TECHNICAL REPORT ECOM-2545

PULSED NUCLEAR RADIATION EFFECTS
ON
RESISTORS AND CABLES, SPRF IV

BY

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DECEMBER 1964

This research on transient radiation effects on electronics is sponsored by the Defense Atomic Support Agency under NWER Subtask 16.009, and conducted under the technical guidance of the U. S. Army Electronics Command, Fort Monmouth, New Jersey, and the DASA TREE Project Officer.

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ABSTRACT

Various cable and resistor types and an operating micromodule multivibrator circuit were exposed to a pulsed nuclear radiation environment (SPRF) and their transient response measured during the pulse. The initial RG-59 B/U cable response was determined to be voltage dependent and averaged 0.15 μa per volt superimposed on a zero voltage "replacement" current of -15 μa. A miniature low noise cable, with conductive interfaces, gave the lowest and most stable response of all cables tested. The attenuation of three different types of RF cables was measured and the signal in JT-205 with foamed polyethylene was attenuated approximately 20%. The US-DEV -15 cable with perforated tape teflon averaged 0.3% and for RG-8 A/U, a solid polyethylene dielectric, attenuation averaged 0.5%. Carbon composition, deposited carbon film, nichrome film, tin oxide, wirewound, cermet, and gas-filled "Minuteman" resistors of various wattages were tested in an unpotted, conformally coated, and potted condition. All low value resistors tested (less than 1500 ohms) maintained tolerance levels even in unpotted conditions. For the unpotted higher-value resistors (10 K ohm) the shunting effect of the ionized air may cause a resistance change of the order of 2% which can be reduced to 1% by conformal coating. The 100 K ohm "Minuteman" gas-filled resistor showed an effective decrease of 7% during exposure. A free running multivibrator in a microcircuit modular configuration underwent both transient and permanent damage.

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INTRODUCTION

The improved reliability of electronic and communication systems in the field is a major objective at these Laboratories. One of the newest environments to be encountered in the field is the intense pulsed radiation environment occurring as a result of a nuclear weapon burst. The current state of the art indicates that many parts and materials are inherently radiation resistant; they contribute insignificant transients to circuits and perform through a nuclear burst with uninterrupted stability. Some parts, however, may contribute substantial transients and collectively cause circuit malfunction; in this group belong capacitors, cables, and insulators. Resistors, while relatively stable in operation, can contribute a measurable transient effect under certain conditions. Because of their extensive use in many critical circuits, both digital and linear, it is necessary to know quantitatively the contribution they can make to the cumulative effect in a circuit. The current data that exist on resistors do not cover all important types and most of the data are for resistors in a potted condition. (Many resistors are used in an unpotted or an uncoated condition.) Much of previous data on resistors was obtained with an unknown spurious cable contribution. For the above reasons, it was considered necessary to characterize important resistor types under conditions of a simulated nuclear weapon burst and to obtain an indication of the amount of potting necessary to limit air ionization effects to a level below resistor tolerance levels.

A few cable experiments were added to provide additional information to the characterization of cables necessary for their proper use in instrumentation. The measurement of attenuation of RF transmission through three experimental cables was also included.

Inasmuch as it is planned to study the pulsed radiation effects on microcircuit modules and elements in the near future, a test was included of an operating module so that preliminary experience could be gained on instrumentation and the extent of changes that might be expected.

EXPERIMENTAL PROCEDURE

The experiment was conducted to determine the behavior of various cables, resistor types, and a micromodule assembly in the Sandia Pulsed Reactor Facility (SPRF) environment. Typical burst characteristics from the SPRF give dose rates of the order of 10^{17} neutrons/cm^2-sec at peak intensity and integrated neutron doses of the order of 10^{13} neutrons/cm^2.

Gamma doses and dose rates are of the order of 10^3 rad and 10^7 rad/sec respectively. The radiation pulse width at half height is approximately 50 μsec. The electrical signals related to the transient part parameter changes were displayed on oscilloscopes and photographed. The specific test procedure for each of the various part types is described.

A. Cables

1. Transient Noise Signals

To provide data on the cable type used for measuring the effects on the resistors and to determine their spurious contribution to the measurement, samples of RG-59 B/U were tested over the range of voltages at which the resistors were to be tested.

The applied voltage sequence from exposure to exposure is shown as follows:

SHOT NUMBER	1	2	3	4	5
			VOLTAGE APPLIED		
RG-59-10	268	268	0	268	-268
1	180	180	0	180	-180
3	45	45	0	45	-45
4	9	9	0	9	-9
5	0	0	0	0	0
11	0	0	0	268	-268
6	-9	-9	0	-9	9
7	-45	-45	0	-45	45
9	-180	-180	0	-180	180
2	-268	-268	0	-268	268

As is shown in the table, the initial voltage was maintained for the first two shots; was zero in the third; changed to the initial value in the fourth; and reversed for the fifth exposure. The cable ends exposed to the reactor were encapsulated in epoxy to eliminate air ionization effects and the cable led along wooden troughs and through conduits out of the reactor room to the test instrumentation in the trailer laboratory located immediately outside the reactor. This configuration was the one used in all the resistor, micromodule, and RF attenuation experiments.

2. Cable Lead Configuration

In order to determine if cable positioning contributes significantly to its radiation response two cable configurations were compared.

In one configuration, the cable was led radially from the reactor and then down to the conduits through the reactor room floor; in the other, the cable was led first directly down to the reactor room floor and then radially along the floor to the conduits. These are shown schematically in Figure 1 as I and III. Configuration II was not investigated.

3. Special Cables

Two cable types were studied to determine if their special dielectric structure would influence the noise signal. These are as follows:

a. RG-157: A coaxial cable designed for pulsed power applications; the dielectric is polyethylene, and conducting polyethylene layers are provided between the dielectric and the center conductor and between dielectric and braid (Figure 2).

b. Low Noise Cable, T- ( ): This is a special miniature cable for low noise applications arbitrarily designated T- ( ). It has a dielectric of fused teflon tape and a conducting coating between dielectric and braid (Figure 2).

4. RF Transmission Attenuation

In addition to the d-c tests, measurements were made of the radiation-induced attenuation of RF signal transmission through RG-8A/U, JT-205, and US-DEV-15 coaxial cables. For the transmission tests, a signal was introduced into one end of a 120 foot length of cable terminated at both ends in its characteristic impedance; the center portion of about 20 feet was wound into a flat spiral on the wooden faceplate (Figure 3) and placed as close as possible to the reactor. The RF output of the JT-205 cable, which was tested at 1.5 mc/s was displayed directly on oscilloscopes; however, the outputs of RG-8A/U and the US-DEV-15, tested with 1 kmc/s and 4.4 kmc/s respectively, were first rectified with diode detectors before being displayed (Figure 4).

5. Dynamic Impedance Change

An RF current modulation measurement was employed to determine the nature of the impedance change in RG-62 A/U and JT-205 cables and its relation to any radiation-induced attenuation of RF signal transmission in these cables. The method is shown in Figure 5. The RF signal was introduced into the cable shield, which was ungrounded. Changes in circuit current amplitude due to changes in the cable dielectric were measured and the impedance change calculated. The current change appeared as a modulation of the RF carrier. The impedance change in one sample of RG-62 A/U containing a composite air-polyethylene dielectric and one of JT-205 cable with a foamed polyethylene dielectric was measured. With a length for the RG-62 A/U and JT-205 cables of 120 feet and 150 feet respectively, the cable impedance was high compared to the 50 ohm measuring resistor at the test frequency (100 kc/s). The middle 20 foot portion of each sample was wound into a flat spiral and mounted as close to the reactor surface as possible; another 30 feet of each sample were inside the reactor room forming straight leads to and from the spiral portion. In this configuration a greater cable length could be exposed for larger total effect.

B. Resistors

Resistors may be affected by ionization at the surface or within the resistor constituent elements, which appear as a shunt resistance to reduce the resistance of the resistor, and injected currents due to secondary emission, which are related to the physical size of the resistor. To study some of these effects in commonly used resistors, resistors of various types, wattage ratings, and nominal values were tested (Table II). Carbon composition, deposited carbon film, nichrome film and tin oxide types were studied in nominal values of 100 and 10 K ohm and wattage ratings ranging from 1/8 to 2 watt; wirewound resistors with either a vitreous enamel or silicone coating in 5 and 1000 ohm values, 1/8 watt; cermet resistors on micromodule wafers in 500 ohm and 1500 ohm values, 1/8 watt; several inert gas-filled film resistors in 100 ohm values, 1/2 to 1 watt; and "Minuteman" resistors of 100 K ohm, 1/8 watt (see Figure 6). The resistors were exposed bare, with a conformal coating of encapsulant, or completely encapsulated.

Conventionally terminated resistors for cordwood type packaging as well as microcircuit thin film types were selected for study. The conventionally terminated coaxial types and the cermet type for micromodule application were each mounted on specially designed circuit boards fixed to one end of a 50 foot length of RG-59 B/U cable; the cables were led along a wooden trough as for the cable tests described previously and through conduits to the outside of the reactor to the test circuits in the trailer laboratory. In order to determine the extent of air ionization effects, some resistors were exposed bare; others were completely encapsulated in epoxy or dipped in the encapsulant for a conformal coating. The cermet samples were dipped in an elastomeric compound prior to encapsulation for relief of mechanical stresses due to the setting up of the encapsulant. Molds were designed for the encapsulation which provided the same thickness of encapsulant above and to the sides of the resistor as between the resistor and the circuit board (Figure 7).

The resistors, which ranged in value from 5 ohms to 100 K ohms, were tested at rated power dissipation using the upper circuit of Figure 8. For the resistors from 5 to 1500 ohms, the circuit resolution was sufficient to determine if the resistance change during exposure exceeded 1%, and the spurious cable signal was not an appreciable portion of the total signal to be observed. However, in the measurements on higher value resistors, 10 K to 100 K ohm, since cable noise was appreciable, the resistor and cable assembly were exposed at least twice with the same voltage applied. After the initial "training"[1] shot, the measurement provided the 1% resolution.

