

Code: 203.143.107
Date: May 14, 1956



TECHNICAL REPORT

COHERER CHARACTERISTICS; PART II:
MATERIALS, LIFE TEST, RELIABILITY,
AND APPLICATIONS

by

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May 14, 1956

ABSTRACT

The potential usefulness of coherers as of March 1955* is discussed. Data is summarized for different materials, surface treatments, atmospheres, relative humidity, and cell shape. Separately connected coherers have regular probability of firing curves from which buffer storage coherers can be designed for a specified accuracy, provided the frequency of erasing information is only a few times a second. The probability of error is decreased by putting three cells in parallel. Coherer matrices without back circuit eliminators are theoretically possible, but have not been satisfactorily realized. The failure to realize satisfactory matrix operation lies primarily in the lack of control of the oxide thickness and rate of growth. "Resistox" treatment of coherer powder has decreased the variation of coherer characteristics with time.

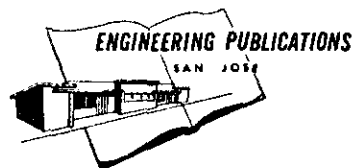
*This report has been edited from unpublished manuscripts of March 1955 and earlier. The basic physical characteristics are described in another report; Part I 203.142.102.

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IV Comparison of Different Coherer Materials

a. Powder Material

Measurements of d-c firing voltage and the decohered resistance are tabulated for various materials in Table IV-1. A typical probability curve for Type AA-36 copper powder shown in Curve A of Figure 4.1. The effect of increasing the series resistance in changing the probability of firing is shown by Curve B. The effect of changing the repetition rate such that there is insufficient rest time following the cohering is shown in Figure 4.2. Typical probability of firing curves for copper, reduced copper, and tungsten powder are shown in Figures 4.1, 4.2 and 4.4 respectively. The current carrying capacity of bronze powders is plotted in current required to discolor the powder versus the mesh size in Figure 4.3.

Probability curves for tungsten powder in Figure 4.4 for .050 and .100" gaps are both Gaussian, while the curve for .200 departs from the Gaussian probability distribution. This difference may be due to the higher field strength involved.

Sample probability of firing curves for other materials are shown as follows:

Figure 3-3 chromium
Figures 3-7, 3-8, 3-10 bronze

b. Surface Layers

Simple oxide layers are variable in thickness depending upon the temperature of the original formation of the powders and its subsequent history. The regrowth of the oxide on a bare spot starts out quickly and then tapers off slowly. Simple oxide coated particles either increase or decrease their firing voltage with time. The firing voltage increases if the oxide layers grow thicker at a rate faster than the material is removed in decohering. The firing voltage decreases, if the oxide is removed, either electrically or from mechanical abrasion faster than the oxide layers regrow.

A treatment developed by the Glidden Co., known as "Resistox", for the preservation of copper powder has been found useful in maintaining a consistent oxide layer. Copper powder obtained from Metals Disintegrating Co. is reduced in hydrogen to remove

the original layers of oxide. A small layer regrows and this reduced powder is sent to the Glidden Co. for the Resistox treatment which stabilizes the thickness of the oxide. Coherers using copper which has been hydrogen reduced and Resistox-treated has given more reliable life test data. The disadvantage of Resistox is that the treatment can be destroyed by temperatures between 150 degrees and 212 degrees Fahrenheit. A sample curve for Resistox powder is given in Figure 4.5. The data for this curve is taken with powder prepared from Glidden Resistox Powder 40 - JB which has been sieved to (-72 + 80 mesh).

Examination of Figure 4-5 shows that the Resistox-treated powder is still very close to the starting probability curve after 98,000 firings.

c. Cell Material and Atmosphere

The effective temperature and relative humidity is shown in the following figures for bronze spheres. Curves of firing voltage vs. relative humidity for different temperatures are plotted in Figure 4-6. These curves are replotted as firing voltage vs. temperature for constant values of relative humidity in Figure 4-7 and for constant values of absolute humidity in Figure 4-8.

If the mechanism of the hygroscopic behavior of the copper and tin oxides were known, these humidity temperature curves could be used to determine whether electronic or ionic conduction of Figure 2.1 predominates. For example, if water absorbed by the oxide is proportional to the absolute humidity these curves would show that the critical temperature is well above room temperature.

Bronze powder suspended in kerosene has been found to give a smaller standard deviation than plain bronze. No extensive life tests have been run but the simple probability curves are flatter when the bronze is lubricated with kerosene. The disadvantage is that the kerosene evaporates so readily. The use of silicone oil with wetting agents and other mixtures are nowhere near as good as kerosene. It has been suggested that radioactive material be included in the coherers to shorten the time lag in the firing. The rough experiments tried with radioactive material were inconclusive. An attempt was made to determine the changes in

the atmosphere of a sealed coherer by use of a mass spectrograph. The tests were not very conclusive. Some tests the probability of mis-firing appear to be higher where the coherer cells have been drilled when a dull drill such as that the phenolic cell wall have been burnished, changing the surface resistivity of the cell wall.

d. Cell Shape

In Figure 3-6 firing voltages are compared for two different shapes of cells having the same separation of electrodes. It should be noticed that it takes a lower firing voltage for the pin to parallel plate than for two parallel plates of the same separation. Refer to IBM Report 216.082.048 for comparison of parallel wire and parallel plate coherers. A variation of unfired resistance of a coherer with cell shape and area of electrodes is shown in Figure 4.9. From Figures 3.6 and 4.9 a correlation of change in prefiring resistance with change in firing voltage in mode and is plotted in Figure 4-10.

TABLE IV - 1

Item	Material	Mesh	Supplier	Type	Lot	Firing Voltage	Resistance	R
1	Neon Tube	————		NE-2		90	$3 \times 10^{11}(a+2.5)$	8.
2	Blank	————		NE-2		—	$10^{12} - 10^{13}$	6.
3	Cadmium	n. s.	MD	M-101	L-4368-S	<10	60 K	1
4	"	-100+150	"	MD-10C			50 K	1
5	"	-325	"	"			100 K	1
6	Copper heated in molten $\text{Li}_2 \text{CO}_3$ (air)	-100 +150	MD	test tube (furnace)		500	1.5×10^8	1
7a	CuO heated in $\text{Li}_2 \text{CO}_3$ powder.	+ 200	Lith. Cap. Cenco			140	1.5×10^8	1
8	Bronze heated in molten lithium (vacuum)	-170+200	MD Cenco	MD-153A		170	4×10^8	2
9	Silver Crown Alloy		GR	Fast		17	5×10^8	1
10	Tungsten		Fansteal	427		150	6×10^8	1
11	NiO heated in $\text{Li}_2 \text{CO}_3$ (air)		Harshaw	441-002-31		<500	7×10^8	5
12	Alurdum		Norton	38-600x		<500	$10^8 - 10^{10}$ min.	
13	Bronze *	-170+200	MD	MD-153A		440	2.5×10^9	7
7a	NiO		Harshaw	441-002-31		7500	2.5×10^8	1
14	Manganese		Plast.	E - 120	L-13138	470	4×10^9	1
15	CuO	-325	Cenco	C1818		7500	5×10^9	8
16	50 Cr, 50 Ni		Mlt	J-1337A-2		340	5×10^9	9
17	Stainless Steel	-100	Sintrex	321		45	7×10^9	1
18	$\text{Cr}_2 \text{O}_3$	Baker				<500	7×10^9	1
19	Molybdenum	80 Mesh	Fansteel	124		138	10^{10}	2
20	20 Cr, 80 Ni		MH	J-1342A		440	10^{10}	8
21	Aluminum		MD	MD-105	L-5185	300	10^{10}	1
22	Ferramic	Powder				7500	1.5×10^{10}	1
23	Copper heated in $\text{Li}_2 \text{CO}_3$	-100 +150		test tu. (bunsenb)		410	2×10^{10}	1
24	15 Ta, 85 Co		MH	LSM-480		350	2×10^{10}	7

MD= Metals Disintegrating Co.
 MH= Metal Hydrides, Inc.

GR = General Refineries, Inc.
 Sintrex = Amer. Electro Metal Corp.

