital electronics. The nuclear radiation effects considered during this test program were endoatmospheric, i.e. neutron and gamma dose rates. The digital electronics employing the semiconductors tested are used in either ground systems or low-flying missiles, therefore, no exoatmospheric effects such as x-rays were evaluated. This report documents the		

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20. (Cont'd)

components tested, test methods, radiation test facilities used and the test results for each component tested. The results prove that digital electronic systems can be hardened against permanent damage from very high neutron and gamma dose levels (10^{14} n/cm² - 1 MeV equivalent and 160,000 rad-Si respectively) using off-the-shelf components. Most system nuclear radiation specifications require the system to be capable of operation after exposure. If, however, a system has to be capable of operation during exposure, transient upset effects must be taken into account. Transient upset in the form of loss of stored information will occur in integrated circuit flip-flops or counters when exposed to high gamma dose rates. Upset is dependent upon both the gamma dose pulse width and dose rate. The wider the pulse, the lower the dose rate needed to cause upset. Present off-the-shelf CMOS integrated circuits will not retain stored information above 3×10^8 rad-Si/sec for a full width half max (FWHM) pulse of 2 nanoseconds. If, however, the FWHM pulse width is 25ns, CMOS integrated circuits will lose stored information in the range of 3×10^8 rad-Si/sec.

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ACKNOWLEDGMENT

The author expresses his appreciation for the technical assistance of Dr. A. H. Kazi and staff, Army Pulse Reactor Facility, Ballistics Research Laboratories, Aberdeen, Maryland, and Mr. Al Hoffland, Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico. He would also like to cite Mr. Arthur Nichols of Picatinny Arsenal for all his efforts in establishing test methods, fabricating all the test fixtures and cabling and his assistance in conducting the actual tests.

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ABSTRACT

Extensive nuclear radiation tests have been conducted on various types of diodes, transistors, silicon controlled rectifiers, DTL and CMOS integrated circuits for use in digital electronics. The nuclear radiation effects considered during this test program were endoatmospheric, i.e. neutron dose, gamma dose rate. The digital electronics employing the semiconductors tested are used in either ground systems or low-flying missiles, therefore, no exoatmospheric effects such as x-rays were evaluated. This report documents the components tested, test methods, radiation test facilities used and the test results for each component tested. The results prove that digital electronic systems can be hardened against permanent damage from very high neutron and gamma dose levels (10^{14} n/cm² - 1 MeV equivalent and 160,000 rad-Si respectively) using off-the-shelf components. Most system nuclear radiation specifications require the system to be capable of operation after exposure. If, however, a system has to be capable of operation during exposure, transient upset effects must be taken into account. Transient upset in the form of loss of stored information will occur in integrated circuit flip-flops or counters when exposed to high gamma dose rates. Upset is dependent upon both the gamma dose pulse width and dose rate. The wider the pulse, the lower the dose rate needed to cause upset. Present off-the-shelf CMOS integrated circuits will not retain stored information above 3×10^9 rad-Si/sec for a full width half max (FWHM) pulse of 2 nanoseconds. If, however, the FWHM pulse width is 25ns, CMOS integrated circuits will lose stored information in the range of 3×10^8 rad-Si/sec to 9×10^8 rad-Si/sec.

INTRODUCTION

Most U.S. Army system nuclear radiation specifications require the system to be capable of operation after, but not during, exposure to the specified nuclear radiation levels; therefore, only permanent damage effects need be considered. The primary cause of permanent degradation, in digital circuits employing bipolar transistors, is the loss of transistor forward current gain due to the neutron dose producing defects in the silicon which act as recombination centers in the base and emitter base depletion region. Since the recombination centers cause a reduction in the minority carrier currents which transistors in common emitter configurations amplify, the end result is a reduction in transistor gain. In some cases, transistor gain can be reduced four orders of magnitude (Ref 1).

Another radiation exposure effect on transistors is the change in $V_{CE(sat)}$ (collector-to-emitter saturation voltage) due to changing resistivity within the transistor for a given constant collector current. Since diodes normally have one order of magnitude higher radiation resistance than transistors, minimal changes should occur in diode electrical characteristics after exposure to a radiation level sufficiently high to cause radical changes in transistor electrical characteristics. Silicon Controlled Rectifiers (SCR's) can be electrically represented as two interconnected transistors. After radiation exposure, the SCR can decrease in sensitivity, as noted in increased I_{GT} (gate trigger current), due to the reduction in the gain of each transistor.

Initially, discrete semiconductor components consisting of diodes, transistors and silicon controlled rectifiers were tested to establish the degree of permanent damage occurring to the components at radiation levels near system specifications in one to two orders of magnitude above. Good radiation hardening practice can minimize neutron dose effects by using narrow basewidth transistors having a high cutoff frequency ($F_t=200\text{MHz}$) and/or allowing for gain reduction through the use of transistors having a minimum gain of 100 to 200 in an application where a gain of five to ten is needed. Based on the test results, not only is the degree of hardness for the discrete components determined, but the degree of hardness assurance is also evaluated. Thus it can be determined whether a component just meets the radiation specification in a circuit application, or if it is capable of meeting radiation levels a hundred times the specification value. Radiation hardness can be assured in the production of a system by using MIL-SPEC-TX discrete components which are significantly overhardened for their application. The advantages in using MIL-SPEC-TX components (Test Extra or 100% tested components, not lot tested components) are that

the manufacturers' are already qualified to the military specifications, and inspection lines have been implemented.

If the gain of a discrete transistor is shown to be marginal in a circuit application after exposure to nuclear radiation, the transistor can easily be changed. For a DTL integrated circuit, the IC parameters are measured, not the individual chip transistor parameters. If a transistor in an IC is marginal, it cannot be easily changed. Fortunately, two facts work in the designer's favor. First, a DTL integrated circuit having a fast switching speed (100 nanoseconds or less) will minimize permanent radiation damage effects. Second, the manufacturer, to minimize lot rejection, usually designs the transistors in the integrated circuit chip to have a gain much higher than is needed in the integrated circuit application. If an integrated circuit is used which does not have a fast switching speed, hardness assurance is difficult to achieve. On some strategic systems, transistor parameters in a chip are measured using probes or chip breakout areas before the chip is hermetically sealed (a very costly process).

Complementary Metal Oxide Semiconductors (CMOS) integrated circuits employ insulated gate Field Effect Transistors (FET) which are unipolar devices that utilize charge carriers of only one polarity. The input signal is used to apply an electric field that in turn varies the effective cross sectional area of a channel of semiconducting material, thereby controlling the output current (Ref 1). Thus, FET transistors, unlike bipolar transistors, should be relatively unaffected by neutron dose-caused defects in the silicon. It has been well documented that the permanent degradation of CMOS integrated circuits is due to the buildup of trapped positive charges in the gate insulator due to high gamma dose exposure (Ref 1, 2). The result of this charge-trapping is a shift in the threshold voltage of both the n and p channel MOS transistors. Gamma dose levels of 10,000 rads are needed to cause threshold shifts of one volt for a supply voltage of ten volts. The gamma dose level radiation specifications for the systems under consideration are for a few hundred rads; therefore, the threshold voltage of CMOS IC's should not shift enough to prevent proper circuit operation after radiation exposure.

If a system is required to operate during exposure to a nuclear radiation environment, several other effects must be considered. Some of the effects are rapid annealing, SCR triggering and loss of stored information. Rapid annealing¹ in this discussion will be considered as the return of the crystalline material in semiconductors to a more

¹Rapid annealing is very dependent upon temperature, radiation levels and semiconductor type

normal condition during the period (microseconds to several seconds) immediately following nuclear radiation. Bipolar transistor gain at several microseconds after radiation exposure is much lower than it is at several seconds after exposure (Ref 1). The gain of an irradiated transistor will slowly improve with increasing time. Due to instrumentation, radiation facility availability, manpower, time and costs, no rapid annealing measurements were made, but most transistors were tested under power at room temperature, and electrical parameter measurements were made a few seconds after exposure. Later test results on functioning digital electronic assemblies showed that the assemblies tested operated properly during radiation exposure. The conclusion is that the gain of the transistor used was very high for circuit application or very insensitive at the radiation test level. SCR's under power in a standby condition can be triggered when exposed to pulse gamma radiation. Triggering of an SCR is a function of the device geometry, radiation pulsewidth, gamma dose rate, and the value of the gate-to-cathode resistor. The wider the pulse or the higher the resistor value, the lower the gamma dose rate needed to cause triggering. Finally, stored information in either integrated circuit Flip-flops or counters can be erased or altered due to high gamma dose rate exposure.

One hardening technique is for integrated circuits to use dielectrically isolated construction in which a dielectric material provides the isolation between transistors on the substrates. Under radiation, this insulator does not produce currents or allow currents to flow from one transistor to another. The usual construction technique (junction isolation) uses reverse biased PN junctions between transistors on a chip. When an IC with this construction is irradiated, currents can flow either in or through the reverse biased junction. This current flow can lead to an effect called latchup. Latchup occurs when an integrated circuit is switched into an abnormal state in which the output is not responsive to variations of input voltage and excess current flows in the circuit voltage supply leads. If damage does not result from the excess currents, the circuit may be restored to normal operation by momentarily interrupting the power supply voltage. Dielectric isolation eliminates this effect. Both junction isolated and dielectric isolated CMOS integrated circuits were tested to note any difference in hardness.