A method for minimizing cable leakage effects in the measurement of parts without the use of encapsulants and for minimizing secondary electron emission effects from the environment was tested and compared with the conventional encapsulation method. This technique, developed under USAEL Contract DA36-039 SC-89112 with Hughes Aircraft Company, employs two coaxial cables mounted in an aluminum can, the test part (in this test a 10 K ohm resistor) being fixed to the two center conductors. One cable is used to apply the test voltage to the part and the other to measure the part parameter changes (lower portion Figure 8). Only the zero voltage cable effect appears in the measurement, since by appropriate choice of the magnitude of the measuring resistor or by application of a suitable bias voltage between shield and center conductor, the voltage across the measuring cable can be maintained close to zero potential. In this manner the spurious cable signal under applied voltage is eliminated. The aluminum can fixed the leakage geometry around the part and intercepts secondary electrons emitted by the environment so that only the direct radiation from the source and any secondary emission from the can reach the part.

C. Micromodule Multivibrator Circuit

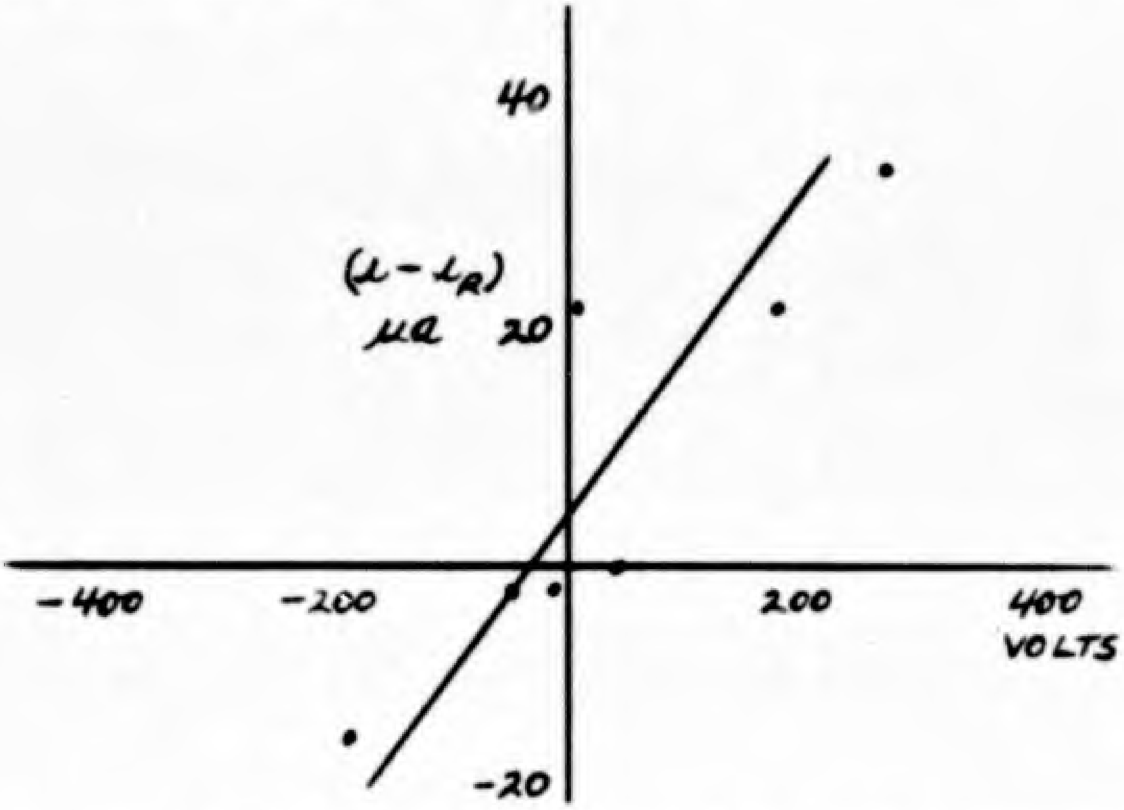
An astable flip-flop circuit incorporating micromodule elements and assembly techniques was designed and several samples constructed. The circuit (Figure 10) consisting of four cermet resistors, two Hi-K ceramic capacitors, and two silicon transistors provided a square wave output voltage of about 3 V p-p at a repetition frequency of about 100 kc/s. The micromodule was soldered to the end of a 50 foot length of RG-59 B/U coaxial cable for monitoring the output waveform and the cable end encapsulated. The free end of the cable was led to the trailer for measurements. Leads were provided for applying 3V B+ to the circuit inside the reactor room. The output waveform of the circuit was monitored for changes in amplitude and repetition frequency before, during, and after the radiation pulse to note any transient or permanent changes in performance. An expanded oscilloscope sweep was used for viewing the individual cycles of the output waveform at a time close to the peak of the burst; amplitude changes were measured on a sweep of longer duration.

DISCUSSION OF RESULTS

A. Cables

1. Transient Noise Signals

The cable response data for the RG-59 B/U are shown in Table 1. Physical data for all cables studied are presented in Figure 2. The data for RG-59 B/U cable samples indicate a replacement current level of about -15 μa* (0 voltage applied) in the initial exposure with a superimposed voltage dependent current (within the limits imposed by the sensitivity threshold of the measurements) of about 0.15 μa per volt applied which is shown in the following figure:



This figure is determined from the approximate slope of a straight line plotted through the points of applied voltage and induced conduction current. While there are many actual deviations from this slope, especially at lower voltages, the reader can obtain an approximate voltage dependency

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*The convention for current polarity is as established in Reference 1; i.e., the current pulse is designated positive when it is in the same direction as the current which flows if a battery is inserted in the ungrounded leg of the circuit with its positive terminal pointing toward the radiation source. Negative current is opposite to that described above.

of the current by this figure. Actually, it was not necessary to apply this value in calculating the resistance change of resistors during nuclear radiation exposures because the cable contribution was negligible. In the zero voltage case, Shot 3, the current responses (μa) are all dependent upon "previous" applied voltage, but the current is opposite in direction or sign as follows:

Shot 2 Previous V	Shot 3 0 V
268	-15
180	-12
45	-6.2
9	-1.5
0	.5
-9	-.5
-45	.9
-180	2.6
-268	10

This appears to be a stored charge and subsequent redistribution effect in which a charge stored previously with an applied voltage, is redistributed under a radiation pulse, and the resultant current is opposite in direction.[2,3]

2. Cable Lead Configuration

The data for the two cables which follow the extreme layouts appear in Table I. The lack of any evident pattern in the data indicates no decisive advantage in either extreme geometric layout.

3. Special Cables

a. The data on the single sample of RG-157 exposed at 135V shows only positive responses as follows:

	Shot No. 1	2	3	4	5
135V	15	15		15	
0V			5		
-135V					10

Currents in microamperes

There is no evidence of training in this cable. From the magnitudes of the responses and, particularly, because of its bulk, this cable offers no advantage over the RG-59 B/U cable for instrumentation purposes.

b. Low Noise Cable

The response of T-1 and T-2 (the samples of low noise, fused teflon dielectric, miniature coaxial cable) were measured at 268V, 0V, or -268V. Data obtained is as follows:

	SHOT NO.	1	2	3	4	5
T-1	268V	<+2.5	<±2.5		NR	
	0 V			<-2.5		
	-268V					NR
T-2	268V				<±2.5	
	0 V	<±2.5	<±2.5	<±2.5		
	-268V					<-2.5

Currents in microamperes

All were found to be lower than the responses observed for the other cables, less than 2.5 μa, the sensitivity threshold of the measurement (see Table I). In T-1 there is evidence of training as the cable response is reduced from a slightly positive value in the first shot to a value closer to zero in the second; decrease of the voltage to zero in the third shot results in a negative current. In Shot 5 for T-2 the current pulse is negative as a result of a negative change in voltage from 268V to -268V. It is not possible with the limited amount of data to establish conclusively the reason for the superior behavior of this cable, but it is probably due to its smaller size and to the conducting layer between dielectric and outside braid which may minimize space charge effects.

4. RF Transmission Attenuation

The work on coaxial cables described in the previous sections is applicable to their use as instrumentation cables in measurements of effects in other parts. The effect upon RF transmission through coaxial cables, which is their primary application, has been studied previously to some extent by USAEL in several experiments at SPRF[3] and at the Diamond Radiation Facility.[4] Figure 4 shows the radiation-induced transient effects in signal transmission through three coaxial cable types: JT-205, RG-8 A/U, and US-DEV-15.

In coaxial cable JT-205, the dielectric consisting of foamed polyethylene, the output signal amplitude was attenuated approximately 20%

in three repetitive exposures; the RF carrier amplitude was varied from a minimum .35V p-p to a maximum 1.25V p-p at 1.5 mc/s in these three repetitive exposures. No permanent effects were observed, the RF signal returning to the pre-burst level after completion of each burst.

A much smaller transient decrease in output signal amplitude was observed for RG-8 A/U, which contains a solid polyethylene dielectric, and US-DEV-15, a developmental cable containing a perforated-taped teflon dielectric. The differences in attenuation for US-DEV-15 are attributed to the limited accuracy of the amplitude measurements and not to the variation in carrier signal levels. No permanent effects in signal transmission were observed in either RG-8 A/U and US-DEV-15.

It may be seen that cables with solid dielectric are quite stable as is the case for RG-59 B/U and RG-8 A/U; however, transmission through cables with a dielectric consisting of a composite with air was markedly attenuated by the radiation pulse as is shown for JT-205 and as has been shown for RG-62 A/U in the SPRF III experiment. The inferior behavior is attributed mainly to ionization of the air in the composite dielectric, but leakage conductance effects in the composite dielectric may also be a factor. The amount of attenuation is related directly to the length of exposed cable. US-DEV-15, a perforated teflon tape dielectric, except for a solid tape layer adjacent to the inner and outer conductor, exhibited relatively more stable behavior than the cables with semi-solid (RG-62 A/U) and the foamed polyethylene dielectric (JT-205).

