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Resistor Pulse Handling Capability

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RESISTOR PULSE HANDLING CAPABILITY

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A B S T R A C T

This report describes methods for calculating pulse-handling capabilities of various resistor types. The work represents a compilation of studies derived from various sources, as indicated in the bibliography. The results indicate that resistors may be subjected to short-duration pulses exceeding their rated powers without sustaining permanent damage.

Introduction

All types of resistors are capable of withstanding short duration spikes above their continuous rated power levels. However, their performance varies depending on the construction. Whereever possible, wirewound, inductively wound styles should be specified for pulse applications. Manufacturers provide nomograghs and charts for selecting appropriate resistors for specific pulse applications.

More susceptible to pulse degradation are metal glaze, thick film, metallic thick film, carbon composition, and carbon film resistor types--the latter being least able to withstand high voltage spikes.

Failure Modes

Under high-energy pulse conditions, resistors fail because of inability to dissipate heat generated due to the electrical energy of the pulse. Failure may occur as a catastrophic shattering of the resistor, internal breakdown causing the resistive element to open, or arcing across the resistor casing (not heat related). A change in resistance value following pulse application can also be considered a failure. No valid method of predicting failure mode was found, although magnitude and repetition rate of pulse application are related to the severity of the failure.

Pulse Handling Computations

The amount of energy to be dissipated through a given resistor is dependent on the voltage, the dc resistance, and the time or pulse length. For repetitive square-shaped pulses, the duty cycle must also be considered. Initially, calculate the pulse power:

$$P = \frac{V^2}{R}$$

where P = pulse power in watts
V = pulse voltage in volts
R = resistance in ohms

The energy of the pulse is then derived:

$$E = Pt$$

when E = energy (watt-seconds or Joules)
t = pulse duration in seconds

next, watt-seconds per ohm are found: $\frac{E}{R}$

Now, the energy-resistance chart (Appendix I) is entered for Dale wirewound resistors with the energy per ohm value equal to or greater than the calculated value. Follow that horizontal line until the desired resistance or next higher value is found. The resistor styles shown at the top of the column are the smallest size capable of handling the pulse.

For TRW-IRC wirewound resistors, curves are provided showing watt-seconds versus ohms. Therefore, it is not necessary to determine watt-seconds per ohm, but merely watt-seconds and the desired value. Appendix II then provides the appropriate IRC style wirewound resistors for a given application.

The above procedures are valid for single pulse applications or repetitive pulses of less than 100 millisecond width for short duration of five seconds or less. For pulse chain applications, the average power in addition to individual pulse energy must be considered. The average pulse power is derived from the single energy pulse as follows:

$$P_A = \frac{Pt}{T}$$

where P_A = average power in watts
P = pulse power in watts
t = pulse width in seconds
T = cycle time in seconds

A new energy based on the summation of pulse energy and the contribution due to average power must then be computed.

$$E_{AP} = E(1 + P_A/P_R)$$

where: E_{AP} = pulse energy + average power energy in watt-seconds
E = pulse energy
P_A = average power
P_R = continuous power rating of a resistor style chosen as a starting point

Divide E_{AP} by R to find the energy per ohm and enter the chart as previously discussed.

For the special case involving a capacitor discharge circuit, calculate the pulse energy as follows:

$$E = \frac{CV^2}{2}$$

where: C = capacitance in farads

V = peak voltage

Extrapolation For Resistors of Other Types

Normally, for pulse applications, wirewound resistors should be selected because their performance is predictable. If other types are desired, calculations based on wirewounds should first be made and then the power ratings should be increased for the resistor type desired as follows:

Metal glaze:	1.5
Metallic thin film:	2.0
Carbon composition:	2.5
Carbon film:	2.0

It should also be noted that the resistance of carbon composition and carbon film resistors may be expected to increase after pulse application.

APPENDICES

The following appendices include charts and tables for use in selecting resistors of various manufacture for specific pulse applications as determined by calculation in the foregoing sections.

APPENDIX I: Tables for use with Dale Electronics EGS, RS, and G series wirewound resistors.

APPENDIX II: Charts for use with IRC-TRW, AS, PW, PPW, and RG style wirewound and metal glaze resistors.

APPENDIX III: Empirical results of tests performed on specific wirewound, metal film, and carbon composition resistors (SC-TM-559).

APPENDIX IV: A bibliography of publications used as source material for this nomograph.

APPENDIX I

Dale Wirewound Resistors
Energy-Resistance Chart

ENERGY PER OHM JOULES OR WATT-SECOND	RESISTANCE (OHMS)								
	EGS-1 RS-1/4 G-1	EGS-2 RS-1/2 G-2	EGS-3 RS-1A G-3	ESS-2B RS-2B G-5	RS-2C G-5C	RS-2 G-6	RS-5 EGS-10 RS-5-69 G-10	RS-7 G-12	RS-10 ESS-10 RS-10-38 G-15
13.9×10^{-6}	3480	4920	10.4K	24.5K	32.3K	47.1K	90.9K	154K	265K
20.3×10^{-6}	2589	3659	7580	18.69K	24.19K	31.79K	69.4K	114.9K	197K
28.7×10^{-6}	1999	2829	5840	14.19K	18.29K	26.99K	51.7K	88K	152K
39.5×10^{-6}	1549	2189	4630	10.89K	13.69K	20.69K	40.4K	68.59K	111K
53.1×10^{-6}	1239	1749	3630	8600	11.39K	16.69K	31.4K	54.39K	93.5K
70.0×10^{-6}		1414	2920	6980	9250	13.59K	25.9K	44.19K	75.5K
90.6×10^{-6}	1000	1149	2740	6550	7560	11.09K	24.5K	36.79K	71.5K
145×10^{-6}	670	947	1960	4650	6260	8910	17.3K	29.5K	50.6K
221×10^{-6}	492	684	1420	3370	4560	6570	12.7K	20.59K	37.4K
324×10^{-6}	355	502	1040	2460	3270	4820	9220	15.69K	26.9K
460×10^{-6}	272	384	792	1860	2480	3640	7000	11.89K	20.4K
632×10^{-6}	206	291	615	1340	1920	2840	5460	9240	15.7K
850×10^{-6}	167	236	487	1150	1530	2260	4310	7320	12.4K
1.12×10^{-3}	131	186	393	935	1201	1800	3850	5900	10K
2.07×10^{-3}	96.3	136	283	671	910	1250	2840	4260	7540
3.54×10^{-3}	65.1	92	192	454	601	875	1690	2870	4920
5.67×10^{-3}	45.7	64.5	134	313	424	617	1160	2030	3460
8.65×10^{-3}	33.2	47	97.7	227	307	444	843	1470	2510
12.7×10^{-3}	23.8	33.6	71.1	168	222	310	622	1073	1840
20.4×10^{-3}	17.9	25.3	51.8	122	163	237	447	777	1340
33.2×10^{-3}	12.2	17.2	36.1	85.5	113	165	320	544	932
56.7×10^{-3}	8.22	11.6	24.2	57.8	76.3	111	215	364	618
.055	6.06	8.56	17.6	42.1	55.5	70.3	156	263	451
.090	4.47	6.32	13.3	31.6	40.5	51.0	116	201	343
.153	2.98	4.07	8.52	21.1	27.9	40.8	78.5	133	229
.245	2.18	3.09	6.28	14.8	19.6	28.6	55.4	95.0	160

APPENDIX I--Continued

ENERGY PER OHM JOULES OR WATT-SECOND	RESISTANCE (OHMS)								
	EGS-1 RS-1/4 G-1	EGS-2 RS-1/2 G-2	EGS-3 RS-1A G-3	ESS-2B RS-2B G-5	RS-2C G-5C	RS-2 G-6	RS-5 EGS-10 RS-5-69 G-10	RS-7 G-12	RS-10 ESS-10 RS-10-38 G-15
.374	1.50	2.13	4.57	10.8	14.2	21.0	40.2	68.2	117
.589	1.12	1.59	3.27	7.86	10.3	14.9	29.0	49.0	84.1
.943	.780	1.10	2.31	5.46	7.22	10.6	20.3	34.4	59.3
1.52	.542	.773	1.61	3.80	5.13	7.40	14.1	24.2	41.6
2.46	383	.538	1.13	2.69	3.56	5.47	10.11	17.2	29.4
3.76	271	.394	.829	1.99	2.61	3.81	7.36	12.4	21.4
5.98			.591	1.41	1.84	2.15	5.24	8.87	15.1
2.00	.178	.244	.423	1.02			3.86	6.44	11.2
2.61	.147	.201	.307	.773	1.36	1.59	2.86	4.79	8.1
4.23	.116	.159	.268	.681	1.00	1.35	2.52	4.09	7.0
5.23		.114	.210	.529	.784	1.04	2.00	3.19	5.4
8.04			.189	.475	.709	.949	1.84	2.99	4.9
13.4			.152	.383	.569	.764	1.43	2.29	3.9
20.9			.121	.297	.439	.591	1.12	1.79	3.1
33.2				.237	.354	.468	.875	1.48	2.52
42.1				.188	.278	.369	.716	1.16	2.00
25.1				.168	.248	.332	.630	1.03	1.74
41.8				.121	.179	.209	.487	.77	1.26
67.7					.139	.196	.380	.60	.992
168.5					.102	.147	.276	.47	.699
100.4							.171	.29	.485
166.8							.114		.310
271								.179	.252
674								.110	.184

APPENDIX II

Chart Reference Guide for AS Resistors

TRW-1RC Wirewound Resistors

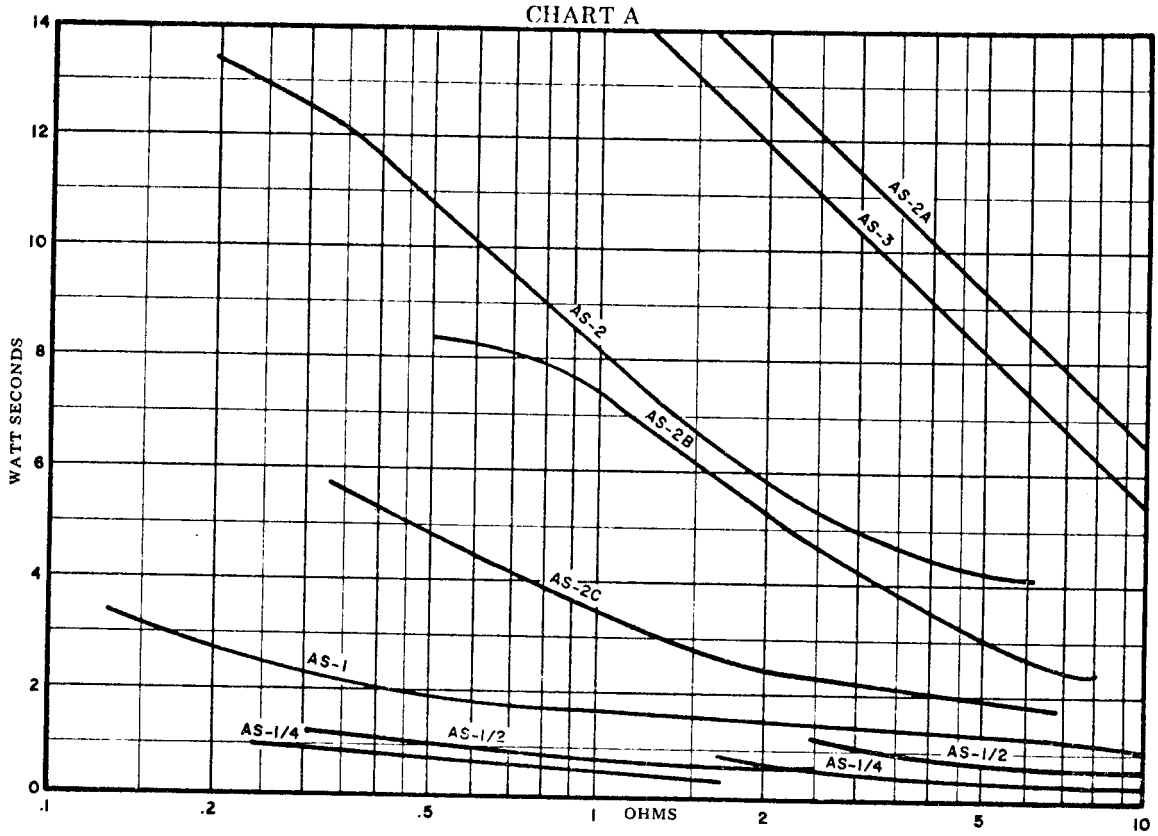
SIZE UNIT	POWER RATING @ 125°C	RANGE IN OHMS	CHART NUMBER
AS 1/4	1/4W	.27 thru 10	A
		10 thru 1K	B
		1K thru 4.3K	C
AS 1/2	1/2W	.3 thru 10	A
		10 thru 1K	B
		1K thru 7.6K	C
AS-1	1W	.15 thru 10	A
		10 thru 1K	B
		1K thru 10K	C
AS-2	2W	.1 thru .2	D
		.2 thru 10	A
		10 thru 1K	E
AS-2A	2.5W	.27 thru .75	D
		1.7 thru 10	A
		10 thru 1K	E
AS-2B	3W	.1 thru.47	D
		.5 thru 10	A
		10 thru 1K	E
		1K thru 27K	F
AS-2C	2W	.1 thru .27	D
		.33 thru 10	A
		10 thru 1K	B
		1K thru 10	F
AS-3	3W	.1 thru .27	K
		.27 thru 1	G
		1 thru 10	A
		10 thru 1K	E
		1K thru 50K	F
AS-5	5W	.1 thru .43	D
		.47 thru 1.8	G
		2.2 thru 10	H
		10 thru 1K	I
		1K thru 100K	F