* Heated in
 $\text{Li}_2 \text{CO}_3$

TABLE IV - 1 (Cont)

Item	Material	Mesh	Supplier	Type	Lot	Firing Voltage	Resistance	Ref
25	Nickel		Cenco	C2747		90	2×10^{10}	1-
26	65Cr, 20Ni, 15Cu		MH	J-1585A		60	25×10^{10}	11
27	Bismuth		MD	M-101	L4360-S	55	3×10^{10}	1-
28	Copper		MD	MD-105	L-3538	227		1-
			MD	MD-201	L-3527		3×10^{10}	1-
29	Bronze	-170+200	MD	M-153A		150	4×10^{10}	3E
30	Tellurium		Fairmount			240	4×10^{10}	1-
31	Aluminum	Powder	Reynolds			450	4×10^{10}	2
32	30 Cr, 70 Co		MH	J-1523A-1		120	8×10^{10}	4
33	30Zr, 70 Ni		MH	J-1073A	1-2	350	10^{11}	3
34	Chromium		MD	M-201-S		195	10^{11}	11
35	Solder	Powder	MD	M-204	L-4666	20 - 50	1.5×10^{11}	1-
	25 Sn, 75 Pb							
36	Nickel	-20 + 42	MD	MD-9119	L-4163-S	400	2.5×10^{11}	11
37	Cu heated in Li ₂ CO ₃ Filtered					150 - 300	3×10^{11}	7:
38	8.4P, H. 6 Cu	-100+150	MD		L-4365-S	40	10^{12}	10
39	Ni heated with Li			MD-9119		75	10^{12}	10
40	80 Cr, 20 Ni		MH	LSM-810		170	10^{12}	10
41	70 G, 30 Co		MH	J-884	M-520	65	1.5×10^{12}	6
42	40 Cr, 60 Co		MH	LSM-518		40	2×10^{12}	5
43	Cassiterite	-100	Cargille			135	3×10^{12}	1

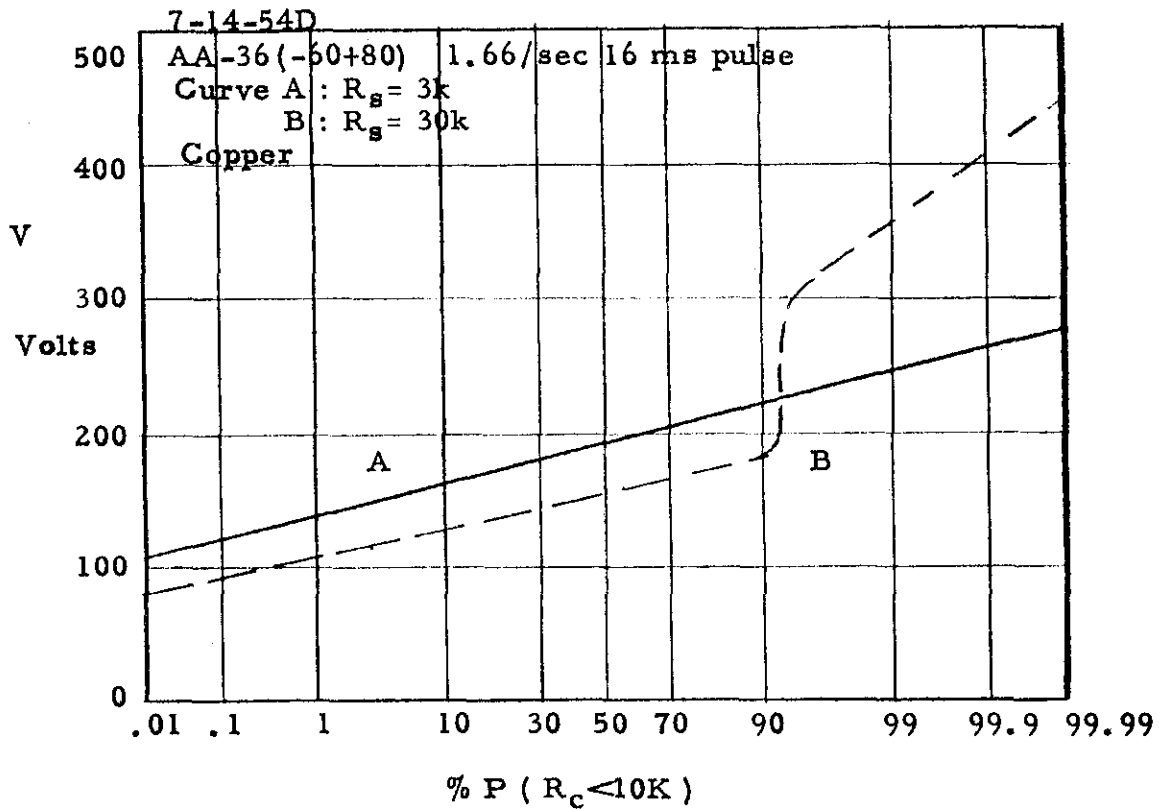


Figure 4-1 Change in Probability of Firing Curve with Increase of Series Resistance.

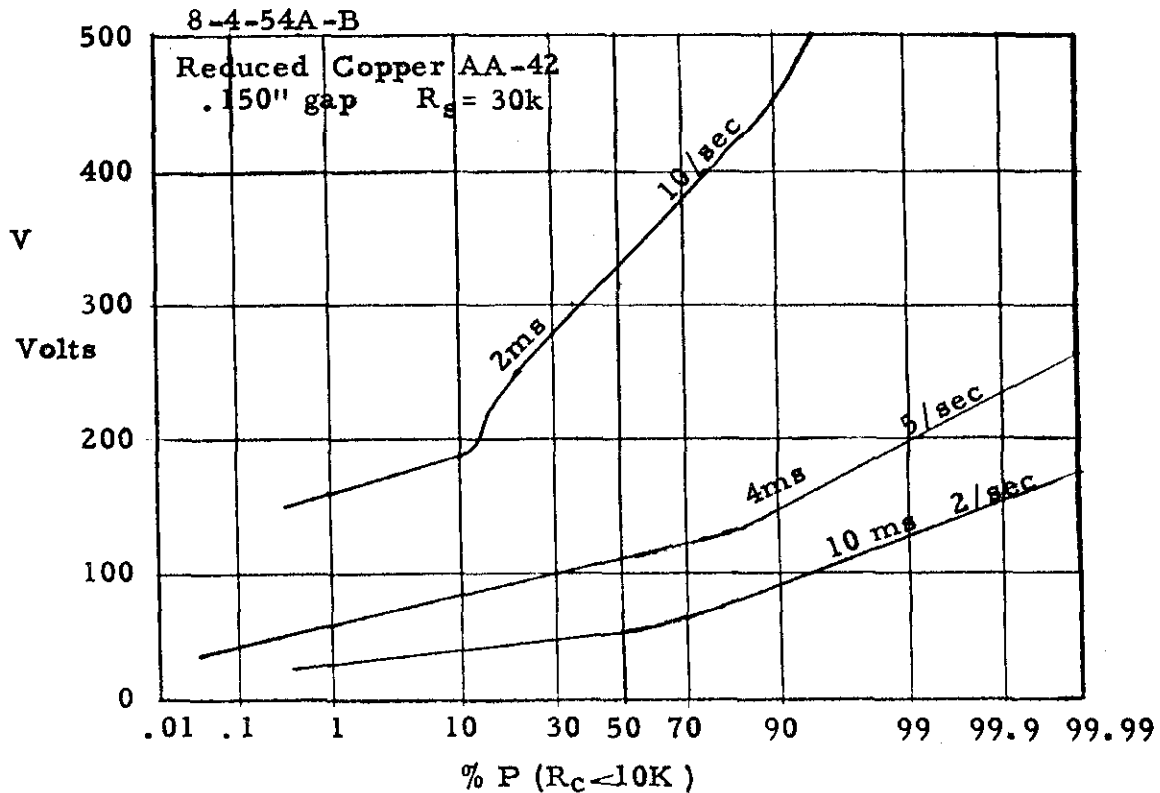


Figure 4-2 Change in Shape of Probability Curve with Change in Pulse Length & Repetition Rate.

