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EXPERIMENTAL RESULTS OF TESTING RESISTORS UNDER PULSE CONDITIONS

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ABSTRACT

This report describes the results of pulse testing limited quantities of wire-wound, metal film, and carbon composition resistors. The results indicate that under certain conditions the resistors may be safely pulsed to more than 5000 times their DC power ratings.

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Introduction

In the application of resistors to a pulse circuit, little information is available concerning the definite limits of pulse voltage and power ratings of components. The conventional pulse power rating of not more than 10 times the DC power rating and the pulse voltage rating of not more than 1000 volts per inch of length may, in fact, unduly advise the applications engineer. Since pulse circuits vary from single pulse to continuous pulse operation, from very low to very high duty cycles, and from very low to very high pulse voltages and powers, it is obvious that different application information may be required for each circuit. One commonly used but only approximate principle at Sandia Laboratory prescribes that pulsed power on a resistor is not to exceed 10 times the DC power rating. For a circuit with a low duty factor or for a circuit that is to be miniaturized, such a general approximation may unnecessarily dictate a physically large component. This fact was introduced by the Electrical Standards Division of the Measurement Standards Development Department in acceptance testing of a 20-kilowatt pulse generator. During the testing procedure, a curiosity developed as to how much pulsed power a 1/2-watt carbon composition resistor could withstand before catastrophic failure occurred. When 20 kilowatts was safely reached, it seemed evident that the possibility of a component with low DC ratings achieving very high pulse power ratings should be investigated. Limited experience with pulsing wire-wound resistors with relatively high power pulses indicated a similar condition for low duty cycles.

Accordingly, a program was initiated in the Electrical Standards Division as a summer hire project to determine if these observed relations were valid. This project consisted of a limited testing of a small quantity of 2- to 10-watt wire-wound resistors, 1/4- to 1-watt carbon composition resistors, and 1/4- to 2-watt metal film resistors. The tests were conducted in an attempt to determine maximum pulse voltage and maximum pulse power capabilities.

Summary Of Results

All three types of resistors tested were able to withstand pulse powers far in excess of their DC power rating. The wire-wound resistors withstood a pulse power of more than 5000 times their DC rating, the metal film resistors more than 1000 times, and the carbon composition resistors more than 500 times.

During the pulse testing of all three types of resistors, the pulse waveforms were not altered in any noticeable way.

Wire-Wound Resistors

Wire-wound resistors manufactured by Dale and by IRC were found to perform equally well. However, Dale wire-wound resistors were used almost exclusively because of their availability for these tests. It did not seem to make any difference whether or not the resistor was the noninductive type: both the regular and the noninductive wire-wound resistors broke down at about the same point. The pulse waveform from the Standards Laboratory pulse generator did not seem to change with either the regular or the noninductive type of resistor.

Metal Film Resistors

Metal film resistors from several different manufacturers were tried during the testing, but the IRC type was found to be the most consistently dependable and predictable. However, Dale resistors were used at high resistance values because they were the only ones available at the time of the testing. These resistors were reasonably consistent with voltages obtained from the IRC resistors tested in the vicinity of these high resistance values.

Carbon Composition Resistors

Test results for the carbon composition resistors were not found to be as predictable as those for the wire-wound and metal film resistors. This may be because of all the carbon composition resistors tested, some were suitable for pulse application and some were not. The resistors which seemed to be most suitable for pulse applications had a large core area and a cylindrical shape with flat ends. The other type which was not suitable for pulsing had a small core area and a cylindrical shape with more rounded ends. The Allen-Bradley carbon composition resistors appear to be shaped similar to the good pulse resistors; the IRC carbon composition resistors seem to be shaped similar to the poor pulse resistors.

Description of Equipment

Two pulse generators (pulsers) were used to test the three types of resistors. One pulser was a Velonex, Model 350A 20-kW pulse generator and the other was a Standards Laboratory pulse generator. Specifications for each pulser accompany the block diagrams of the pulsers and the associated equipment.

Velonex 350A Pulser

The Velonex pulser (Figure 1) used to test the carbon composition and metal film resistors. The output of the pulser was connected directly across the resistor under test. A Beckman 7370 counter was used to count the number of pulses applied to the resistor under test. A Tektronix

Type 555 oscilloscope with Type Z pre-amplifiers was used to monitor the test current and voltage. The Velonex pulser specifications were as follows:

Voltage	0-1 kV, 0-20 kV
Power	0-20 kW
Pulse width	0.1 - 100 μsec
Pulse repetition frequency	2-200,000 pps
Output impedance	50 and 20 kΩ

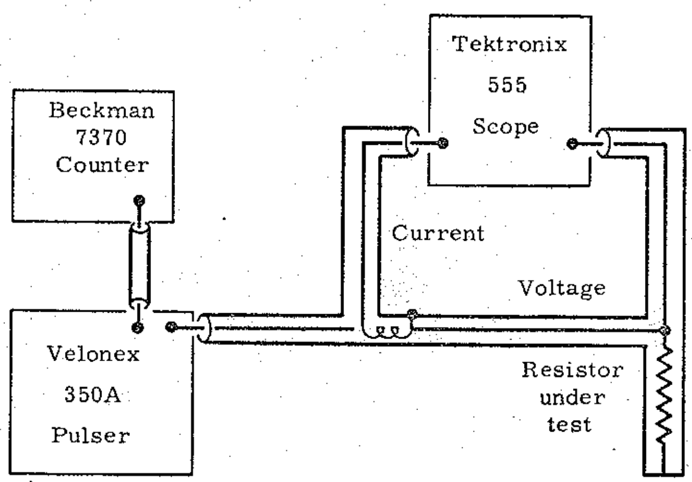

Figure 1. Velonex Model 350A pulser and associated equipment

Standards Laboratory Pulser

The Standards Laboratory pulser (Figure 2) was used to test all of the wire-wound resistors and the larger metal film and carbon composition resistors. The output of the pulser was connected across the resistor under test. The pulse repetition frequency (PRF) was selected and the pulsers were counted by internal circuitry. The output current and voltage were monitored in the same manner as the output of the Velonex pulser. The Standard Laboratory pulser specifications were as follows:

