CONF-910116--7

MULTIPLEXER/AMPLIFIER TEST RESULTS FOR SP-100*

Donald B. King, Spencer Michael Luker
Sandia National Laboratories
Division 6474
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 846-7635, (505) 844-7232

Rodger Ryan
General Electric Company
P.O. Box 350954
San Jose, CA 95153
(406) 365-6474

SAND--90-2730C

DE91 004504

ABSTRACT

Multiplexer and amplifier systems must be designed with transistors that can perform satisfactorily over ten years to a total gamma dose of 120E6 rads and a total neutron fluence of 1.6E15 nvt for the SP-100 reactor system. Series of gamma and neutron tests have been completed to measure transistor degradation as a function of total dose, fluence, and temperature. Test results indicate that modest increases in temperature result in substantial improvement of transistor performance at a neutron flux of 8E8 n/cm^2/s.

INTRODUCTION

Future space-based reactors will rely on sophisticated instrumentation and control (I&C) circuitry to autonomously monitor and control the reactor over its mission life. Parts of the circuitry must be placed near the reactor and will be exposed to high total dose radiation levels and elevated temperatures. The severity of the radiation and temperature environmental threats to the electronic components could be reduced by adding additional shielding around the reactor or by adding systems to convectively or radiatively cool the instrumentation and control circuitry. These options would result in a substantial increase in the reactor platform mass (Dobranich 1987). Increased cooling capacity would require larger refrigerator systems or larger thermal radiators to dissipate heat to space. Any increase in system mass would result in sizeable, and possibly prohibitive, increases in launch costs. Therefore, mass minimization of cooling and shielding systems will result in elevated temperatures and radiation environments. A third option to reduce the reactor environmental threat to the electronic components would be to physically separate the components from the reactor; however, the tradeoff between lower environmental threats and long cable runs, and the resulting signal degradation and increased cable weight, might be unacceptable. The most obvious way to circumvent these problems would be to design electronic components that can withstand higher temperatures and total radiation doses. Several space reactor program studies have indicated the I&C systems will need to withstand temperatures of up to 620 K, gamma radiation exposures above 1E7rads, and neutron exposures beyond 1E15 nvt (Ortiz 1985). Little work has been done to evaluate the combined effects of temperature and radiation to the levels stated above. Therefore, the response of electronic components to anticipated platform environments is uncertain.

DISCUSSION

This paper will focus on I&C system development and testing for the SP-100 space reactor program. The reactor is nominally rated at 2 MWt (with a 100 KWe output) and delivers its thermal energy to liquid lithium at 1350 K. A shield is mounted directly behind the reactor and is made of both gamma and neutron shield segments. The reactor must produce rated power for 7 years. Operation at house load (15% power) is required for 3 years, resulting in a total reactor lifetime of 10 years. Many sensors are installed in and around the reactor region and cannot be replaced or repaired during the system's lifetime.

Sensor signals are in the millivolt range and must be transmitted along a 25 m boom to signal conditioning equipment. Maintaining the fidelity of the sensor signals while minimizing the volume and weight of cabling provides a strong incentive to amplify the signal before transmission along the boom cables. A multiplexing system in the vicinity of the sensors and their amplifiers would also help to reduce the number of cables.

The SP-100 reactor has 12 I&C multiplexers installed circumferentially at the perimeter of the reactor support structure and just behind the reactor shield. The multiplexer/amplifier system is made of semiconductor switches to select the appropriate sensor, amplifiers to increase the level of the sensor signal, and a multiplexer controller to cycle the switches and provide timing control for the multiplexer. The multiplexer system will be used to measure temperature, pressure, flow, and control element positions, and to control motors, brakes, and clutches for control element drive systems. The multiplexer system enclosure will be located in a 600 K to 700 K environment and has a thermal management system to maintain the multiplexer between 273 K and 370 K. The multiplexer system must function through 1.2E8 rads (Si) and 1.6E15 n/cm^2 (1 MeV silicon equivalent). The SP-100 program requirement dictates that the multiplexer system be tested to twice the expected gamma and neutron exposures.

TEST METHODS

The SP-100 multiplexer system plan requires long-term radiation-tolerant hardware to be identified and configured into an amplifier and multiplexing system. No funding was available to develop radiation- and temperature-tolerant discrete and integrated electronics; therefore, commercially available electronic parts were selected for testing to the SP-100 environments. Junction field effect transistors (JFETs) were selected as the leading electronic devices to test because their total dose hardness is determined by layout and not process techniques. Their radiation tolerance was also expected to be sufficient for the SP-100 environment. JFETs are also very low noise devices and can be used for high-sensitivity instrumentation functions required by the SP-100 program. Both silicon and gallium arsenide JFETs are being considered. The electronic parts must be tested at dose rates well above those required by SP-100. A typical radiation test might run between 1 and 3 months.