APPENDIX II--Continued

TRW-1RC Wirewound Resistors

SIZE UNIT	POWER RATING @ 125°C	RANGE IN OHMS	CHART NUMBER
AS-7	7W	.1 thru .16	L
		.16 thru .6	K
		.68 thru 2.7	G
		3.3 thru 10	H
		10 thru 1K	I
AS-10	10W	.1 thru .43	L
		.43 thru 1.2	K
		1.3 thru 5.2	G
		6 thru 27	H
		33 thru 1K	I
		1K thru 100K	J

CHART A



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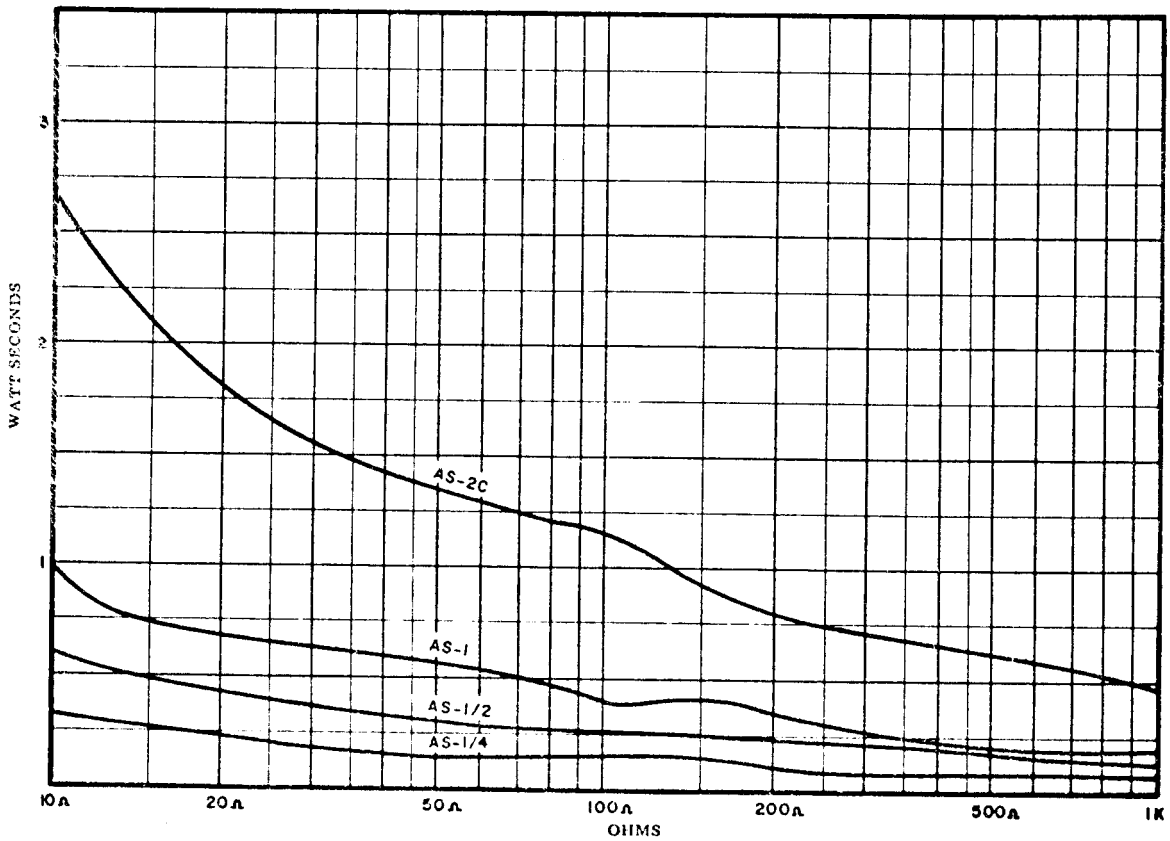

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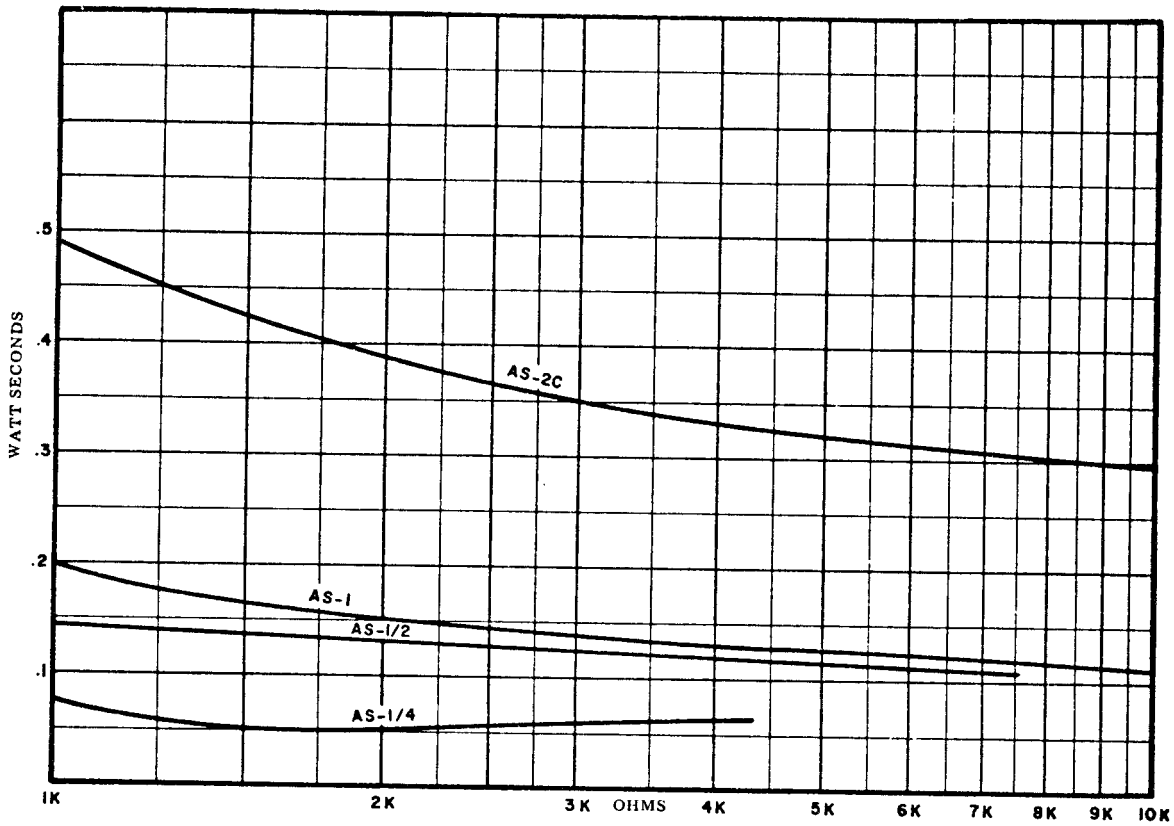

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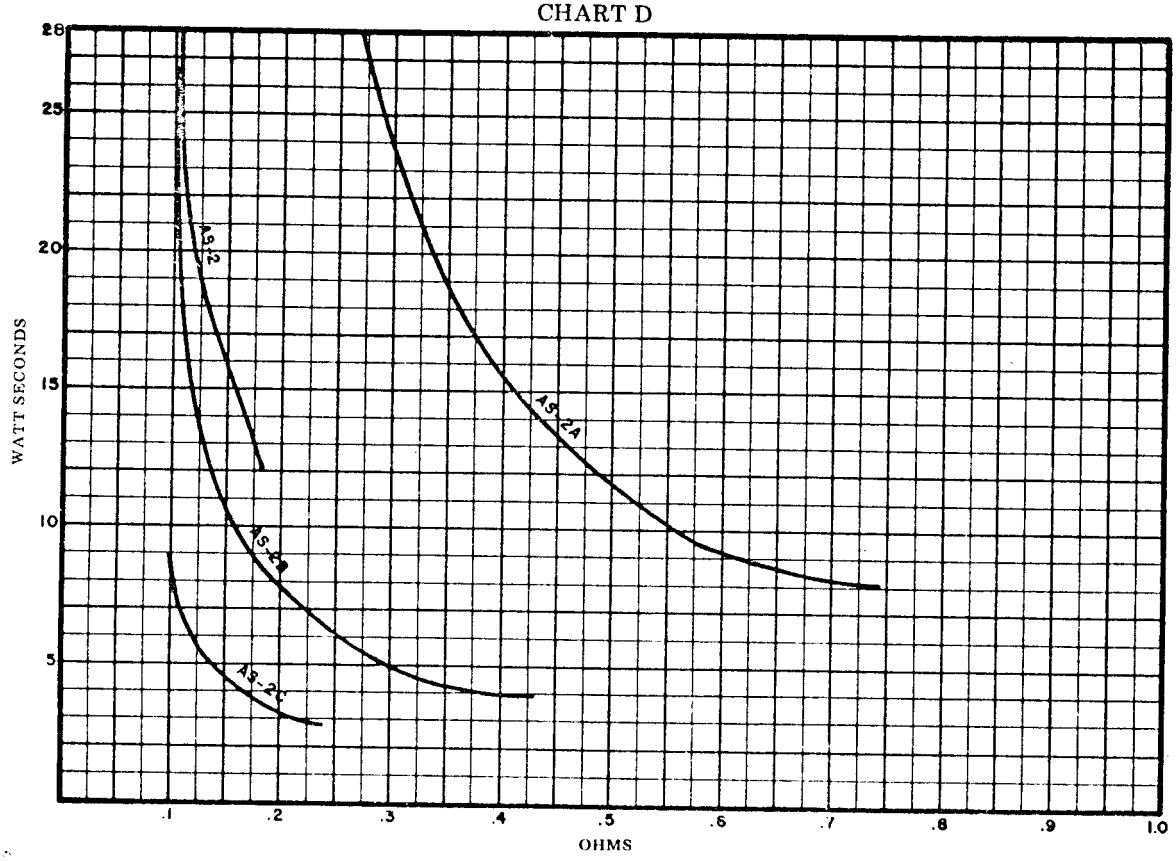

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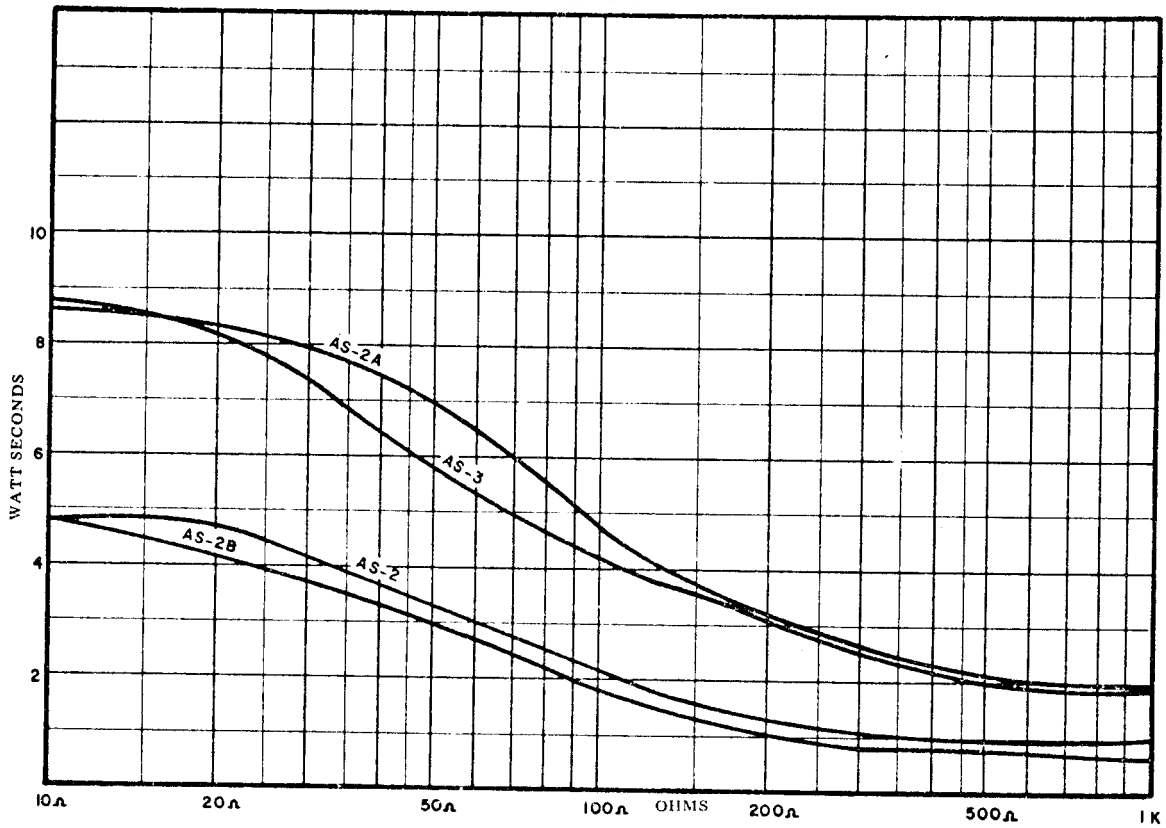