Voltage	0-60 kV
Power	0-20 MW
Pulse width	20 μsec
Pulse repetition frequency	0.01-30 pps
Output impedance	128 Ω

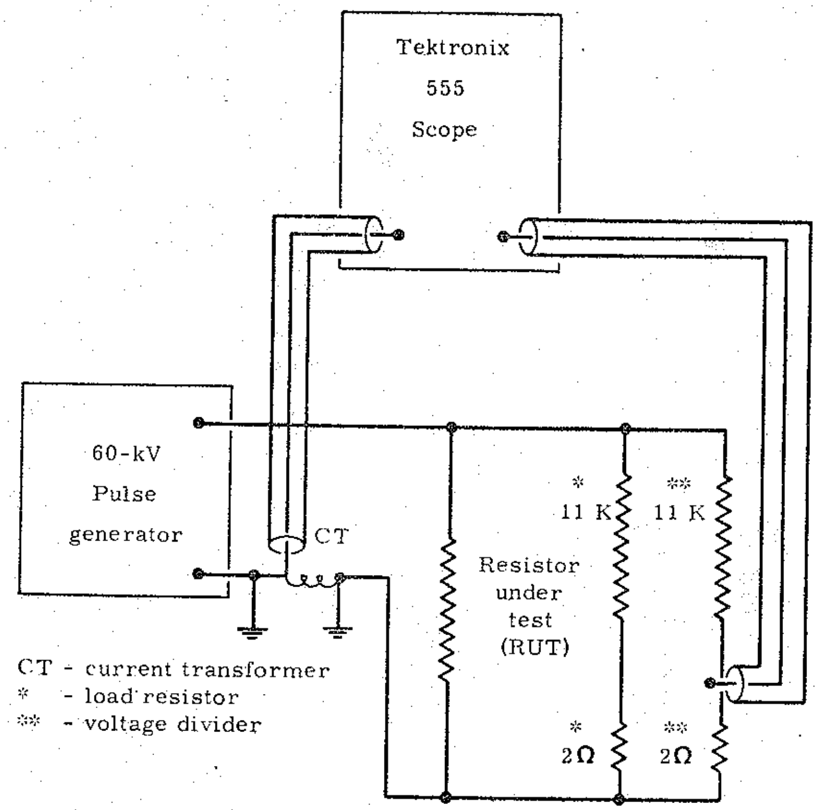

Figure 2. Standards Laboratory pulser and associated equipment

Testing and Calculating Procedure

Stress-Step Method

The stress-step method[1] was used to pulse test the resistors. This method is a means of testing electronic components by which failure can be approached in a series of steps with each step increasing the stress on the resistor.

The stress-step method used to test the resistors was applied as follows:

1. The pulse voltage across the resistor under test was incrementally increased until the resistance value changed by a predetermined percentage.
2. A new resistor was tested at the breakdown voltage determined in Step 1 until it also changed in resistance.
3. Another new resistor was tested at a lower voltage until it changed in resistance.

[1] W. T. Sackett, Jr., "The Stress Step Method of Obtaining Short-Term Life Ratings on Electronic Components." National Electronic Conference Procedures, Volume 8 (1952), pp. 267-273.

These steps were repeated until the resistor did not change in resistance over a sufficiently long period of time (100 pulses or more).

Pulse Waveforms

During these tests, the average power of the pulse was equal to or less than the average power rating of the respective resistor.

The output from both of the pulsers was a rectangular pulse with a variable PRF. The form of the pulse from both pulsers conformed closely to the rectangular pulse shown in Figure 3. The pulse from the Velonex pulser had a variable width; the Standards Laboratory pulser had a fixed pulse width.

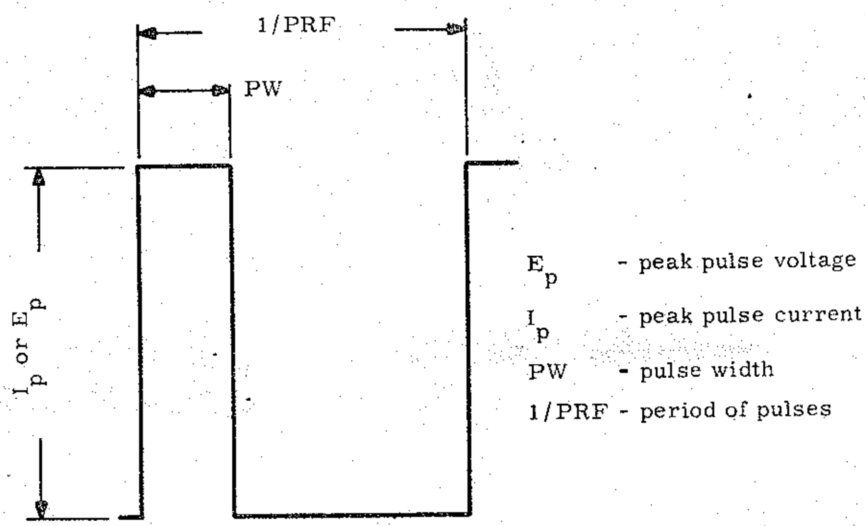

Figure 3. Pulse waveform

Power of the pulse: $P_{pulse} = (Ip) \times (Ep)$ or $P_{pulse} = \frac{(Ep)^2}{R}$

Energy of the pulse: $E_{pulse} = (P_{pulse}) \times (PW)$

Average power of the pulse: $P\ avg. = (P_{pulse}) \times \frac{(PW)}{(1/PRF)}$

Duty factor of the pulse: $DF = \frac{PW}{(1/PRF)}$

Determining Maximum Safe Voltage

The maximum safe voltage (for the resistor under test) versus the resistance value (for each of the three types of resistors tested) is plotted on the graphs shown on the following pages (Figures 4 through 11). Data Tables I through III follow each set of graphs. The maximum safe voltage (E_{pulse}) is the voltage at which the resistor* did not change in value during a minimum of 100 pulses. In most cases, the maximum pulse voltage is conservative by at least 10 percent. The graphs were drawn so that the lowest breakdown voltage sets the pattern of the curve. Two examples illustrating the use of the graphs follow.