Shielding of electronic assemblies is not always practical due to the size and weight of the shields needed. A brute force technique (Ref 9) is illustrated by the following example. To shield a 12 by 12 in. area and reduce the effects of fast neutrons, thermal neutrons (neutrons with energies below 1 eV) and fast gammas by a factor of 10^4 would require:

7 lb of 1/2 in. thick aluminum (for fast neutron capture)

59 lb of 14 in. thick tetra methyl ammonia boro hydride
(Captures fast neutrons and thermalizes them)

3.3 lb of 1/4 in. thick boron (captures thermal neutrons)

236 lb of 4 in. thick lead (reduces gammas)

The total thickness of all the shielding elements is thus 18.75 in. and the total weight is 305.3 lb.

To shield a 7 in. cube electronics package to the same factor of 10^4 reduction in radiation effects, with shielding completely surrounding the electronics package, would require 3,536 lb of shielding and would increase the size from a 7 in. cube to a 43 in. cube.

Clearly, the brute force shielding technique is not considered practical. Selective shielding and hardening of the electronics to withstand high levels of radiation seem to be the approach that is considered most feasible. No shielding was used on the electronic assemblies tested.

Finally, an off-the-shelf DC to DC converter consisting of unknown transistors was tested. It failed measurably, and is an example of what can happen if radiation effects are not considered for all semiconductor components in a system. If this item were to be used in a system in which all other components were hardened to radiation, the system would have failed also, since the converter supplies the power to the system electronics.

TEST FACILITIES AND TEST METHODS

Permanent damage effects were measured by testing components at the Army Pulsed Reactor Facility, Aberdeen, Maryland. This is an unreflected, metallic uranium reactor designed primarily for pulsed operation. The reactor was used in the pulsed mode during testing of all discrete components and DTL integrated circuits. All semiconductors tested were under power except for the 2N5552, 2N4399 and other high voltage transistors. The electrical parameter measurements were made in accordance with applicable military standard test methods, with military specification parameter values used as a reference and with changes in parameter values noted after exposure. Test equipment consisted of ammeters, VTVMs, test fixtures, power supplies and a 100-foot interconnecting cable between the reactor area and the

instrumentation room where the measurements were made. The length of the cable caused no problems in measuring low current components. When high wattage (115 watts) transistors were measured, the voltage drop in the cable made measurements difficult. In this case, measurements were made after exposure. For transistors tested under, h_{FE} was measured at the time of the pulse by noting any changes in ammeter readings. Various resistors were used to limit the current to specification limits. Usually only one of each component was tested due to availability problems (although some tests had two to four samples). The number tested is shown on the data sheets. Electronic assemblies consisting of previously tested diodes, transistors and DTL integrated circuits were later tested in a power-on standby state. Only transistors which performed well under previous radiation tests were used in the electronic assemblies (JTX2N2222A, JTX2N2907A, JTX2N2484, etc). As expected from the individual component tests, the electronic assemblies functioned correctly after exposure of 1.17×10^{13} neutrons/cm² (1 MeV equiv) and 2,387 rad-Si gamma dose.

A total of ten each CMOS integrated circuits from four manufacturers was tested for this program. Due to the high number of test samples, only flip-flops and counters were tested in a power-on state during the reactor pulse. Most other CMOS integrated circuits were tested with the reactor in the steady state mode. A Spectrum Dynamics Inc (formerly AEI) Model 101 integrated circuit tester was used to measure CMOS electrical parameters. Later electrical assemblies consisting of diodes, transistors and CMOS integrated circuits were subjected to levels up to 1.26×10^{13} neutrons/cm² (1 MeV equiv) and 2800 rad-Si gamma dose. The assemblies functioned correctly when tested after exposure. A total of over 500 CMOS integrated circuits were tested during this program (individual chips and chips in electronic assemblies).

For permanent damage tests, no individual CMOS integrated circuit data sheets were used because of the large number of CMOS integrated circuits tested and the high probability that they would still be capable of proper circuit operation until exposure to dose levels up to 5×10^{14} n/cm² and 100,000 rad-Si gamma dose.

Transient radiation effects testing was performed on SCR's and CMOS integrated circuit flip-flops and counters. The Air Force Weapons Laboratory 2 MeV Flash X-ray Facility was used for prompt gamma radiation testing. The Army Pulsed Reactor Facility operating in the pulsed mode was used for secondary gamma radiation testing. Prompt gamma radiation (according to Ref 3) is "the gamma rays produced in fission, while secondary radiation is produced by the interaction of matter (air for example) with radiation regarded as prompt". Shielded interconnecting cables were used to reduce any electromagnetic noise coupling.

All prompt radiation testing was conducted within a screen room with oscilloscopes monitoring instrumentation lines for noise (none was noted). During secondary radiation testing, noise response on test items was noted during the reactor mini-pulse (a calibration pulse of 1/100 the test reactor pulse value) which occurs prior to the reactor pulse. The reactor mini-pulse and test pulse emit the same electromagnetic noise. Therefore, if no upset was caused during the mini-pulse but did occur during the test pulse, the upset was due to nuclear radiation and not reactor electromagnetic noise.

Calcium Fluoride TLD dosimeters were used and calibrated by Air Force Weapons Laboratory personnel. Initially, sulfur tablet (neutron dose) dosimeters were used with glass rod (gamma dose) dosimeters at the Army Pulsed Reactor Facility. Later, since the reactor had established a constant neutron/gamma dose ratio, glass rods were no longer used. PIN diodes were used to measure reactor pulse width during pulsed operation.

The reactor radiation units appearing on the component test data sheets are: neutron dose in n/cm^2 (1 MeV equivalent), gamma dose in rad-Si and gamma dose rate in rad-Si/sec.

The following test methods were used to measure electrical parameters of the semiconductors tested. The test values of each parameter were from the MIL-SPEC or manufacturers' data sheets.

Diodes, Switching, Rectifier, and Diode Matrix Fusible Link

V_F , Forward Voltage Drop, MIL-STD-750B, Method 4011.3

I_R , Reverse Leakage Current, MIL-STD-750B, Method 4016.2

Diodes, Zener

B_V , Zener Breakdown Voltage, MIL-STD-750B, Method 4022

I_R , Reverse Leakage Current, MIL-STD-750B, Method 4016.2

Transistors

h_{FE} , Gain, Forward Current Transfer Ratio, MIL-STD-750B, Method 3076.1

$V_{CE(sat)}$, Collector-to-Emitter Saturation Voltage, MIL-STD-750B,
Method 3071

Silicon Controlled Rectifiers

V_{GT} , Gate Trigger Voltage, MIL-STD-750B, Method 4221.1

I_{GT} , Gate Trigger Current, MIL-STD-750B, Method 4221.1

V_F , Forward "On" Voltage Drop, MIL-STD-750B, Method 4226.1

I_{HO} , Holding Current, MIL-STD-750B, Method 4201.2

Integrated Circuit, Bipolar, Diode Transistor Logic

I_{CCL} , Power Supply Current, down level (low level) at output,
MIL-STD-883, Method 3005
 I_{CCH} , Power Supply Current, up level (high level) at output,
MIL-STD-883, Method 3005
 V_{OH} , High Level Output Voltage, MIL-STD-883, Method 3006
 V_{OL} , Low Level Output Voltage, MIL-STD-883, Method 3007
Check for logic operation and latchup.

Integrated Circuit, CMOS

Since no MIL-SPEC for CMOS IC's existed at the time of these tests, manufacturers' data sheets were used.

V_{OUT} "0", "0" Output Voltage
 V_{OUT} "1", "1" Output Voltage
 P_T , Quiescent Device Dissipation
 $V_{TH}(\emptyset)$, $\emptyset$ Threshold Voltage. Due to the large number of devices tested (500), the threshold voltage value used was one volt below V_{DD} .
Checked for logic operation and latchup.

CONCLUSIONS

Permanent Damage Test Results

The one switching diode tested was within specifications after exposure to $2 \times 10^{13} \text{ n/cm}^2$. While rectifier diodes survived levels to 10^{12} n/cm^2 , they were severely degraded and out of specifications at $9 \times 10^{12} \text{ n/cm}^2$. All zener diodes were well within specifications up to $2 \times 10^{13} \text{ n/cm}^2$.

The fusible link dielectrically isolated diode matrix showed no change in test parameters after an exposure of $8.9 \times 10^{13} \text{ n/cm}^2$.

Switching and power transistors were tested with the high JEDEC number transistors having significantly better results. In general, all switching transistors with Joint Electronic Device Engineering Council (JEDEC) numbers above 2N2000 were within specification values up to 10^{12} n/cm^2 . A few were still within specifications after an exposure above 10^{13} n/cm^2 . The old slow switching speed low-gain transistors with JEDEC numbers less than 2N1000 gave very poor test results after an exposure of 10^{12} n/cm^2 . As expected, power transistors generally gave poorer test results than switching transistors due to their wider basewidths, making them more vulnerable to neutron dose

produced defects. Very high wattage (90 to 150 watt) germanium transistors gave the poorest test results of all. The newer 2N5000 series power transistors were almost within specifications after an exposure of 10^{12} n/cm².

The silicon controlled rectifiers tested, all of which have fast switching speeds, were within specification values after 10^{12} n/cm² exposure, and some showed very little parameter change after 2×10^{13} n/cm² exposures.