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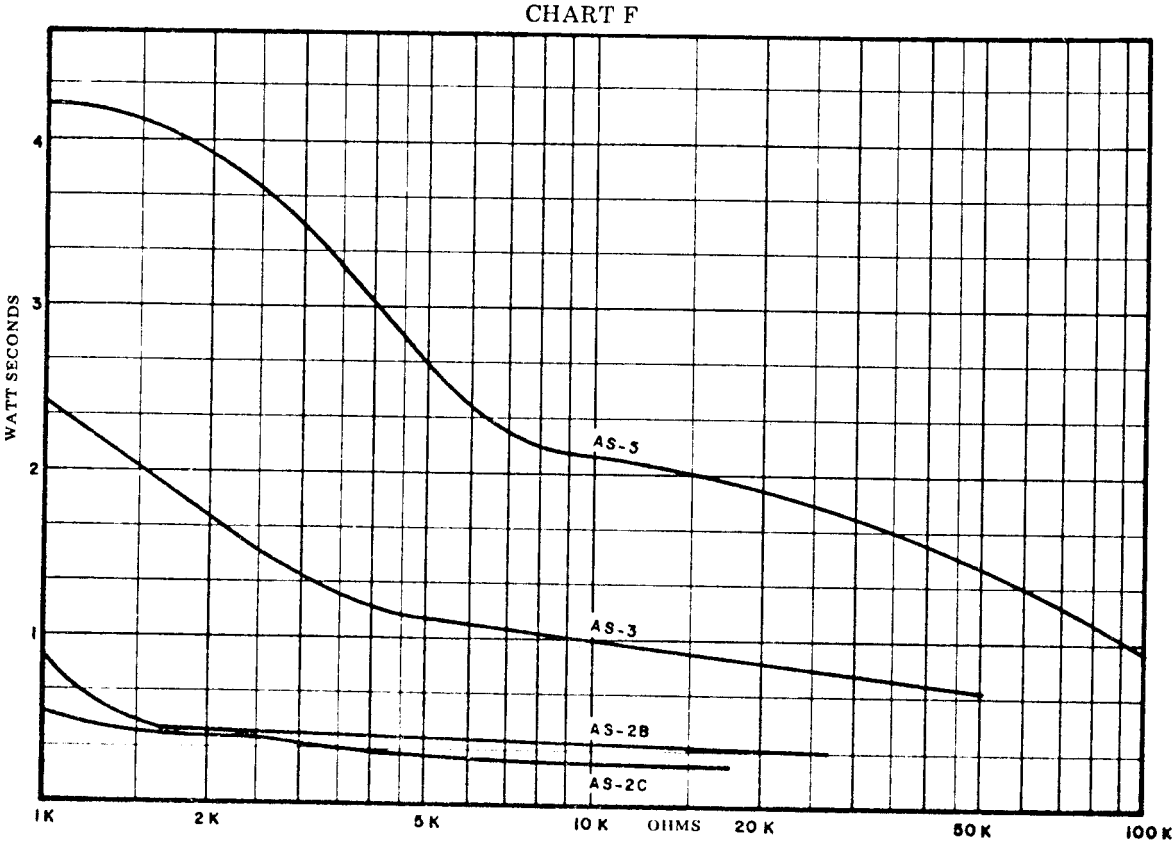

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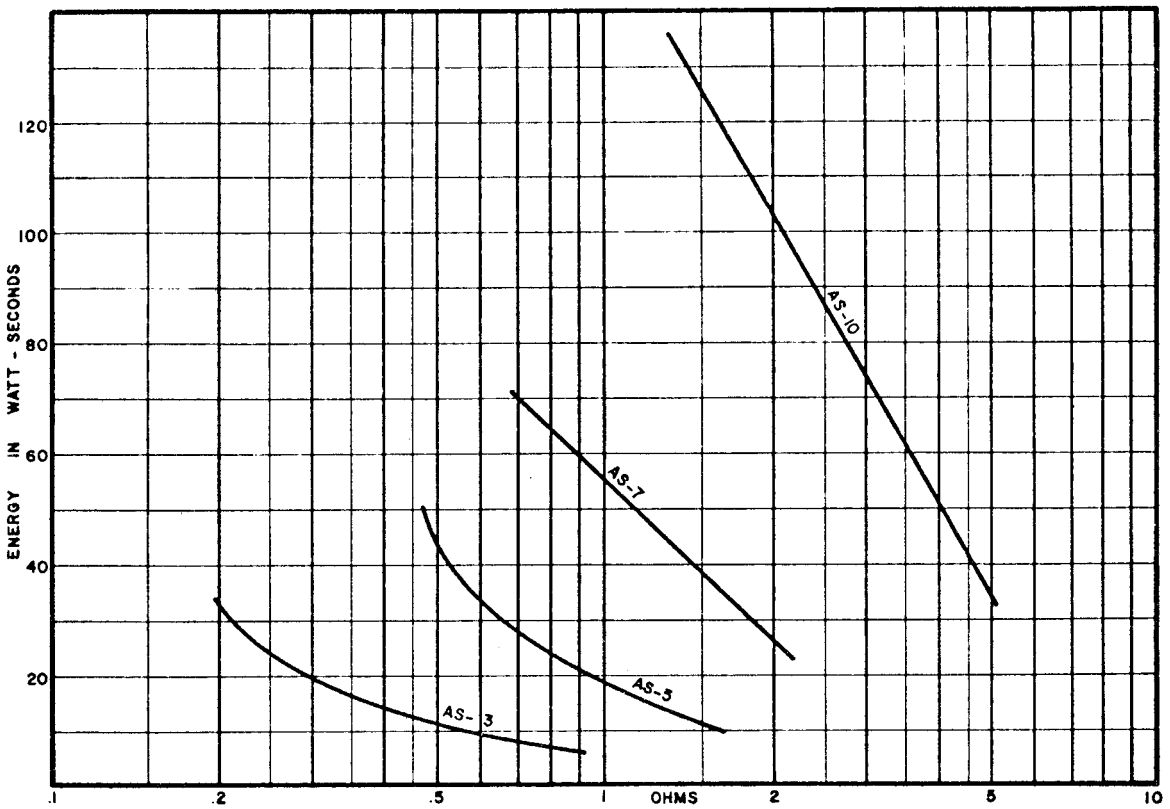

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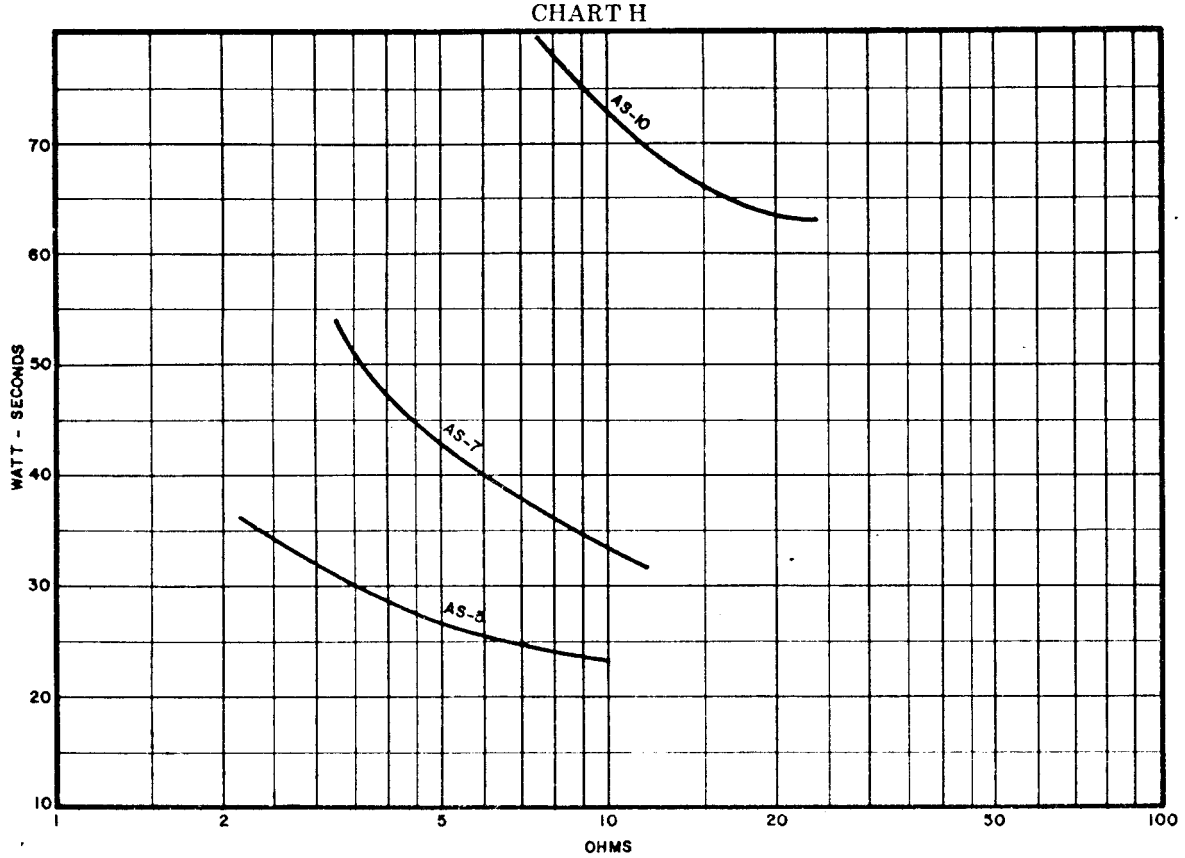

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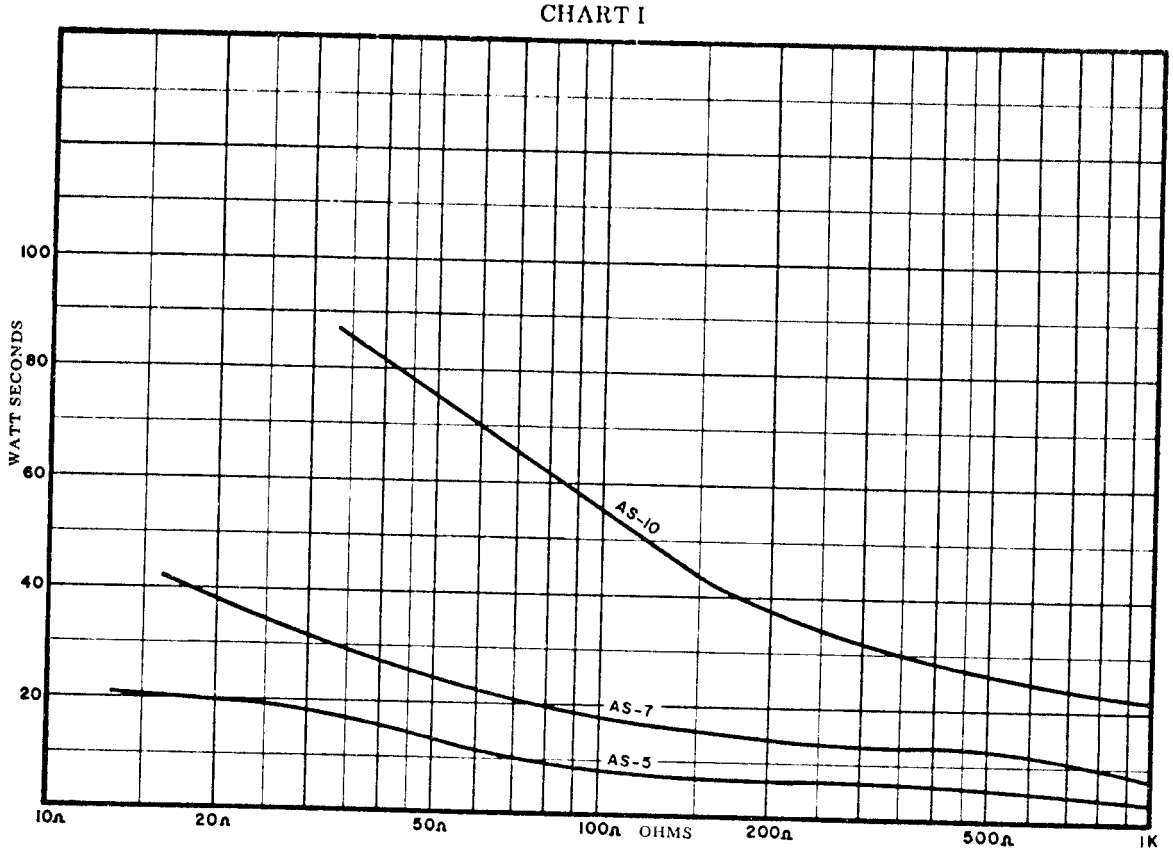

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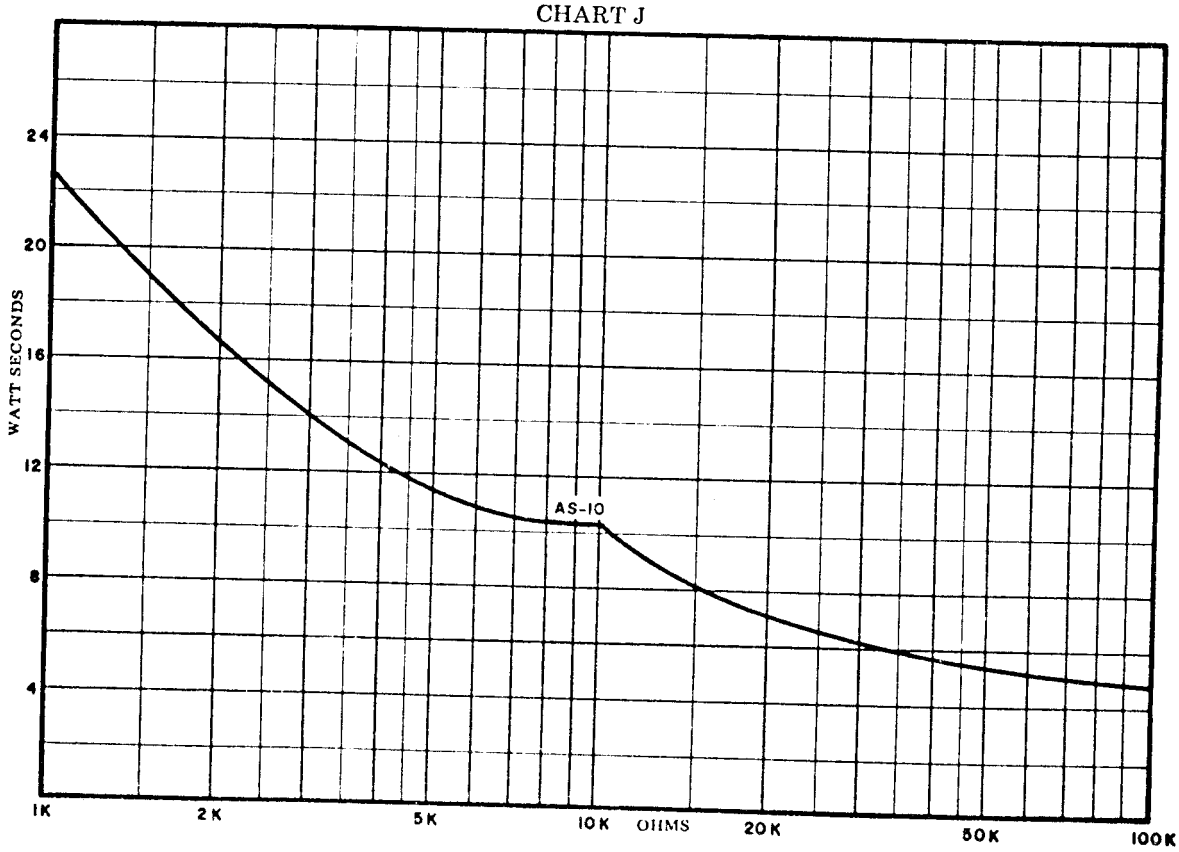