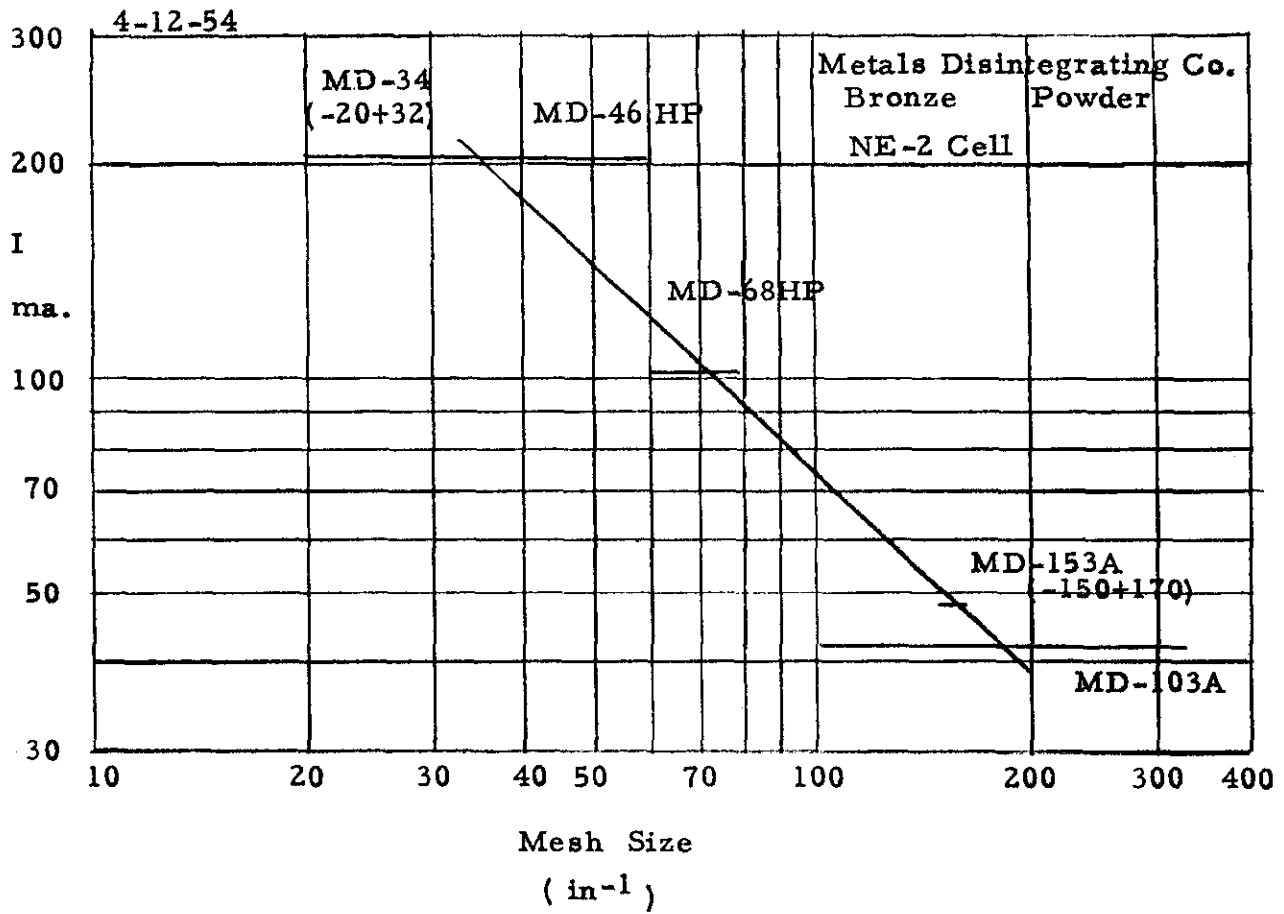


Figure 4-3 Current at Which Bronze Powder Discolors.