Diode Transistor Logic integrated circuit test results varied depending on circuit function, power consumption, and time between exposure and measurement. For the high power DTL integrated circuits, they were generally within specifications for levels up to 10^{13} n/cm² and out of specification at 9×10^{13} n/cm². But they returned to within specification limits after two hours. The lower power DTL integrated circuits were within specifications after an exposure of 9.77×10^{13} n/cm².

At no time did a CMOS integrated circuit fail to function correctly until reaching an exposure of 1.6×10^{15} n/cm² and 352,000 rad-Si gamma dose. At this point, five of 30 chips failed to function after exposure. At least ten of each type listed were exposed from the four manufacturers' products tested (RCA, Motorola, Solid State Scientific, and Harris Semiconductor). Including the CMOS integrated circuits from the electronic assembly tests, over 500 CMOS integrated circuits were tested to levels between 10^{12} n/cm² and 222 rad-Si gamma dose and 7.7×10^{13} n/cm² and 17,000 rad-Si gamma dose without a failure.

A hermetically sealed DC to DC converter consisting of unknown transistors was tested at 1.4×10^{12} n/cm² and 324 rad-Si gamma dose and was a total failure.

A powered electronic assembly consisting of carbon film resistors, ceramic capacitors, switching transistors, switching and zener diodes, fusible link diode matrices and high power DTL integrated circuits functioned correctly one-half hour¹ after an exposure of 1.17×10^{13} n/cm² and 2,387 rad-Si gamma dose.

¹This item was later tested at AFWL for gamma dose rate effects and results are not covered in this report.

A powered electronic assembly consisting of carbon film resistors, ceramic capacitors, switching transistors, switching diodes, fusible link diode matrices and CMOS integrated circuits functioned correctly one-half hour² after an exposure of 1.128×10^{13} n/cm² and 2,030 rad-Si gamma dose. An operating sequential timer consisting of carbon film resistors, ceramic and tantalum capacitors, switching and power transistors, switching diodes, crystal oscillators and CMOS integrated circuits functioned correctly during a pulsed radiation exposure of 1.26×10^{13} n/cm² and 2800 rad-Si gamma dose.

Transient Effects

As was stated in the introduction, the only components tested for transient effects were CMOS integrated circuit flip-flops, counters and silicon controlled rectifiers. System requirements did not require DTL integrated circuit operation during radiation exposure, but only the capacity of operation after exposure. Due to the number of tests conducted on CMOS integrated circuits and the different test results, only the significant test data will be reviewed.

Commercially available junction isolated and dielectrically isolated 4013 dual flip-flops were tested for prompt radiation effects. Five each of the integrated circuits were tested at the AFWL Flash X-ray Facility (FXR) and the lowest radiation level which caused malfunction was recorded. The junction isolated flip-flops in the "set" state operated properly at 4.4×10^9 rad-Si/sec and malfunctioned at 6.3×10^9 rad-Si/sec. In the "reset" state, a ten times higher gamma dose rate was needed to change state. The dielectric isolated flip-flops in the "set" state operated properly only up to 6×10^8 rad-Si/sec.

Five each junction isolated 4017 decade counter/dividers, when FXR tested, retained information at 9×10^8 rad-Si/sec but malfunctioned at 1×10^9 rad-Si/sec.

Secondary gamma dose rate testing was conducted at APRF on 4013 flip-flops and 4017 decade counter/dividers using a neutron-to-gamma dose converter shield to achieve high gamma dose rates with a wide (79 us) FWHM pulse width (Ref 4). Both types of junction isolated integrated circuits retained stored information at 3.1×10^8 rad-Si/sec.

² Reactor personnel safety requirements dictated a one-half hour interval after exposure prior to the recovery of the electronic assembly for a functional test.

Other CMOS integrated circuits tested included binary counters and shift registers. The following table reviews all CMOS transient testing and shows the levels at which these devices fail. Results from other test programs are included (Ref 2, 8).

<u>FWHM pulse width</u>	<u>Radiation level which produced circuit malfunction</u>
2 ns	3×10^9 rad-Si/sec
25 ns	3×10^8 to 9×10^8 rad-Si/sec
79 us	1.05×10^8 rad-Si/sec

A sequential timer, consisting of switching and power transistors, switching diodes, crystal oscillators and CMOS integrated circuits functioned correctly during exposure to prompt gamma dose rates up to 6.8×10^8 rad-Si/sec with a FWHM pulse width of 25 ns. At 7.3×10^8 rad-Si/sec, the timer malfunctioned. The timer was then tested for secondary gamma dose rate effects and functioned correctly when exposed to dose rates up to 5.7×10^8 rad-Si/sec with a FWHM pulse width of 53 us and an accompanying neutron dose of 1.26×10^{13} n/cm² and gamma dose of 2800 rad-Si.

Pulsed reactor tests were performed on the following SCR's while under power for synergistic effects:

	<u>Gate-to-Cathode Resistor Value (ohms)</u>	<u>Forward Blocking Voltage, DC</u>
JTX2N2323A	200	12V
JTX2N3030	1000	12V
Motorola2N4184	1000	32V

Neutron dose: 2.1×10^{12} n/cm², gamma dose: 10,000 rad, gamma dose rate: 10^8 rad-Si/sec, FWHM pulse width: 85 us

The SCR's all turned on due to pulsed radiation.

RECOMMENDATIONS

The switching and zener diodes tested are recommended for use in systems having nuclear radiation specification values up to 10^{13} n/cm². The rectifier diodes tested are only within specifications up to 10^{12} n/cm² and should not be used when higher radiation levels are specified.

The fusible link dielectrically isolated diode matrix provides an excellent means of storing information at high radiation dose levels and gamma dose rates.

The use of high gain (100-250) transistors in low gain switching applications provides radiation hardness in electronic assemblies up to 10^{13} n/cm². This design method allows low cost, multiple source, high reliability MIL-SPEC transistors to be used instead of specially developed, high cost, sole source transistors which may be non-MIL-SPEC and of questionable reliability. As an example, the JTX2N2907A transistor tested had a gain reduction from 233 to 98 after 2×10^{13} n/cm² and is more than acceptable for a circuit application requiring a gain of 5 to 10. This transistor was used in circuit applications in all the electronic assemblies which functioned correctly after an exposure of 1.26×10^{13} n/cm².

The newer power transistors (series JTX2N5000 and above) should be used for radiation hardness since they have narrow basewidths which provide significant radiation hardness.

CMOS should be used rather than DTL integrated circuits for digital systems that have high neutron and gamma dose requirements (7.7×10^{13} n/cm² and 17,000 rad-Si respectively). These radiation levels, although probably conservative, do represent radiation levels at which commercially available CMOS integrated circuits are capable of proper electrical operation. Another radiation hardening advantage of CMOS over DTL integrated circuits is in voltage regulation requirements. Power transistors usually found in DC to DC converters can be sensitive to radiation exposure. If so, the radiation will alter converter output voltage (frequently this is integrated circuit supply voltage). CMOS integrated circuits, which operate over a range of 3 to 18 volts are much less sensitive to changes in supply voltage than are DTL integrated circuits, some of which only operate properly over a range of 4.5 to 5.5 volts.

Silicon on sapphire CMOS integrated circuits, according to published reports (Ref 1, 2), have significantly higher transient radiation resistance than present off-the-shelf CMOS integrated circuits.

For applications which have high gamma dose rate requirements (in excess of 3×10^9 rad-Si/sec) with a short 2 ns pulse width, Silicon on Sapphire (SOS) should be used in place of present CMOS integrated circuits if possible.

Silicon Controlled Rectifiers (SCR's) can be used as fast, high current switching devices in systems required to be capable of operation only after exposure to nuclear radiation. SCR's, with careful selection, will survive neutron dose levels up to 2×10^{13} n/cm². If, however, the system must be capable of operation during exposure (i.e. transient radiation requirements), SCR's should not be used when the gamma dose rate is above 10^8 rad-Si/sec. Tests have been conducted using a 2 ns FWHM pulse width on a 2N2323A SCR with the following results for gamma dose rate turn on (Ref 8).

<u>Lowest gamma dose rate needed to cause SCR turn on</u>	<u>R_{GK}</u>
3.5×10^8	5,500
4.4×10^8	4,400
1.1×10^9	200

As can be seen from these test results, an improvement on SCR transient radiation hardness can be made by lowering the value of the gate-to-cathode resistor.

Shielding is not recommended for SCR hardening, since lead one inch thick will only increase gamma dose rate tolerance one order of magnitude. Other SCR hardening measures should be considered, such as capacitors across the gate, chokes in the anode leads and photo-current compensating diodes across the gate (Ref 10).