5. Dynamic Impedance Change

In two successive bursts, the observed current amplitude and consequently impedance increased by about 15% for RG-62 A/U and about 13% for JT-205. If the dielectric leakage conductance is considered to be negligible relative to air leakage conductance, a total capacitance increase of 62% occurred in RG-62 A/U cable and 58% in JT-205 cable. In fact, if one postulates that the major effect is in the spiral portion close to the reactor, the actual capacitance change in this portion increased to about 460% for RG-62 A/U cable and about 440% for JT-205 cable.

These results are not inconsistent with the hypothesis that ionization of the air in the air portion of the dielectric of these cables causes a capacitance increase. Calculations for the increase of cable capacitance in RG-62 A/U cable assuming that the air in the air-polyethylene dielectric becomes conductive during a burst indicate that a 700% increase in capacitance is possible. Such an increase compares favorably with the 460% measured experimentally. The calculation assumes a negligible change in the dielectric leakage conductance which may be significant. Whether or not the difference between measured and calculated values is due to an increase in this conductance is still to be determined. In view of the comparable behavior of the RG-62 A/U and the JT-205, it would appear that the ionization in each dielectric produces the same response.

B. Resistors

All resistor data are shown in Tables II and III. In all cases, the cable contribution was low enough to be neglected and the values listed represent the maximum change that could have occurred in the various resistors.

The data in Table II shows that for 100 ohms, of the resistor types studied, no significant changes were noted regardless of the type, wattage, or condition of encapsulation. This is also true for the 5 ohm and 1000 ohm power wirewound types and the 500 ohm and 1.5 K ohm cermet resistors.

The data for the 10 K ohm resistors appear in Table III. The data show no potting is necessary to maintain the carbon composition and tin oxide resistors within their tolerance limit during a pulsed nuclear event similar to the SPRF environment. However, for the closer tolerance deposited carbon and metal film types, a conformal coating may be required to maintain tolerance. The data do not support any advantage of complete potting over conformal coating at these dose rates. The significant shunting observed for the 10 K ohm resistors indicates that resistors of a higher value may require coating or potting of some type to suppress air ionization. This would be especially true at higher dose rates since gas ionization effects increase with dose rate.

Two metal film, gas-filled resistors (MIL-R-10509, 100 ohm and MIL-R-55182, 100 K ohm) were also tested and their results are shown in Table II and Table III. As expected, the 100 K ohm resistor decreased (about 7%) due to ionization of the inclosed gas. (In experiments conducted by Hughes, air-filled 1 megohm resistors with inclosed air produced shunt resistances ranging from about .5 to 6 megohms resulting in a total resistance decrease of 70% in some cases.) The structure of the resistor is shown in Figure 9. The inclosed gas is seen to be in intimate contact with the resistor element. As was expected also, the 100 ohm gas-filled resistors, because of their low value, underwent negligible changes in resistance.

No significant trend was obtained for resistors of different wattage, since injected currents due to secondary emission in these low value resistors was negligible within the available resolution.

The tests applying the electrostatic shielding technique to measurement on a 10 K ohm carbon composition resistor show that the resistance change is within the 1% tolerance limit and the same as that measured with an identical part encapsulated in potting compound. In any case, encapsulating the part or eliminating the electric field lines around the signal cable and the part by electrostatic shielding proved to be effective in eliminating air ionization effects. It can be seen that electrostatic shielding affords a supplementary method for minimizing air leakage and secondary emission effects in part testing, although in some cases the part configuration may prohibit the use of this method. Potting is effective, but secondary emission effects tend to increase with bulk of potting material added to the part, and charge pile-up effects in the potting can also occur; furthermore, some leakage may occur within the potting material. Nevertheless, if the secondary emission effects and charge pile-up effects in the bulk potting material are negligible compared to the part response under radiation, potting is preferred because it is the simpler of the two design techniques.

C. Micromodule Multivibrator Circuit

The output waveforms of several micromodule free-running multivibrators were monitored prior to, during, and after each of several repetitive exposures to determine the performance of these circuits with respect to repetition rate and pulse amplitude. The output waveforms of each multivibrator circuit, which consists of two common emitter connected transistors each cross-coupled from its collector to the alternate base (Figure 10), were measured across one of the collector load resistors.

From the observed output waveforms, of which typical ones are shown in Figure 11 along with the calculated per cent change in measured values, it is apparent that both transient effects during the radiation pulse and permanent damage effects occurred to repetition rate and pulse amplitude. There was a permanent change of the repetition rate from burst to burst; tests on the same circuits one month later in the laboratory under similar input conditions show that the circuit characteristics remain unchanged and that the effects are truly permanent. A partial recovery in the repetition rate after each burst was observed, but the repetition rate was always changed from the pre-burst measurement. The maximum transient effect during a burst was coincident with the power pulse peak. The repetition frequency for one multivibrator increased from an initial 120 kc/s to approximately 420 kc/s in five repetitive bursts, a second from 104 kc/s to 80 kc/s in two repetitive bursts, and a third from 120 kc/s to 450 kc/s in six repetitive shots. It would appear that the observed differences in repetition rate changes for the three identical circuits are dependent upon accumulated dose effects. The pulse amplitude for all three multivibrator circuits decreased, but ringing due to the 50 foot length of cable used to transmit the signal from the micromodule circuit prevented determination of the actual pulse amplitude change in many of the tests.

The increase in repetition frequency and degradation in signal amplitude is presently attributed to damage to the silicon transistors. The cermet resistors do not affect circuit response since these were tested previously as discrete parts and found to be relatively unaffected. Also, data reported recently[5] indicate that the effects in ceramic capacitors could not account for any appreciable portion of the degraded circuit response. However, the current gain for silicon transistors is greatly decreased when exposed to nuclear radiation ($>10^{13}$ nvt), and this change in current gain as a function of accumulated dose can cause both the decrease in pulse amplitude and the increase in repetition frequency. In addition, the performance of this circuit is particularly sensitive to changes in transistor current gain.

CONCLUSIONS

A. Cables

1. Transient Noise Signals

The response of an RG-59 B/U cable to a SPRF nuclear pulse in the normal geometric configuration described in this report is voltage dependent and for the initial exposure (no previous nuclear exposure) can be estimated at .15 μa per volt applied, which is superimposed on the zero voltage "replacement current" of -15 μa. With repetitive exposure under unchanged voltage conditions, the replacement current is reduced by a factor of five and the conduction component by a factor of ten.

No advantage was found by arranging the cables in either extreme geometric layout whether directing it radially to the wall or dropping it immediately at the reactor to the floor and then proceeding to the reactor wall.

2. Special Cables

RG-157, a relatively larger cable with conductive interlayers at inner and outer conductors showed a significant response which was positive with all voltages. A much smaller cable in bulk, low noise cable, T-1, with conductive interfaces showed a small response and was the least affected of the cables tested.

3. <u>RF Attenuation</u>

RF transmission through cables with a dielectric consisting of a composite with air is markedly attenuated for the duration of the radiation pulse. JT-205, with foamed polyethylene, underwent an attenuation of approximately 20%. Attenuation for the US-DEV-15 cable, with perforated-tape teflon dielectric, averaged .3% and for RG-8 A/U, a solid polyethylene dielectric, attenuation averaged .5%. No permanent effects were observed.

B. Dynamic Impedance Change

An experiment with the RG-62 A/U cable has further confirmed the hypothesis that air dielectric cables are subject to a transient capacitance increase of about 460%; most of which is due to the ionization of the air in the cable structure or dielectric. This method cannot separate reactive and resistive changes occurring simultaneously.

C. Resistors

The results on resistors can be summarized as follows:

1. Low-value resistors (< 1500 ohm) do not require coating or encapsulation for stability in the SPRF environment. The shunting effect of the ionized air is not sufficient to cause a resistance change greater than about .2%.

2. For the higher-value resistors (10 K ohm), the shunting effect of the ionized air may cause a resistance change of the order of 2%, thus those with a required closer 1% tolerance such as deposited carbon and metal film will require a protective coating of the resistor leads whereas those with higher tolerance limits will not.

3. Inasmuch as the resistance change is a transient, lasting for only the duration of the burst, potting is not necessary if permanent change is the sole concern.

4. Electrostatic shielding techniques where feasible may be considered as an alternate to potting or coating.

5. The 100 K ohm gas-filled "Minuteman" resistor showed a pronounced resistance decrease of 1% during radiation exposure.

6. Within the range of resistor wattages tested, no dependency with physical size could be discerned.

D. Micromodule Multivibrator Circuit

A free running multivibrator circuit which contained resistors, capacitors, and transistors, and packaged in a micromodular configuration underwent both transient and permanent damage when exposed to one or more nuclear bursts at the SPRF. The degradation in repetition frequency appears to be dose dependent, the repetition frequency increasing by as much as 250 per cent in five to six repetitive bursts. The pulse amplitude decreased sharply in all units tested. Permanent degradation was attributed to the transistor radiation sensitivity characteristics and to circuit performance which was sensitive to changes in transistor current gain.

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Members of the Reliability and Electronic Parts Branch provided assistance in the selection and acquisition of resistors and cables and members of the Modular Assemblies Branch also provided assistance in the planning of the microcircuit module portion of the study.

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TABLE I

INDUCED CABLE CURRENTS

CABLE SAMPLE	APPLIED VOLTAGE	CURRENT-MICROAMPERE SHOT 1	SHOT 2	SHOT 3	SHOT 4	SHOT 5
59-10	+268	+20	+5.0		+40	
	0			-15		
	-268					-50
59-1	+180	-2.7*/+7.7*	~ +12		~ +15	
	0			~ -12		
	-180					-37
59-3	+45	~ -15	-5.4		+6.9	
	0			-6.2		
	-45					-17.7
59-4	+9	+5.7	-2.7		-3.8	
	0			-1.5		
	-9					-3.8
59-5	0	~ -18	-5.5	< +.5 -.5	+.9	+2.0

(continued)

R - Samples led radially from reactor then directly down through conduit to measuring instrumentation (Configuration I, Figure 1). All others led down to floor at reactor, then along floor through conduit to measuring instrumentation (Configuration III, Figure 1).

* - Peaks not coincident with radiation pulse.

~ - Estimate of peak from off-scale trace. < Less than. NR - No Reading.