1. An application requires that a resistor can withstand a pulse of 2 kilovolts at a pulse width of 20 microseconds with a resistance value of 2 kilohms. From the graphs, it is seen that the following resistors would meet the requirements:
   a. wire-wound - 3 watts or larger
   b. metal film - 1 watt or larger
   c. carbon composition - 1 watt or larger.
2. Another application requires that a resistor can withstand a pulse of 10 kilovolts at a pulse width of 20 microseconds with a resistance value of 100 kilohms. Again from the graphs it is seen that the following resistors would fill the requirements:
   a. wire-wound - 3 watts or larger
   b. metal film - 1 watt or larger
   c. carbon composition - 1 watt or larger.

If the pulse width is narrower than 20 microseconds, then the recommended maximum pulse voltage may be exceeded. If the pulse width is wider than 20 microseconds, then the maximum pulse voltage must be reduced. Figure 12 shows how the pulse width affects the maximum pulse voltage for one particular case.

During all of these tests the duty factor of the pulse was always less than 1 percent, and the average power was kept at or below the DC power rating of the resistor.

*A minimum of three resistors was tested in order to establish a reliable maximum safe voltage.

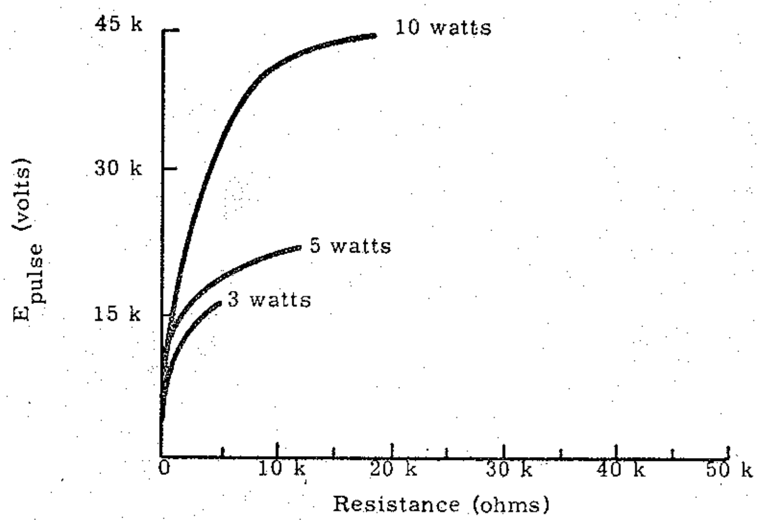

Figure 4. Wire-wound resistors

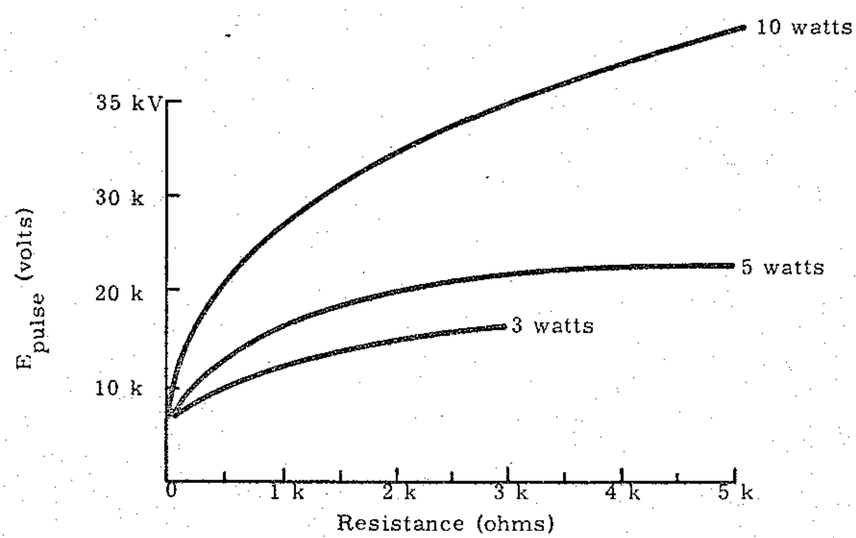

Figure 5. Wire-wound resistors

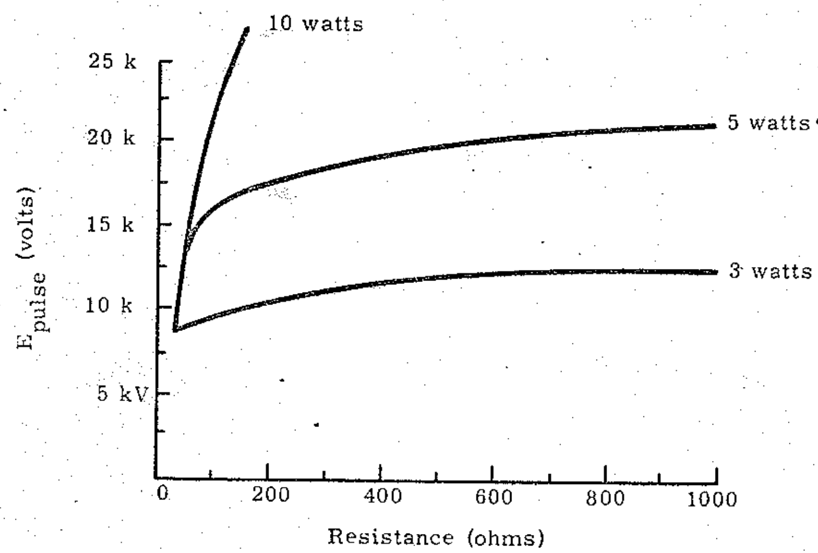

Figure 6. Wire-wound resistors

TABLE I

Wire-Wound Resistors Tested

Manufacturer and type	Power rating (watt)	Nominal resistance (ohms)	Maximum safe volt. (kV)	Pulse width (μsec)	Pulse power (MW)
Dale NS-2	2	50	8	20	1.3
Dale NS-2	2	100	12	20	1.4
Dale NS-2	2	600	16	20	0.4
Dale NS-2	2	1000	14	20	0.2
Dale NS-2	2	3000	20	20	0.13
Dale RS-2C	3	200	12	20	0.75
Dale RS-2C	3	499	14	20	0.40
Dale RS-2C	3	1000	12	20	0.14
Dale RS-2C	3	3000	16	20	0.09
Dale RS-5	5	50	>10	20	>2
Dale NS-5	5	100	20	20	4
Dale RS-5	5	200	24	20	2.9
Dale RS-5	5	499	22	20	1.0
Dale NS-5	5	1 k	20	20	0.4
Dale NS-5	5	4 k	<28	20	0.2
Dale NS-5	5	5 k	24	20	0.12
Dale RS-5	5	6 k	20	20	0.07
Dale NS-5	5	10 k	24	20	0.06
Dale RS-5	5	12 k	30	20	0.07
Dale NS-10	10	50	>10	20	>2
Dale NS-10	10	100	>24	20	>6
Dale NS-10	10	200	40	20	8
Dale RS-10	10	499	40	20	3.3
Dale NS-10	10	1000	30	20	0.9
Sprague	10	4.5 k	36	20	0.3
Dale RS-10	10	4.99 k	48	20	0.5
Dale NS-10	10	10 k	45	20	0.2
Ohmite	10	30 k	20	20	--
Dale NS-10	10	37 k	44	20	0.05
Sprague	10	70 k	20	20	--