LIST OF SEMICONDUCTORS NUCLEAR RADIATION TESTED

Diodes

1N751A	Zener Diode, MIL-S-19500/127
JTX1N965B	Zener Diode, MIL-S-19500/117C
JTX1N3020B	Zener Diode, MIL-S-19500/115E
1N3024A	Zener Diode, MIL-S-19500/115E
JTX1N3611	Rectifier Diode, MIL-S-19500/228E
JTX1N3614	Rectifier Diode, MIL-S-19500/228E
1N3890	Rectifier Diode, MIL-S-19500/304A
JTX1N4148	Switching Diode, MIL-S-19500/116E
JTX1N4961	Zener Diode, MIL-S-19500/356B
1N4964	Zener Diode, MIL-S-19500/356B
1N5637A	Zener Diode

Diode Matrix (Fusible Link)

P9258797	Harris Semiconductor
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Transistors

JTX2N720A	NPN, MIL-S-19500/182C
JTX2N930	NPN, MIL-S-19500/253B
2N1021	PNP, MIL-S-19500/217B
2N1120	PNP, MIL-S-19500/68A
JTX2N2219A	NPN, MIL-S-19500/251E
JTX2N2222A	NPN, MIL-S-19500/255E
2N2484	NPN, MIL-S-19500/376A
JTX2N2905A	PNP, MIL-S-19500/290B
JTX2N2907A	PNP, MIL-S-19500/291B

2N3749	NPN, MIL-S-19500/315C
2N4399	PNP, MIL-S-19500/433
2N5552	NPN
2N5662	NPN, MIL-S-19500/454
2N5665	NPN, MIL-S-19500/455
2N5745	PNP, MIL-S-19500/433

Silicon Controlled Rectifiers

JTX2N2323A	MIL-S-19500/276A
JTX2N2324	MIL-S-19500/276A
JTX2N3030	MIL-S-19500/419
P8866261	Motorola 2N4184
P8875513	Motorola MCR 1336-9

Bipolar Integrated Circuits

<u>P.A. Drawing No. (Fairchild No.)</u>	<u>Function</u>
P8874352 (U6A994651XQL)	Quad 2 - Input NAND Gate (High Power)
P8874353 (U6A904651XQL)	Quad 2 - Input NAND Gate (Low Power)
P8874354 (U6A904751XQL)	Triple 3 - Input NAND Gate (Low Power)
P8874355 (U6A904051XQL)	Clocked Flip-Flop (Low Power)
P8874356 (U6A904451XQL)	Dual 4 - Input NAND Gate (Lower Power)
P8874357 (U6A962051XQL)	Dual Differential Line Receiver

P8874790 (U6A993251XQL)	Dual 4 - Input NAND Gate Driver (High Power)
P8874791 (U6A993051XQL)	Dual 4 - Input NAND Gate (High Power)
P8874792 (U6A909351XQL)	Dual Clocked Flip-Flop (High Power)
P8874793 (U6A996251XQL)	Triple 3 - Input NAND Gate (High Power)

Complementary Metal Oxide Semiconductor (CMOS) Integrated Circuits

16 Bit Memory

CD 4005AD	RCA (now discontinued)
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Dual Complementary Pair Plus Inverter

CD4005AD	RCA
SCL4007AD	Solid State Scientific Inc
MC14007AL	Motorola

Hex Buffer/Converter Inverting Type

SCL4009AD	Solid State Scientific
MC14009AL	Motorola
HD-1-4009-2	Harris Semiconductor

Quad 2 Input NAND Gate

CD4011AD	RCA
SCL4011AD	Solid State Scientific
MC14011AL	Motorola
HD-1-4011-2	Harris Semiconductor

Dual 4 - Input NAND Gate

CD4012AD	RCA
SCL4012AD	Solid State Scientific
MC14012AL	Motorola
HD-1-4012-2	Harris Semiconductor

Dual D Flip-flop with Set/Reset Capability

CD4013AD	RCA
SCL4013AD	Solid State Scientific
MC14013AL	Motorola
HD-1-4013-2	Harris Semiconductor

Dual 4 - Stage Shift Register with Serial Input/Parallel Output

CD4015AD	RCA
SCL4015AD	Solid State Scientific
MC14015AL	Motorola

Decade Counter/Divider

CD4017AD	RCA
SCL4017AD	Solid State Scientific
MC14017AL	Motorola

Quad and/or Select Gate

CD4019AD	RCA
SCL4019AD	Solid State Scientific

14 Stage Ripple - Carry Binary Counter/Divider

CD4020AD	RCA
SCL4020AD	Solid State Scientific

Triple 3 Input NAND Gate

CD4023AD	RCA
SCL4023AD	Solid State Scientific
MC14023AL	Motorola

7 Stage Ripple - Carry Binary Counter

CD4024AD	RCA
SCL4024AD	Solid State Scientific

Quad Exclusive or Gate

CD4030AD	RCA
SCL4030AD	Solid State Scientific

Quad NOR Reset/Set Latch

CD4043AD	RCA
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Quad NAND Reset/Set Latch

CD4044AD	RCA
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Hex Buffer/Converter

CD4049AD	RCA
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Hex Buffer/Converter

CD4050AD	RCA
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DC to DC Converter

P9239238

REFERENCES

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2. "Digital Logic for Radiation Environments: A comparison of Metal Oxide--Semiconductor and Bipolar Technologies", by W. J. Dennehy et al, RCA Review December 1969, Vol 30, No. 4.
3. "Definitions of Nuclear Terms Including Formulas and Tables" Report 1001, Volume 1, U.S. Naval Weapons Evaluation Facility, 1 May 1967. U126,832. Available from DDC.
4. "Design and Performance of Pulsed Fast Neutron-To-Gamma Converter Shields", by A. H. Kazi et al, Report No. 1662, Ballistics Research Laboratories, August 1973. Available from DDC.
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9. "Packaging Considerations For Shielding Electronic Packages", by L. J. Johnson et al, Autonetics Division, North American Aviation (now Rockwell International).
10. "Radiation Effects on Guided Missile Electronic Equipment III", F. E. Bell, Report No. FR 64-10-267, 15 July 1964, C 111,126. Available from DDC.

DIODES

Diode, Zener, IN751A, MIL-S-19500/127

<u>Symbol</u>	<u>Spec value</u>		<u>Sample No.</u>	<u>Pre-radiation</u>	<u>Post-radiation reactor pulse No. P73-23</u>
	<u>Min</u>	<u>Max</u>			
V_Z , volts, test current = 20 ma	4.85	5.35	1	--	5.0
			2	--	5.1
test current = 250 ua	3.3	5.35	1	--	4.0
			2	--	4.3
I_R , ua	--	5	1	.5	.5
			2	.5	.5

I_R @ 2 VDC

<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>	<u>Gamma dose rad-Si</u>
P73-23	1.37×10^{12}	307

Diode, Zener, JTX1N965B, MIL-S-19500/117C

<u>Symbol</u>	<u>Spec value</u>		<u>Sample No.</u>	<u>Pre-radiation</u>	<u>Post-radiation reactor pulse No. P73-24</u>
	<u>Min</u>	<u>Max</u>			
V_Z , volts test current = 8.5 ma	14.25	15.75	1	15.1	15.0
			2	15.1	15.0
I_R , ua	--	5 ua	1	1	1
			2	1	1

I_R @ 11 VDC

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm^2</u>	<u>Gamma dose</u> <u>rad-Si</u>
P73-24	1.35×10^{12}	302

Diode, Zener, JTX1N3020B, MIL-S-19500/115E, Dickerson Electronic Corp

Symbol	Spec Value		Pre-radiation	Post-radiation Pulse No. 1	Pre-radiation	Post-radiation Pulse No. 2
	Min	Max				
V _Z , volts, test current = 25 ma	9.5	10.5	9.6	9.8	9.4	9.4
I _R , ua	--	25	0.81	1.66	0.81	0.81
I _R @ 7.6 VDC						

22

Pulse No.	Neutron dose n/cm^2	Gamma dose rad-Si
(1) P7294	1.69×10^{13}	3,460
(2) P7295	1.02×10^{13}	208

Note: Change diode after pulse No. 1

Diode, Rectifier, JTX1N3611, MIL-S-19500/228E, Microsemiconductor Corp

<u>Symbol</u>	<u>Spec value</u>	<u>Post-radiation</u>	
		<u>Pulse No. 1</u>	<u>Pulse No. 2</u>
V_F volts	1.1 volts, max at $I_F = 1$ amp, pulsed	.47	3.6
I_R ua	1.0 ua max at 200 VDC	.125	.17
		<u>Pre-radiation</u>	
		.47	
		.125	
		<u>Gamma dose</u>	
		rad-Si	<u>Total</u>
<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>		
(1) P72-121	1.26×10^{12}	260	
(2) P72-122	9.3×10^{12}	2,150	2,410
		1.06×10^{13}	

Note: Monitored I_R , reverse current

Diode, Rectifier, JTX1N3614, MIL-S-19500/228E, Microsemiconductor

<u>Symbol</u>	<u>Spec value</u>	<u>Post-radiation</u>	
		<u>Pulse No. 1</u>	<u>Pulse No. 2</u>
V_F volts	1.1 volts max at $I_F = 1$ amp, pulsed	.47	3.6
I_R ua	1.0 ua max at 800 VDC	.27	.27
		<u>Pre-radiation</u>	
		.47	
		.27	
		<u>Gamma dose</u> <u>rad-Si</u>	
		260	
		2,150	
		<u>Total</u>	

		1.06 x 10 ¹³	
		<u>Neutron dose</u> <u>n/cm²</u>	
		1.26 x 10 ¹²	
		9.3 x 10 ¹²	
		<u>Total</u>	

		1.06 x 10 ¹³	
		<u>Gamma dose</u> <u>rad-Si</u>	
		260	
		2,150	
		<u>Total</u>	

		2,410	

Note: Monitored I_R , reverse current and noted no shift

Diode, Rectifier, IN3890, MIL-S-19500/304A, General Electric

<u>Symbol</u>	<u>Spec value</u>	<u>Sample No.</u>	<u>Pre-radiation</u>	<u>Post-radiation Reactor Pulse No. P73-22</u>
V _F volts	1.5 volts, max, at I _F = 2 amps pulsed	1	0.8	0.8
		2	0.8	0.9
I _R ua	25 ua max at 100 VDC	1	0.5	0.5
		2	0.5	0.5
<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>	<u>Total</u>	<u>Gamma dose rad-Si</u>	<u>Total</u>
P73-22	1.4 x 10 ¹⁸	---	312	---