Table I INDUCED CABLE CURRENTS (continued)

		CURRENT-MICROAMPERE				
CABLE SAMPLE	APPLIED VOLTAGE	SHOT 1	SHOT 2	SHOT 3	SHOT 4	SHOT 5
T-1	+268	< +2.5	< +2.5 -2.5		NR	
	0			< -2.5		
	-268					NR
T-2	+268				< +2.5 -2.5	
	0	< +2.5 -2.5	< +2.5 -2.5	< +2.5 -2.5		
	-268					< -2.5

Table I INDUCED CABLE CURRENTS (continued)

CABLE SAMPLE	APPLIED VOLTAGE	CURRENT-MICROAMPERE SHOT 1	SHOT 2	SHOT 3	SHOT 4	SHOT 5
59-11	+268				NR	
	0	-15	<-2.5	<+2.5 -2.5		
	-268					NR
59-6	+9					+3.7
	0			+.9		
	-9	~ -17	-1.7		+2.6	
59-7	+45					+52
	0			+2.6		
	-45	~ -17	~ -22		~ -26	
59-9	+180					+40
	0			+10		
	-180	-30	-5.0		-25	
$59\text{-}2^R$	+135	+2.3*/-3.2*	+4.1		~ +14	
	0			-9.6		
	-135					-31
$59\text{-}8^R$	+135					~ +25
	0			+10.8		
	-135	~ -17	-3.3		-16.7	
$\text{RG-}157^R$	+135	+15	+15		+15	
	0			+5		
	-135					+10

(continued)

TABLE II

RESISTORS 5, 100, 500, 1000, 1500 OHM

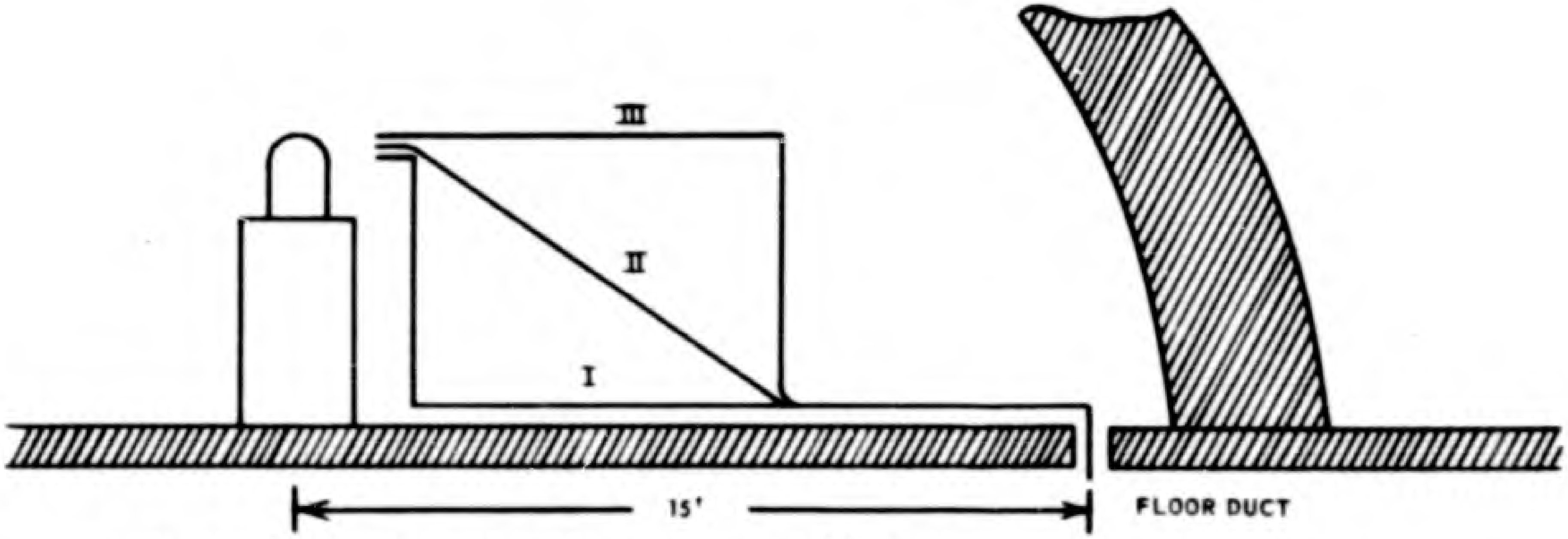
TYPE	VALUE OHMS	TOLERANCE %	DISSIPATION WATTS	QUANTITY			Δ R/R%		
				POTTED	CONFORMAL COATING	UNPOTTED	POTTED	CONFORMAL COATING	UNPOTTED
Carbon Composition	100	10	1/8	1			<.1		
MIL-R-11			1/4	7	3	1	<.1	<.1	<.1
			2	1	1		<.02	<.02	
Deposited	100	1	1/8	4	3		<.1	<.1	
Carbon			1/4	1			<.06		
MIL-R-10509			2	1	1		<.02	<.02	
Film Char B									
Metal Film	100	1	1/8	3	7	1	<.1	<.1	<.1
MIL-R-10509			1/4	1			<.06		
Char C			1/2			1			<.04
			2	1			<.02		
Gas-Filled	100	1	1/2	3			<.04		
MIL-R-10509			1	3			<.03		
Tin Oxide	100	3	1/4	5	4	2	<.06	<.06	<.06
MIL-R-22R84			1/2	1	1		<.04	<.04	
			1	1	1		<.03	<.03	
			2	1	1		<.02	<.02	
Power Wirewound	5	1	1/8(ve)	1	1	1	NR	<.1	NR
			1/8(s)	1	1		NR	<.1	
MIL-R-26	1000	1	1/8(ve)	1	1		NR	NR	
			1/8(s)	1	1	1	<.03	<.3	<.03
Cermet	500	5	1/8	3			<.2		
SCL-7705	1500	5	1/8	4			<.02		

ve - vitreous enamel
s - silicone coating
NR - No Reading

TABLE III

RESISTORS - 10,000 and 100,000 OHM

TYPE	TOLERANCE %	DISSIPATION WATTS	QUANTITY			ΔR/R %			UNPOTTED RESISTOR EQUIV. SHUNT RESISTANCE
			POTTED	CONFORMAL COATING	UNPOTTED	POTTED	CONFORMAL COATING	UNPOTTED	
10,000 Ohm Carbon Composition MIL-R-11	10	1/8		1			<1		
		1/4	4	7	2	<1	<1	2.2, 1.3	.5M, .8M
		1/2		1			<1		
		1		1			<1		
		2		1			<1		
Deposited Carbon MIL-R-10509 Film Char B	1	1/8	4	4	1	<1	<1	1.9	.5M
		1/4	1	1		<1	<1		
		1/2	1	1	1	<1	<1	3.4	.3M
		1	1	1		<1	<1		
		2	1	1		<1	<1		
Metal Film MIL-R-10509 Char C	1	1/8	2	1		<1	<1		
		1/4	2	1		<1	<1		
		1/2		1	1		<1	1.4	.7M
		1		1			<1		
		2		1			<1		
Tin Oxide MIL-R-22R84	3	1/4	5	4	2	<1	<1	1.6, 1.3	.6M, .8M
		1/2		1			<1		
		1	1	1		<1	<1		
		2	2	1		<1	<1		
100,000 Ohm Minuteman MIL-R-55182 He-Filled	1	1/8	4			7			



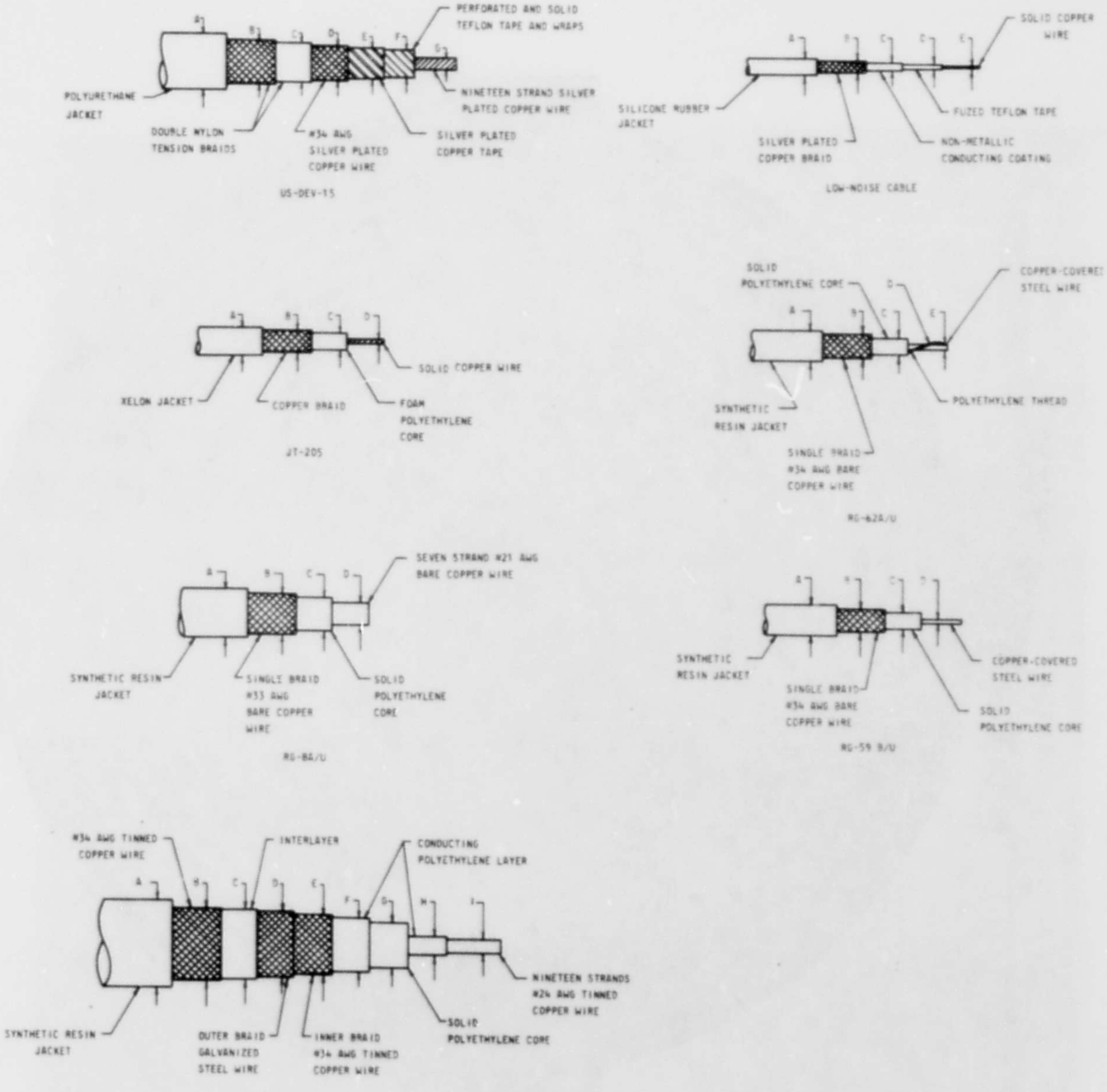
I. CABLES LED DIRECTLY TO FLOOR AND ALONG FLOOR TO CONDUITS