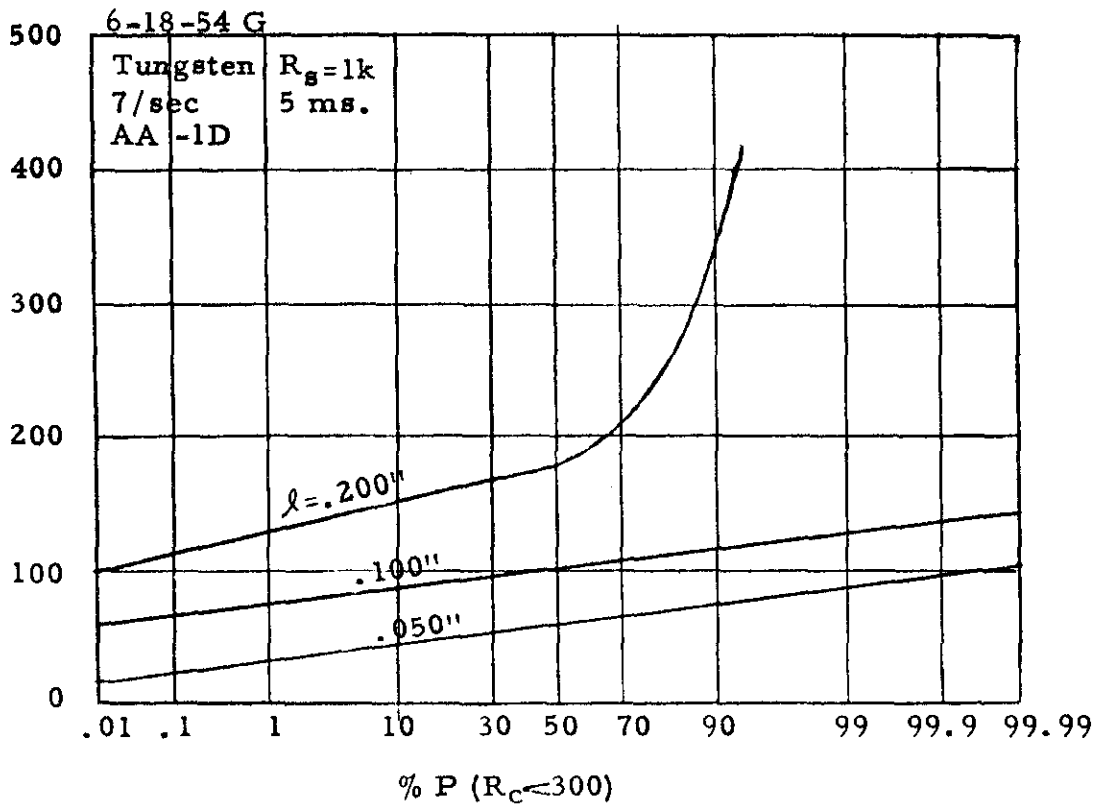
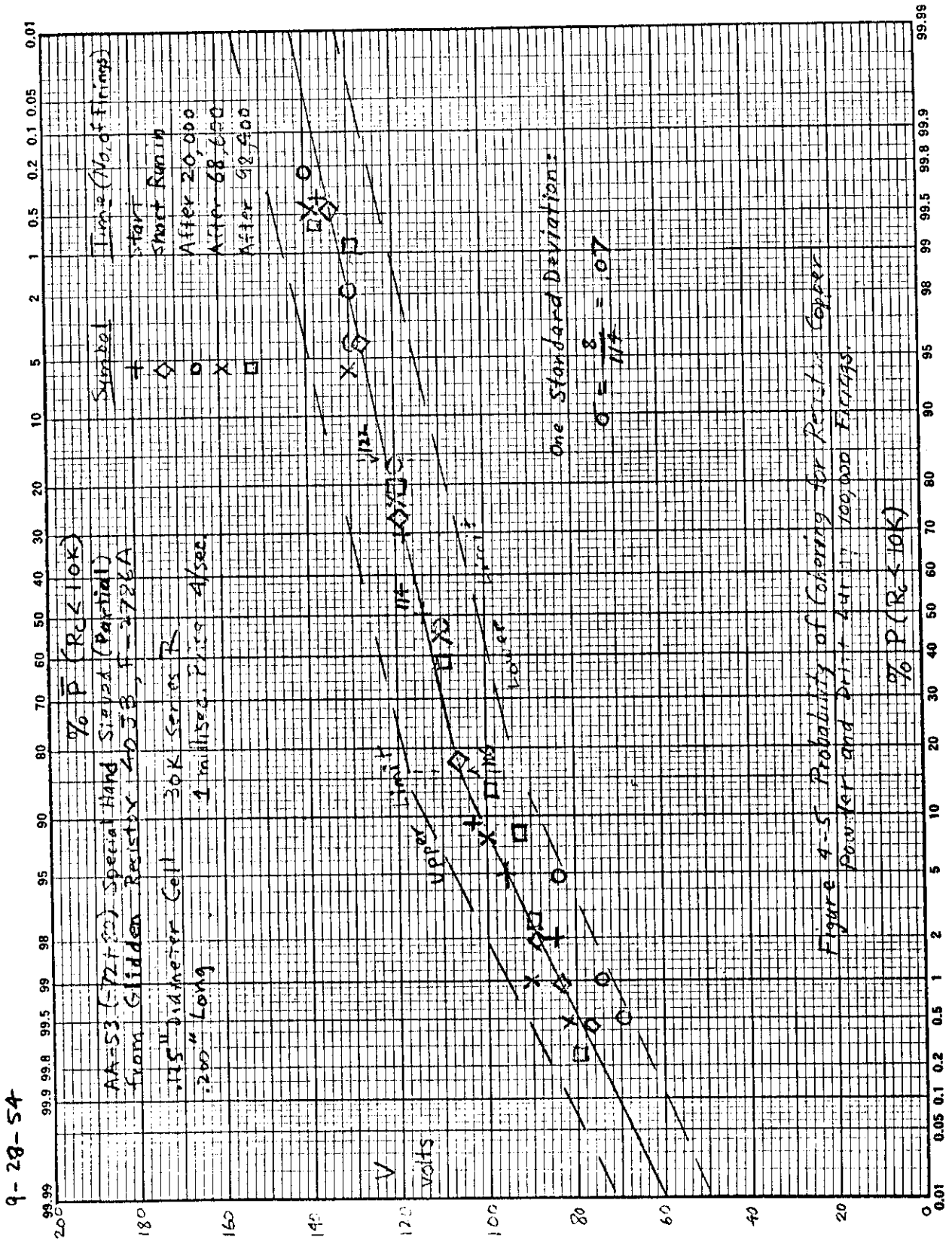
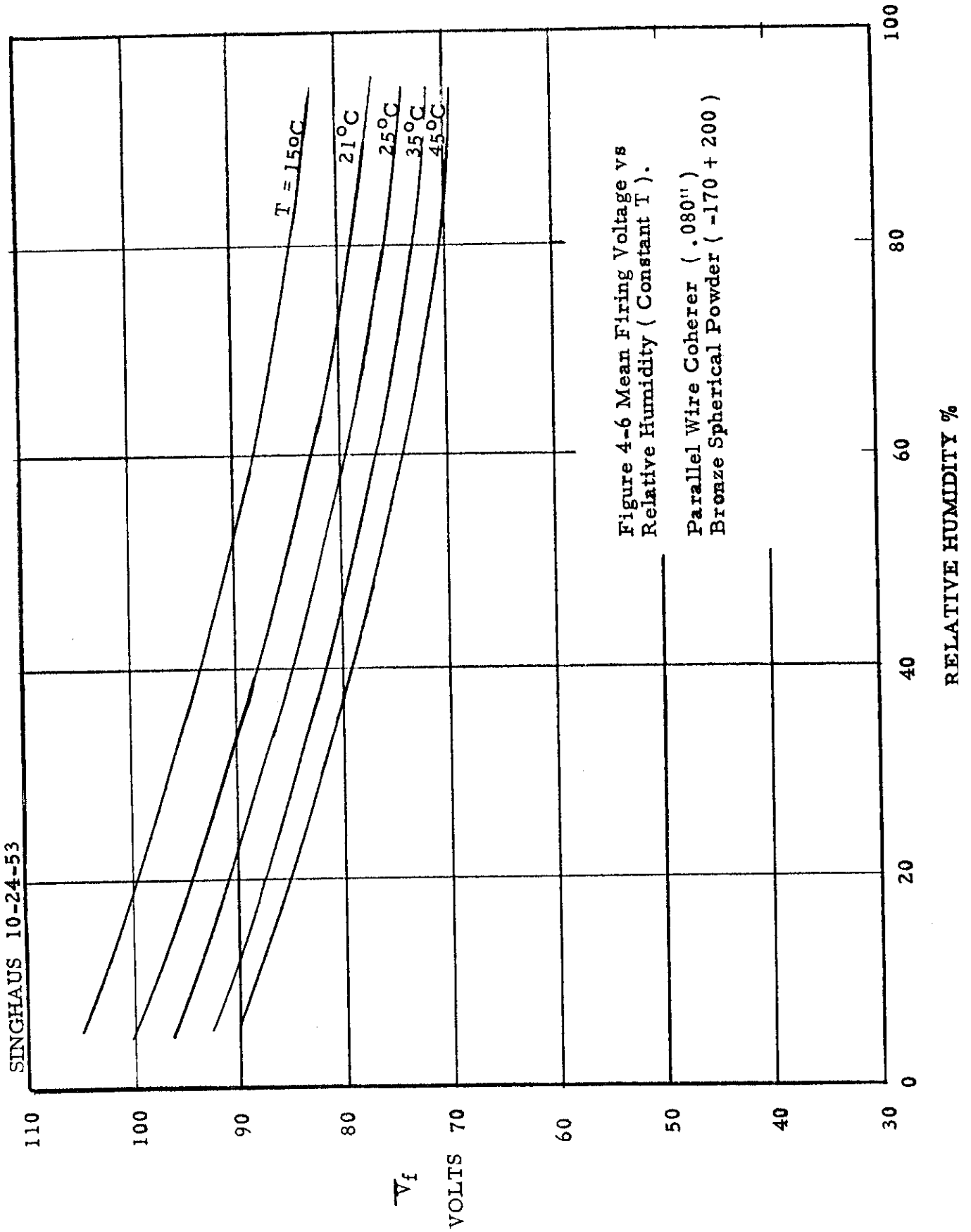


Figure 4-4 Effect of Increasing Coherer Gap Length.