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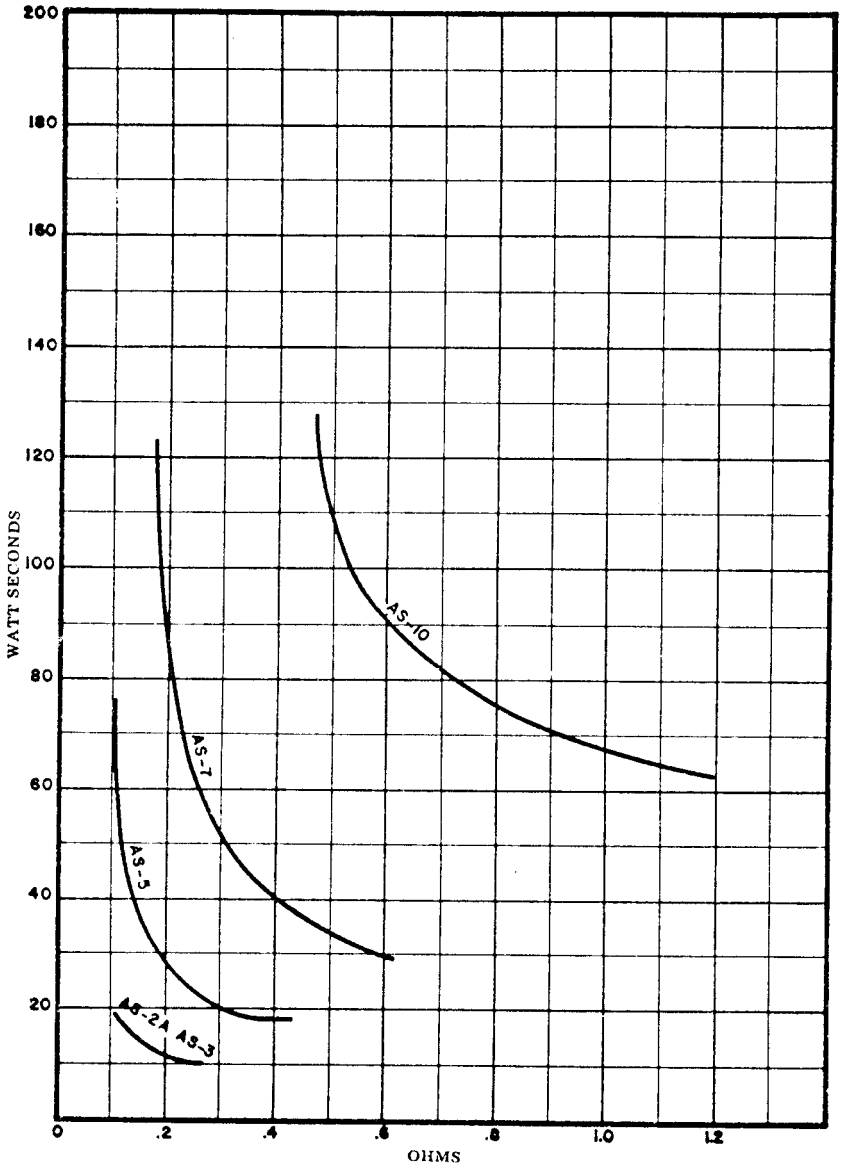
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140
120
100
80
60
40
20
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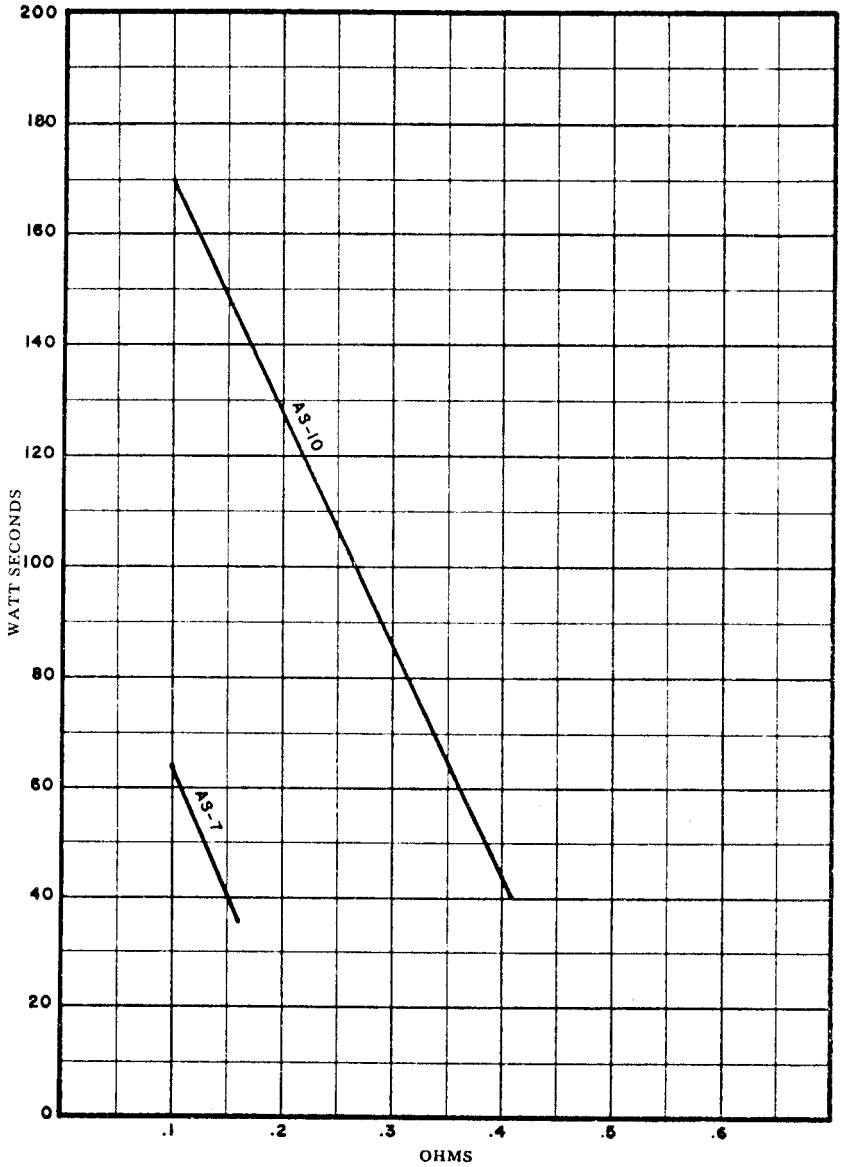
0
.2
.4
.6
.8
1.0
1.2
OHMS
AS-10
AS-7
AS-5
AS-2A
AS-3

CHART L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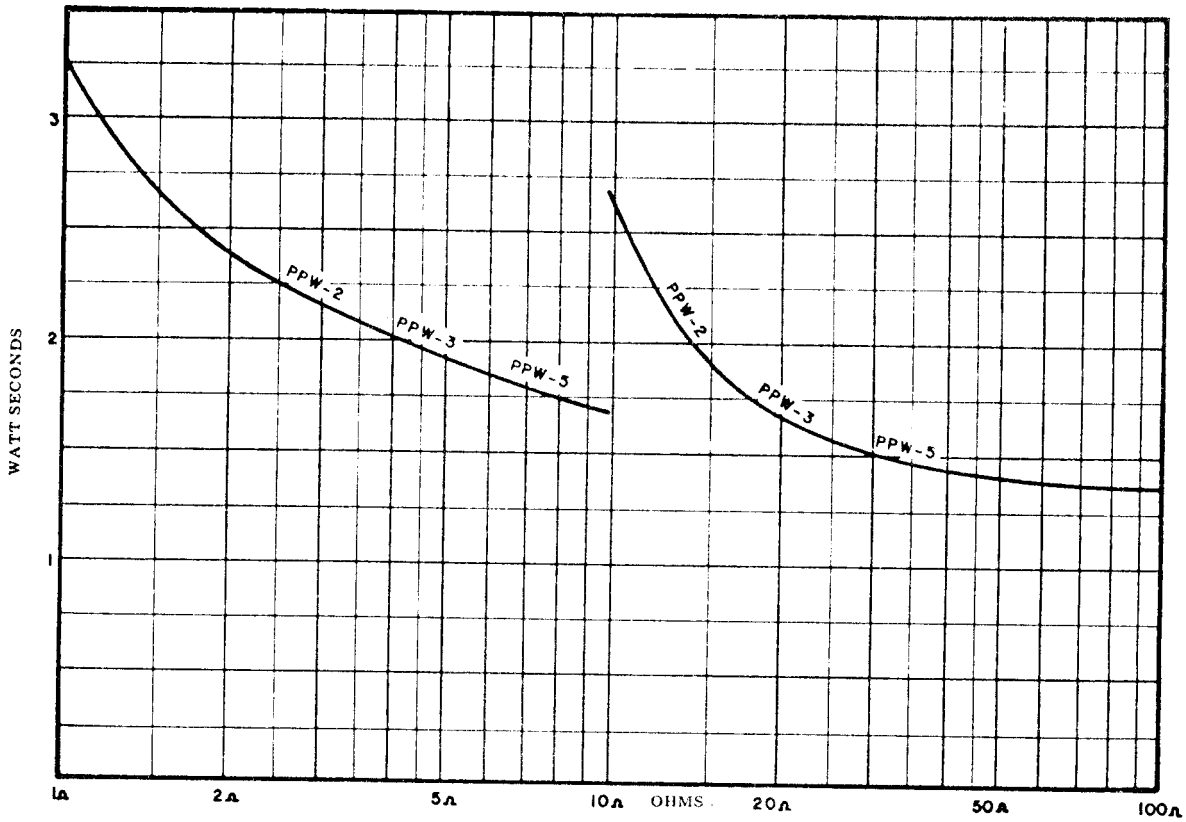
160
140
120
100
80
60
40
20
0
WATT SECONDS
AS-10
AS-7
.1
.2
.3
.4
.5
.6
OHMS

Chart Reference Guide for PPW Resistors

UNIT SIZE	POWER RATING @ 125°C	RANGE IN OHMS	CHART NUMBER
PPW-2	2W	1 thru 100	M
		100 thru 1.6K	N
PPW-3	3W	1 thru 100	M
		100 thru 1.6K	N
PPW-5	5W	1 thru 100	M
		100 thru 1.6K	N
PPW-7	7W	1 thru 100	O
		100 thru 3K	P
PW-10	10W	1 thru 100	O
		100 thru 5.2K	P
PW-15	15W	1 thru 100	O
		100 thru 5.1K	P

CHART M



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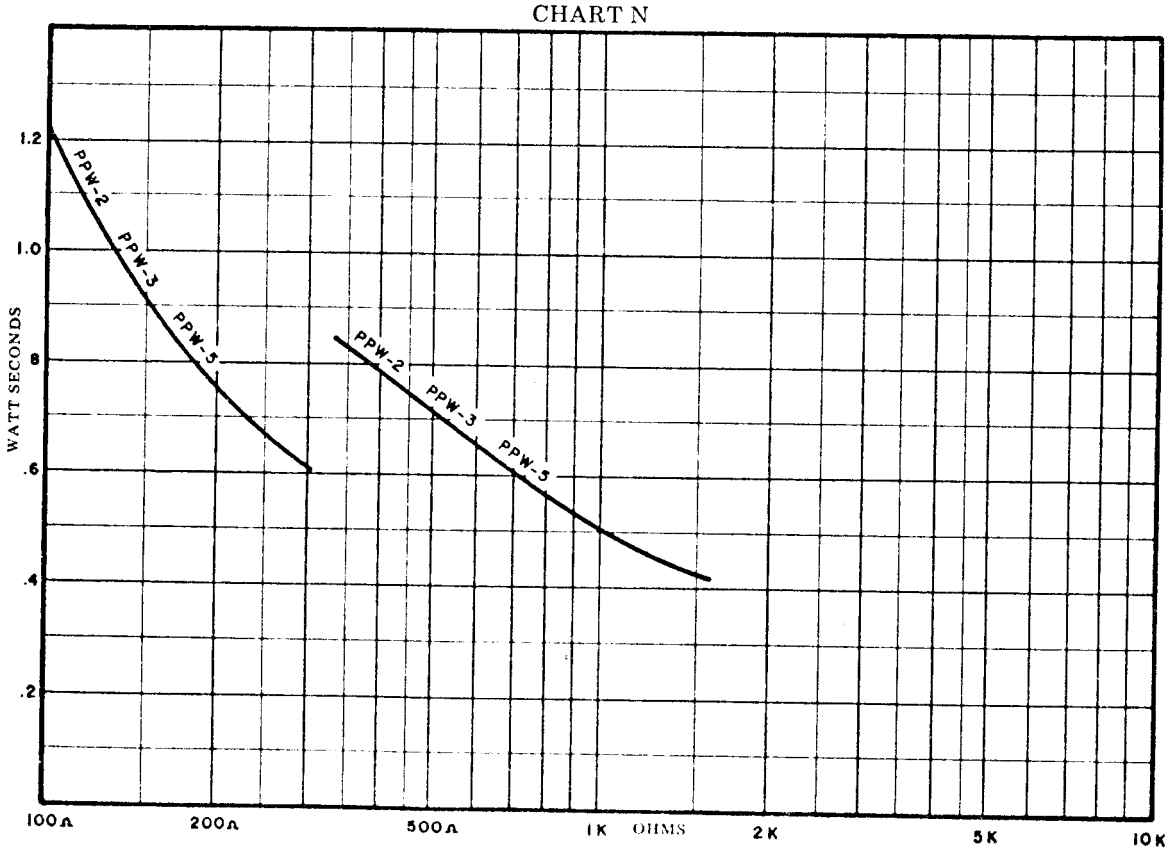