Diode, Switching, JTX1N4148, MIL-S-19500/116E

<u>Symbol</u>	<u>Spec value</u>	<u>Pre-radiation</u>		<u>Post-radiation</u>	
		<u>Pulse No. 1</u>	<u>Pulse No. 2</u>	<u>Pulse No. 1</u>	<u>Pulse No. 2</u>
V_F , volts, test current = 10 ma	1.0 max	0.72	0.8	0.9	0.9

I_R , ua	25 max	0	0	0	0
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I_R @ 20 VDC

<u>Pulse No.</u>	<u>Neutron dose</u>		<u>Gamma dose</u>		<u>Total</u>
	<u>n/cm²</u>	<u>Total</u>	<u>rad-Si</u>	<u>rad-Si</u>	
1	2.5×10^{12}	---	558	---	---
2	1.75×10^{13}	$2 \times 10^{13} \text{ n/cm}^2$	3,900	---	4,458

Diode, Zener, JTX1N4961, MIL-S-19500/356B, Microsemiconductor Corp

Symbol	Spec value		Pre-radiation	Post-radiation Pulse No. 1	Pre-radiation	Post-radiation Pulse No. 2
	Min	Max				
V _Z volts, test current = 100 ma	12.35	13.65	13.4	13.5	13.4	13.5
I _R , ua	---	10	1.0	1.5	1.05	1.1
I _R @ 9.9 VDC						

Pulse No.	Neutron dose n/cm ²	Gamma dose rad-Si
(1) P7294	1.69 x 10 ¹³	3,460
(2) P7295	1.02 x 10 ¹³	208

Note: Changed diode after pulse no. 1

Diode, Zener, 1N4964, MIL-S-19500/356B, Unitrode

<u>Symbol</u>	<u>Spec value</u>		<u>Pre-radiation</u>	<u>Post-radiation Pulse No. 1</u>
	<u>Min</u>	<u>Max</u>		
V_Z , volts, test current = 65 ma	17.1	18.9	18	18
I_R , ua	---	5	0	0
I_R @ 13.7 VDC				
<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>		<u>Total</u>	<u>Gamma dose rad-Si</u>
1	2×10^{13} n/cm ²		---	45,000
				<u>Total</u>

Diode, Zener 1N5637A, General Semiconductor Industries Inc.

<u>Symbol</u>	<u>Spec Value</u>		<u>Pre-radiation</u>		<u>Post-radiation</u>	
	<u>Min</u>	<u>Max</u>	<u>Pulse No. 1</u>		<u>Pulse No. 2</u>	
V_Z , volts test current = 1 ma	14.3	15.8	14.3	14.3	14.3	14.4
I_R , ua		5	1	1	1	1
I_R @ 13 VDC						

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm^2</u>	<u>Total</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>
(1) P72-121	1.26×10^{12}	---	260	---
(2) P72-122	9.3×10^{12}	1.06×10^{13}	2,150	2,410

Note: Monitored I_R , reverse current and noted no shift

DIODE MATRIX (FUSIBLE LINK)

Diode Matrix, P9258797, Fusible Link, Harris Semiconductor

<u>Symbol</u>	<u>Spec value</u>	<u>Pre-radiation</u> Pulse No. 1	<u>Post-radiation</u> Pulse No. 2
V_F	1.3 V max at $I_F = 20 \text{ ma}$	0.9	0.92
I_R	250 na max at $V_R = 25V$	2	2

Note: All above values were measured for diodes 11, 12 and 13
 I_R did rise momentarily to 4 nanoamperes during each pulse

<u>Pulse No.</u>	<u>Neutron dose</u> n/cm^2	<u>Total</u>	<u>Gamma Dose</u> rad-Si	<u>Total</u>
(1) P7292	7.23×10^{12}	---	1,480	---
(2) P7293	8.19×10^{13}	8.913×10^{13}	16,700	18,180

SILICON CONTROLLED RECTIFIERS

Characteristic Degradation vs Neutron Environment for Silicon Controlled Rectifier, JTX2N2323A

<u>Neutron dose</u>	<u>I_{GT}</u> <u>ua</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	< 1	.55	1.0	.15
2.5 x 10 ¹² n/cm ²	5	.55	1.1	.31
5 x 10 ¹² n/cm ²	7	.57	1.1	.32
10 ¹³ n/cm ²	8	.57	1.1	.6
1.5 x 10 ¹³ n/cm ²	19.6	.57	1.1	.6
2 x 10 ¹³ n/cm ²	26.5	.57	1.1	.7
spec limit, max. (a)	20.0	.6	2.2	2.0

(a) Per Dwg 8866275 and MIL-S-19500/276A

To obtain rad-Si, divide n/cm² by 4.49 x 10⁹

Characteristic Degradation vs Neutron
Environment for Silicon Controlled
Rectifier, JTX2N2324, Sample No. 1

<u>Neutron dose</u>	<u>I_{GT}</u> <u>ua</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	2.5	0.63	---	---
1.01 x 10 ¹² n/cm ²	55	0.69	---	3.0
6.08 x 10 ¹² n/cm ²	1500	0.74	---	7.6
spec limit ^(a)	200	0.8	---	2

(a) Per MIL-S-19500/276A

To obtain rad-Si, divide n/cm² by 4.49 x 10⁹

Characteristic Degradation vs Neutron
Environment for Silicon Controlled
Rectifier, JTX2N2324, Sample No. 2

<u>Neutron dose</u>	<u>I_{GT}</u> <u>ua</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	8	0.63	---	0.60
$1.01 \times 10^{12} \text{ n/cm}^2$	42	0.66	---	2.8
$6.08 \times 10^{12} \text{ n/cm}^2$	800	0.78	---	7.8
spec limit ^(a)	200	0.8	---	2

(a) Per MIL-S-19500/276A

To obtain rad-Si, divide n/cm^2 by 4.49×10^9

Characteristic Degradation vs Neutron
Environment for Silicon Controlled
Rectifier, JTX2N3030

<u>Neutron dose</u>	<u>I_{GT}</u> <u>ua</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	< 1	.54	1.0	.15
2.5 x 10 ¹² n/cm ²	< 1	.54	1.1	.24
5 x 10 ¹² n/cm ²	< 1	.56	1.1	.25
10 ¹³ n/cm ²	< 1	.56	1.1	.38
1.5 x 10 ¹³ n/cm ²	< 1	.56	1.1	.38
2 x 10 ¹³ n/cm ²	< 1	.56	1.1	.39
spec limit, max ^(a)	20	.6	1.5	4.0

(a) Per MIL-S-19500/419

To obtain rad-Si, divide n/cm² by 4.49 x 10⁹

Characteristic Degradation vs Neutron
Environment for Silicon Controlled
Rectifier, 2N4184

<u>Neutron dose</u>	<u>I_{GT}</u> <u>MA</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	1.7	.63	1.0	3.0
2.5 x 10 ¹² n/cm ²	1.8	.65	1.0	5.4
5 x 10 ¹² n/cm ²	1.8	.66	1.0	6.1
10 ¹³ n/cm ²	2.0	.66	1.0	8.8
1.5 x 10 ¹³ n/cm ²	2.4	.67	1.0	8.8
2 x 10 ¹³ n/cm ²	2.8	.67	1.0	8.9
spec limit, max ^(a)	20.0	1.5	1.3	25.0

(a) Per Dwg P8866261

To obtain rad-Si, divide n/cm² by 4.49 x 10⁹

Characteristic Degradation vs Neutron
Environment for Silicon Controlled
Rectifier, P8875513, MCR 1336-9, Motorola, Sample No. 1

<u>Neutron dose</u>	<u>I_{GT}</u> <u>MA</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	8.7	0.86	---	23
$1.01 \times 10^{12} \text{ n/cm}^2$	6.4	0.9	---	27
$6.08 \times 10^{12} \text{ n/cm}^2$	SCR will not stay switched			
spec limit, max ^(a)	40	1.25	---	50

(a) Per Dwg P8875513

To obtain gamma dose in rad-Si, divide n/cm^2 by 4.49×10^9

Characteristic Degradation vs Neutron
Environment for Silicon Controlled
Rectifier, P8875513, MCR 1336-9, Motorola, Sample No. 2

<u>Neutron dose</u>	<u>I_{GT}</u> <u>MA</u>	<u>V_{GT}</u> <u>Volts</u>	<u>V_F</u> <u>Volts</u>	<u>I_{HO}</u> <u>MA</u>
Pre-radiation	5.8	0.88	---	11.6
$1.01 \times 10^{12} \text{ n/cm}^2$	9.5	0.88	---	13.0
$6.08 \times 10^{12} \text{ n/cm}^2$	SCR will not stay switched			
spec limit, max ^(a)	40.0	1.25	---	50.0

(a) Per Dwg P8875513

To obtain gamma dose in rad-Si, divide n/cm^2 by 4.49×10^9

TRANSISTORS

JTX2N720A, NPN, 0.5 Watt, MIL-S-19500/182C, Motorola

<u>Symbol</u>	<u>Spec value</u>	<u>Pre-radiation</u>	<u>Post-radiation Pulse No. 1</u>	<u>Pre-radiation</u>	<u>Post-radiation Pulse No. 2</u>
h_{FE}	20 min	67	3.7	.67	45.4

$$h_{FE} = \frac{I_C}{I_B} \text{ with } V_{CE} = 10 \text{ VDC}$$

V_{CE} (sat) volts	1.2 max	--	0.98	--	0.51
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<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>	<u>Gamma dose rad-Si</u>
(1) P7294	1.69×10^{13}	3,460
(2) P7295	1.02×10^{13}	208