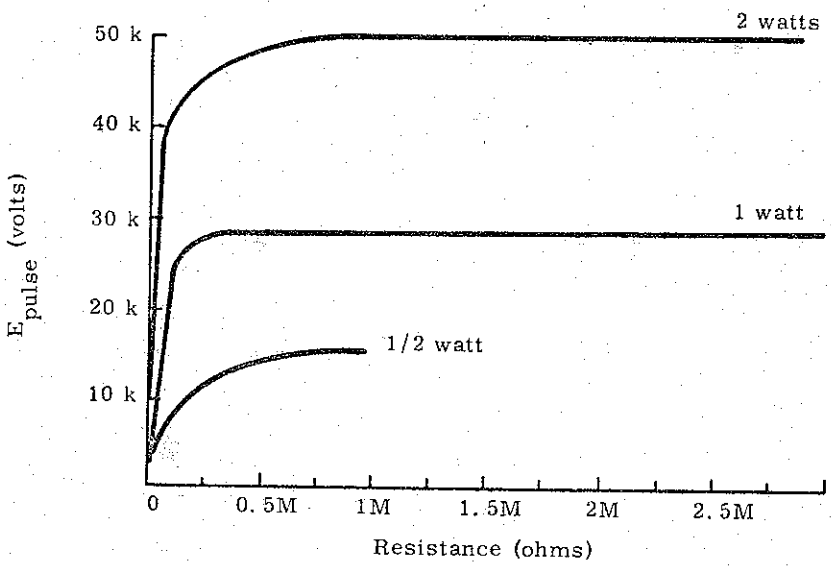

Figure 7. Metal film resistors

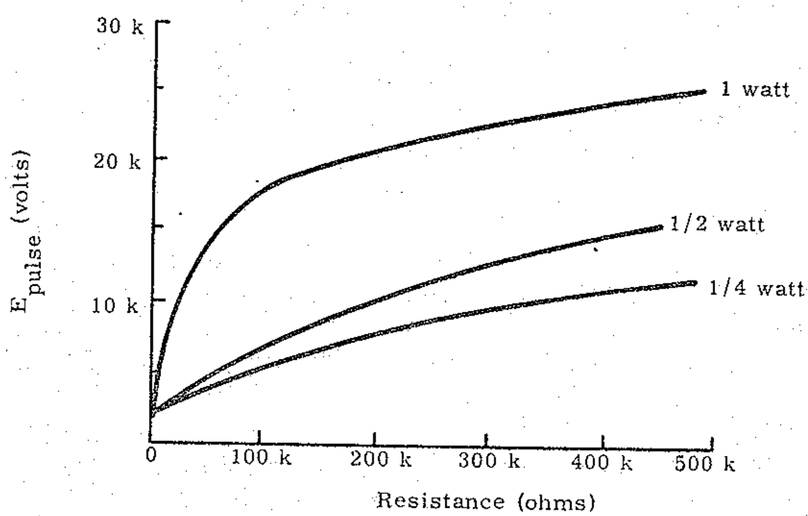

Figure 8. Metal film resistors

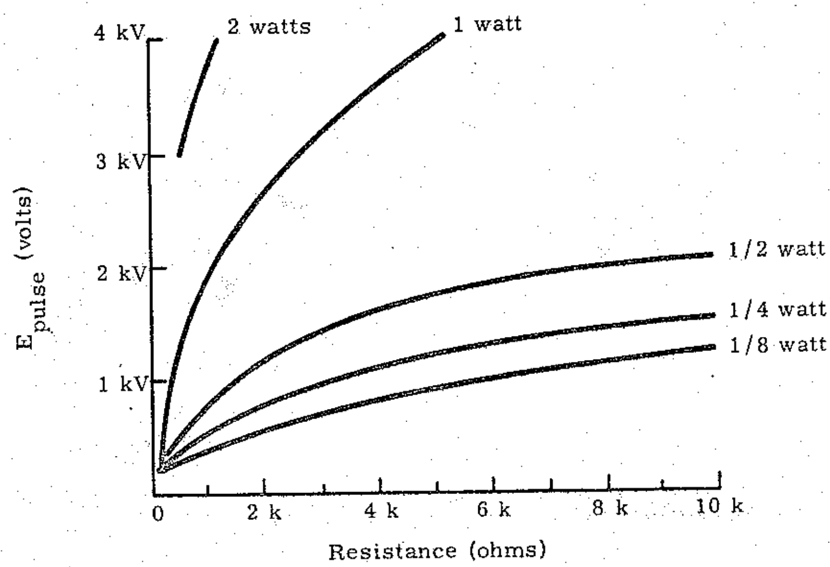

Figure 9. Metal film resistors

TABLE II

Metal Film Resistors Tested

Manufacturer and type	Power rating (watts)	Nominal resistance (ohms)	Maximum safe volt. (volts)	Pulse width (μsec)	Pulse power (watts)
IRC-MEA	1/8	100	200	20	400
IRC-MEA	1/8	178	250	20	350
IRC-MEA	1/8	442	200	20	90
IRC-MEA	1/8	825	600	20	450
IRC-MEA	1/8	1100	1250	20	1400
IRC-MEA	1/8	1540	500	20	166
IRC-MEA	1/8	3480	1250	20	400
IRC-MEA	1/8	6191	1000	20	160
IRC-MEA	1/8	11 k	1250	20	145
IRC-MEB	1/4	100	150	20	225
IRC-MEB	1/4	196	200	20	200
IRC-MEB	1/4	365	300	20	250
IRC-MEB	1/4	750	400	20	210
IRC-MEB	1/4	1050	700	20	490
IRC-MEB	1/4	1960	1250	20	800
IRC-MEB	1/4	4220	1750	20	700
IRC-MEB	1/4	10.5 k	1500	20	225
IRC-MEB	1/4	20 k	2 kV	20	200
IRC-MEB	1/4	40 k	3.5 kV	20	300
IRC-MEB	1/4	60 k	5 kV	20	400