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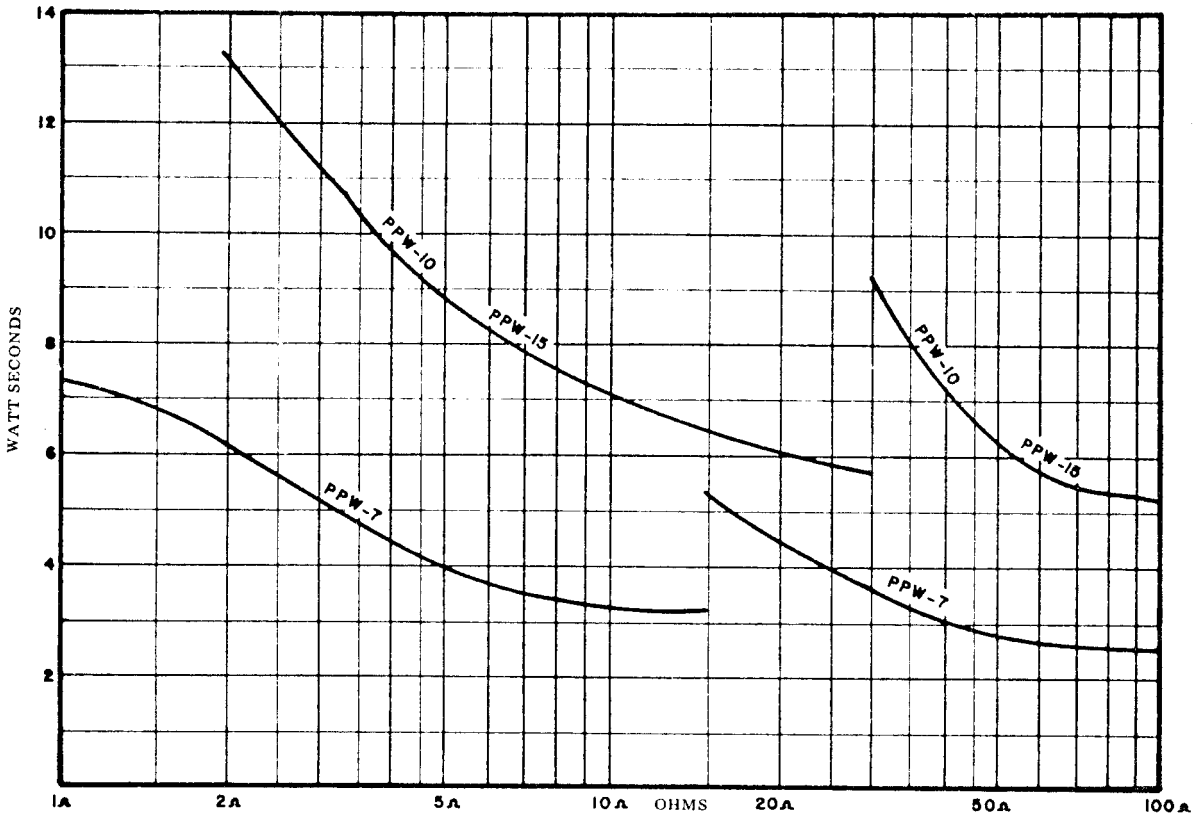

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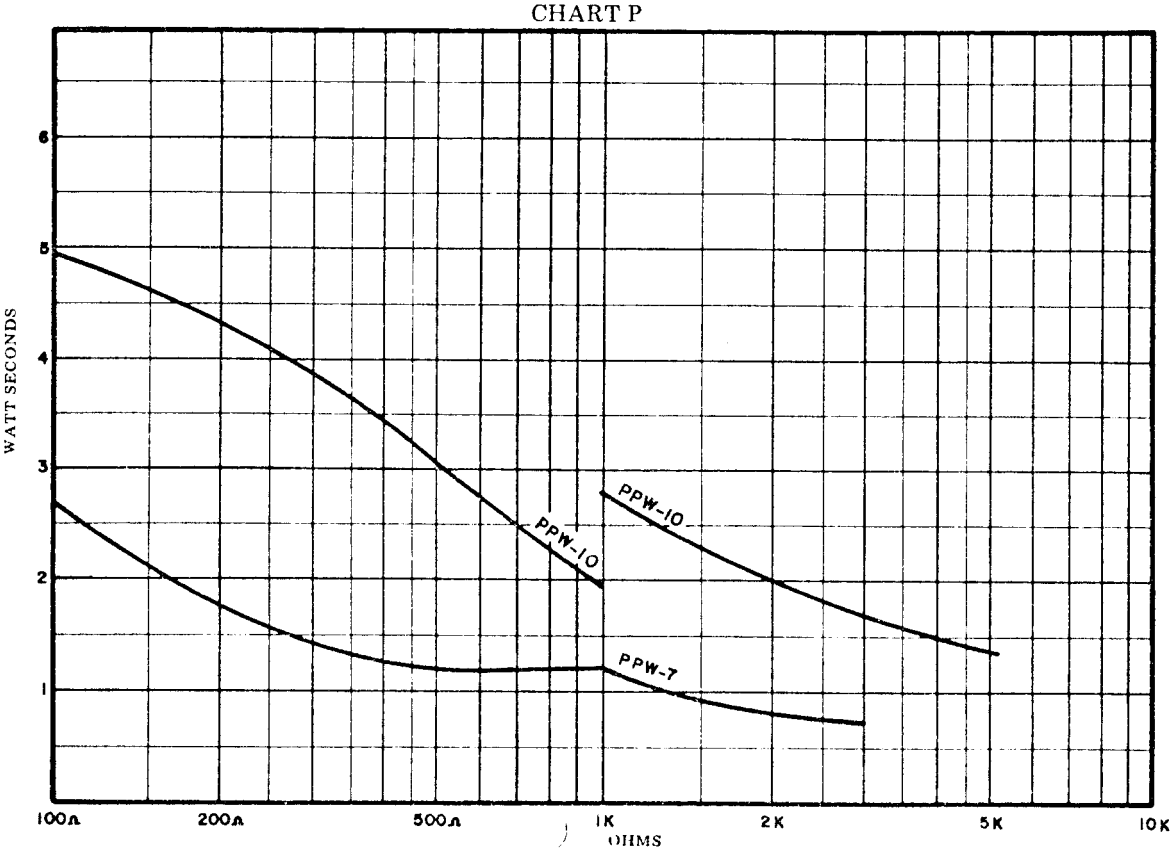
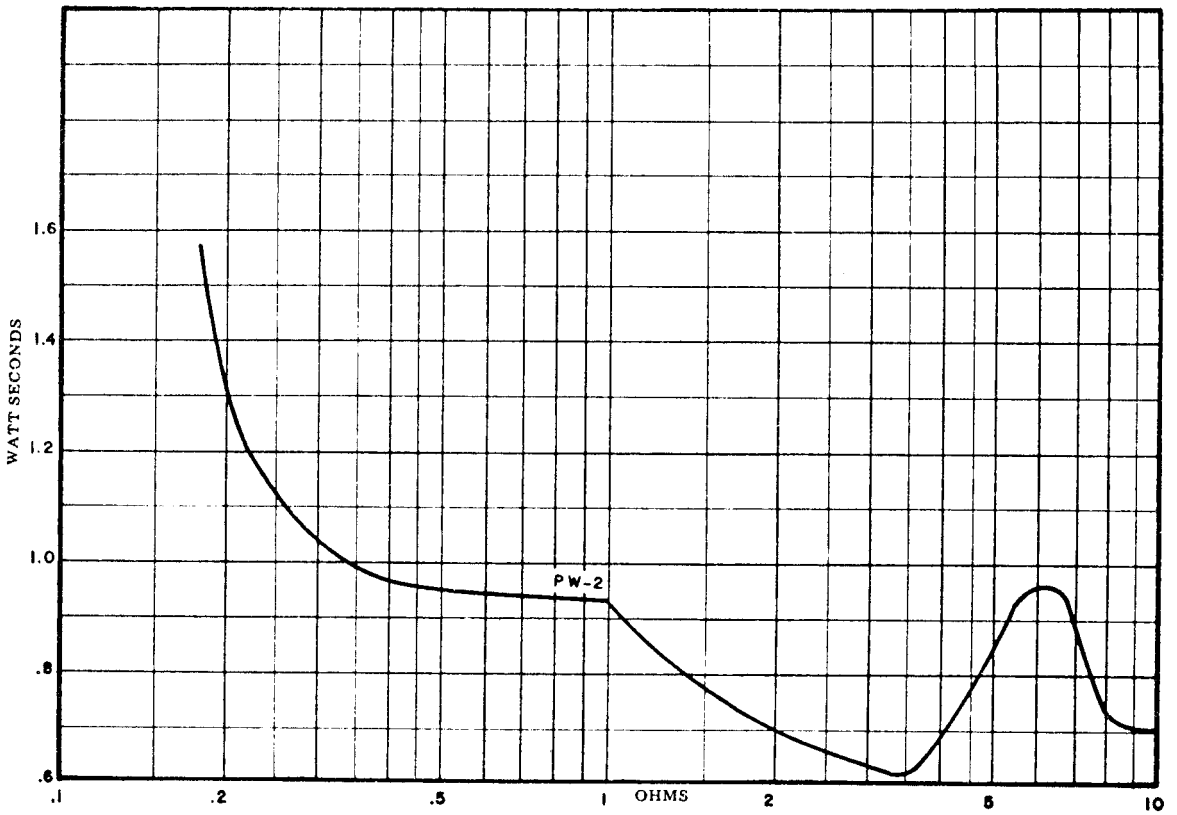


Chart Reference Guide for PW Resistors

SIZE UNIT	POWER RATING @ 125°C	RANGE IN OHMS	CHART NUMBER
PW-2	2W	.18 thru 10	Q
		10 thru 1K	R
PW-3	3W	.1 thru 10	S
		10 thru 1K	R
PW-5	5W	.1 thru 10	T
		10 thru 1K	R
PW-7	7W	.1 thru 10	T
		10 thru 1K	U
PW-10	10W	.1 thru 10	V
PW-15	15W	10 thru 1K	U
PW-18	18W	.2 thru 10	V
		10 thru 1K	U
PW-22	22W	.18 thru 10	V
		10 thru 1K	U
PW-20	20W	.24 thru 10	W
		10 thru 1K	X
PW-30	30W	.47 thru 10	W
		10 thru 1K	X
PW-40	40W	.62 thru 10	W
		10 thru 1K	X
PW-50E	50W	.8 thru 10	W
		10 thru 1K	X

CHART Q



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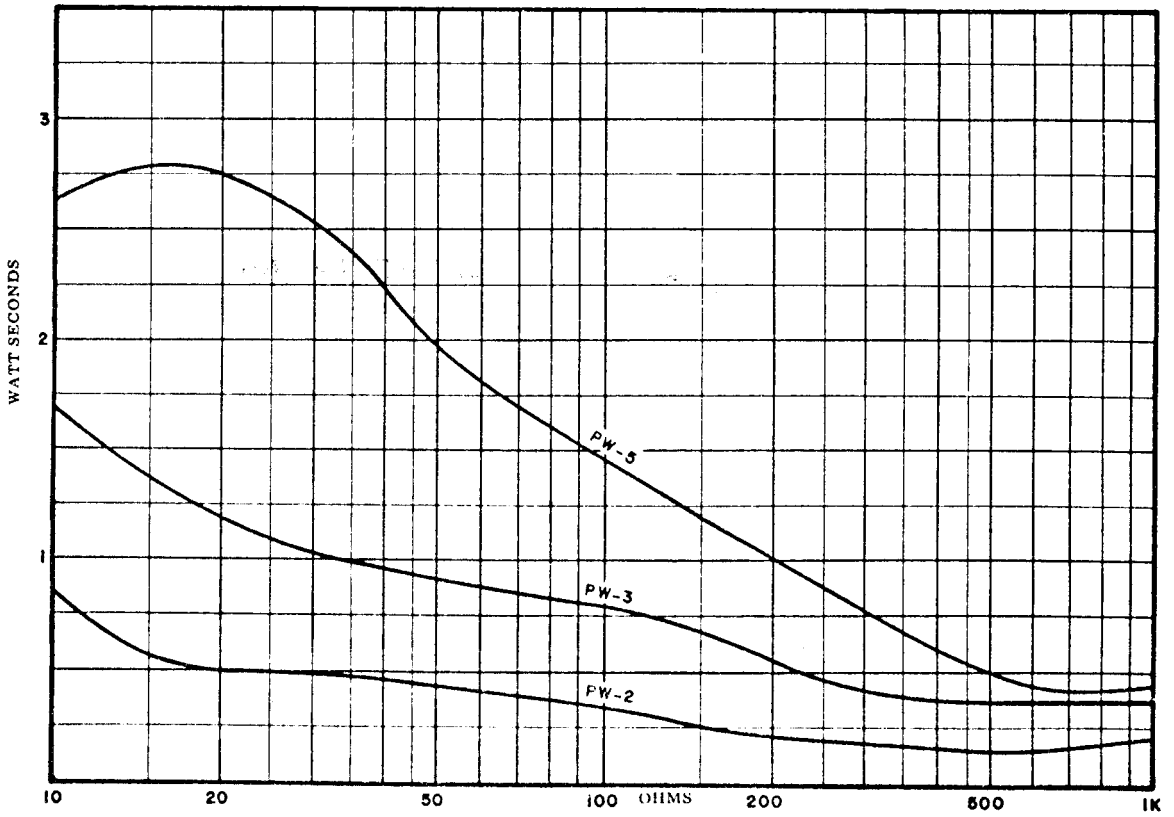