II. CABLES LED DIAGONALLY TO FLOOR AND ALONG FLOOR TO CONDUITS

III. CABLES LED RADIALLY AWAY AND THEN DIRECTLY DOWN TO FLOOR AND ALONG FLOOR TO CONDUITS

TESTS OF OPTIMUM CABLE CONFIGURATION FOR MINIMUM CABLE RESPONSE

Figure 1



US-DEV-15

LOW-NOISE CABLE

JT-205

RG-62A/U

RG-8A/U

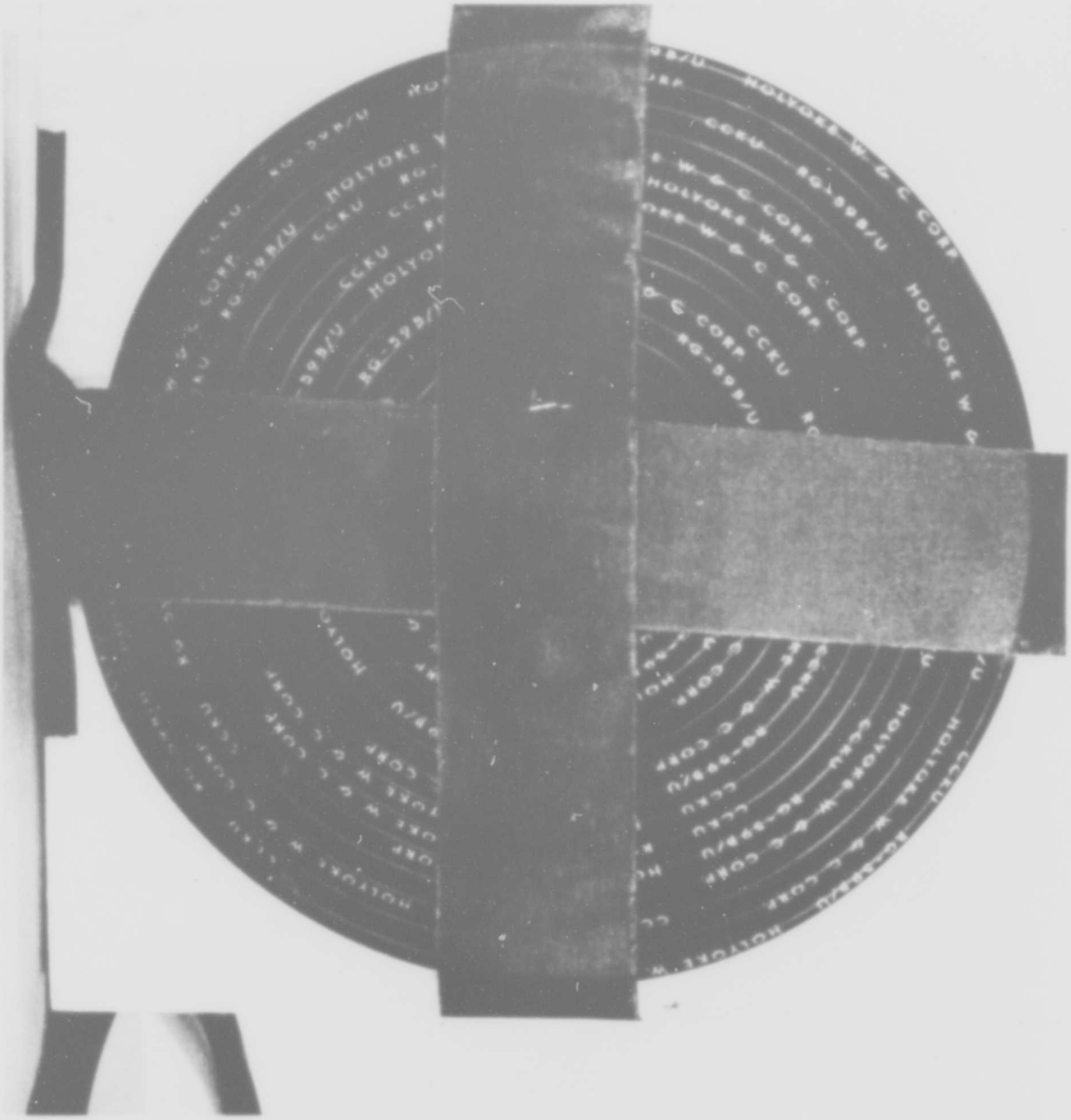
RG-59 B/U

RG-157

CABLE	DIMENSION (INCHES)								
	A	B	C	D	E	F	G	H	I
US-DEV-15	.465 MAX .030 MINWALL	.350 NOM.	.320 NOM.	.292 NOM.	.262 NOM.	.254 NOM.	.090 ± .002		
JT-205	.235 NOM.	.200 NOM.	.171	.028					
RG-8A/U	.405 ± .010	.340 MAX.	.285 ± .010	.199					
RG-157	.725 ± .015	.615 MAX.	.580 MAX.	.540 MAX.	.500 MAX.	.455 ± .010	.390 ± .010	.142 ± .005	.101
LOW-NOISE CABLE	.100 NOM.	.081 NOM.	.062 NOM.	.040 NOM.	.014 NOM.				
RG-62A/U	.242 ± .007	.191 MAX.	.146 ± .005	.035	.0253 NOM.				
RG-59 B/U	.242 ± .004	.191 MAX.	.146 ± .004	.0230					

COAXIAL CABLE SPECIFICATIONS

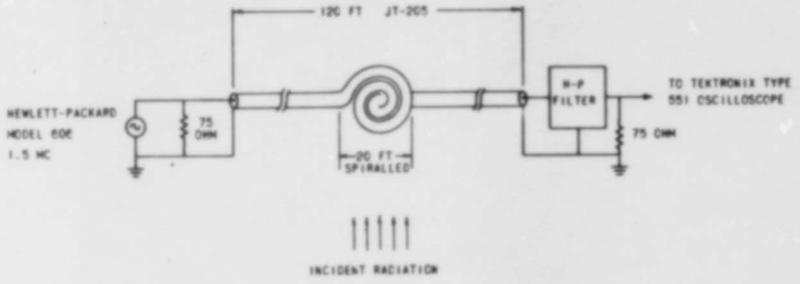
Fig. 2

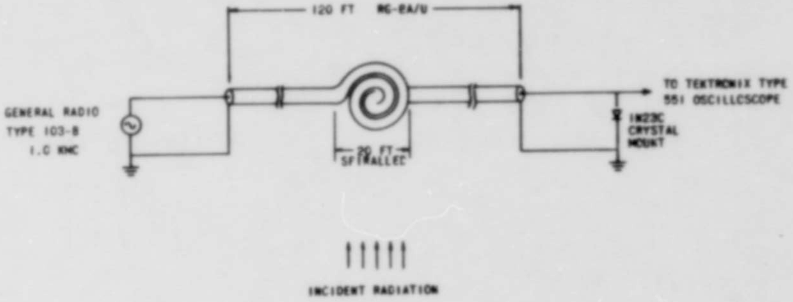


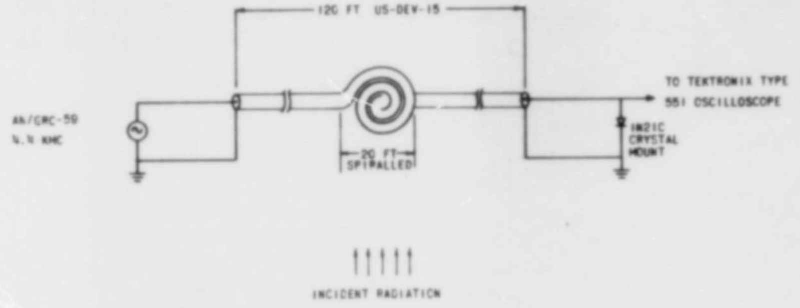
Spiral Portion of Exposed Cable for RF Transmission Test

Fig. 3

RADIATION EFFECTS ON R.F. TRANSMISSION THROUGH
JT-205, US-DEV-15, AND RG-8A/U COAXIAL CABLES







		EXPOSURE 1	EXPOSURE 2	EXPOSURE 3
JT-205 *	△ R.F. OUTPUT AMPL.	-19 %	-19%	-20%
	R.F. OUTPUT AMPL. (p-p)	350 mv	700 mv	1250 mv
US-DEV 15	△ R.F. OUTPUT AMPL.	-.3%	-.6%	1.0%
	R.F. OUTPUT AMPL. (p-p)	.8 V †	1.6 V	1.6 V
RG-8 A/U	△ R.F. OUTPUT AMPL.	-.4%	-.5%	-.5%
	R.F. OUTPUT AMPL. (p-p)	1.8 V	0.5 V	14.7

