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SEQUOYAH UNIT 1 CHARGE CONVERTER EXAMINATION RESULTS

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ABSTRACT

The accident at Three Mile Island subjected loose parts monitoring system charge converters to moderate levels of radiation that caused them to fail. Two charge converters exhibiting similar failure symptoms were removed from an operating plant, Sequoyah Unit 1, and examined at Sandia Laboratories to determine their failure modes and to estimate the total radiation doses received by each. Radiation degradation of the circuit was found to be highly dependent on the value of a select resistor.

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INTRODUCTION

On October 5, 1981 two loose parts monitoring (LPM) system charge converters were removed from the Sequoyah Unit 1 plant operated by the Tennessee Valley Authority. Allen Morris, Supervisor, Vibration & Diagnostics Section, had suspected that these devices had failed as a result of high accumulated radiation dose in much the same manner as similar ones had at GPU's TMI-2 plant. In situ bias voltage measurements made on September 1, 1981, revealed that the voltages supplied to both devices was "100%" or, in other words, had reached the power supply rail of approximately 30 volts. Other LPM channels had similar voltages.

The two charge converters were a part of a Technology for Energy (TEC) LPM system installed in Sequoyah Unit 1. These two units were contained inside galvanized piping within the keyway some three meters outside the mirror insulation underneath the reactor vessel. This location placed them in the high radiation field of the reactor vessel itself. The associated accelerometers were mounted on the incore guide tubes approximately 0.5 meters below the reactor vessel. The charge converters were in place when the reactor first went critical on July 19, 1980, and they had thus experienced 156.6 effective full power days at the time of removal. The two devices were packaged and sent to Sandia National Laboratories for failure analysis.

Endevco Charge Converter Description

Both charge converters were manufactured by Endevco Inc., San Juan Capistrano, California. The unit having Sequoyah tag number XT-52-111 (SN 2G39) was a Model 2652 while that having tag number XT-52-101 (SN 2J73) was a Model 2652 M3. Both devices had conversion gains of 2. We believe these two models to be the same except for the output connection on each. The 2652 M3 has a standard BNC coaxial connector, and the 2652 has two solder terminals. A picture of the 2652 M3

is shown in Figure 1. A complete description of operation of a "recommended" LPM system incorporating these charge converters is given in Reference 2. A more detailed circuit description is given in Reference 1.

FINDINGS

We found the two charge converters to be non-functional and to still exhibit the same characteristics as were measured in the Sequoyah plant; i.e., abnormally high bias voltages. The cause of failure of these converters appears to be identical to that of the TMI-2 charge converters: radiation degradation of the MEM 511 MOS transistor in the Q2 slot. In addition to this, an important difference between the TMI-2 and Sequoyah devices was found.

Figures 2 and 3 show signal input vs signal output characteristics for both devices using the same driver circuit as given in Reference 1. The power supply rail was 30 V and the constant current supply was 7mA. neither unit responds properly to the signal input even when the input level becomes quite high. This same phenomenon was also seen in the TMI-2 units; however, here the effect is even more pronounced. As with the TMI-2 charge converters, accumulated radiation dose causes the gate-to-source threshold voltage (VGSth) of Q2 to increase. The design of this particular circuit is tolerant of some change in the value of VGSth; however, when VGSth gets too large the drain current of Q1 cannot produce a voltage large enough to exceed the threshold voltage of Q2. Under DC operating conditions, since the entire charge converter must sink the 7 mA constant current, Q2 must stay in its active region in order to keep Q3 turned on. As VGSth increases with the accumulation of radiation dose, the charge converter bias voltage must increase (so that the drain current of Q1 will also increase). When the bias voltage reaches the power supply rail, no further increase in Q1 drain current is possible; and, Q2 and Q3 are forced out of their

is shown in Figure 1. A complete description of operation of a "recommended" LPM system incorporating these charge converters is given in Reference 2. A more detailed circuit description is given in Reference 1.

FINDINGS

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active regions. Only large input signals can cause conduction of Q2 and Q3 when this happens.