Note: Changed transistor after pulse no. 1

JTX2N930, NPN, 0.3 Watt, MIL-S-19500/253E, National Semiconductor

<u>Symbol</u>	<u>Spec value</u>	<u>Pre-radiation</u>	<u>Post-radiation</u>	<u>Pre-radiation</u>	<u>Post-radiation</u>
			<u>Pulse No. 1</u>	<u>radiation</u>	<u>Pulse No. 2</u>
h_{FE}	150 min	225.0	14.0	225.0	137.0

$$h_{FE} = \frac{I_C}{I_B} \text{ with } V_{CE} = 5 \text{ VDC}$$

V_{CE} (sat) volts	1.0 max	0.15	0.36	0.15	0.19
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<u>Pulse No.</u>	<u>Neutron dose</u>	<u>Gamma dose</u>
	<u>n/cm^2</u>	<u>rad-Si</u>
(1) P7294	1.69×10^{13}	3,460
(2) P7295	1.02×10^{12}	208

Note: Changed transistor after pulse no. 1

2N1021, PNP, 150 Watt, MIL-S-19500/217B, Bendix

18 hours after
reactor pulse P72-23

Pre-radiation

Sample No.

Spec
value

50.0

250.0

1

40 min

35.7

250.0

2

$h_{FE} = \frac{I_C}{I_B}$ with $V_{CE} = 1.5$ VDC

-0.7

-0.3

1

-0.5 max

V_{CE} (sat) volts

-0.7

-0.3

2

Gamma dose
rad-Si

307

Neutron dose
 n/cm^2

1.37×10^{12}

Pulse No.

P72-23

2N1120, PNP, 90 Watt, MIL-S-19500/68A, Motorola

16 hours after
reactor pulse P72-23

Pre-radiation

Sample No.

Spec
value

31.4

55.5

1

20 min

$h_{FE} = \frac{I_C}{I_B}$ with $V_{CE} = -2.0$ VDC

19.3

55.5

2

42

V_{CE} (sat) volts

-0.7 max

-0.23

-0.27

-0.14

2

Gamma dose
rad-Si

Neutron dose
 n/cm^2

Pulse No.

P72-23

1.37×10^{12}

307

JTX2N2219A, NPN, 0.8 Watt, MIL-S-19500/251E, National Semiconductor

<u>Symbol</u>	<u>Spec value</u>	<u>Pre-radiation</u>	<u>Post-radiation</u> <u>Pulse No. 1</u>	<u>Pre-radiation</u>	<u>Post-radiation</u> <u>Pulse No. 2</u>
h_{FE}	100 min	166.0	41.5	166.0	135.0

$$h_{FE} = \frac{I_C}{I_B} \text{ with } V_{CE} = 10 \text{ VDC}$$

V_{CE} (sat) volts	0.3 max	0.15	0.14	0.15	0.19
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<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Gamma dose</u> <u>rad-Si</u>
(1) P7294	1.69×10^{13}	3,460
(2) P7295	1.02×10^{13}	208

Note: Changed transistor after pulse no. 1

JTX2N2222A, NPN, 0.5 Watt, MIL-S-19500/255E, National Semiconductor

<u>Symbol</u>	<u>Spec value</u>	<u>Post-radiation</u>	
		<u>Pulse No. 1</u>	<u>Pulse No. 2</u>
h_{FE}	100 min	175.0	84

$$h_{FE} = \frac{I_C}{I_B} \text{ with } V_{CE} = 10 \text{ VDC}$$

V_{CE} (sat) volts	0.3 max	0.15	0.16	0.19
----------------------	---------	------	------	------

<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>		<u>Gamma dose rad-Si</u>	
	<u>Total</u>		<u>Total</u>	
(1) P72-121	1.26 x 10 ¹²		260	
(2) P72-122	9.3 x 10 ¹²		2,150	
	1.06 x 10 ¹³		2,410	

JTX2N2484, NPN, 0.36 Watt, MIL-S-19500/376

<u>Symbol</u>	<u>Spec value</u>	<u>Pre-radiation</u>	<u>Pulse No. 1</u>	<u>Post-radiation Pulse No. 2</u>	<u>Pulse No. 3</u>
h_{FE}	250 min	333.0	287.0	250.0	154.0

$$h_{FE} = \frac{I_C}{I_B} \text{ with } V_{CE} = 5 \text{ VDC}$$

V_{CE} (sat) volts	0.7 max	0.07	0.08	0.09	0.10
----------------------	---------	------	------	------	------

<u>Pulse No.</u>	<u>Neutron dose n/cm^2</u>	<u>Total</u>	<u>Gamma dose rad-Si</u>	<u>Total</u>
(1)	1×10^{13}	---	1080	---
(2)	1.5×10^{13}	2.5×10^{13}	2790	3870
(3)	2×10^{13}	4.5×10^{13}	3750	7620

JTX2N2905A, PNP, 0.6 Watt, MIL-S-19500/290B, National Semiconductor

Symbol	Spec value	Pre- radiation	Post-radiation Pulse No. 1	Pre- radiation	Post-radiation Pulse No. 2
h_{FE}	100 min	143.0	37.0	143.0	192.3

$$h_{FE} = \frac{I_C}{I_B} \text{ with } V_{CE} = -10 \text{ VDC}$$

V_{CE} (sat) volts	-0.4 max	-0.16	-0.08	-0.16	-0.09
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Pulse No.	Neutron dose n/cm^2	Gamma dose rad-Si
(1) P7294	1.69×10^{13}	3,460
(2) P7295	1.02×10^{12}	208

Note: Changed transistor after pulse no. 1

JTX2N2907A, PNP, 0.4 Watt, MIL-S-19500/291B, Transistron Corp

<u>Symbol</u>	<u>Spec value</u>	<u>Post-radiation</u>	
		<u>Pulse No. 1</u>	<u>Pulse No. 2</u>
h_{FE}	100 min	186.0	98.0

$\frac{I_C}{I_B} = \frac{I_C}{I_B}$ with $V_{CE} = -10$ VDC

V_{CE} (sat) volts	-0.4 max	-0.2	-0.31
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<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>		<u>Gamma dose rad-Si</u>	
	<u>Total</u>		<u>Total</u>	
(1) P72-121	1.26 x 10 ¹³	--	260	---
(2) P72-122	9.3 x 10 ¹³	1.06 x 10 ¹³	2,150	2,410

JTX2N3749, NPN, 30 Watt, MIL-S-19500/315C, Solitron Devices, Inc

<u>Symbol</u>	<u>Spec value</u>	<u>Sample No.</u>	<u>Pre-radiation</u>	<u>Reactor Pulse P73-45</u>
h_{FE}	40 min	1	---	62
$I_C = I_B$ with $V_{CE} = 5 \text{ VDC}$		2	---	50
		3	---	42

48

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Gamma dose</u> <u>rad-Si</u>
P73-45	1.45×10^{12}	324

2N4399, PNP, 115 Watt, MIL-S-19500/433 (EL), Motorola

<u>Symbol</u>	<u>Spec value</u>	<u>Sample No.</u>	<u>Pre-radiation</u>	<u>23 hours after reactor Pulse P73-45</u>				
h_{FE}	40 min	1	191	63				
$\frac{I_C}{I_B}$ with $V_{CE} = -2.0$ VDC		2	148	63				
V_{CE} (sat) volts	-0.75 max	1,2	--	-0.25				
<u>Pulse No.</u>	<table><tr><th><u>Neutron dose n/cm²</u></th><th><u>Gamma dose rad-Si</u></th></tr><tr><td>1.45 x 10¹²</td><td>324</td></tr></table>				<u>Neutron dose n/cm²</u>	<u>Gamma dose rad-Si</u>	1.45 x 10 ¹²	324
<u>Neutron dose n/cm²</u>	<u>Gamma dose rad-Si</u>							
1.45 x 10 ¹²	324							
P73-45								

2N5552, NPN, 10 Watt, P9258813, Power Physics Inc

<u>Symbol</u>	<u>Spec value</u>	<u>Sample No.</u>	<u>Pre-radiation</u>	<u>Reactor Pulse P73-45</u>
h_{FE}	40 min	1	--	167
$h_{FE} = \frac{I_C}{I_B}$ with $V_{CE} = 5.0$ VDC		2	--	125
		3	--	144
		4	--	83
V_{CE} (sat) volts	0.25 max	1,2,3,4	0.15	.15

<u>Pulse No.</u>	<u>Neutron dose n/cm^2</u>	<u>Gamma dose rad-Si</u>
P73-45	1.45×10^{12}	324

2N5662, NPN, 1.2 Watt, MIL-S-19500/454, Unitrode

<u>Symbol</u>	<u>Spec value</u>	<u>Sample No.</u>	<u>Pre-radiation</u>	<u>20 hours after reactor pulse P73-22</u>
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h_{FE}	15 min	1	25	14.3
----------	--------	---	----	------

$I_C = \frac{I_C}{I_B}$ with $V_{CE} = 5.0$ VDC

		2	25	14.3
--	--	---	----	------

V_{CE} (sat) volts	0.4 max	1	.4	1.8
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		2	.4	0.75
--	--	---	----	------

Gamma dose
rad-Si

312

Neutron dose
 n/cm^2

1.4×10^{12}

Pulse No.