* WITH HIGH-PASS FILTER
† 6 DB FIXED ATTENUATOR IN EXPOSURE 1

Figure 4

DETERMINATION OF DYNAMIC IMPEDANCE CHANGE
BY RF CURRENT MODULATION MEASUREMENT

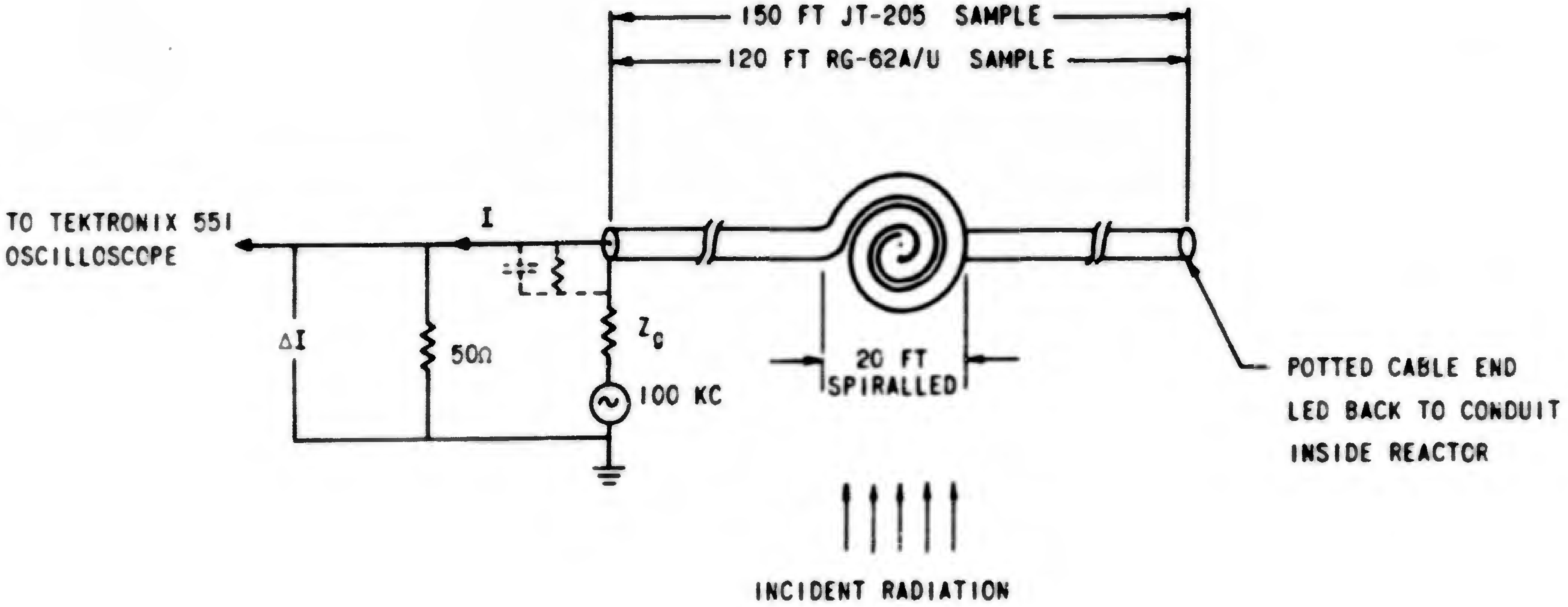


Figure 5

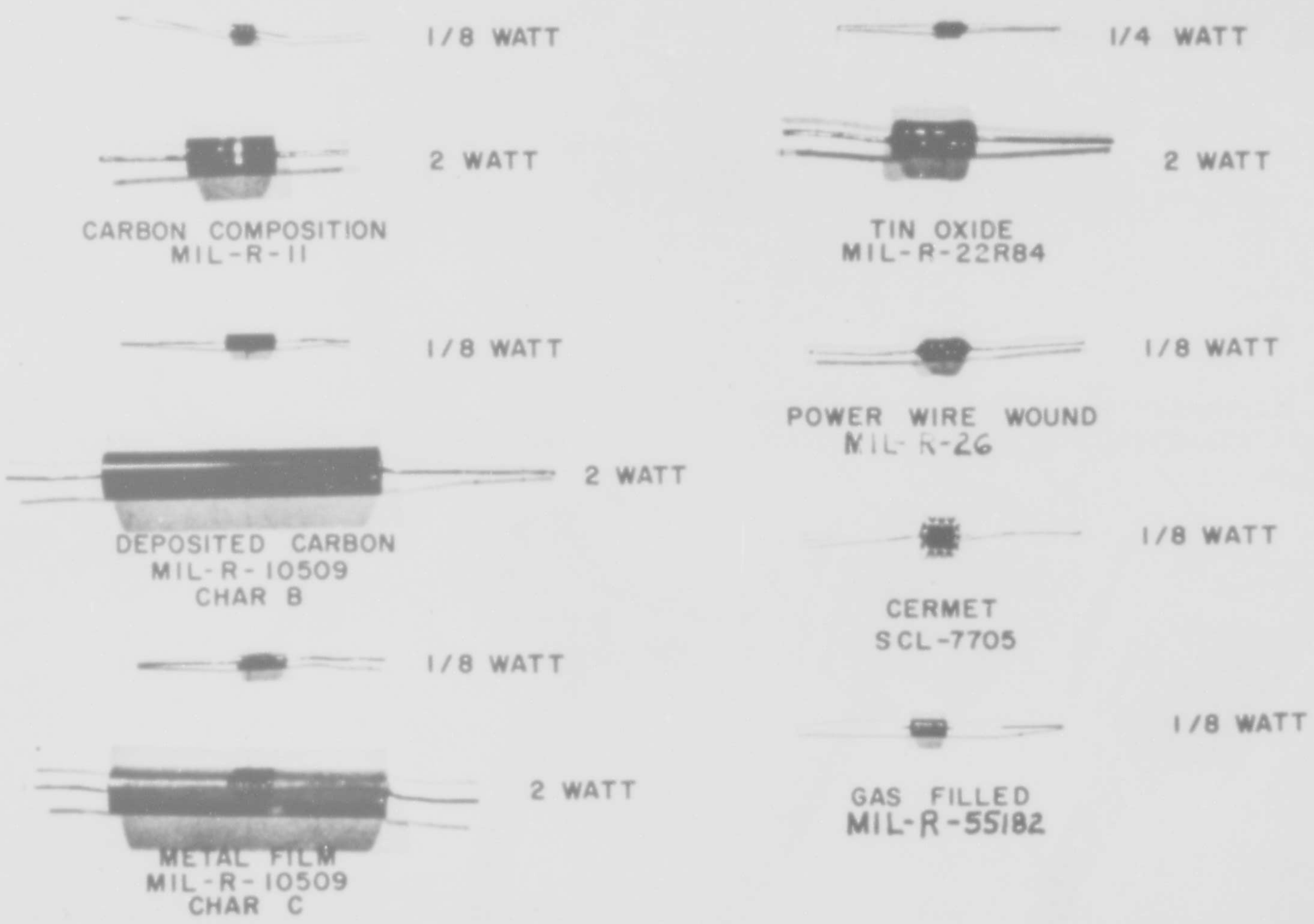


Figure 6

TEST RESISTORS

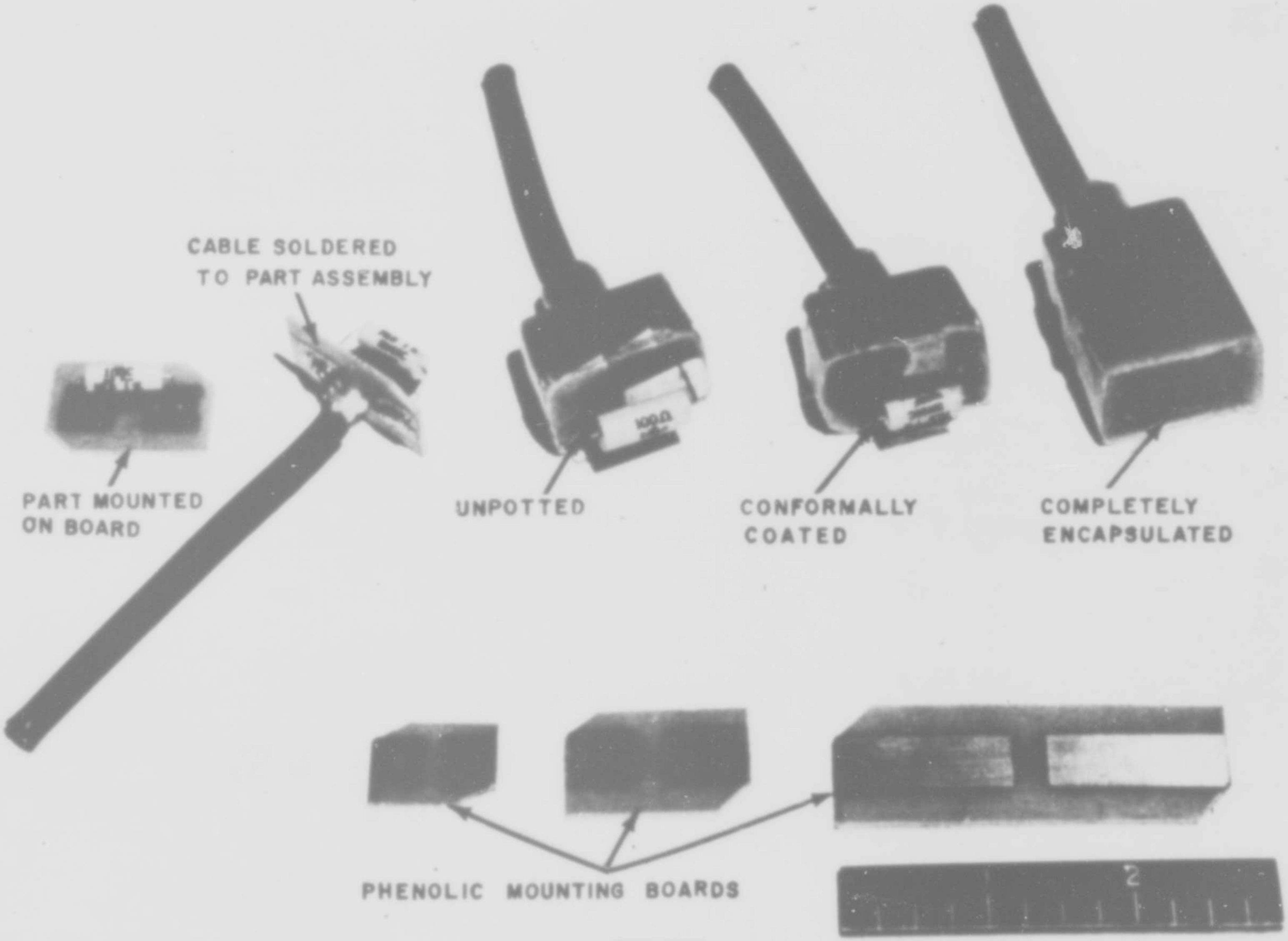
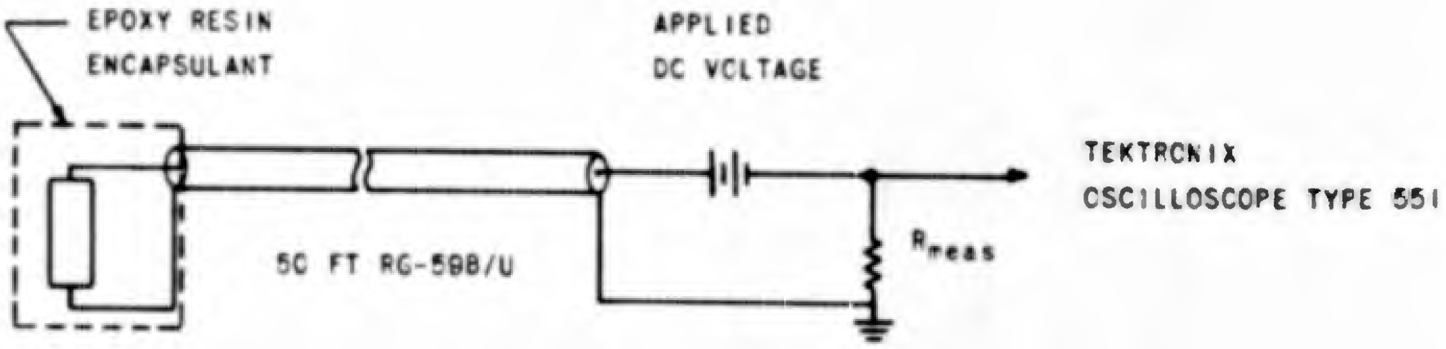