The effects of gamma and neutron degradation to the JFETs will initially be decoupled. Separate gamma and neutron tests will be run to determine device degradation during the SP-100 mission total doses. A 1-year test combining both gamma and neutron radiation at suitable SP-100 operating temperatures will be conducted after completion of the separate gamma and neutron tests.

A series of screening tests has been completed to characterize JFET performance in accelerated radiation environments and to observe if any unanticipated failures would occur. JFET characteristics measured during the testing included the saturation current (I_{dss}), linear region channel resistance (r_{dson}), the gate-source cutoff voltage (V_{gsoff}), gate reverse current (I_{gss}), and the gate-source breakdown voltage (BV_{gss}). The screening tests included both neutron and gamma exposures.

A gamma radiation screening test was conducted to observe potential damage to JFETs at an SP-100 like operating temperature and at an accelerated dose rate. The devices were tested at a temperature of 320 K and at a gamma dose rate of 600 Krad/h (Si). The test conditions represented a more conservative (or damaging) environment than the SP-100 environment. The n-channel JFETs showed up to 10-20% degradation in measured characteristics through 440 Mrad total dose. After passing the SP-100 total gamma dose requirement, the JFETs were placed in Cobalt-60 sources of 150 Krad/h (Si) and 40

Krad/h (Si) to determine whether the 320 K test temperature would anneal out radiation damage at lower dose rates. The JFETs were exposed to an additional 100 Mrad at 150 Krad/h (Si) and 320 K; degradation of characteristics was still occurring to the JFETs, but at a smaller rate when compared to the 600 Krad/h damage. Degradation of JFET characteristics stopped or reversed when the JFETs were placed in the 40 Krad/h Cobalt-60 source at 320 K. The parts have been exposed to 60 Mrad total dose in the 40 Krad/h source and are still under test.

A neutron screening test was also conducted using n-channel JFETs. The JFETs were exposed to total doses of 1E14 nvt, 1E15 nvt, 5E15 nvt, 1E16 nvt, and 1.11E16 nvt (1 MeV equivalent). All doses were achieved in under 4 hr and at temperatures less than 305 K. All of the JFETs showed minor degradation at 1E14 nvt. All of the JFETs showed substantial degradation between 1E14 and 1E15 nvt, but continued to show useful transistor action. All JFETs showed no transistor action (or failed) beyond 5E15 nvt. A series of thermal annealing tests were conducted with the JFETs which were exposed to 1E14 nvt and 1E15 nvt. All of the JFETs exposed to 1E14 nvt were nearly restored to their original characteristics at annealing temperatures ranging from 370 to 420 K. JFETs exposed to 1E15 nvt could not be annealed appreciably at 420 K. All anneals were performed at a specified temperature for three or four 10-minute intervals.

A second neutron test to observe the effects of temperature annealing on transistors at a flux of 8E8 n/cm^2/s has been recently completed. The test flux is 80 times that of the actual SP-100 flux. The n-channel JFETs were tested at 310 K, 325 K, and 370 K. The test results indicate that operating the JFETs at higher temperatures results in increased annealing and decreased device degradation. Degradation appears to be dependent on feature size and saturation current magnitude for small signal JFETs. Smaller JFETs display greater degradation than larger JFETs. Figure 1 illustrates the effect of temperature and neutron fluence on the saturation current of a small JFET (model 2N4867), and Figures 2 shows the saturation current of a large JFET (model 2N4393) versus temperature and fluence. Power JFETs degrade much more than small signal JFETs because of their light channel doping which is required for high breakdown voltages. Figure 3 demonstrates the degradation in channel resistance versus temperature and neutron fluence. Two power JFETs are shown in Figure 3. The power JFET which displays the earliest degradation has a lighter doped channel compared to the second power JFET.

SUMMARY

Radiation and temperature environments in reactor regions pose new and unique threats to electronic devices. The devices may be exposed to total gamma and neutron doses in the range from 200 to 300 Mrad (Si) and greater than 1E15 nvt (1 MeV equivalent), respectively, while simultaneously being subjected to a temperature up to 620 K. Because the total doses occur over up to 10 years, operation at elevated temperatures beyond MIL SPEC may provide thermal annealing, which will allow selected electronic parts to operate beyond 300 Mrad (Si) and 1E15 nvt. Future test results from the SP-100 I&C Amplifier/Multiplexer test program should help to specify operating conditions and electronic part types to operate in the reactor environments.