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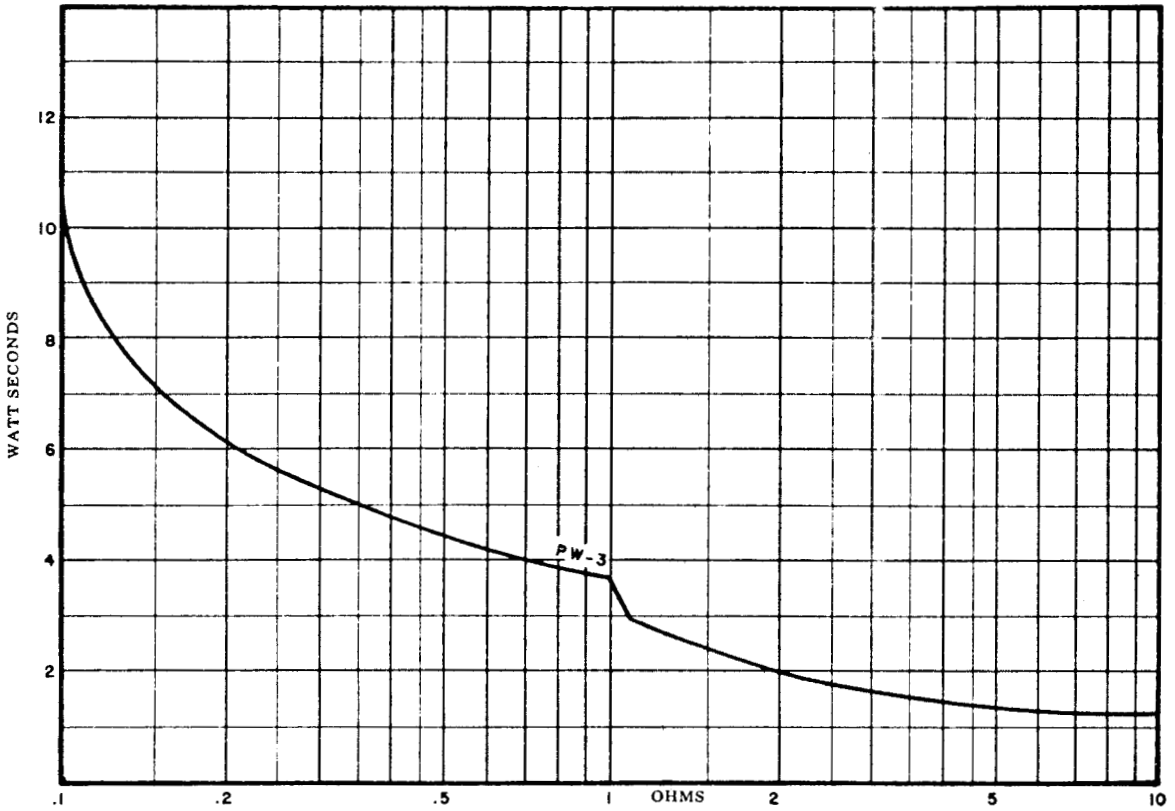

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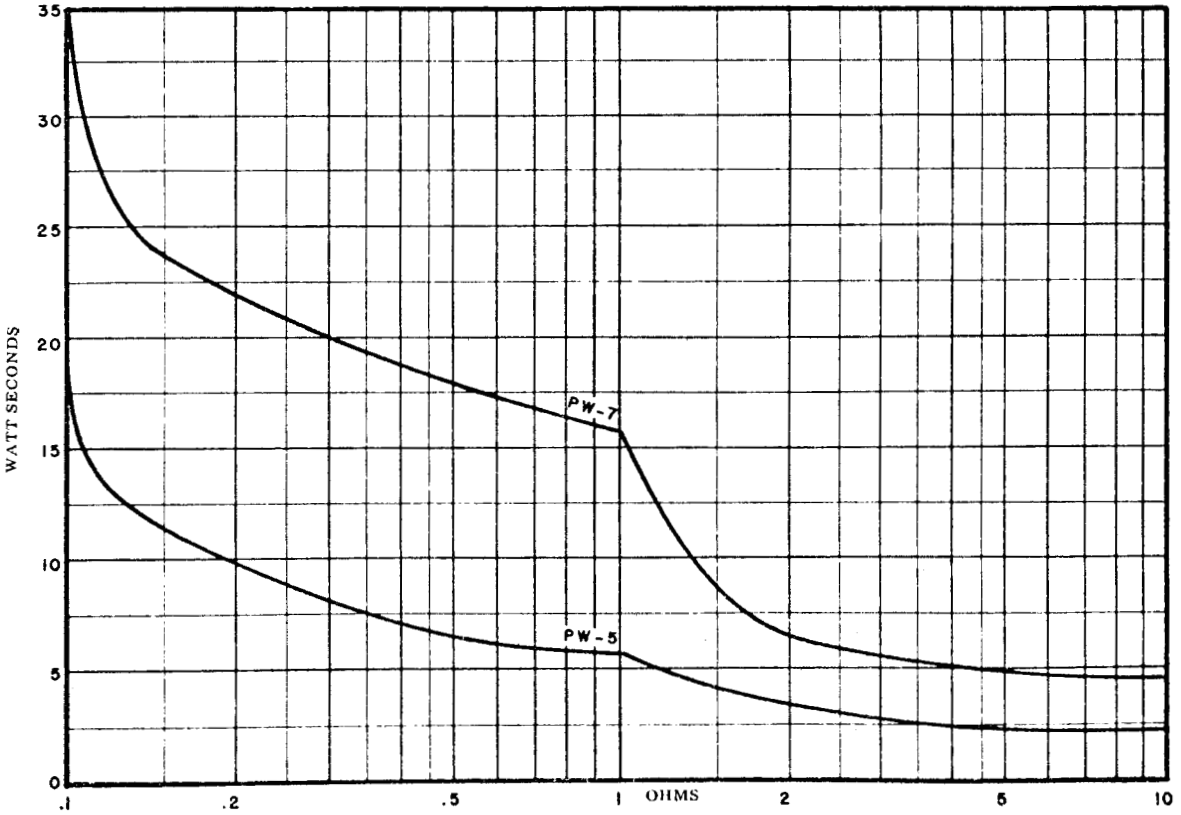

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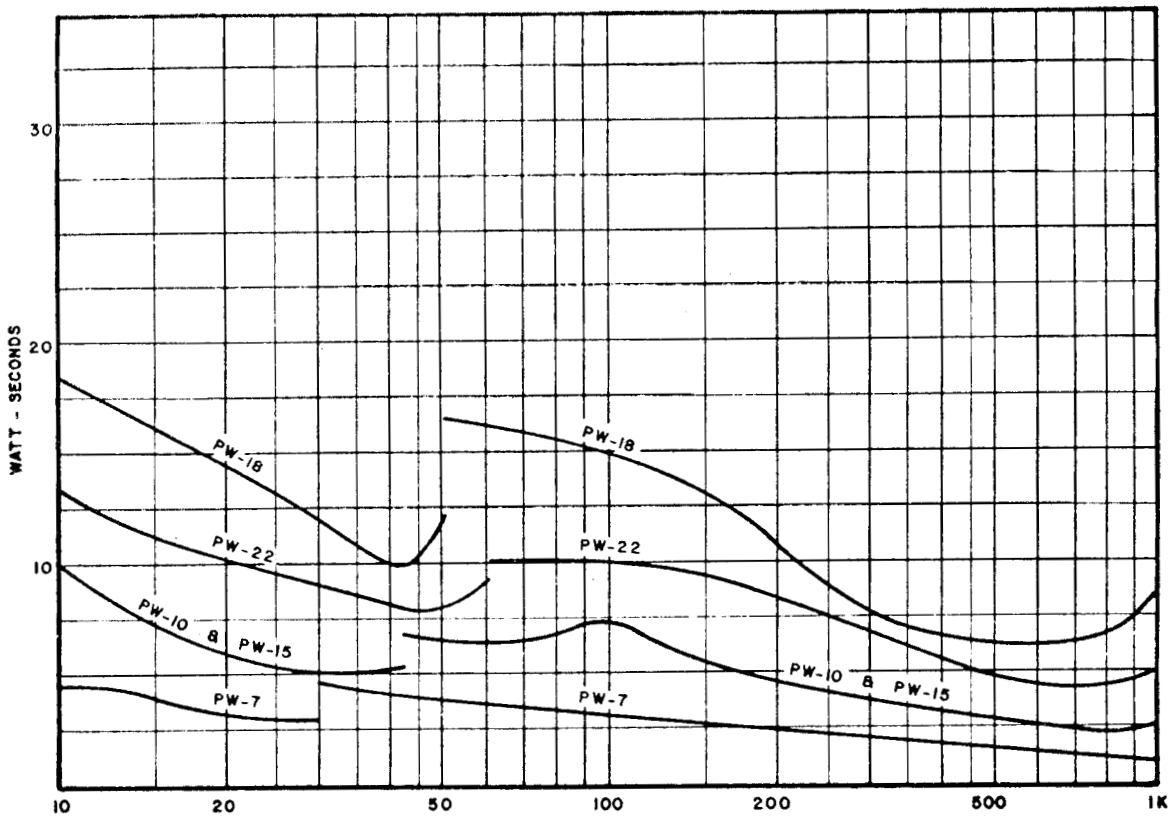

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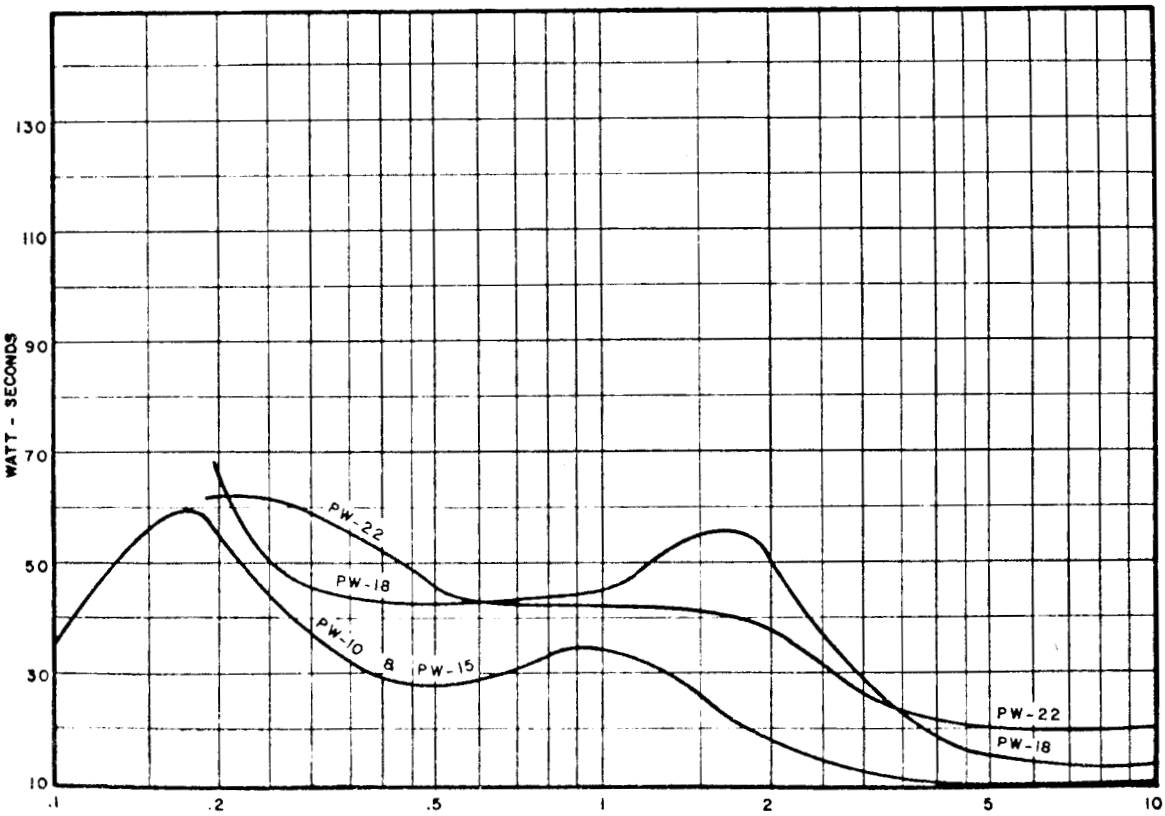