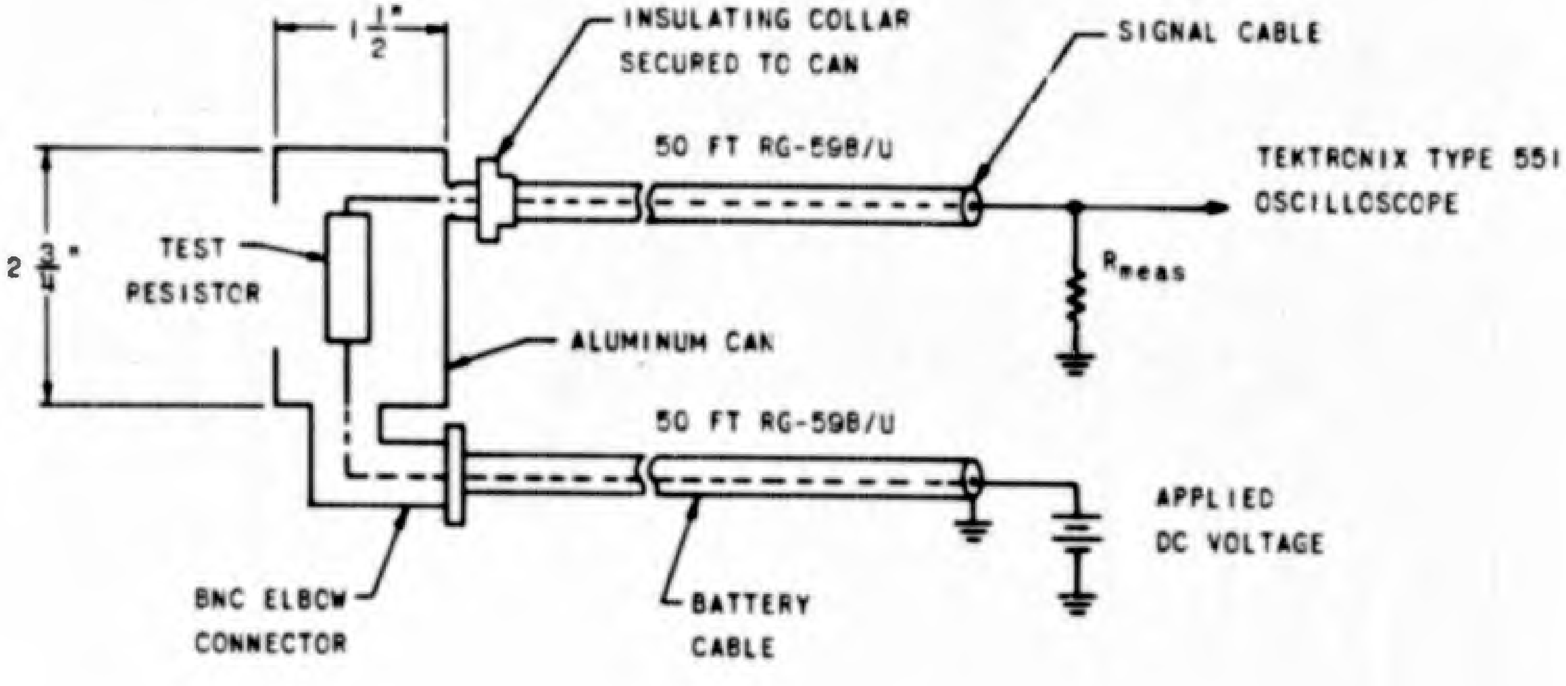
Fig. 7

RESISTOR MOUNTING ASSEMBLY

MEASURING SYSTEMS FOR RESISTOR TESTS

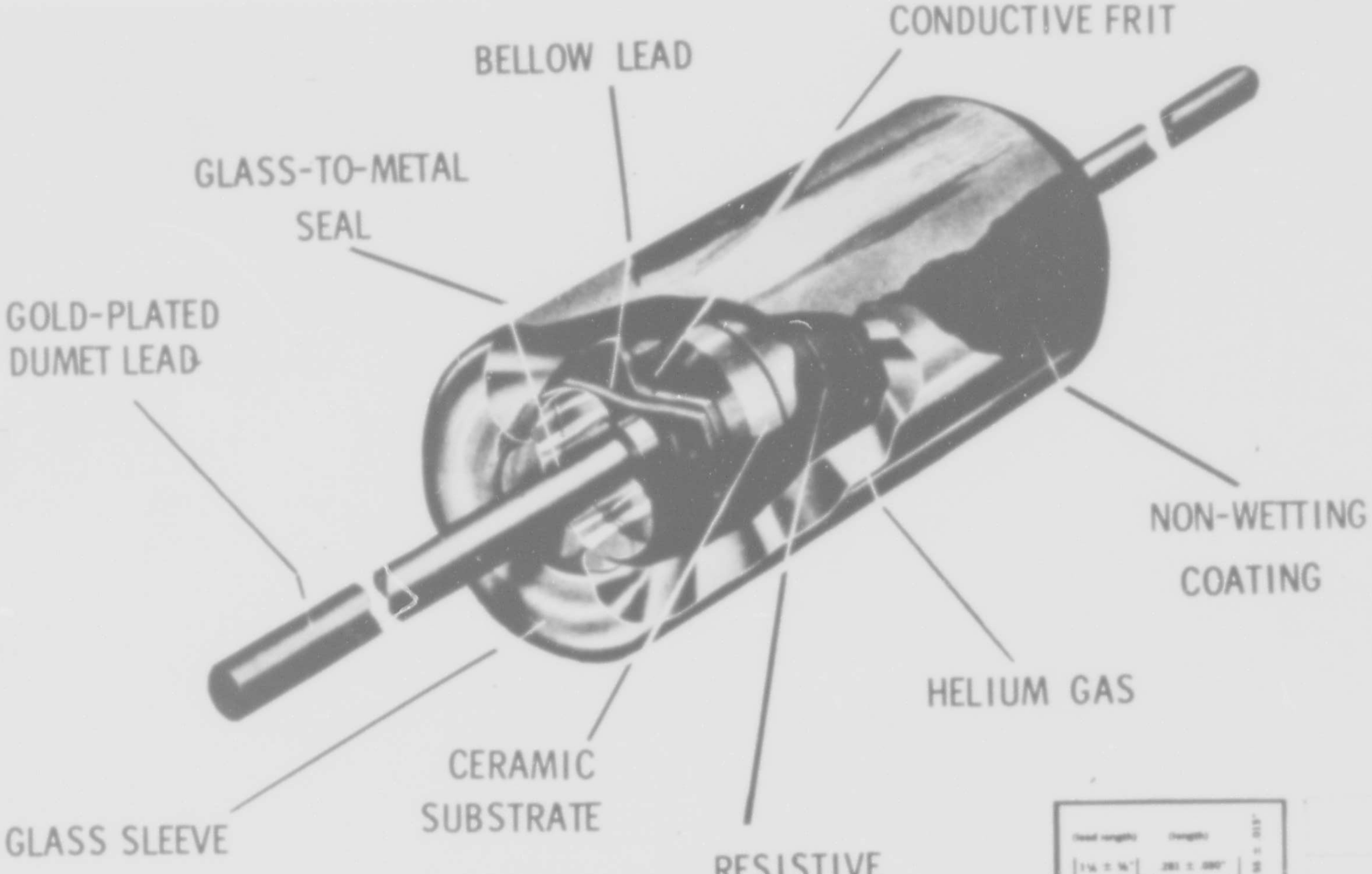


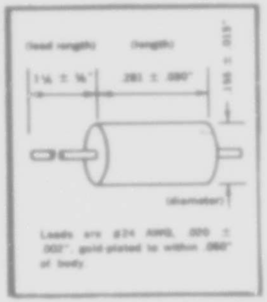
A. BASIC TEST CIRCUIT



B. CIRCUIT USING ELECTROSTATIC SHIELDING FOR MINIMIZING AIR IONIZATION EFFECTS WITHOUT ENCAPSULATION

Fig. 8

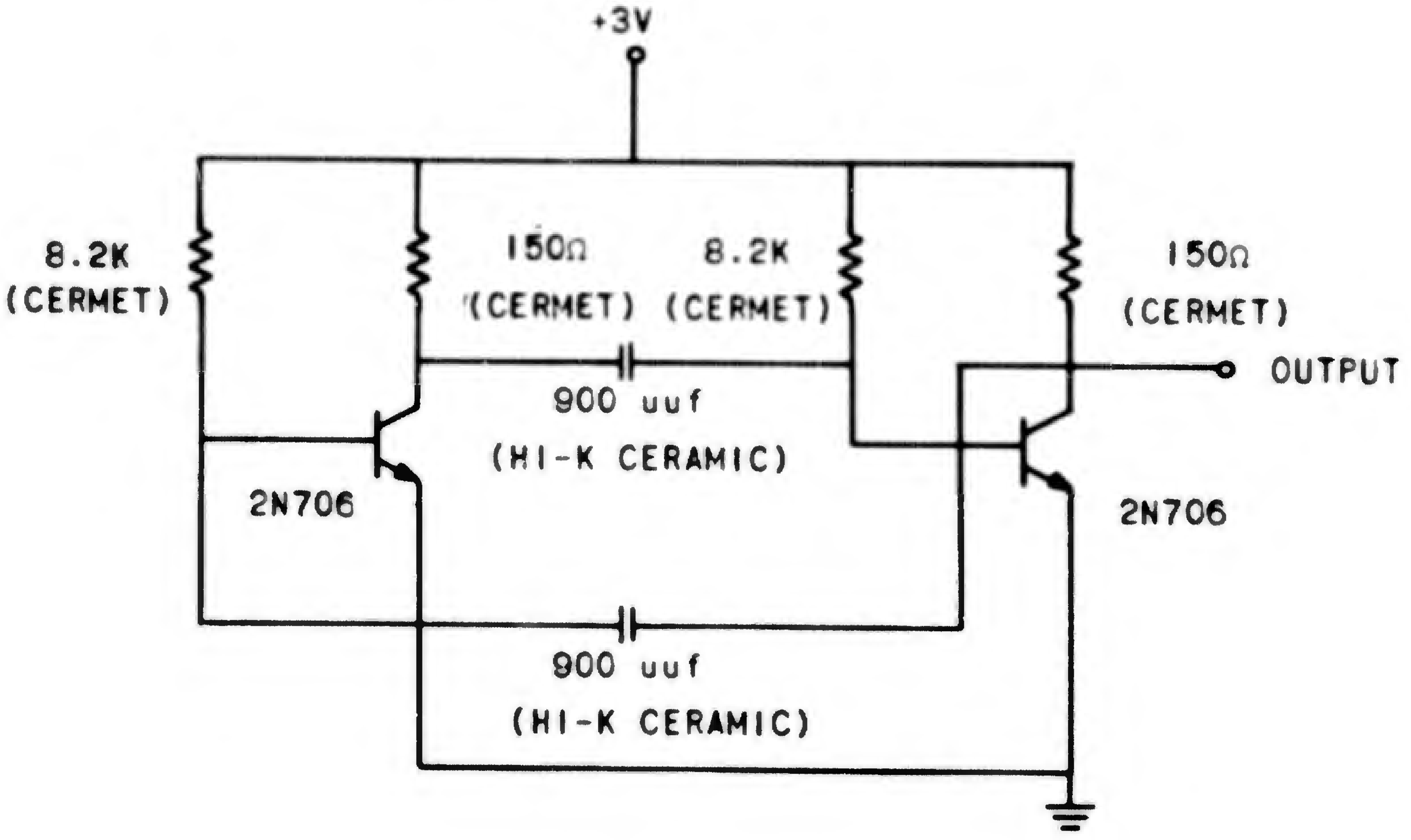




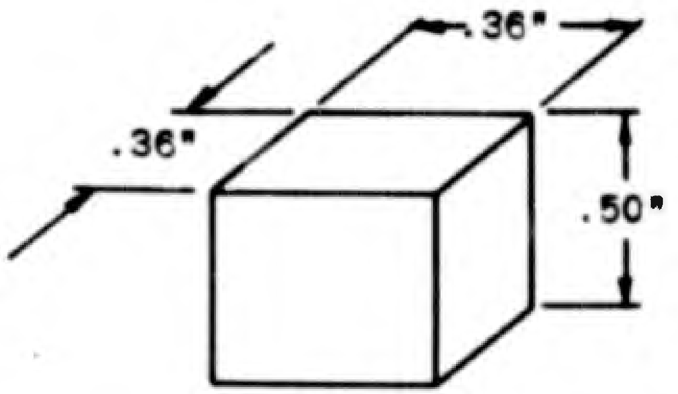
PHYSICAL STRUCTURE, MINUTEMAN 100 K OHM RESISTOR

Fig. 9

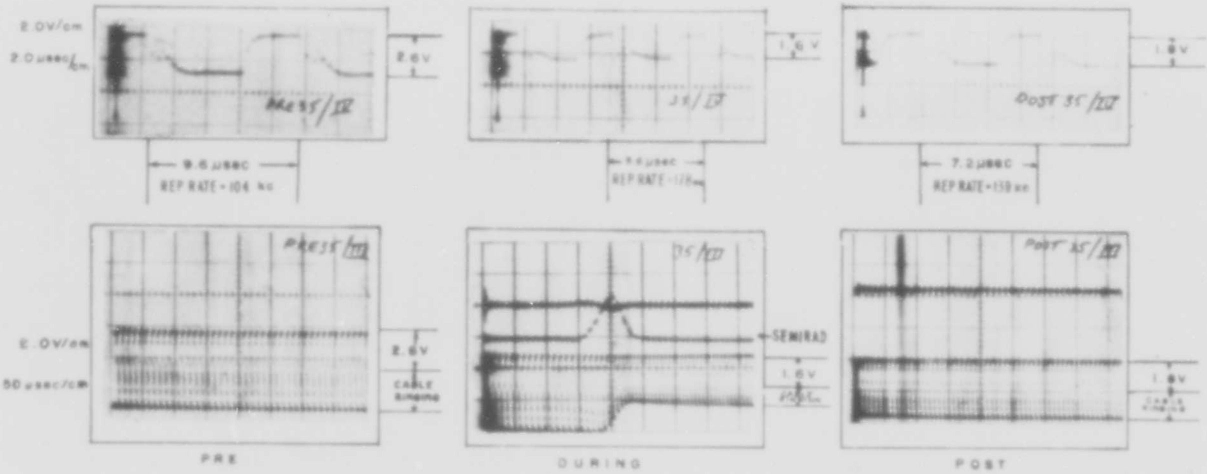
ASTABLE MULTIVIBRATOR CIRCUIT
(MICROMODULE ASSEMBLY)



CIRCUIT



ENCAPSULATED MODULE DIMENSIONS
Fig. 10



TYPICAL OSCILLOSCOPE TRACES

			PERCENT CHANGE FROM INITIAL VALUE											
		INITIAL MEASUREMENT	EXPOSURE 1		EXPOSURE 2		EXPOSURE 3		EXPOSURE 4		EXPOSURE 5		EXPOSURE 6	
			DURING	POST	DURING	POST	DURING	POST	DURING	POST	DURING	POST	DURING	POST
MM 1	REP. RATE	120 kc	73	39	NR	73	179	146	248	178	246	248		
	PULSE AMPL.	2.4 V	-42	-33	NR	-50	*	-50	*	*	*	*		
MM 2	REP. RATE	104 kc	71	34	85	60								
	PULSE AMPL.	2.6 V	-39	-31	-46	-42								
MM 3	REP. RATE	90 kc	69	16	105	74	132	99	NR	NR	NR	154	250	200
	PULSE AMPL.	1.9 V	*	-26	-32	*	-37	*	*	NR	NR	*	*	*

NR: NO READING
* PULSE AMPLITUDE MEASUREMENT OBSCURED BY CABLE RINGING

SUMMARY OF REPETITION RATE AND PULSE AMPLITUDE MEASUREMENTS IN THREE MICROMODULE MULTIVIBRATOR CIRCUITS.

Fig. 11

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13. ABSTRACT