IRC-MEB	1/4	75 k	6 kV	20	480
IRC-MEB	1/4	100 k	7 kV	20	500
IRC-MEB	1/4	150 k	7 kV	20	330
IRC-MEB	1/4	215 k	12 kV	20	700
IRC-MEB	1/4	487 k	12 kV	20	300
IRC-MEC	1/2	100	400	20	1.6
IRC-MEC	1/2	200	600	20	1.8
IRC-MEC	1/2	300	600	20	1.2
IRC-MEC	1/2	600	700	20	0.8
IRC-MEC	1/2	1000	800	20	0.6
IRC-MEC	1/2	1620	1500	20	1.5
IRC-MEC	1/2	3160	1500	20	0.8
IRC-MEC	1/2	5900	>2000	20	0.7
IRC-MEC	1/2	8600	>2000	20	0.5
IRC-MEC	1/2	50 k	6 k	20	0.7
IRC-MEC	1/2	100 k	7 k	20	0.5
IRC-MEC	1/2	464 k	16 k	20	0.5
IRC-MEC	1/2	750 k	16 k	20	0.3
IRC-MEC	1/2	909 k	16 k	20	0.3
IRC-MEF	1	200	600	20	1.8
IRC-MEF	1	1 k	2 k	20	4.0
IRC-MEF	1	10 k	8 k	20	6.4
IRC-MEF	1	100 k	18 k	20	3.6
IRC-MEF	1	1 M	32 k	20	1.0

TABLE II (cont)

Manufacturer and type	Power rating (watts)	Nominal resistance (ohms)	Maximum safe volt. (volts)	Pulse width (μsec)	Pulse power (watts)
Dale	1	3 M	28 k	20	0.3
IRC-MEH	2	1 k	3 k	20	9
IRC-MEH	2	10 k	40 k	20	160
IRC-MEH	2	100 k	46 k	20	23
Dale	2	1 M	50 k	20	2.5
Dale	2	5 M	50 k	20	0.5