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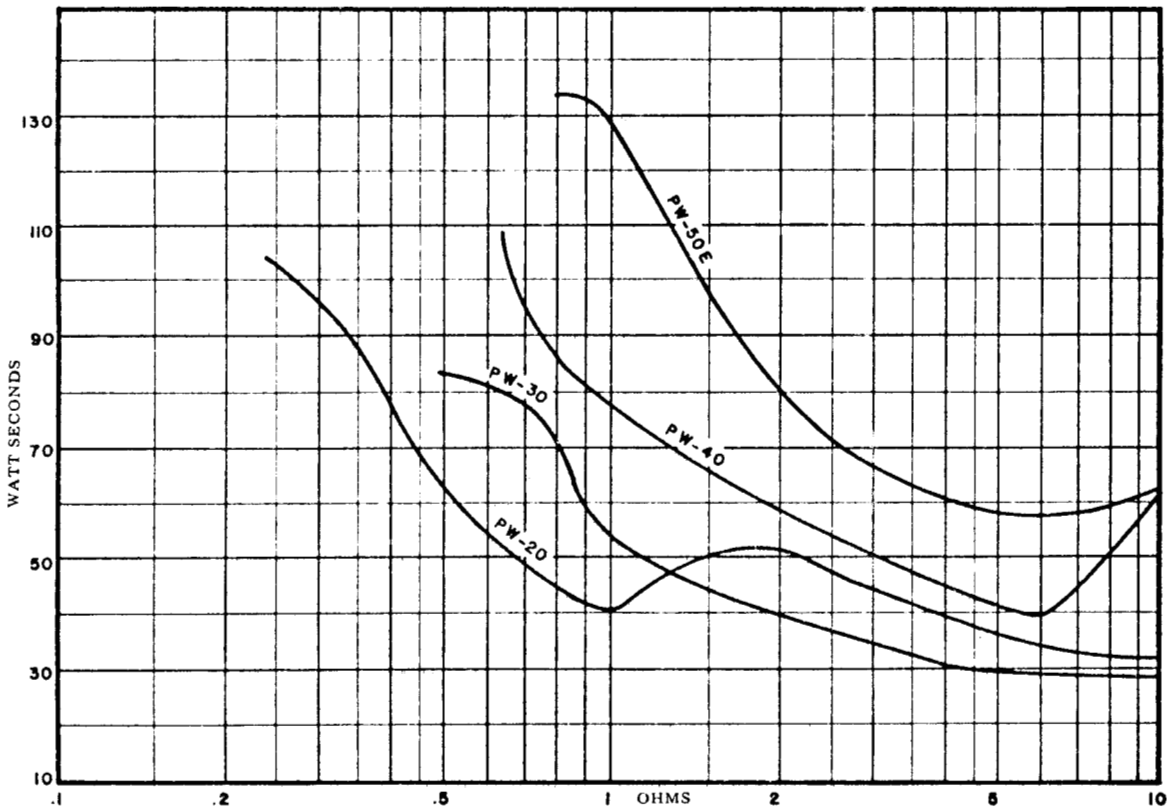

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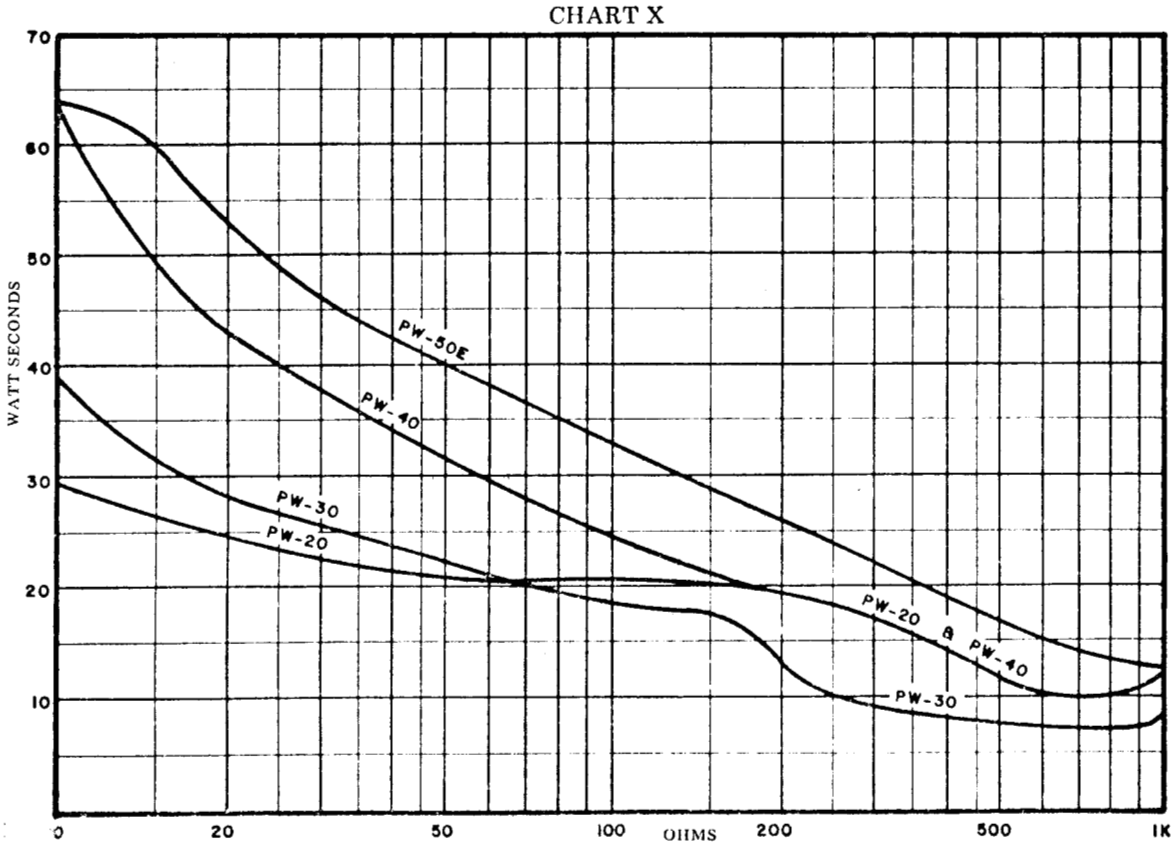
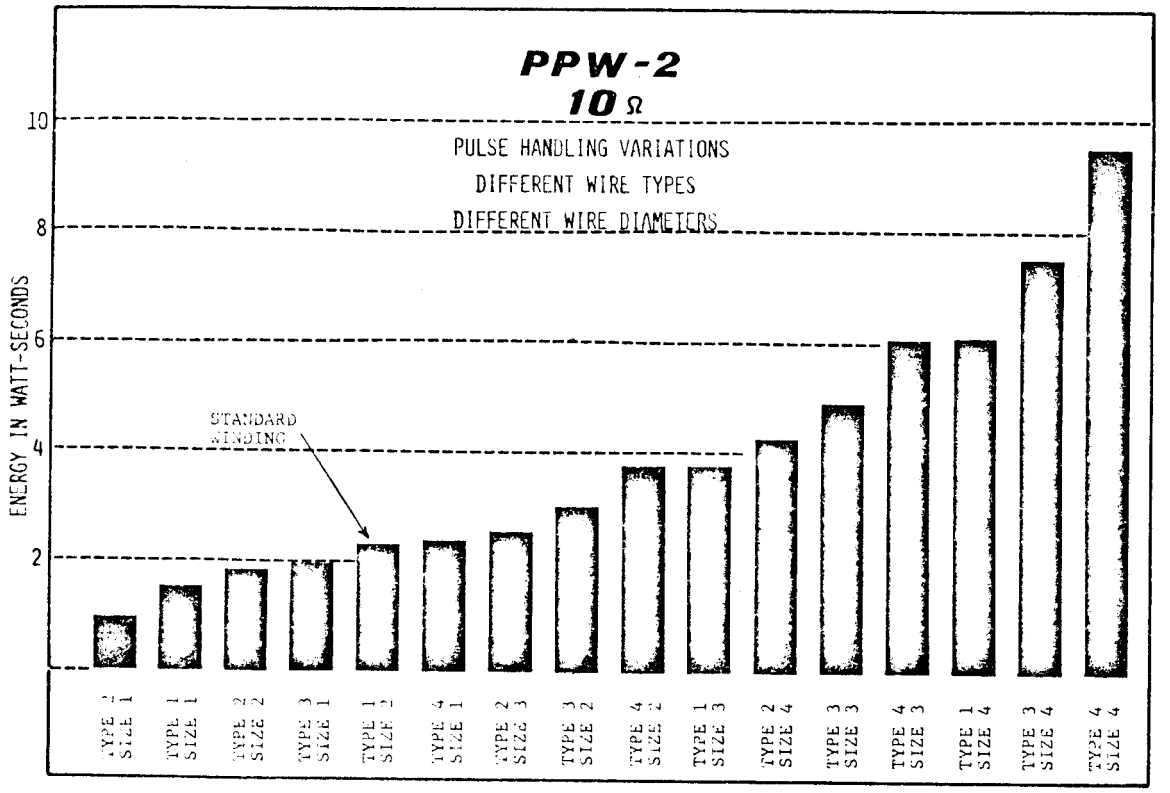
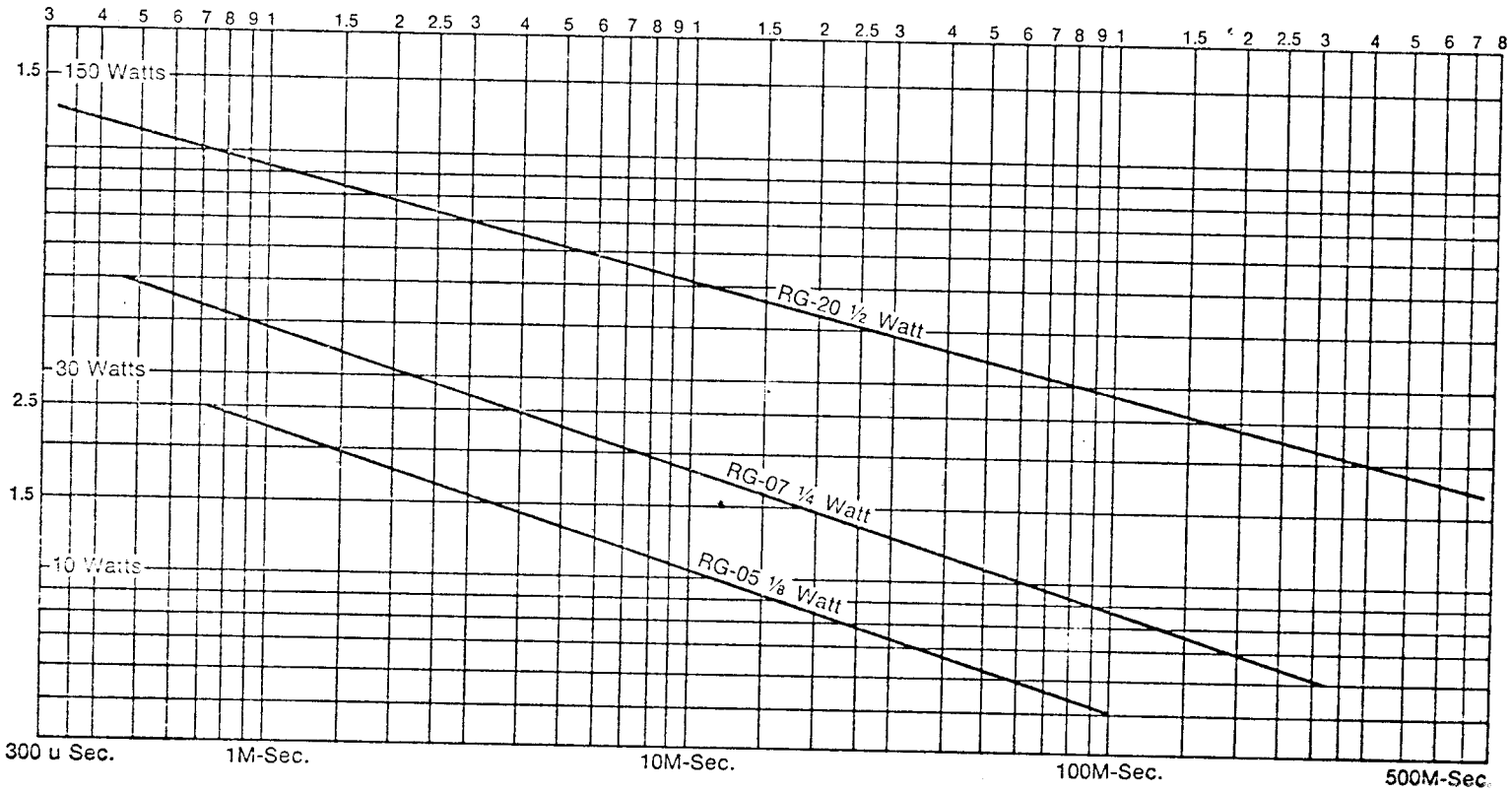



PPW-2
10 Ω
PULSE HANDLING VARIATIONS
DIFFERENT WIRE TYPES
DIFFERENT WIRE DIAMETERS
ENERGY IN WATT-SECONDS
10
8
6
4
2
STANDARD WINDING
TYPE 1 SIZE 1
TYPE 1 SIZE 1
TYPE 2 SIZE 2
TYPE 3 SIZE 1
TYPE 1 SIZE 2
TYPE 4 SIZE 1
TYPE 2 SIZE 3
TYPE 3 SIZE 2
TYPE 4 SIZE 2
TYPE 1 SIZE 3
TYPE 2 SIZE 4
TYPE 3 SIZE 3
TYPE 4 SIZE 3
TYPE 1 SIZE 4
TYPE 3 SIZE 4
TYPE 4 SIZE 4



The chart shows maximum safe operating power vs. pulse duration in pulse or repetitive surge applications. When operating with high energy—short duty cycle pulses—the average power dissipation is not to exceed the component rating. As an example: An RG-20 operating with 50 watt, 10 m-sec. pulses requires an off time of 1 sec. Expected Δ R % <0.1% after 100,000 pulses. For operation above room temperature derate linearly from 25° C to zero power at 175° C.

APPENDIX III

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 1 through 8). 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 ten 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. Wirewound--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. Wirewound--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 9 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 one percent, and the average power was kept at or below the DC power rating of the resistor.