P73-22

2N5665 NPN, 2.5 Watt, MIL-S-19500/455, Unitrode

<u>Symbol</u>	<u>Spec value</u>	<u>Sample No.</u>	<u>Pre-radiation</u>	<u>Reactor pulse P73-24</u>
h_{FE}	25 min	1	50.0	35.7
$h_{FE} = \frac{I_C}{I_B}$ with $V_{CE} = 2.0$ VDC		2	59.6	41.7
V_{CE} (sat) volts	0.4 max	1	0.2	0.30
		2	0.2	0.23
<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>		<u>Gamma dose</u> <u>rad-Si</u>	
P73-24	1.35 x 10 ¹²		302	

2N5745, PNP, 115 Watt, MIL-S-19500/433 (EL), Motorola

23 hours after
reactor
pulse P73-45

Pre-radiation

Sample No.

Spec
value

40

109

1

40 min

$I_C = \frac{I_C}{I_B}$ with $V_{CE} = -2.0$ VDC

36

77

2

V_{CE} (sat) volts

-0.75 max

1,2

-0.26

Gamma dose
rad-Si

324

Neutron dose
 n/cm^2

1.45×10^{12}

Pulse No.

P73-45

DIODE TRANSISTOR LOGIC INTEGRATED CIRCUITS

Quad 2 - Input NAND Gate, P8874352

SN 1

Symbol	Spec value	Pre	1	1A	2	Pre	3	3A	3B
I _{ccl} (ma)	---	9	9	9	9	10	10	9	10
V _{cc} = 5V									
I _{ccH} (ma)	---	7	7.5	7	6.9	7.2	7.8	7.8	7.2
V _{cc} = 8V									
V _{OH} (volts)	2.6 min	3.2	1.5	3.2	3.1	3.25	1.5	1.5	3.2
V _{cc} = 4.5V									
V _{OL} (volts)	0.4 max	0.2	4.5	0.3	0.2	0.2	4.4	4.5	0.2
V _{cc} = 4.5V									

Pulse No.	Neutron dose n/cm ²	Total	Gamma dose rad-Si	Total	Gamma dose rate rad-Si/sec
(1) P7269	1.3 x 10 ¹²	---	366	---	4.68 x 10 ⁶
(2) P7270	1.01 x 10 ¹³	1.14 x 10 ¹³	2,050	2,416	3.54 x 10 ⁷
(3) P7271	9.77 x 10 ¹³	---	20,000	---	3.44 x 10 ⁸

Note: 1, 2, 3 measured immediately after pulse no. 1, 2, 3 respectively
 1A measured 35 minutes after pulse no. 1
 3A measured 25 minutes after pulse no. 2
 3B measured 120 minutes after pulse no. 3

Note: 9946 (SN2) was used for pulse no. 3
 Measurement errors were assumed for pulse no. 1 since testing to higher levels in pulse no. 2 revealed no failures

Quad 2 - Input NAND Gate, P8874352

SN 12

Symbol	Spec value	Pre	$\frac{1}{-}$	$\frac{2}{-}$
I_{ccL} (ma)	13.0 max	8	9	9
$V_{cc} = 5V$				
I_{ccH} (ma)	11.0 max	11	11	11
$V_{cc} = 8V$				
V_{OH} (volts)	2.6 min	3.0	3.2	3.2
$V_{cc} = 4.5V$				
V_{OL} (volts)	0.4 max	.15	.15	.15
$V_{cc} = 4.5V$				
Pulse No.	Neutron dose $\frac{n}{cm^2}$	Total	Gamma dose rad-Si	Gamma dose rate $\frac{rad-Si}{sec}$
(1) P72-123	1.31×10^{12}	---	366	7.3×10^6
(2) P72-124	7.18×10^{12}	8.49×10^{12}	1,450	2.9×10^7

Note: V_{OL} and I_{CCL} were monitored during P72-123
 V_{OH} and I_{CCH} were monitored during P72-124

Quad 2 - Input NAND Gate, P8874352

SN 13

<u>Symbol</u>	<u>Spec value</u>	<u>Pre</u>	<u>1</u>	<u>2</u>	<u>3</u>
I_{ccl} (ma)	13.0 max	9	9	9	9
$V_{cc} = 5V$					
I_{cch} (ma)	11.0 max	7	7	7	7
$V_{cc} = 8V$					
V_{OH} (volts)	2.6 min	3.1	3.1	3.1	3.1
$V_{cc} = 4.5V$					
V_{OL} (volts)	0.4 max	.15	.15	.15	.15
$V_{cc} = 4.5V$					

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Total</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>	<u>Gamma dose rate</u> <u>rad-Si/sec</u>
(1) P72-125	8.61×10^{12}	---	1,760	---	3.5×10^7
(2) P72-126	8.62×10^{12}	1.72×10^{13}	1,761	3,521	3.5×10^7
(3) P72-127	8.3×10^{12}	2.55×10^{13}	1,700	5,221	3.4×10^7

Note: V_{OL} and I_{CCL} were monitored during P72-125 and P72-127
 V_{OH} and I_{CCH} were monitored during P72-126

Quad 2 - Input NAND Gate, P8874353

<u>Symbol</u>	<u>Spec value</u>	<u>Pre</u>	<u>1</u>	<u>2</u>	<u>3</u>
IPDH (ma)	1.55 max	1.35	1.2	1.2	1.2
$V_{CC} = 5V$					
IPDL (ma)	0.66 max	0.55	0.40	0.40	0.40
$V_{CC} = 5V$					
V_{OH} (volts)	2.7 min	3.1	3.2	3.2	3.1
$V_{CC} = 4.5V$					
V_{OL} (volts)	0.2 max	0.14	0.15	0.14	0.18
$V_{CC} = 5.5V$					

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Total</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>	<u>Gamma dose rate</u> <u>rad-Si/sec</u>
(1) P7272	1.55×10^{12}	---	318	---	5.46×10^6
(2) P7273	9.77×10^{12}	1.13×10^{13}	2,000	2,318	3.44×10^7
(3) P7274	8.64×10^{13}	9.77×10^{13}	17,700	20,018	3.04×10^8

Note: 9946 (SN2) was used for pulse no. 3

Triple 3 - Input NAND Gate, P8874354

<u>Symbol</u>	<u>Spec value</u>	<u>Pre</u>	<u>1</u>	<u>2</u>	<u>3</u>
IPDH (ma)	1.16 max	0.80	0.82	0.83	0.84
$V_{CC} = 5V$					
IPDL (ma)	0.495 max	0.350	0.370	0.390	0.400
$V_{CC} = 5V$					
V_{OH} (volts)	2.7 min	3.2	3.1	3.2	3.05
$V_{CC} = 4.5V$					
V_{OL} (volts)	0.2 max	0.12	0.13	0.13	0.165
$V_{CC} = 5.5V$					

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Total</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>	<u>Gamma dose rate</u> <u>rad-Si/sec</u>
(1) P7272	1.55×10^{12}	---	318	---	5.46×10^6
(2) P7273	9.77×10^{12}	1.13×10^{13}	2,000	2,318	3.44×10^7
(3) P7274	8.64×10^{13}	9.77×10^{13}	17,700	20,018	3.04×10^8

Clocked Flip-flop, P8874355

<u>Symbol</u>	<u>Spec value</u>	<u>1</u>	<u>2</u>
I_{PD} (ma)	1.1 max	0.84	0.81
$V_{CC} = 3.0V$			
V_{OH} (volts)	2.7 min	3.28	3.05
$V_{CC} = 4.5V$			
V_{OL} (volts)	0.2 max	0.12	0.17
$V_{CC} = 5.5V$			
No circuit latchup was observed			
<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>	<u>Gamma dose rad-Si</u>	<u>Gamma dose rate rad-Si/sec</u>
(1) P7275	9.66×10^{12}	1,975	---
(2) P7276	8.98×10^{13}	18,400	20,375
			3.40×10^7
			3.17×10^8

Note: Did not record pre-radiation values

Dual 4 - Input NAND Gate, P8874356

<u>Symbol</u>	<u>Spec value</u>	<u>Pre</u>	<u>1</u>	<u>2</u>	<u>3</u>
IPDH (ua)	775 max	520	510	520	520
$V_{CC} = 5V$					
IPDL (ua)	330 max	220	210	220	230
$V_{CC} = 5V$					
V_{OH} (volts)	2.7 min	3.2	3.15	3.2	3.08
$V_{CC} = 4.5V$					
V_{OL} (volts)	0.2 max	0.12	0.16	0.15	0.21
$V_{CC} = 5.5V$					
<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Total</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>	<u>Gamma dose rate</u> <u>rad-Si/sec</u>
(1) P7272	1.55×10^{12}	---	318	---	5.46×10^6
(2) P7273	9.77×10^{12}	1.13×10^{13}	2,000	2,318	3.44×10^7
(3) P7274	8.64×10^{13}	9.77×10^{13}	17,700	20,018	3.04×10^8