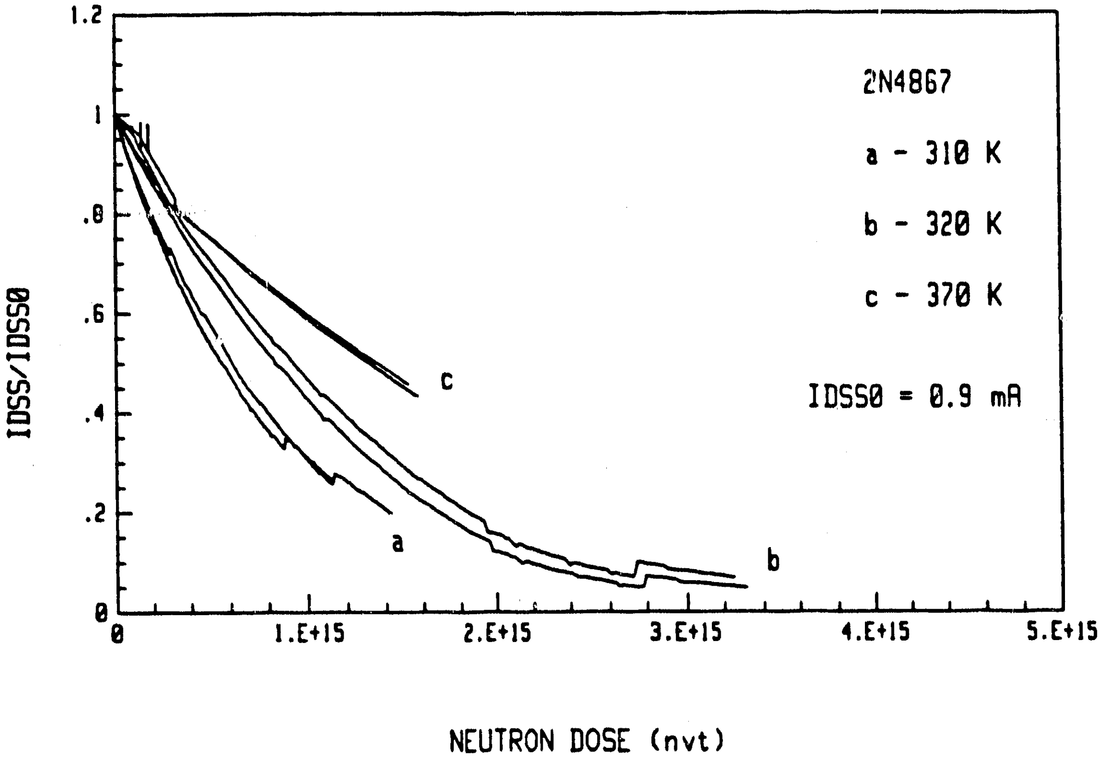

FIGURE 1. Temperature Dependence of Normalized Saturation Current (IDSS/IDSSO) Degradation Due to Neutron Dose for a 2N4867 JFET.