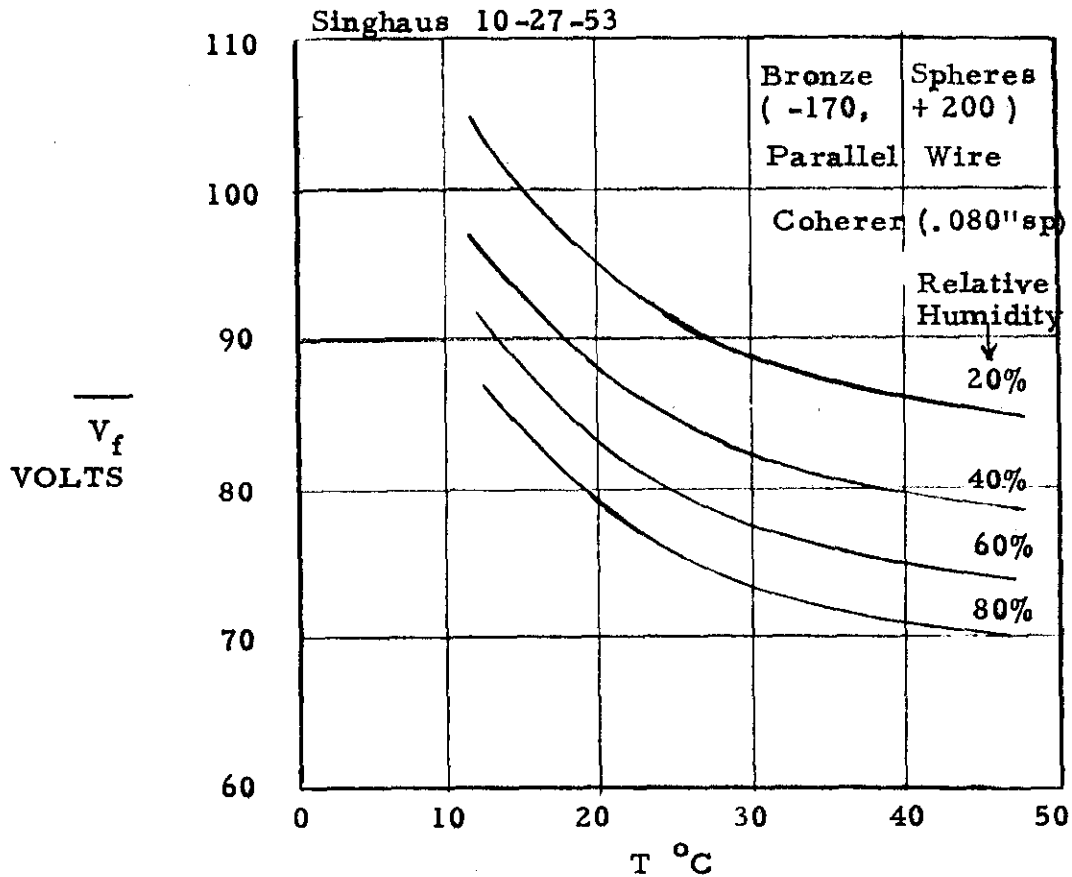


Figure 4-7. Firing Voltage vs Temperature for Constant Relative Humidity

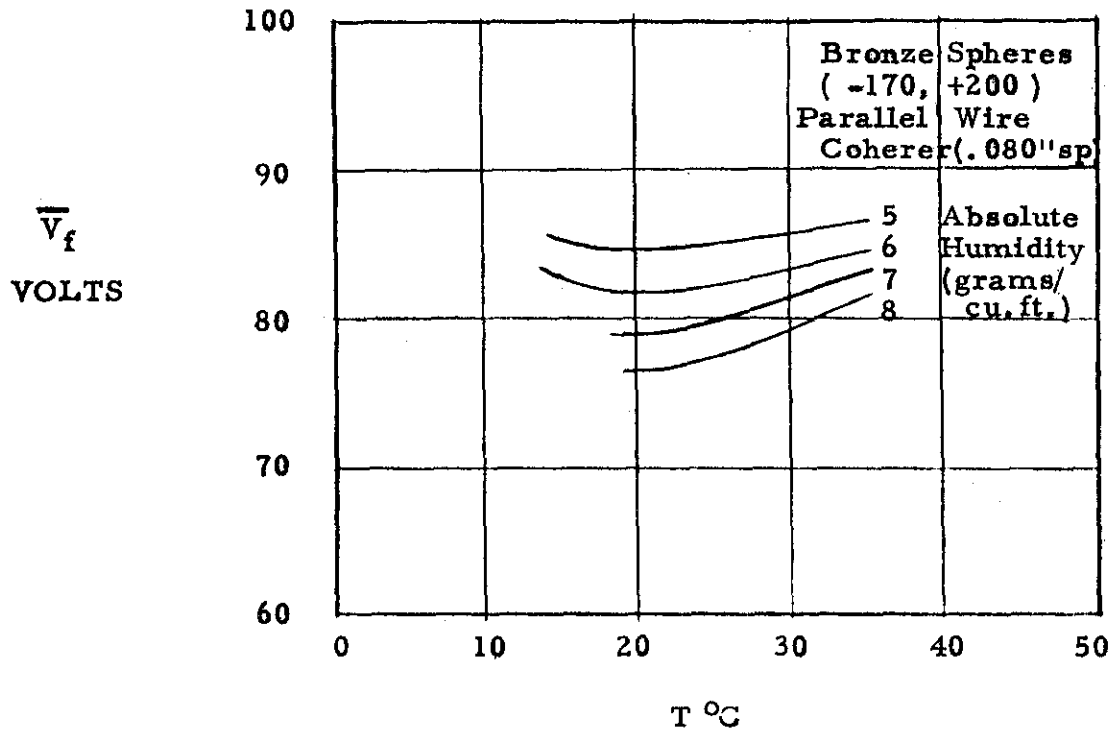


Figure 4-8 Firing Voltage vs Temperature for Constant Absolute Humidity.