A subtle but important difference distinguishes the Sequoyah charge converters from those removed from TMI-2. When the two transistors from the Q2 slots were removed and their threshold voltages measured, both showed less degradation than either TMI-2 transistor - recall, that the input/output characteristics indicated more damage! The difference between devices lies in the value of the select resistor R6. Table 1 gives comparative data for all four charge converters. The Sequoyah units were set up to operate normally at 18V and 10mA. To achieve 18V the value of R6 must be set at approximately 30KΩ (versus 12KΩ for the TMI-2 units). Using these values, we have calculated the maximum VGSth allowed before signal degradation begins for each case (see "Analysis"). This is shown in Table 1 wherein the Sequoyah converters begin to degrade with VGSth's of about -5 volts, and the TMI-2 units can tolerate values of up to -11.4 volts. The value of the select resistor R6 thus has a significant influence on the radiation tolerance of these charge converters. As shown in Table 1, the threshold voltages of the Sequoyah transistors were both about -7 volts. Using our previous transistor degradation data, we estimate that the two converters accumulated a radiation dose of approximately 4×10^4 Rads each.

ANALYSIS

In order to explain the greater radiation dependency of the Sequoyah charge converters it is necessary to relate the values of R6, the gate to source voltage of Q2, and the bias voltage. Using the schematic shown in Figure 4 we derive an expression for the gate-to-source voltage of transistor Q2:

$$VGS2 = \frac{R5}{R6}\left[\frac{R3}{R2 + R3}\,VB - VGS1\right]$$

where: VGS2 = gate-to-source voltage of Q2

VG = 2652 bias voltage

VGS1 = gate-to-source voltage of Q1.

For purposes of comparison we will assume the drain characteristics of transistors Q1 can be held constant; thus, VGS1 will be some constant negative voltage. The value of VGS2 is then seen to be dependent only on the value of VB and the resistor values. If the VGSth of transistor Q2 increases, VB must increase accordingly in order to maintain the necessary condition of Q2 being in its active region. Notice that for the Sequoyah charge converters R5 $\cong$ R6; however, for the TMI-2 converters R5 $\cong$ 2R6. Thus, for a given value of VB, more range is available for VGS2. This means that the gate-to-source threshold voltage of Q2 for the TMI-2 units can get substantially larger before the charge converter becomes inoperable. Using nominal values of components, the value of VGSth for the TMI-2 units can degrade to -11.4 volts before signal degradation becomes significant. That same value for the Sequoyah units is only approximately 5 volts.

CONCLUSION

To summarize, the Model 2652 appears to be well designed for non-nuclear applications; however, its sensitivity to radiation generally makes it unsuitable for use in nuclear applications. The charge converter is not designed to be radiation tolerant, nor does the manufacturer Endevco claim it to be. In the case of TMI-2, the converters were mounted well away from the normal

radiation sources; however, the subsequent accident exposed them to moderate levels of radiation. At Sequoyah Unit 1 the converters were mounted only a few meters from the normal radiation source, thus placing them in a high radiation field constantly.

The difference between the Sequoyah and TMI-2 units serves to point out a recurrent difficulty in instrument selection. The schematics of the models are all essentially identical: they differ only in the value of the gain select capacitor. Yet the radiation tolerance is significantly different. The value of a single select resistor, one which serves only to increase the normal bias level slightly, is very critical. This is why it is so important to use only a design that has been thoroughly tested; and allow no changes in design, even though apparently minor in nature, until that design has been tested.

