SECTION 9. JUNCTION FIELD-EFFECT TRANSISTORS

9.1. INTRODUCTION

The silicon junction field-effect transistor (JFET) has many of the characteristics required to withstand heavy radiation damage. Amplification is produced by the transport of majority carriers through a channel which is quite heavily doped. Unlike the MOSFET, current flow is remote from the surface of the silicon. Thus, both the major effects which degrade bipolar and MOS transistors in a radiation environment (ionisation and bulk damage) are absent. Commercial JFET devices have indeed proved in practice to be tolerant of the effects of heavy ionisation and bulk damage, and some work has also been done in the USA to produce special JFET devices which are even more tolerant of neutrons. Despite these advantages, the use of the JFET in "hardened" equipment has not been extensive. For space environments, where ionisation is dominant, the advantages are not as great as in nuclear environments. However, in the field of instrumentation amplifiers, the properties of the silicon JFET as a low-noise, high-impedance input device have already been appreciated in commercial use and are attractive for some uses in space. The gallium arsenide JFET is now increasingly used in microwave circuits.

As expected, gamma and particle irradiations to a total dose of 10^6 rads cause only minor degradation in JFET (Martin, 1985; Rudie, 1972). Normally, transconductance, pinch-off voltage, "on" resistance and other channel parameters are practically unchanged. Due to oxide charge build-up, surface leakage may manifest itself as an increase in I_{GSS} , but this appeared to remain in the nanoampere range under the highest doses used. Reactor neutron irradiation causes minor degradation at 10^{13} n.cm^{-2}. , but severe degradation at 10^{15} n.cm^{-2}.

Notthoff (1971) finds that matched pairs of discrete commercial JFET devices, which are suitable as input devices for a differential amplifier, operate well after exposure to a reactor neutron fluence of about 10^{14} n.cm^{-2}.. Compared with bipolar equivalents, integrated operational amplifiers with JFET structures as input devices may therefore be preferred for very high radiation environments. Other radiation-hardened circuits that include JFET's are multiplexers and ladder networks for data-acquisition circuits. An application which suggests itself for future space use is as the amplifying element for a highly exposed photodetector, say in the parts of a data link which must survive for a long time in a robot exposed to reactor or RTG radiation. A "Photo JFET" would consist essentially of a photodiode with built-in amplification by the JFET mechanism. No test data are available for this type of device. However, if radiation problems associated with amplification or light detection arise in future projects, the possibilities of JFET devices should be investigated in some detail.

A more specialised device that has been finding commercial use lately is the microwave JFET in silicon or gallium arsenide. The mobility of III-V semiconductors leads to good high-frequency operation. GaAs FETs are used routinely as low-noise input devices for microwave amplifiers, while very fast logic devices are under development. Several investigations have shown that neutron irradiation of GaAs FETs has the effects predicted. Studies of bulk properties on III-V compounds, for example, have shown the reduction of conductivity. As for silicon devices, the resulting device degradation only becomes apparent in the range 10^{14} to 10^{15} $n.cm^{-2}$ (1 MeV).

Several authors emphasise that the JFET structure is "hardenable" and the choice of electronic devices in very high particle fluxes may often lie between vacuum tubes and specially "hardened" JFETs. This choice applies to amplification, switching and light detection.

REFERENCES

J.M. Borrego, R.J. Gutmann, B. Moghe and M.J. Chudzicki, "Radiation Effects on GaAs MESFET's, IEEE Transnucl.Sci. NS-26 (6), pp. 1436-1443 (Dec. 1978)

J.M. Borrego, R.M. Gutmann and S.B. Moghe, IEEE Trans.Nucl.Sci. NS-26 (6), pp. 5092-5100 (Dec. 1979)

B. Buchanan, R. Dolan and W. Shedd, IEEE Proceedings 55 (12) (Dec. 1967)

W.L. George, IEEE Trans.Nucl.Sci. NS-16 (6) (Dec. 1969)

D. Long, IEEE Trans.Nucl.Sci. NS-18 (6), pp. 332-339 (Dec. 1971)

K.E. Martin et al, "Total Dose Radiation Effects Data for Semiconductor Devices" JPL Publication 85-43, Vol. 1, NASA-JPL, Pasadena, CA (1985)

D. Neamen, W. Shedd and B. Buchanan, IEEE Trans.Nucl.Sci. NS-22 (6), pp. 2203-2207) (Dec. 1975)

D.M. Newall, P.T. Ho, R.L. Mencik and J.R. Pelose, "Total Dose Hardness of Microwave GaAs Field-Effect Transistors", IEEE Trans.Nucl.Sci. NS-28 (6), pp. 4403-4406 (Dec. 1981)

J.K. Notthoff, IEEE Trans.Nucl.Sci. NS-18 (6), pp. 397-403 (Dec. 1971)

N. Rudie, "Principles and Techniques of Radiation Hardening", (Western Periodicals (1972))

W. Shedd, B. Buchanan and R. Dolan, IEEE Trans.Nucl.Sci. NS-16 (6) (Dec. 1969)

M. Simons, IEEE Trans.Nucl.Sci. NS-26 (6), pp. 5080-5086 (Dec. 1979)

R. Zuleeg and K. Lehovec, IEEE Trans.Nucl.Sci. NS-25 (6), pp. 1444-1449 (Dec. 1978) IEEE Trans.Nucl.Sci. NS-26 (6), pp. 1436-1443 (Dec. 1978)

R. Zuleeg and K. Lehovec, "Neutron Degradation of Ion-implanted and Uniformly Doped Enhancement Mode GaAs JFET's", IEEE Trans.Nucl.Sci. NS-25 (6), pp. 1444-1449 (Dec. 1978)

R. Zuleeg, J.K. Notthoff and G.L. Troeger, "Ionising Radiation Response of GaAs JFET's and DCFL Circuits", IEEE Trans.Nucl.Sci. NS-29 (6), pp. 1656-1661 (Dec. 1982)

R. Zuleeg, J.K. Notthoff and G.L. Troeger, "Channel and Substrate Currents in GaAs FET's due to Ionizing Radiation", IEEE Trans.Nucl.Sci. NS-30 (6), pp. 4151-4156 (Dec. 1983)