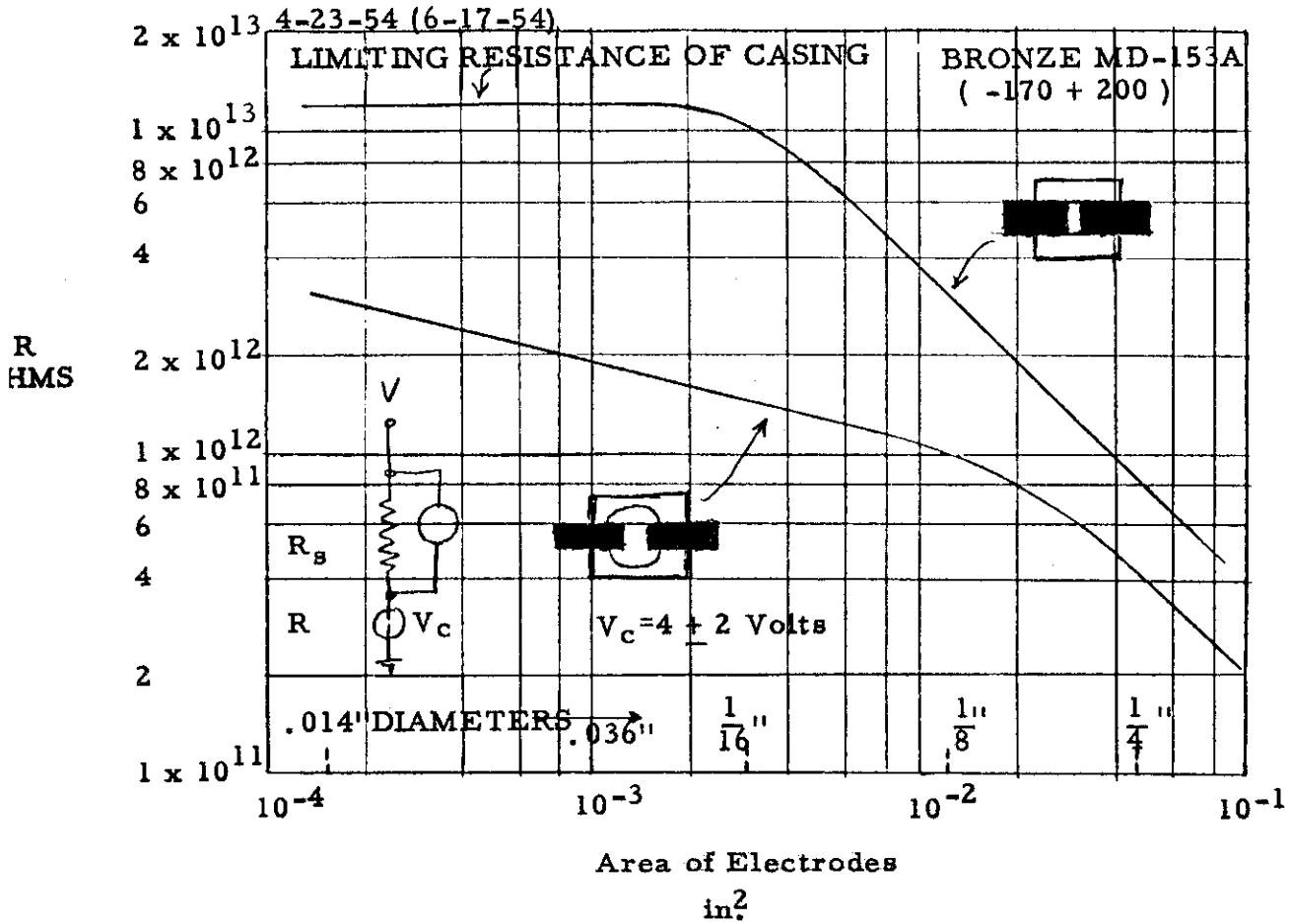


Figure 4-9 Variation of Coherer Resistance with Electrode Size and Cell Shape

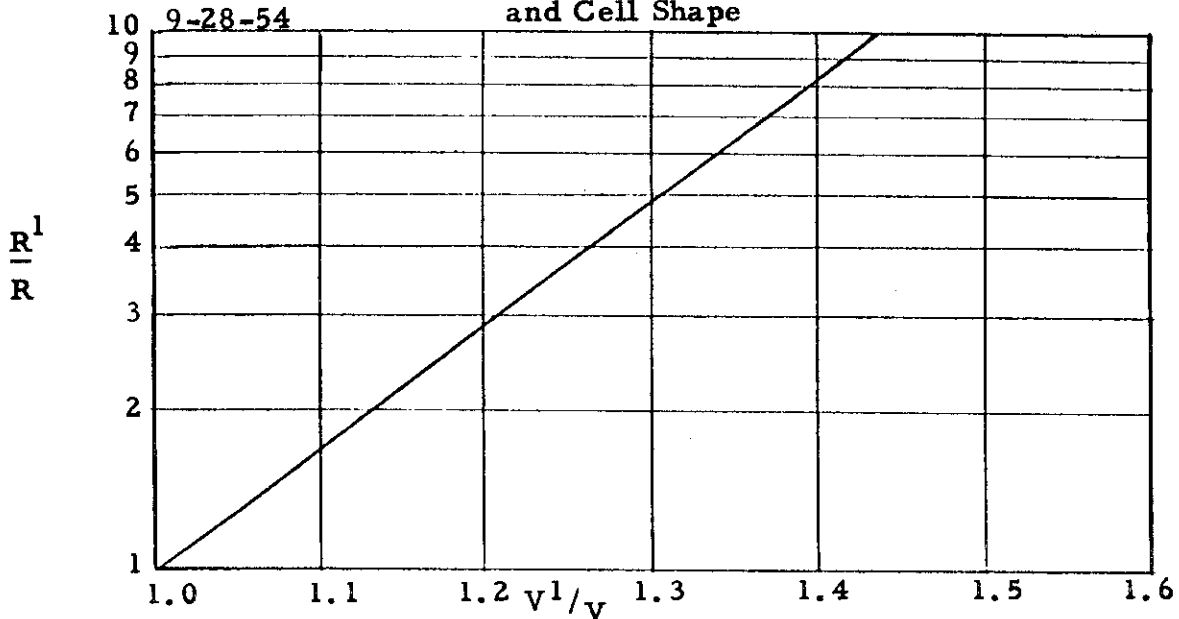


Figure 4-10 Change in Firing Voltage as a Function of Change in Prefiring Resistance of a Coherer.

V Life Test and Reliability of Coherers

a. Single Cells

The reliability of coherers is dependent first upon the plot of firing voltage versus probability of firing and second on the change in this probability curve with number of firings. Figure 3.8 is a plot of the probability of firing for a bronze sphere coherer. The curves have been plotted on an extreme value of probability paper. These curves show that if the experimental curves remain the same for one million cycles the probability of misfiring would be one in a million for 143 volt pulse of 5.2 milliseconds. The probability of misfiring on reading would be 1 in a million for a 40 volt 5.2 microsecond pulse. Fresh powder from Metals Disintegrating Co. changes its probability of firing during the first hour of operation so that the powder must either be prefired or reduced in hydrogen to maintain the same mean firing voltage on a long life test.

Figure 4-5 shows that the Resistox-treated copper powder can maintain a mean firing voltage and standard deviation within reasonable limits for 100,000 firings.

Figure 5.1 shows the effect of changing the decohering energy. The curves are for gradually increasing the length of travel of the decohering hammer as indicated in the diagram. If there is insufficient decohering energy the coherer does not follow the Gaussian distribution, but has a break in the curve such that the coherer would be useless due to misfirings at very low voltages. Variation of the probability curve with change in the amount of powder in a given cell is given in Table V-2. Life tests of the order of magnitude of one million firings are tabulated in Table V-1.

b. Parallel Cells

The first consideration of parallel cells was to increase the current carrying capacity of coherers so that they could be used to fire high current 40 volt relays. Three chromium powder cells were used in parallel as shown in Figure 5.3. From the data shown in the figure it can be seen that all three cells cannot cohere equally well. For all practical purposes two of the three cells are in use. A second use of parallel coherers is to increase the probability of firing. In such a case the variation of cohered resistance would not matter as long as the cohered resistances were below the required reference value. Some coherers may have a probability of failing to fire at the specified

firing voltage of 0.001 which is not low enough for computer storage use. The failures can be reduced by increasing the energy used in firing. However, this may increase the energy required to decohere in addition to increasing the operating power requirements. The combination of a set of coherers in parallel could improve the reliability. If $p(v)$ is the probability that a coherer will fire at a voltage v then the probability of not firing $q(v)$, $q = 1-p$. If $p(v) = 0.999$ then $q = 0.001$. Three coherers in parallel would then give $q' = (1-p)^3$ $q' = 0.001^3 = 10^{-9}$. This would require separate coherers in series resistors as shown in Figure 5.3. The three coherers in parallel could be consolidated into one unit by making a printed circuit type series resistor and using a single cell powder. This could be done by making conductive strip electrodes. Experimental tests have been made with such a coherer and it has been found possible to get three separate paths cohered using Resistox type printed resistors. The theoretical probability of firing curves for a single coherer and for three coherers in parallel are compared in Figure 5.2. It can be seen that the probability of failing to fire decreases while the probability of misfiring increases slightly. It can be seen that the experimental probability curves in Figure 6-2 are shifted in the direction of the theoretically predicted change. However, in practice, not as close agreement is obtained between experiment and theory. It may be that the amount of powder in each cell has to be controlled more carefully and the sieve sized more carefully so that each cell will be close enough to the others so that one cell will not predominate.

Table V-1 COHERER
 LIFE TEST DATA

11-1-54

Number of Cycles	Firing Voltage (and $\Delta = \sigma V$)		
	Cell A	Cell B	Cell G
START	71	92	140 (13)
220,000	71 (6)	81 (11)	
370,000	74 (7)	81 (9)	
480,000			140
605,000			117 (11)
660,000	78	83	
760,000	81	88	120 (12) *
870,000	71	86	
915,000			
950,000	76	86	
1,000,000			122
1,100,000			133
Powder	AA-50X Red Copper -60+80	AA-53 -72+80SP Resistox	AA-54D -80+100

* Decohering Hammer Broke
 And Was Repaired.

Table V - 2:

11-10-54D Effect of Changing The
 Amount of Powder in Cell

Amount of Powder	V_f P=50% volts	Δ volts	$\sigma = \frac{\Delta}{V}$
4 pts.	207	14	.068
8 pts.	188	14	.075
10 pts.	182	15	.082