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

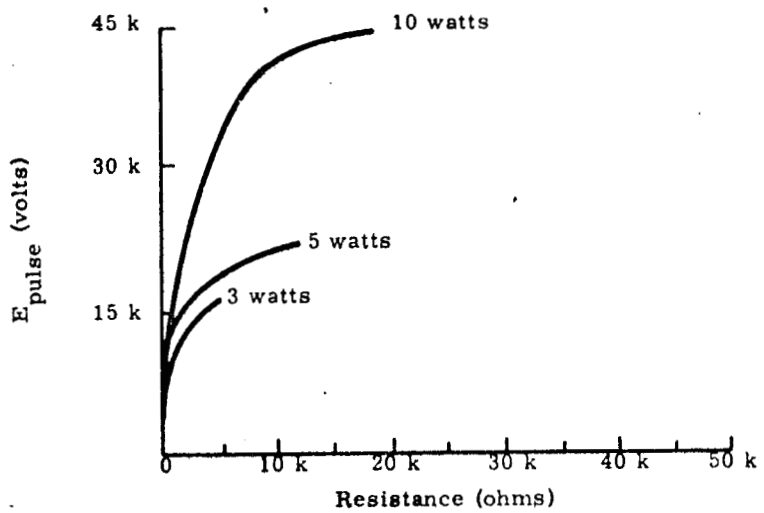

Figure 1. Wirewound Resistors

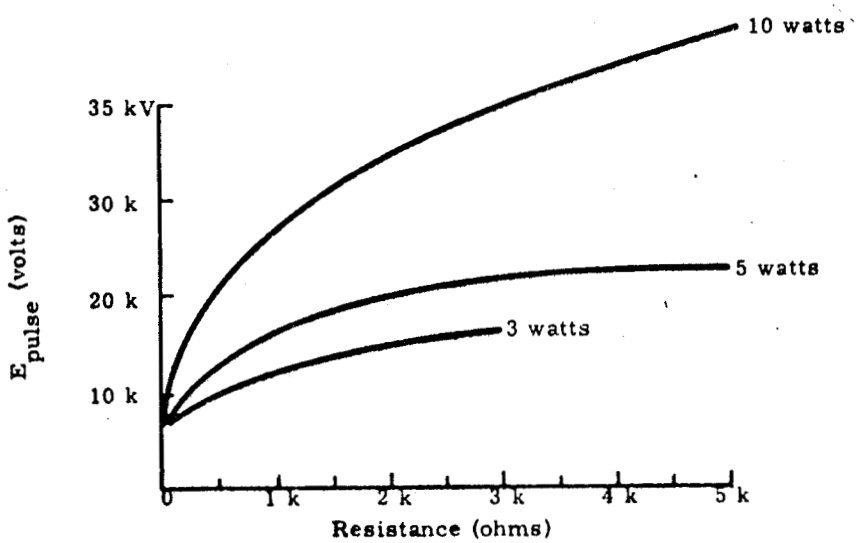

Figure 2. Wirewound Resistors

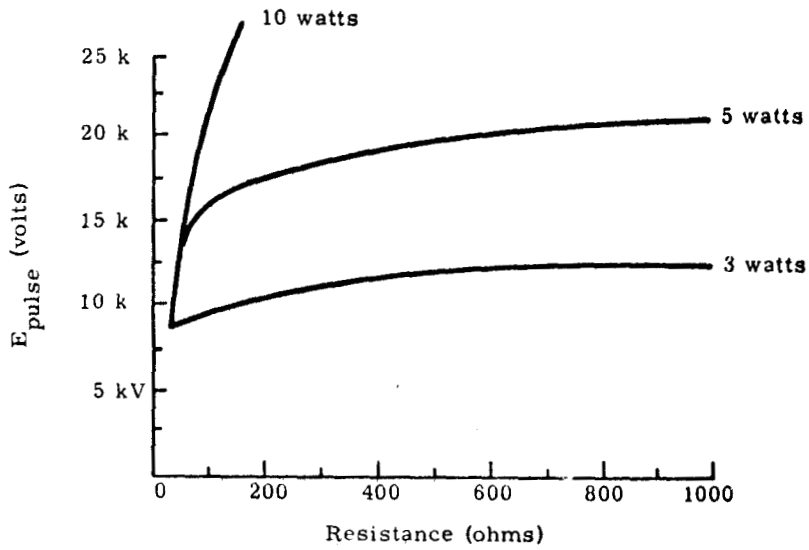

Figure 3. Wirewound Resistors

TABLE I

Wirewound 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	--

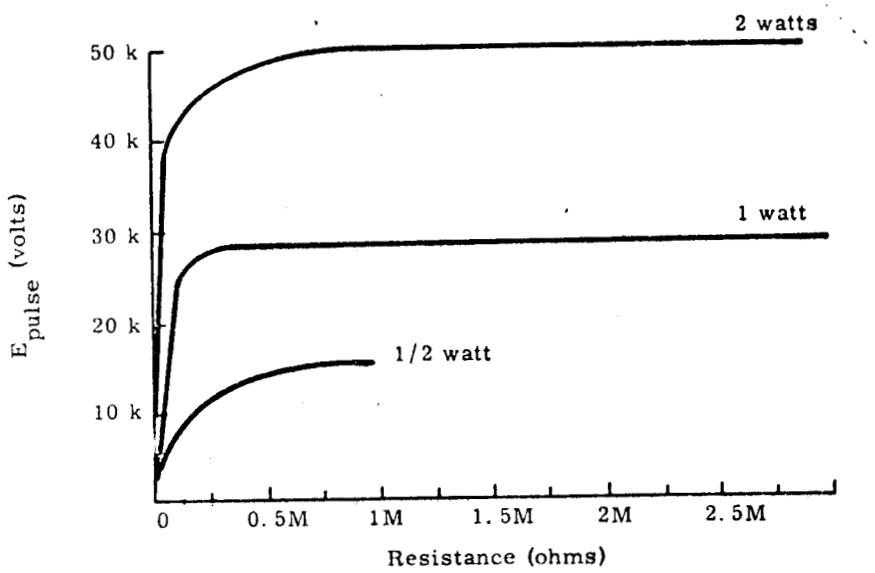

Figure 4. Metal Film Resistors

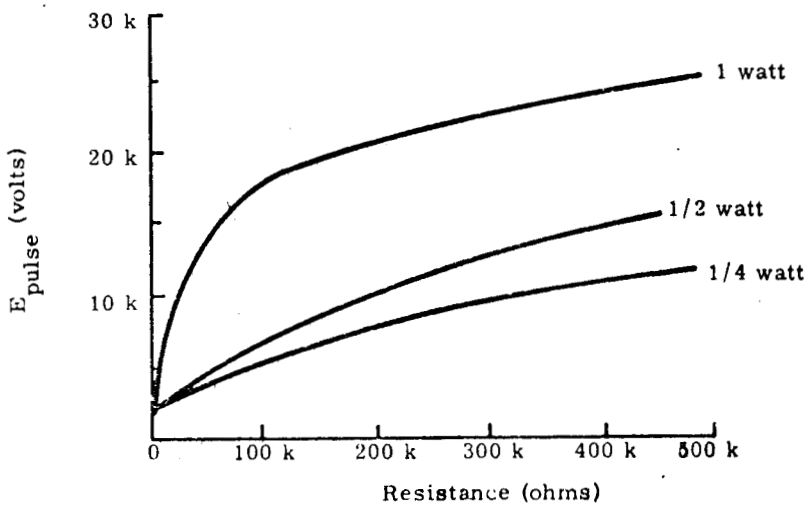

Figure 5. Metal Film Resistors

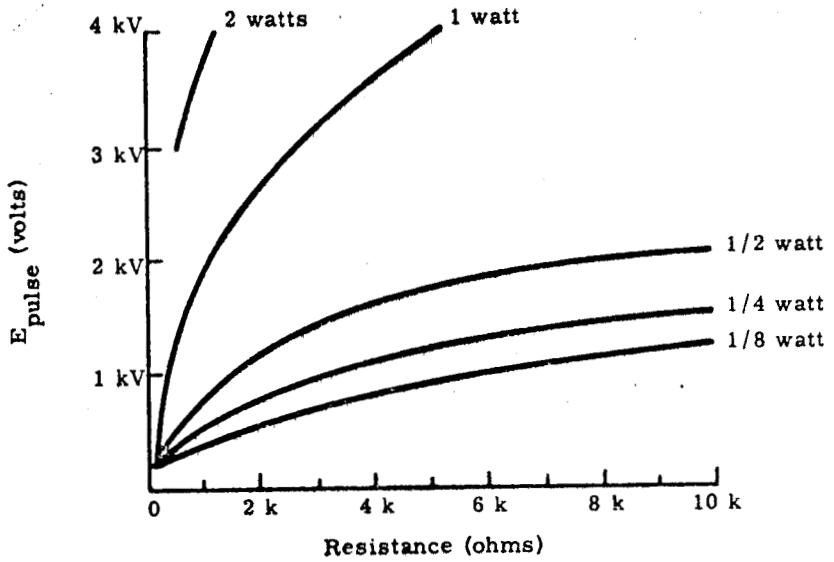

Figure 6. Metal Film Resistors

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

TABLE II--Continued

Metal Film Resistors Tested

Manufacturer and type	Power rating (watts)	Nominal resistance (ohms)	Maximum safe volt. (volts)	Pulse width (μsec)	Pulse power (watts)
IRC-MEF	1	100 k	18 k	20	3.6
IRC-MEF	1	1 M	32 k	20	1.0
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

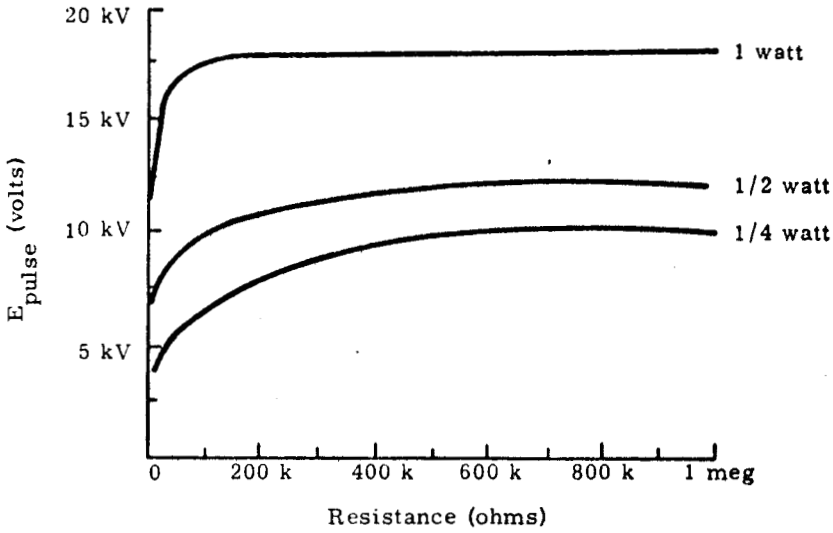

Figure 7. Carbon-Composition Resistors

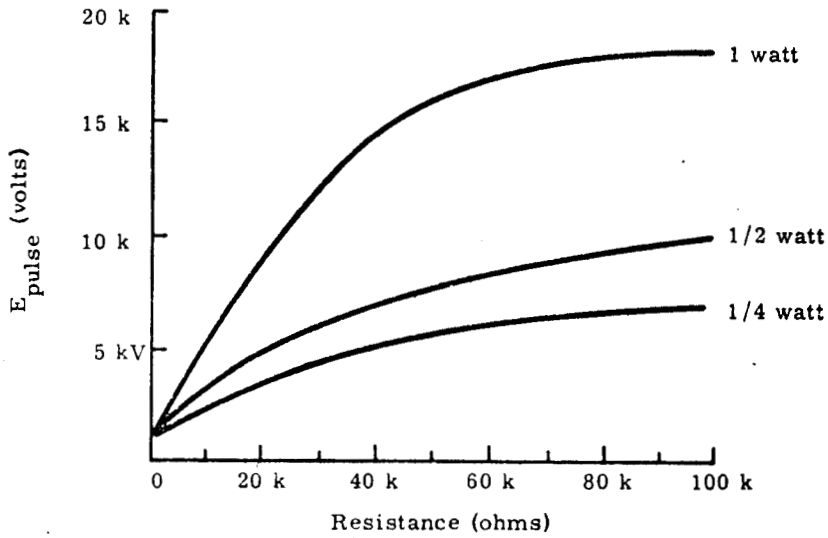

Figure 8. Carbon-Composition Resistors

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 9) 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.

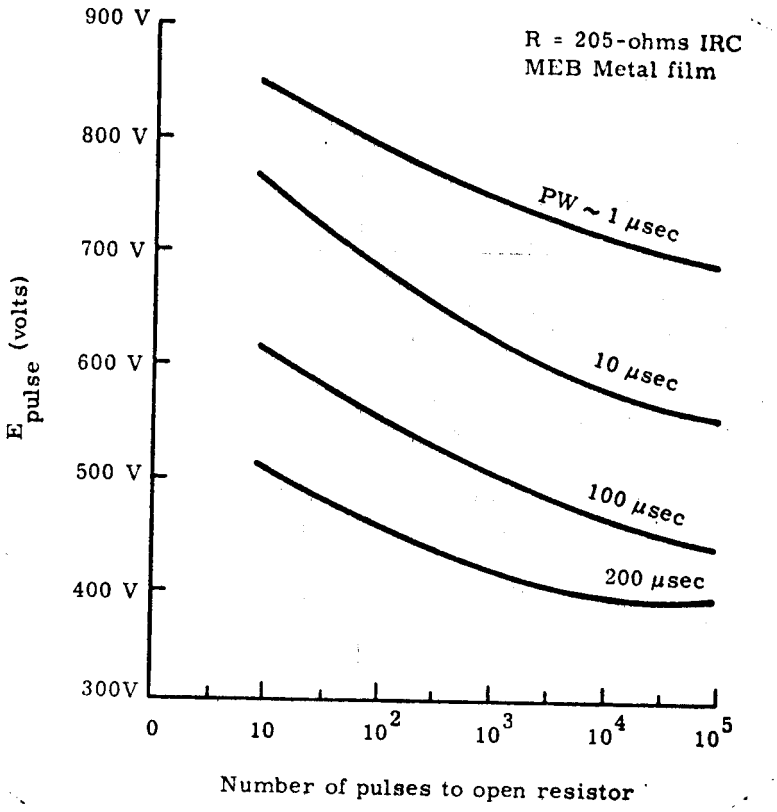

Figure 9. Pulse Width vs. Maximum Pulse Voltage

APPENDIX IV

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