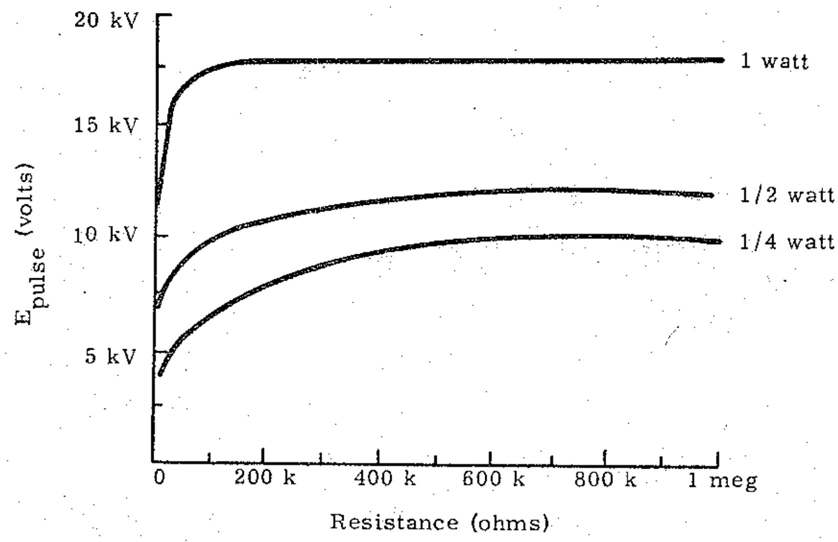

Figure 10. Carbon-composition resistors

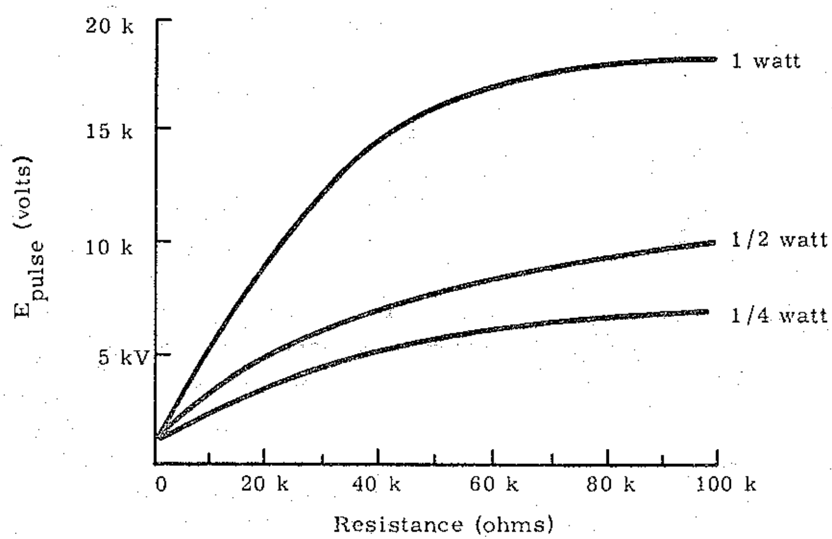

Figure 11. Carbon-composition resistors

TABLE III

Carbon-Composition Resistors Tested

Manufacturer and type	Power rating (watt)	Nominal resistance (ohm)	Maximum safe volt. (volts)	Pulse width (μsec)	Pulse power (kW)
Allen-Bradley	1/4	51	200	20	0.8
Allen-Bradley	1/4	100	500	20	2.5
Allen-Bradley	1/4	200	500	20	1.2
Allen-Bradley	1/4	300	1250	20	5.0
Allen-Bradley	1/4	500	2000	20	8.0
Allen-Bradley	1/4	750	2000	20	5.0
Allen-Bradley	1/4	1000	750	20	0.6
Allen-Bradley	1/4	2000	2 k	20	2.0
Allen-Bradley	1/4	5100	2 k	20	0.8
Allen-Bradley	1/4	7500	2 k	20	0.5
Allen-Bradley	1/4	10 k	4 k	20	1.6
Allen-Bradley	1/4	51 k	6 k	20	0.7
Allen-Bradley	1/4	75 k	8 k	20	0.9
Allen-Bradley	1/4	110 k	9 k	20	0.7
Allen-Bradley	1/4	150 k	10 k	20	0.7
Allen-Bradley	1/4	200 k	8 k	20	0.3
Allen-Bradley	1/4	1.2 M	10 k	20	0.1
Allen-Bradley	1/2	51	750	20	11
Allen-Bradley	1/2	100	750	20	5.6
Allen-Bradley	1/2	200	750	20	2.8
Allen-Bradley	1/2	300	750	20	1.9
Allen-Bradley	1/2	500	750	20	1.1
Allen-Bradley	1/2	1 k	2 k	20	4.0
Allen-Bradley	1/2	2 k	2 k	20	2.0
Allen-Bradley	1/2	20 k	12 k	20	7.0
Allen-Bradley	1/2	56 k	14 k	20	4.0
Allen-Bradley	1/2	100 k	7 k	20	0.5
Allen-Bradley	1/2	160 k	11 k	20	0.8
Allen-Bradley	1/2	390 k	12 k	20	0.4
Allen-Bradley	1/2	1 M	12 k	20	0.1
Allen-Bradley	1	51	>1 k	20	>2
Allen-Bradley	1	110	>1 k	20	>1.0
Allen-Bradley	1	200	>2 k	20	>20
Allen-Bradley	1	240	8 k	20	250
Allen-Bradley	1	390	8 k	20	130
Allen-Bradley	1	1 k	8 k	20	64
Allen-Bradley	1	2.2 k	12 k	20	67
Allen-Bradley	1	3.6 k	14 k	20	58
Allen-Bradley	1	6.2 k	16 k	20	40
Allen-Bradley	1	9.1 k	14 k	20	22
Allen-Bradley	1	20 k	20 k	20	20
Allen-Bradley	1	39 k	18 k	20	8
Allen-Bradley	1	62 k	18 k	20	5
Allen-Bradley	1	220 k	18 k	20	1.4
Allen-Bradley	1	1.1 M	18 k	20	0.3

The following graph (Figure 12) shows that resistor life is a function of pulse voltage with varying pulse widths. From the graph, it is seen that the narrower the pulse width the longer the life of the resistor. For example, a pulse of 800 volts will open the resistor in less than 10 pulses at a pulse width of 10 microseconds; on the other hand, the resistor will still be good at the end of 100 pulses at a pulse width of 1 microsecond.