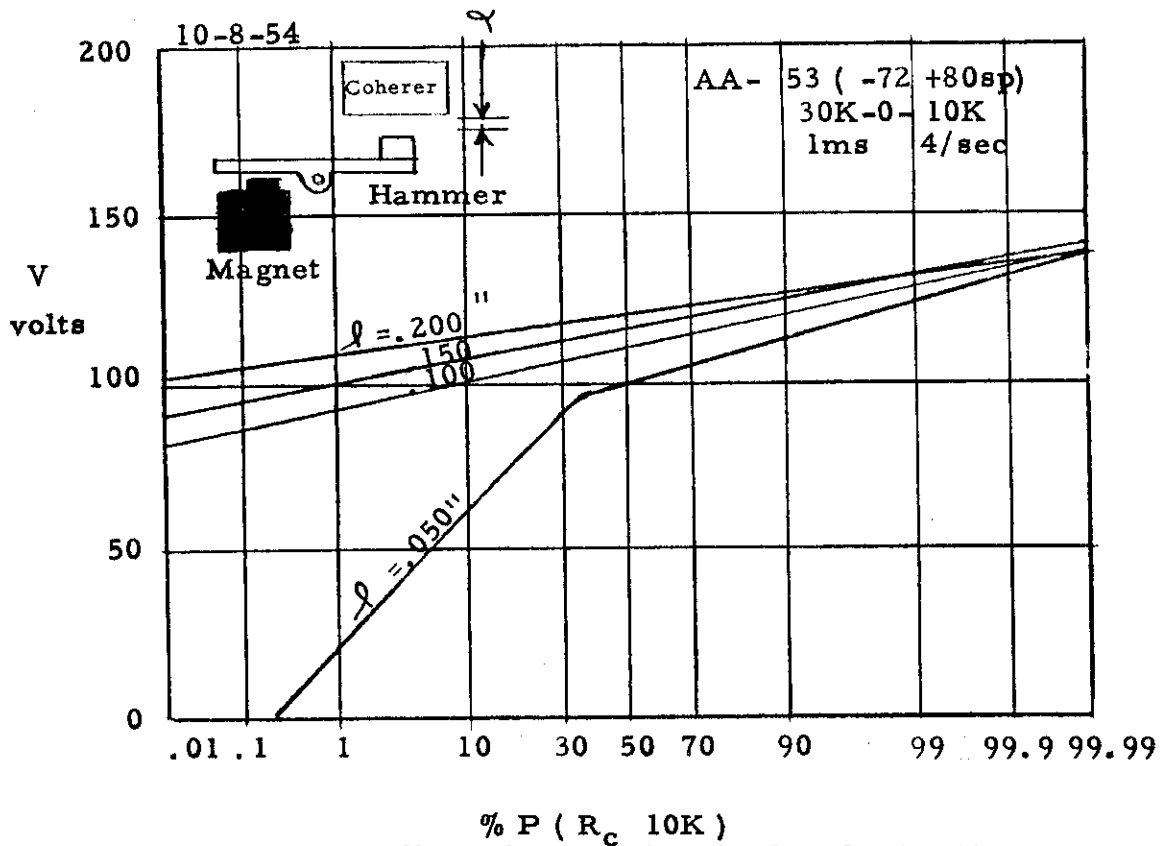


Figure 5-1 Effect of Increasing the Decohering Energy

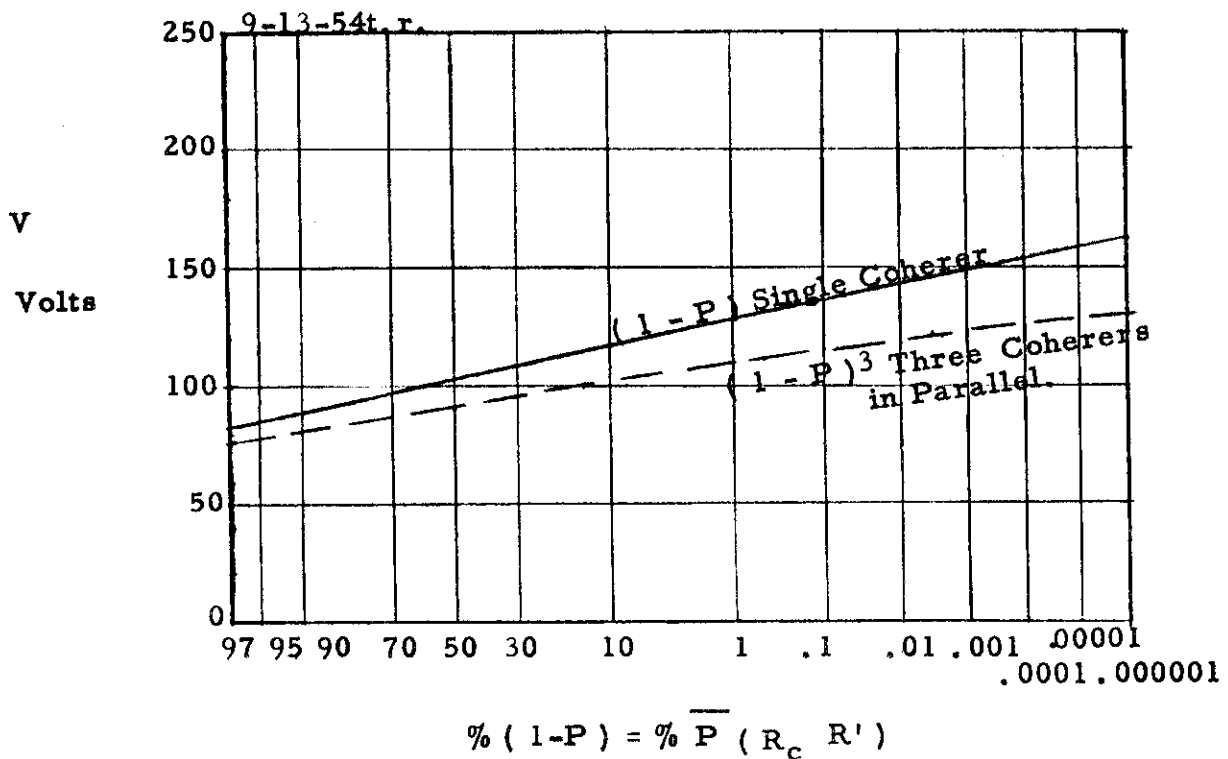


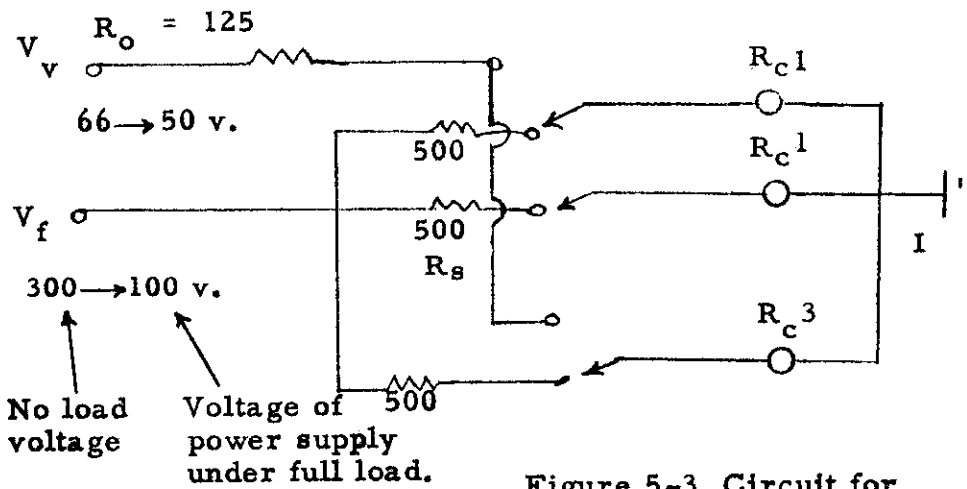
Figure 5-2 Theoretical Probability Curve for Three Coherers in Parallel.

5 - 4 - 54

Data of 5-3-54

F. B. W

Parallel Coherers



1/4" Diameter Electrodes
 7/8" Separation
 -42 + 60 Chromium

$$I = \frac{V}{R_o \left\{ 1 + \frac{1}{\frac{R_o}{R_{c1}} + \frac{R_o}{R_{c2}} + \frac{R_o}{R_{c3}}} \right\}}$$

Figure 5-3 Circuit for Three Coherers in Parallel.

	Cohered R	Calculated I	Exp. I *
# 1	170 \simeq	.170	.210
# 2	1700 \simeq	.028	.060
# 3	130 \simeq	.195	.210
All Three	80 \simeq	.256	.280

R _s	V _f
500	250 v.
125	140 v.

* — est #5

Figure 5-4 Data on Firing of Three Coherers in Parallel.

VI Firing of Thyratrons from Separately Connected Coherers

The firing of thyratrons through separately connected coherers has been found to be very reliable. The reason for checking coherers in circuits reading out to thyratrons is that it is difficult to make reliable coherers that can stand up under the high current required for direct operation of 40 volt wire relays.

Experiments have been made with special materials such as chromium and tungsten powders to withstand the high current. A 4 x 6 matrix of coherer cells separately connected was designed and constructed for firing 30 milliampere relays. Tungsten powder minus 80 plus 100 mesh was used and successful cells were obtained in 19 of the 24 cells. In the 19 successful cells no errors occurred in 500 firings on the test bench, and no errors occurred in 5000 cycles of punching cards on the reproducing punch in June, 1954. In these tests an error consisted of a coherered resistance higher than 300 ohms. Tests for longer periods were not as satisfactory, so thyratrons were introduced between the coherers and the relays for read-out.