Various cable and resistor types and an operating micromodule multivibrator circuit were exposed to a pulsed nuclear radiation environment (SPRF) and their transient response measured during the pulse. The initial RG-59 B/U cable response was determined to be voltage dependent and averaged .15 μa per volt superimposed on a zero voltage "replacement" current of -15 μa. A miniature low noise cable, with conductive interfaces, gave the lowest and most stable response of all cables tested. The attenuation of three different types of RF cables was measured and the signal in JT-205 with foamed polyethylene was attenuated approximately 20%. The US-DEV -15 cable with perforated tape teflon averaged .3% and for RG-8 A/U, a solid polyethylene dielectric, attenuation averaged .5%. Carbon composition, deposited carbon film, nichrome film, tin oxide, wirewound, cermet, and gas-filled "Minuteman" resistors of various wattages were tested in an unpotted, conformally coated, and potted condition. All low value resistors tested (less than 1500 ohms) maintained tolerance levels even in unpotted conditions. For the unpotted higher-value resistors (10 K ohm) the shunting effect of the ionized air may cause a resistance change of the order of 2% which can be reduced to 1% by conformal coating. The 100 K ohm "Minuteman" resistor decreased 7% during exposure. A free running multivibrator in a microcircuit modular configuration underwent both transient and permanent damage.

DD FORM 1 JAN 64 1473

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pulsed Nuclear Radiation Effects						
Transient						
Permanent						
Resistors						
Coaxial Cables						
Micromodule Multivibrators						
Effective Resistance Changes						
Leakage Effects						
RF Transient Attenuation						
Potted						
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