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TRANSFER CHARACTERISTIC

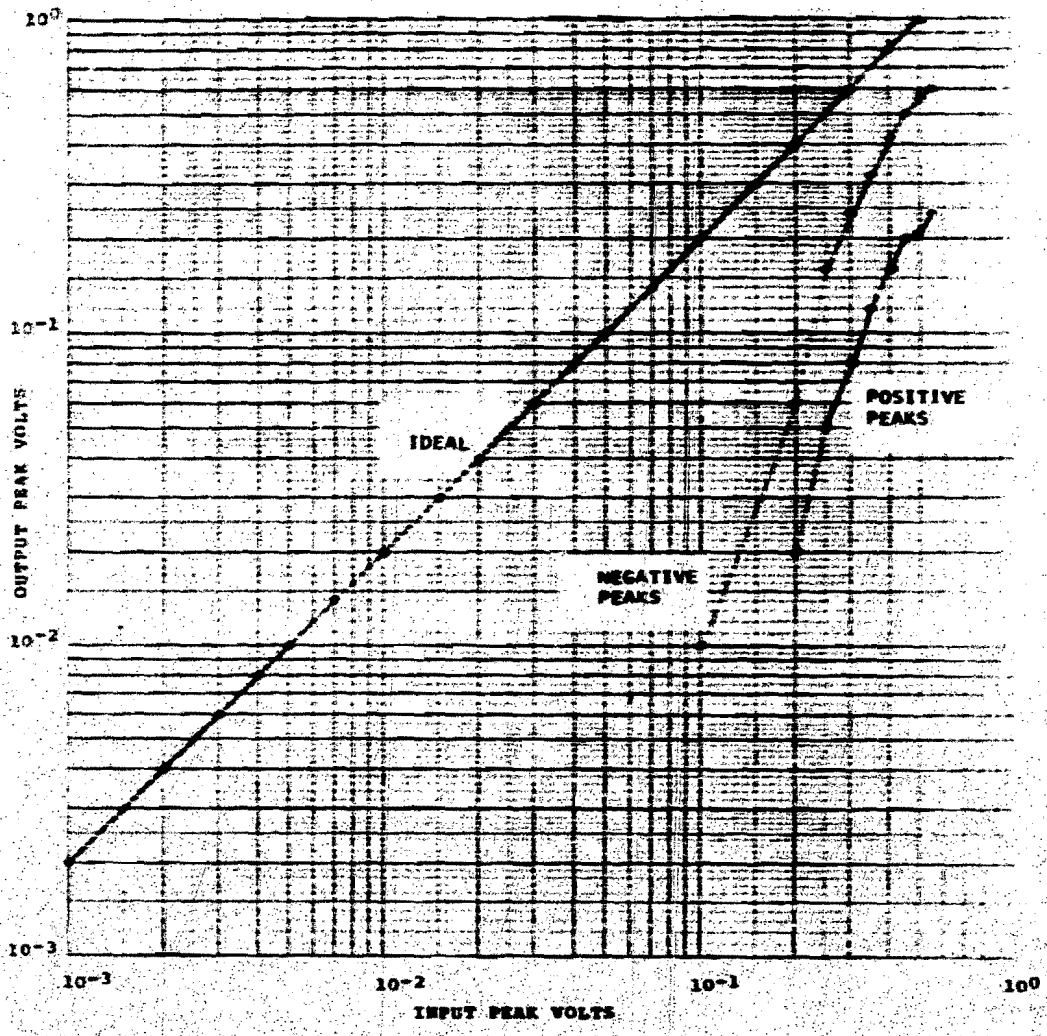

FIGURE 3 . . . TRANSFER CHARACTERISTIC XT-52-101 (MODEL 2652 M3)