A coherer matrix was tested as a buffer storage in a tape to card machine in October, 1954. Resistox treated copper powder was used, and the read-out was to thyratrons. Each cell of the matrix had its own lead. The best cells in the separately connected matrix of the card-to-tape machine gave between 2 and 4 per cent error except on some occasions where periods of operation were obtained with only 0.1% error. In these tests it was found that the firing voltage gradually increased, as it did in some of the life tests on Resistox treated copper, which indicates the heating evaporated off some of the resistox treatment which was controlling the oxide thickness.

To see if greater reliability could be obtained, a set of coherers were hooked up to the test circuit of Figure 6-1 to simulate use in a card-to-tape machine without introducing any circuits which might confuse the life tests by introducing errors. Tests were run on single cells and on three coherers in parallel as shown in Figure 6-2. The curves of Figure 6-2 confirm the shapes of the theoretical curves of Figure 5-2. The coherer cells used in the March, 1955 tests were larger than the earlier tests in an attempt to keep the temperature rise lower. One set of three coherers in parallel were fired and decoherered for 120,000 cycles and no errors occurred during the run.

WH 3/1/55

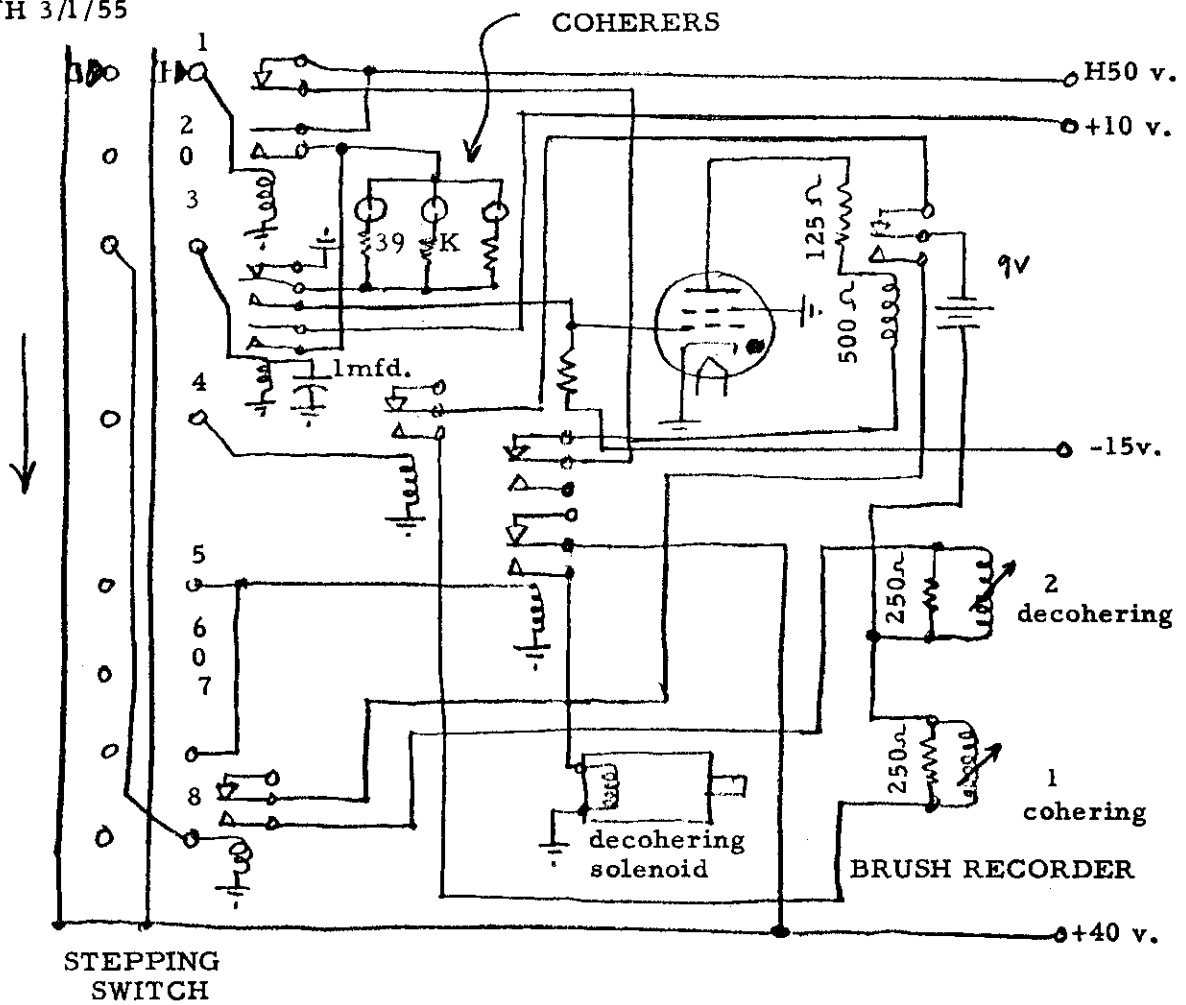


Figure 6-1. Readout of Coherer Through Thyatron

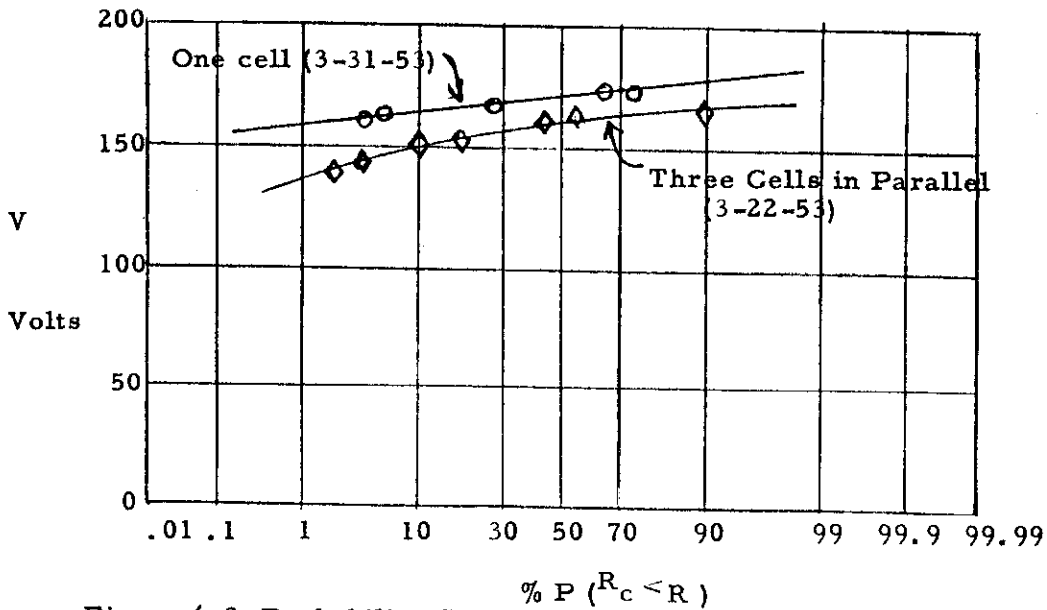


Figure 6-2 Probability Curves for One and Three Cells in Parallel, Read Out Through Thyatron

VII Matrix Firing of Coherers

Coherer matrix units using neon cells or selenium back circuit eliminators have been previously reported. See Report 203.003.059. The use of neon tube glow lamps as back circuit eliminators increases the cost and also puts restrictions on the pulse length and voltage that could be used on a coherer cell. Attempts have been made to design a coherer matrix that did not require the use of any back circuit eliminators. A matrix circuit has been proposed shown in Figure 7-1. The first feature of the proposed matrix coherer storage system without back circuit eliminators is to use three coherer cells in parallel for each element. This improves the probability of firing curve as indicated in figure 5-2. A second feature shown in Figure 7-1 is to use the combination of plus and minus $\frac{V}{2}$ and $+V$ voltages in applying the voltages to the rows and columns so that the cells that are to be fired have three times the voltage of the cells not to be fired. Then the problem is to design cells and find suitable powder such that probability that the cells will fire at a voltage V and the probability they will not fire at $1/3$ the voltage V have reasonable values.

The system of determining the required characteristics are shown in Figure 7-2. Referring to Figure 7-1 can be seen that the rows are normally at $\frac{+V}{2}$ the columns are normally grounded. To store