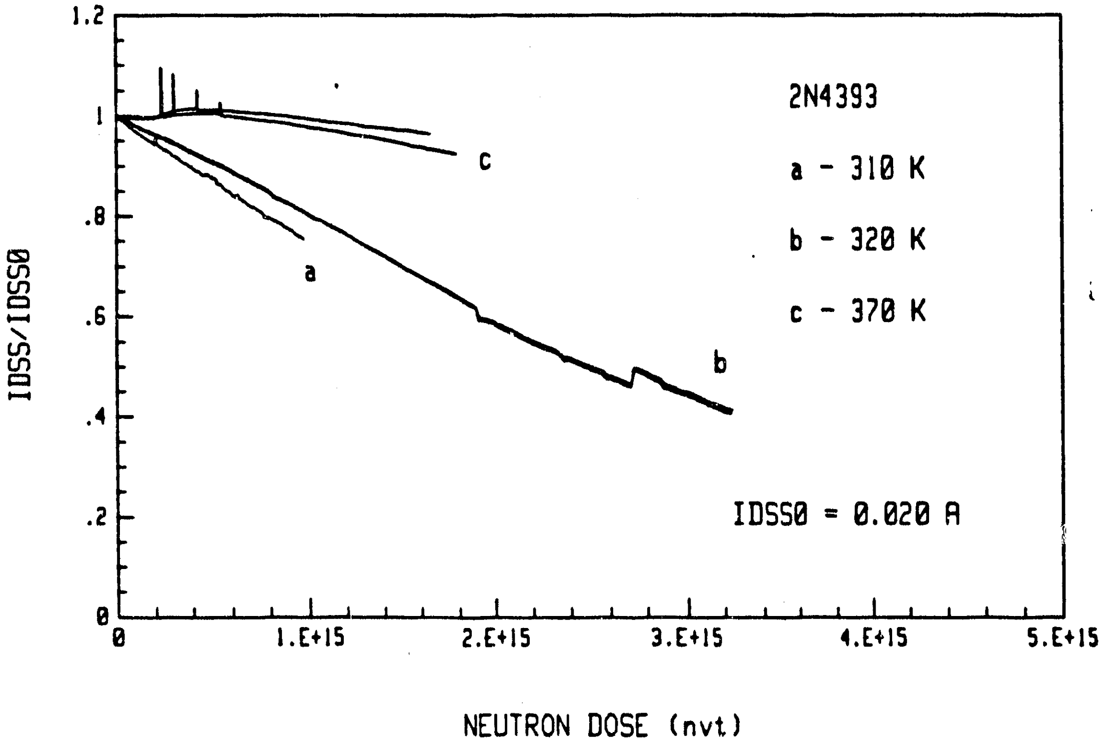

FIGURE 2. Temperature Dependence of Normalized Saturation Current (IDSS/IDSSO) Degradation Due to Neutron Dose for a 2N4393 JFET.

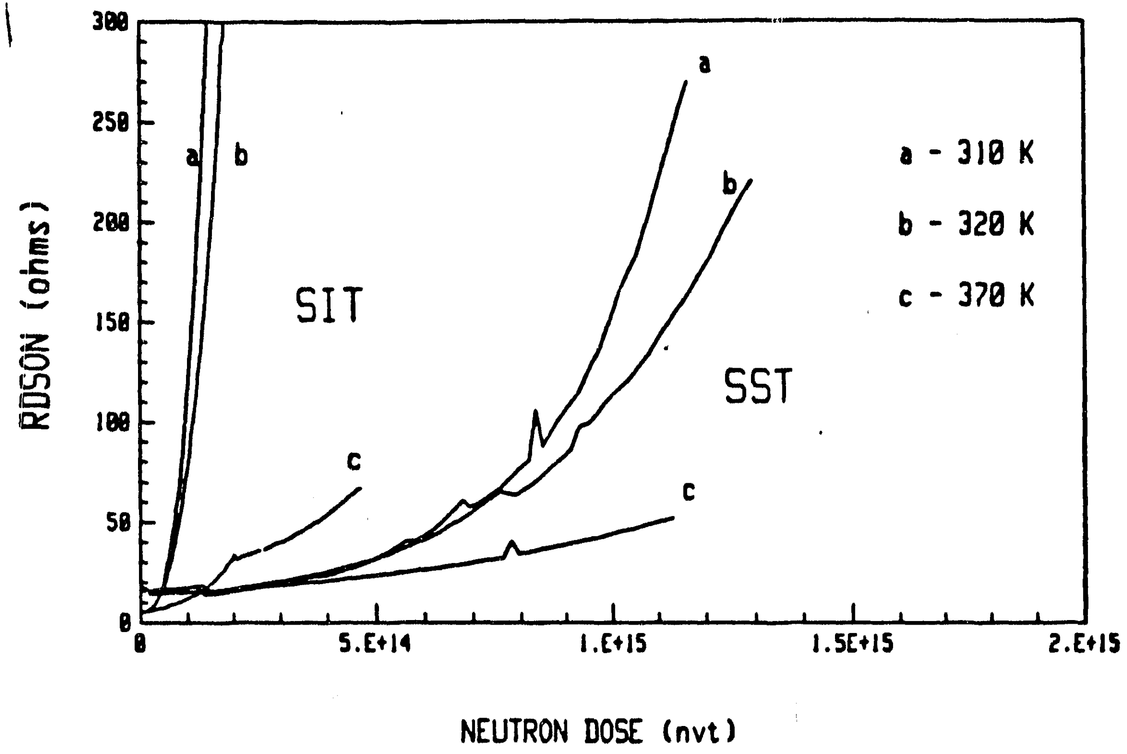

FIGURE 3. Temperature Dependence of Channel Resistance (RDSON) Degradation Due to Neutron Dose for Two Power JFETs.

Acknowledgments

*This work was supported by the United States Department of Energy under Contract DE-AC04-76DP00789.

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