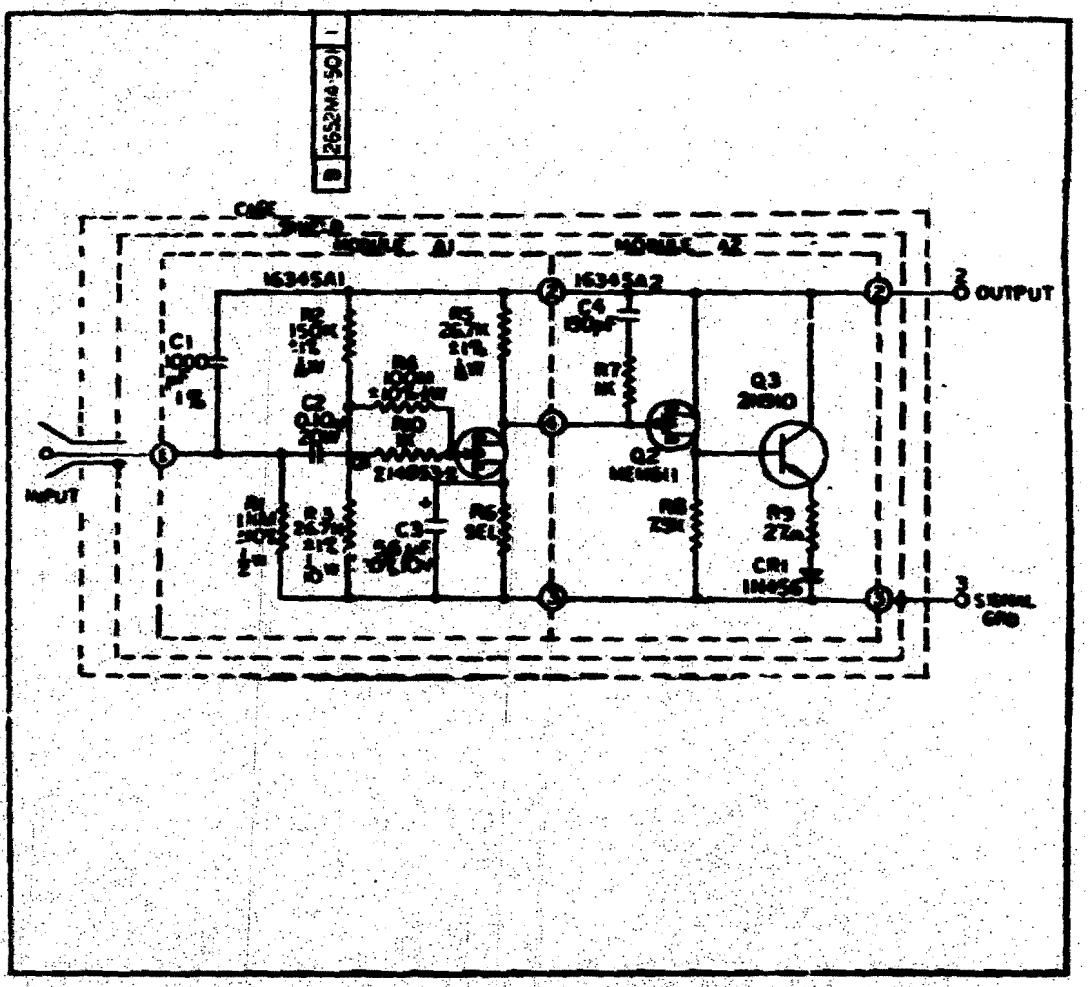

FIGURE 4 ... CHARGE CONVERTER SCHEMATIC
(FOR MODELS 2652 M3 AND 2652, C1 IS 500pf)