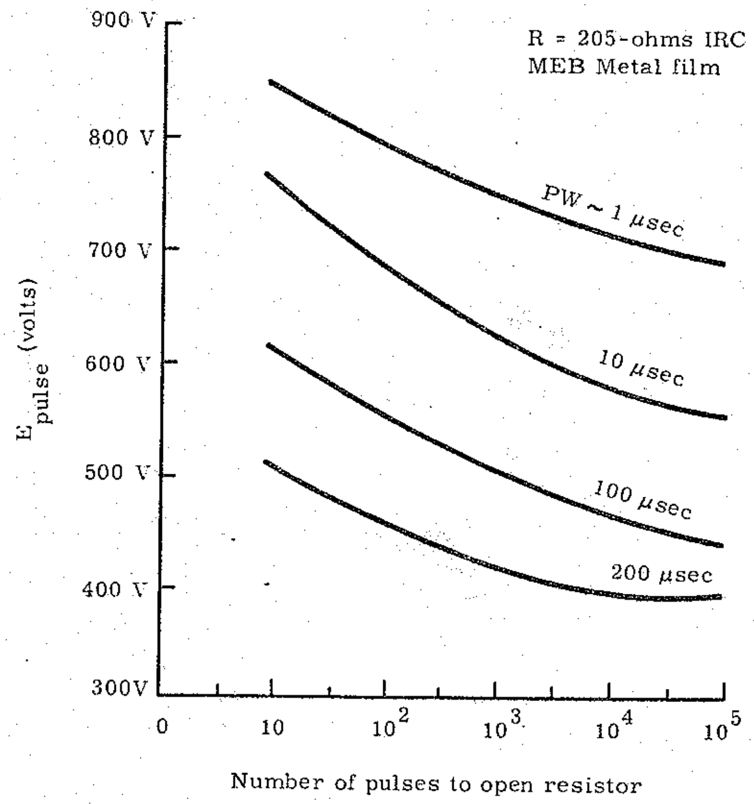

Figure 12. Pulse width vs maximum pulse voltage

Types of Failures

Figure 13 is a photograph of some of the resistors tested for this report. The first column of Figure 13 shows the Dale wire-wound resistors ranging from the large 10-watt type to the smaller 2-watt type. The second column shows the IRC metal film resistors ranging from the 2 watts (MEH) to the 1/8 watt (MEA). The resistor at the top of the third column is a Dale 2-watt metal film resistor. The remaining three resistors in the third column are the carbon-composition type ranging from 1 watt on top to the 1/4 watt on the bottom.

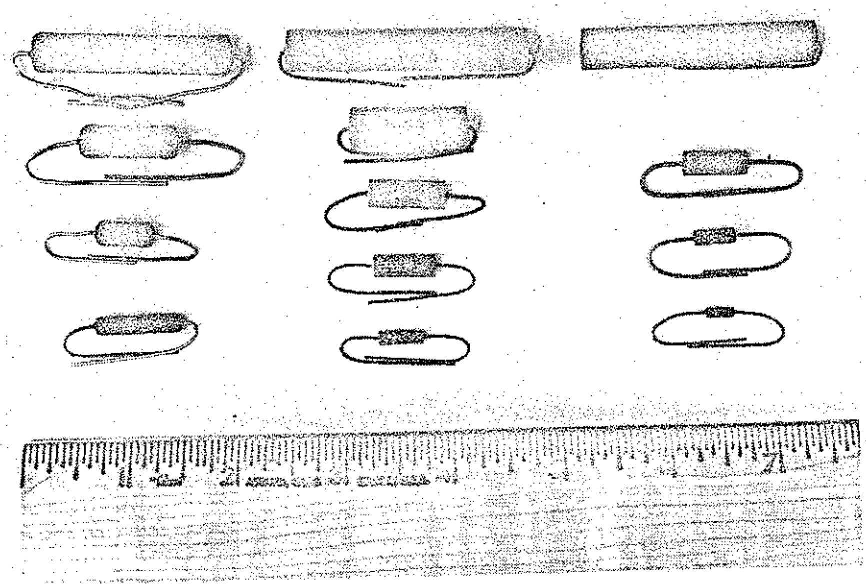

Figure 13. Types of resistors used for testing

Figure 14 shows some of the other types of resistors tried during the testing. All of these resistors were found to be inferior or not as predictable as the resistors on which this report is based. For example, the Ohmite 10-watt wire-wound resistor was found to stand up well under a high-voltage pulse in two of the three resistors tried, but the third resistor tried failed at about half the pulse voltage the others withstood. Also, the film resistors on the right of the photograph broke down at less than half the pulse voltage the IRC film resistors withstood.

Figures 15, 16, and 17 show the wire-wound metal film, and carbon-composition resistors before and after the pulse tests. However, not all the resistors failed by blowing the outer casing off as these pictures might indicate. There were actually three types of failures which were noted while testing the resistors.

1. Internal Breakdown -- This breakdown occurred when the resistor under test opened but did not blow apart or was not accompanied by any noticeable arcing. Internal breakdown was usually found in the lower value of metal film and carbon-composition resistors below 5000 ohms.

2. Arc Across Resistor Casing -- This type of breakdown was exemplified by an arc across the top of a resistor. However, upon checking the resistor at a lower pulse voltage, it was found to be in good condition. Then when the resistor was again tested at the higher voltage, it again arced. Evidently the ceramic casing was giving the pulse a lower path resistance than the resistor core, and a large pulse was traveling across the casing of the resistor without reentering the core area. This type of failure was most common among the higher resistance values of all three types of resistors tested.

3. Catastrophic Breakdown -- This type of breakdown is actually a special case of the previous type of breakdown. All of the resistors which failed, pictured in Figures 15, 16 and 17, are in this third category. The method of failure is as follows: normally, a pulse moves through a resistor by means of current which travels in the core. But in the resistors under test, an arc starts across the top of the resistor casing and then finds a path back through the ceramic casing into the core. This new path (part way on the casing and part way in the core) is of lower resistance than the path through the core. The lower resistance is then subjected to a higher pulse power than the total resistance would have been. This higher power heats up the remaining core area causing it to open and blow the casing off as shown.

Figure 18 illustrates the two different types of carbon-composition resistors tried during the testing. These two types can be distinguished in the photograph since the structure of the resistor with the smaller core area has rounded ends, while the structure of the resistor with the larger core area has square ends. The larger core area type of resistor withstood a pulse of more than 10 times the power of the smaller core area type of resistor.