Dual Differential Line Receiver, P8874357

Symbol	Spec value	Pre	1	Pre	2
V_{TH}	500 mv max	227	238	7	50
V_{cc1} at 5V, I_{vcc1} (ma), $V_{TH} = 0$		6	6	5	5
V_{cc2} at 12V, I_{vcc2} (ma), $V_{TH} = 0$		5.8	5.8	4	4
I_{vcc1}	13 ma max	8	8	8	8
$V_{cc1} = 5.5V$, $V_{cc2} = 13.2V$					
I_{vcc2}	8.0 ma max	5.2	5.2	5.2	5.2
V_{OL}	0.40V max	0.44	0.45		0.65 (a)
$V_{cc1} = 4.5V$, $V_{cc2} = 10.8V$					
$V_{TH} = 0.5V$					
V_{OH} (See Note)	3.0V min	.45	3.3		3.4

Pulse No.	Neutron dose n/cm ²	Total	Gamma dose rad-Si	Total	Gamma dose rate rad-Si/sec
(1) P7292	7.23×10^{12}		1,480		2.53×10^7
(2) P7293	8.19×10^{13}	8.913×10^{13}	16,700	18,180	2.87×10^8

(a) Read 0.61V at 17 hours later and V_{OL} maybe out of spec due to the long reactor test cable resistance (particular loop resistance)

Note: V_{cc1} , V_{cc2} , V_{DIFF} same values as V_{OL} except V_{TH} polarity is reversed

Dual 4 - Input NAND Gate Driver, P8874790

SN 187

Symbol	Spec value	Pre	1	1A	2	Pre	3	3A	3B
I_{ccL} (ma) $V_{cc} = 5$ volts	26.0 max	24	24	24	24	23	22	22	23
I_{ccH} (ma) $V_{cc} = 8$ volts	6.0 max	5	9	5	5	5	8	8.1	5
V_{OH} (volts) $V_{cc} = 4.5V$	2.6 min	4.0	2.6	4.0	4.0	4.0	1.75	1.75	4.0
V_{OL} (volts) $V_{cc} = 4.5V$	0.4 max	0.2	4.5	0.3	0.3	0.2	4.5	4.5	0.3

63

Pulse No.	Neutron dose n/cm^2	Total	Gamma dose rad-Si	Total	Gamma dose rate rad-Si/sec
(1) P7269	1.3×10^{12}	---	366	---	4.68×10^6
(2) P7270	1.01×10^{13}	1.14×10^{13}	2,050	2,416	3.54×10^7
(3) P7271	9.77×10^{13}	---	29,000	---	3.44×10^8

Note: 1, 2, 3 measured immediately after pulse no. 1, 2, 3, respectively
 1A measured 35 minutes after pulse no. 1
 3A measured 25 minutes after pulse no. 3
 3B measured 120 minutes after pulse no. 3

Note: 9932 (SN188) was used for pulse no. 3
 Measurement errors were assumed for pulse no. 1 since testing to higher levels in pulse no. 2 revealed no failures

Dual 4 - Input NAND Gate Driver, P8874790

SN 189

<u>Symbol</u>	<u>Spec value</u>	<u>Pre</u>	<u>1</u>	<u>2</u>
I_{CCL} (ma) $V_{CC} = 5$ volts	26.0 max	21	21	21
I_{CCH} (ma) $V_{CC} = 8$ volts	6.0 max	4.5	4.5	5
V_{OH} (volts) $V_{CC} = 4.5V$	2.6 min	3.7	3.7	3.7
V_{OL} (volts) $V_{CC} = 4.5V$	0.4 max	.23	.23	.23
<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>	<u>Gamma dose rate</u> <u>rad-Si/sec</u>
(1) P72-123	1.31×10^{12}	366	---	7.3×10^6
(2) P72-124	7.18×10^{12}	1,450	1,816	2.9×10^7

Note: V_{OL} and I_{CCL} were monitored during P72-123
 V_{OH} and I_{CCH} were monitored during P72-124

Dual 4 - Input NAND Gate Driver, P8874790

SN 190

Symbol

I_{ccl} (ma)
 $V_{cc} = 5$ volts

I_{cch} (ma)
 $V_{cc} = 8$ volts

V_{OH} (volts)
 $V_{cc} = 4.5V$

V_{OL} (volts)
 $V_{cc} = 4.5V$

<u>Spec value</u>	<u>Pre</u>	<u>1</u>	<u>2</u>	<u>3</u>
26.0 max	22	22	22	22
6.0 max	4.4	4.4	4.4	4.4
2.6 min	3.7	3.8	3.8	3.8
0.4 max	.26	.26	.26	.26

<u>Pulse No.</u>	<u>Neutron dose</u> <u>n/cm²</u>	<u>Total</u>	<u>Gamma dose</u> <u>rad-Si</u>	<u>Total</u>	<u>Gamma dose rate</u> <u>rad-Si/sec</u>
(1) P72-125	8.61×10^{12}	--	1,760	--	3.5×10^7
(2) P72-126	8.62×10^{12}	1.72×10^{13}	1,761	3,521	3.5×10^7
(3) P72-127	8.3×10^{12}	2.52×10^{13}	1,700	5,221	3.4×10^7

Note: V_{OL} and I_{CCL} were monitored during P72-125 and P72-127
 V_{OH} and I_{CCH} were monitored during P72-126

Dual 4 - Input NAND Gate, P8874791

Symbol	Spec value	Pre	1	1A	2	Pre	3	3A	3B
I_{ccL} (ma) $V_{cc} = 5V$	6.5 max	4	4	4	4	4	4	5	4
I_{ccH} (ma) $V_{cc} = 5V$	5.6 max	4	4	4	4	4	4	5.5	4
V_{OH} (volts) $V_{cc} = 4.5V$	2.6 min	3.2	3.2	3.2	3.2	3.25	1.5	1.6	3.2
V_{OL} (volts) $V_{cc} = 4.5V$	0.4 max	0.2	0.2	0.2	0.2	0.25	4.4	4.4	0.2

Pulse No.	Neutron dose n/cm^2	Total	Gamma dose rad-Si	Total	Gamma dose rate rad-Si/sec
(1) P7269	1.3×10^{12}	---	366	---	4.68×10^6
(2) P7270	1.01×10^{13}	1.14×10^{13}	2,050	2,416	3.54×10^7
(3) P7271	9.77×10^{13}	---	20,000	---	3.44×10^8

Note: 1, 2, 3 measured immediately after pulse no. 1, 2, 3 respectively
 1A measured 35 minutes after pulse no. 1
 3A measured 25 minutes after pulse no. 3
 3B measured 120 minutes after pulse no. 3

9930 (SN 12) was used for pulse no. 3

Dual Clocked Flip-Flop, P8874792

<u>Symbol</u>	<u>Spec value</u>	<u>1</u>	<u>2</u>
I _{ccL} (ma)	28 max	14	14
V _{cc} = 5.0V			
I _{ccH} (ma)	40 max	26	26
V _{cc} = 8.0V			
V _{OH} (volts)	2.5 min	3.1	3.1
V _{OL} (volts)	0.40 max	0.22	0.27

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No circuit latchup was observed

<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>	<u>Total</u>	<u>Gamma dose rad-Si</u>	<u>Total</u>	<u>Gamma dose rate rad-Si/sec</u>
(1) P7275	9.66 x 10 ¹²	---	1,975	---	3.40 x 10 ⁷
(2) P7276	8.98 x 10 ¹³	9.95 x 10 ¹³	18,400	20,375	3.17 x 10 ⁸

Note: Did not record pre-radiation values

Triple 3 - Input NAND Gate, P8874793

Symbol	Spec value	Pre	1	1A	2	Pre	3	3A	3B
I_{ccL} (ma) $V_{cc} = 5V$	9.75 max	7	7	7	7	7	7	7	7
I_{ccH} (ma) $V_{cc} = 8V$	8.25 max	6	5.2	6	6	6	6	9.6	6
V_{OH} (volts) $V_{cc} = 4.5V$	2.6 min	3.2	3.2	3.2	3.2	3.2	3.2	1.5	3.2
V_{OL} (volts) $V_{cc} = 4.5V$	0.4 max	0.2	0.2	0.2	0.2	0.2	0.2	4.4	0.3
Pulse No.	Neutron dose n/cm^2	Total	Gamma dose rad-Si		Total	Gamma dose rate rad-Si/sec			
(1) P7269	1.3×10^{12}	---	366		---	4.68×10^6			
(2) P7270	1.01×10^{13}	1.14×10^{13}	2,050		2,416	3.54×10^7			
(3) P7271	9.77×10^{13}	---	20,000		---	3.44×10^8			

Note: 1, 2, 3 measured immediately after pulse no. 1, 2, 3 respectively
 1A measured 35 minutes after pulse no. 1
 3A measured 25 minutes after pulse no. 3
 3B measured 120 minutes after pulse no. 3

9946 (SN 2) was used for pulse no. 3

DC TO DC CONVERTER
p9239238

	<u>Spec value</u>	<u>Pre</u>	<u>6 hrs after Reactor pulse</u>
Input current at 5 volts	---	.65 amps	.14 amps
Input current at 10 volts	---	.35 amps	.068 amps
Output, +12 volts	146 ma	11.5V at 120 ma	1.8v at 4 ma
Output, -12 volts	6 ma	-11.6V at 5.5 ma	-1.85V at 1.0 ma
Output, +5 volts	50 ma	47 ma	4 ma

No power was applied during reactor pulse. Above readings were noted with all outputs loaded.

<u>Pulse No.</u>	<u>Neutron dose n/cm²</u>	<u>Gamma dose rad-Si</u>
P73-45	1.4 x 10 ¹²	324