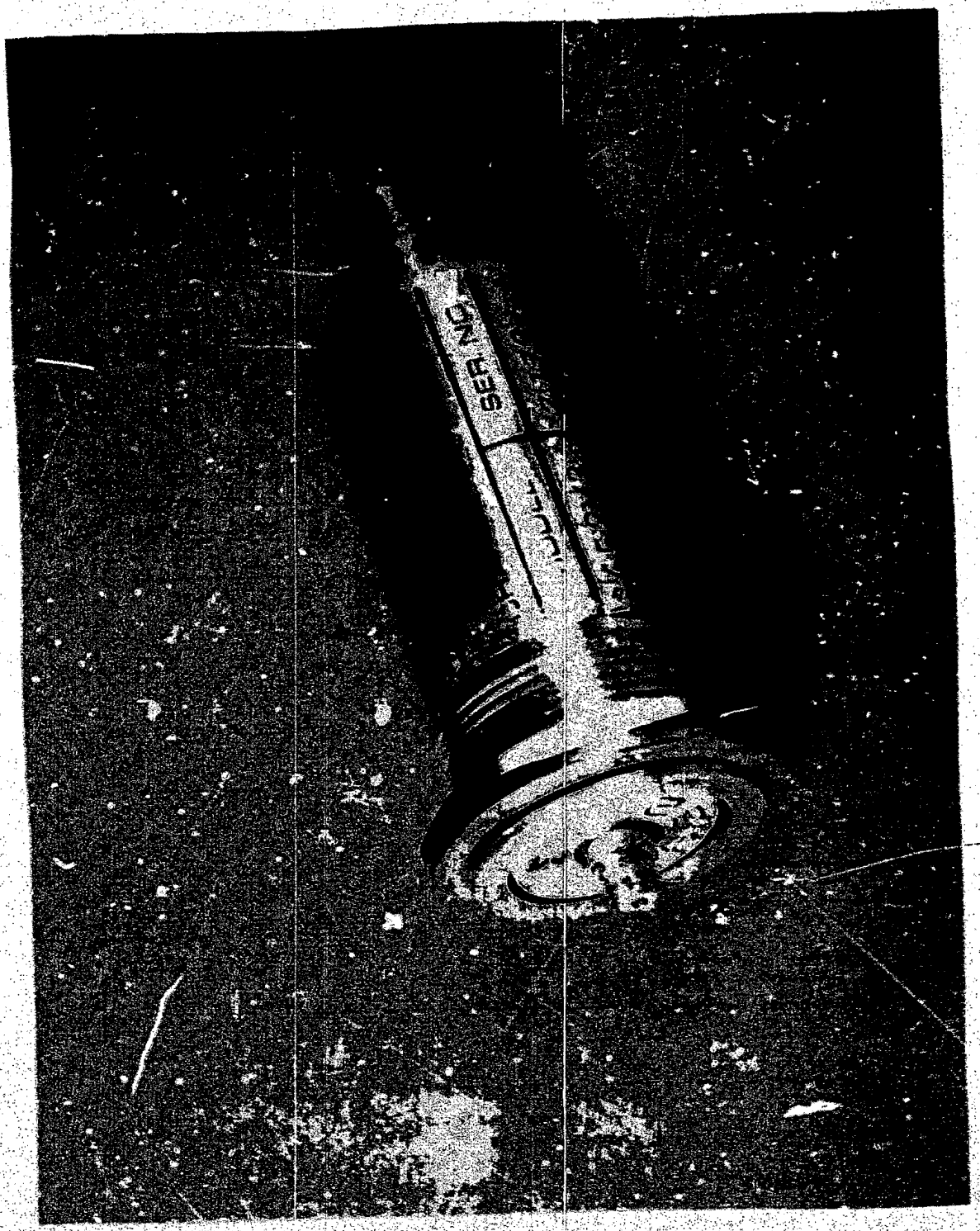

FIGURE 1 ... XT-52-101. ENDEVCO CHARGE CONVERTER

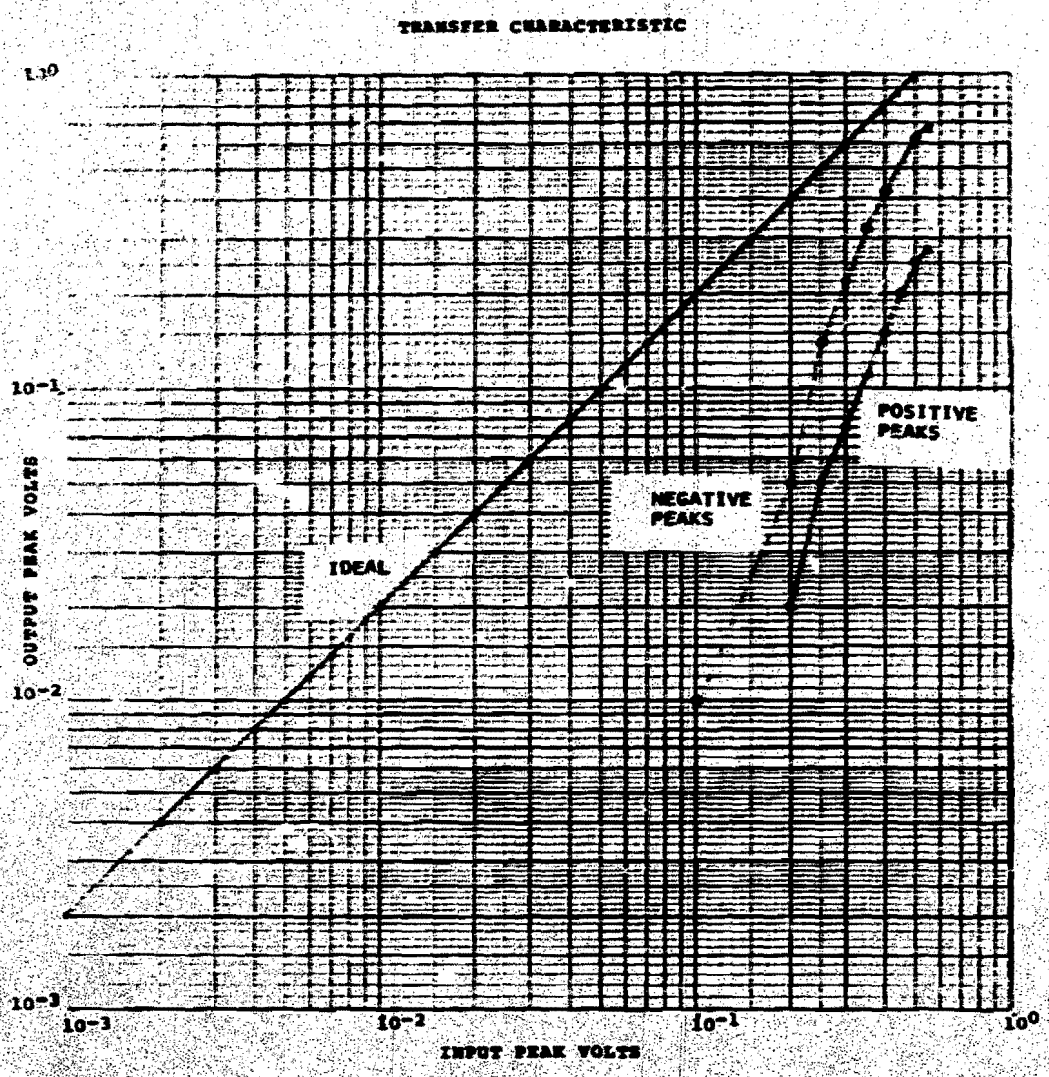

FIGURE 2 ... TRANSFER CHARACTERISTIC XT-52-111 (MODEL 2652)

	SEQUOYAH #1 Tag # XT-52		TMI-2 Tag # YM-AMP-	
MANUFACTURER'S SPEC	-101	-111	7023	7025
BIAS VOLTAGE	18V	18V	13.5V	13.5V
BIAS CURRENT	10ma	10ma	8ma	8ma
VGS_{th}	-4.5V	-4.5V	-4.5V	-4.5V
DEGRADED				
BIAS VOLTAGE	29.35V	29.34V	28.72V	29.28
BIAS CURRENT	379.6μa	382.6μa	2.80ma	484.0μa
VGS_{th}	-7.4V	-7.2V	-8.92V	-11.46V
EST. GAMMA DOSE	4.0×10^4 RADS	3.5×10^4 RADS	1.8×10^5 RADS	5.4×10^5 RADS
R6 SELECT (KΩ)	27	31	13.0	13.0
MAX VGS_{th} BEFORE DEGRADATION (MON)	-5.5V	-4.8V	-11.4	-11.4V

TABLE 1 ... ENDEVCO CHARGE CONVERTER DATA

REFERENCES

1. Michael B. Murphy, Richard E. Heintzleman; "Examination Results on TMI-2 LPM Charge Converters YM-AMP-7023 and YM-AMP-7025"; SAND82-0980; September 1982

2. Endevco Instruction Manual, "Model 4479.1/2652 Remote Charger Converter and Condition Mode Card," dtd 8/71

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