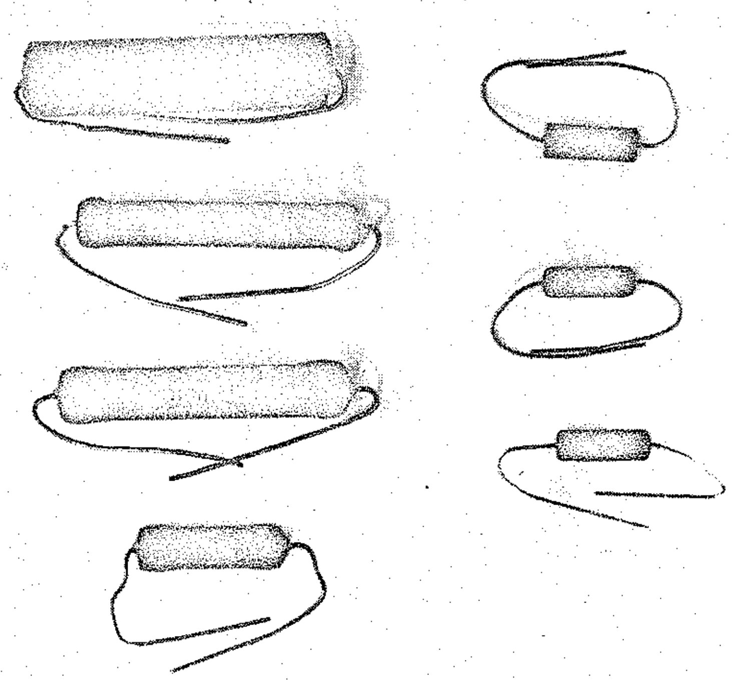

Figure 14. Other types of resistors tried for testing

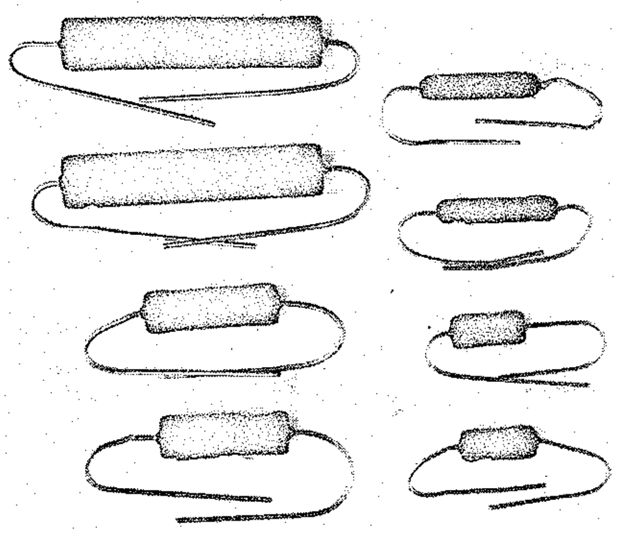

Figure 15. Wire-wound resistors before and after pulse tests

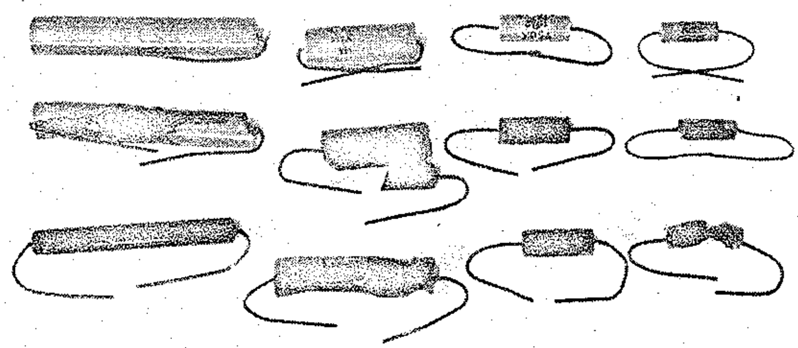

Figure 16. Metal film resistors before and after pulse tests

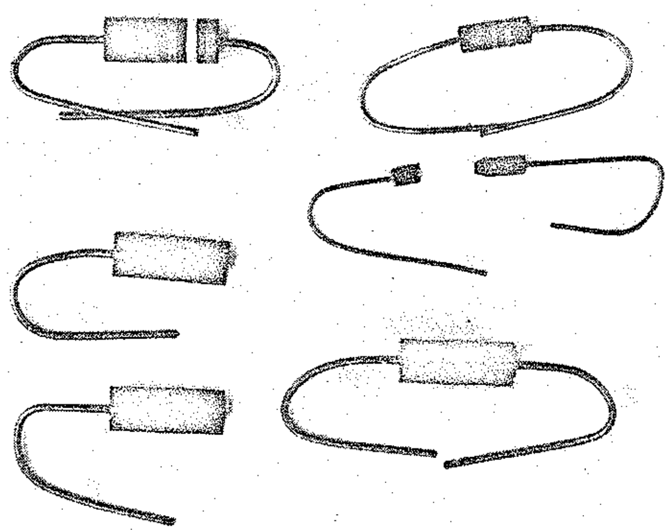

Figure 17. Carbon-composition resistors before and after pulse tests

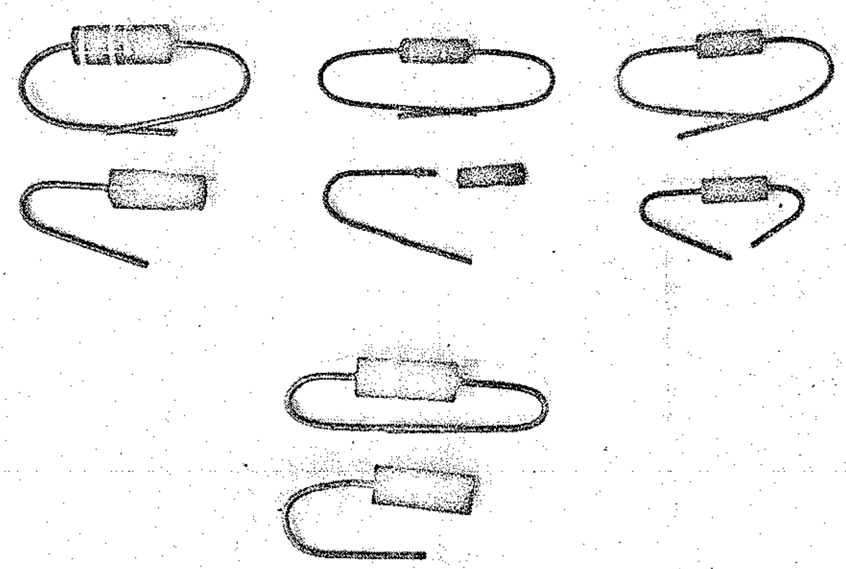

Figure 18. Internal and external differences in carbon-composition resistors

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