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

by

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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*This report has been edited from unpublished manuscripts of March 1955 and earlier.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 amd .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 usec 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 coheres 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	3x10''(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 Li_2CO_3(air)	-100 +150	MD Lith. Cap.	test tube (furnace)		500	1.5×10^8	1
7a	CuO heated in Li_2CO_3 powder.	+ 200	Cenco			140	1.5×10^8	1
8	Bronze heated in molten lithum (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 Li_2CO_3(air)		Harshaw	441-002-31		<500	7×10^8	5
12	Alurdum		Norton	38-600x		<500	10^8-10^{10} h1in.	
13	Bronze *	-170+200	MD	MD-153A		440	2.5×10^9	7
7b	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	StainlessSteel	-100	Sintrex	321		45	7×10^9	1
18	Cr_2O_3	Baker				<500	7×10^9	1
19	Mdybdenum	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 Li_2CO_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 Li_2CO_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}	3I
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 25 Sn, 75 Pb	Powder	MD	M-204	L-4666	20 - 50	1.5×10^{11}	1.
36	Nickel	-20 + 42	MD	MD-9119	L-4163-S	400	2.5×10^{11}	11
37	Cu heated in Li_2CO_3 Filtered					150 - 300	3×10^{11}	7:
38	8.4P,H.6 Cu	-100+150	MD		L-4365-S	40	10^{12}	1
39	Ni heated with Li			MD-9119		75	10^{12}	1
40	80 Cr, 20 Ni		MH	LSM-810		170	10^{12}	1(
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

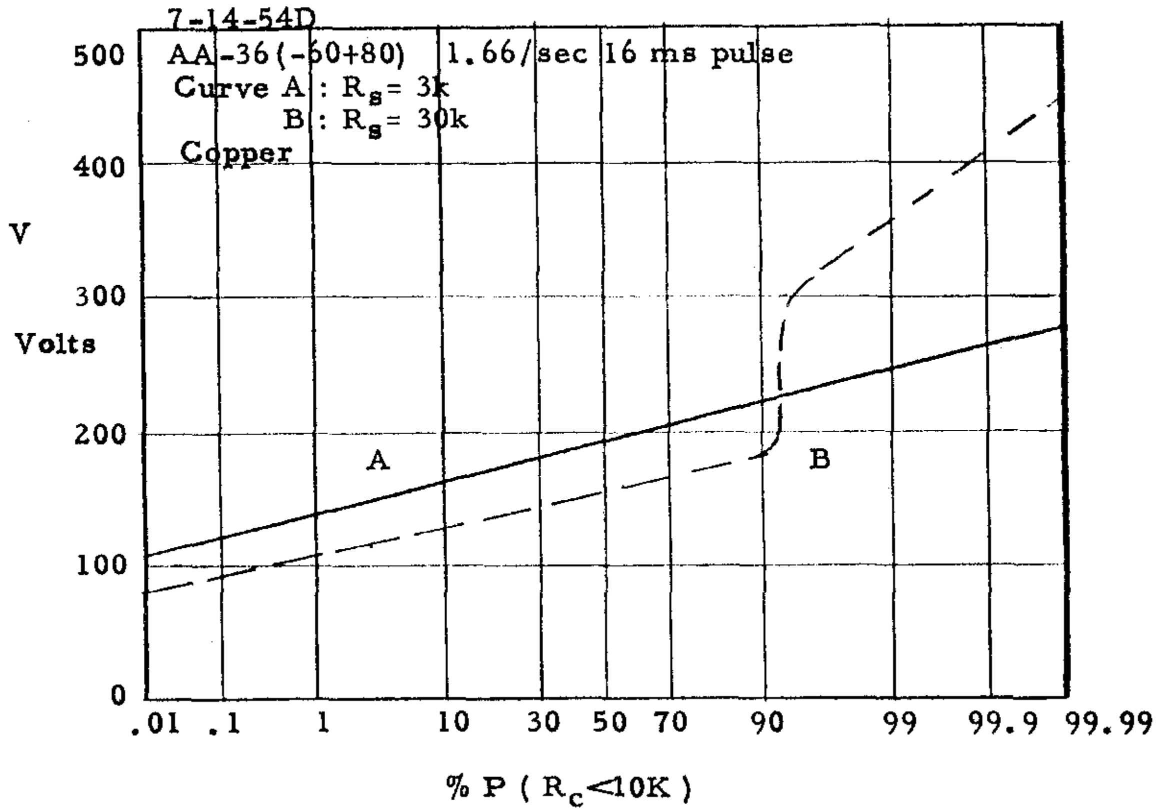


Figure 4-1 Change in Probability of Firing Curve with Increase of Series Resistance.

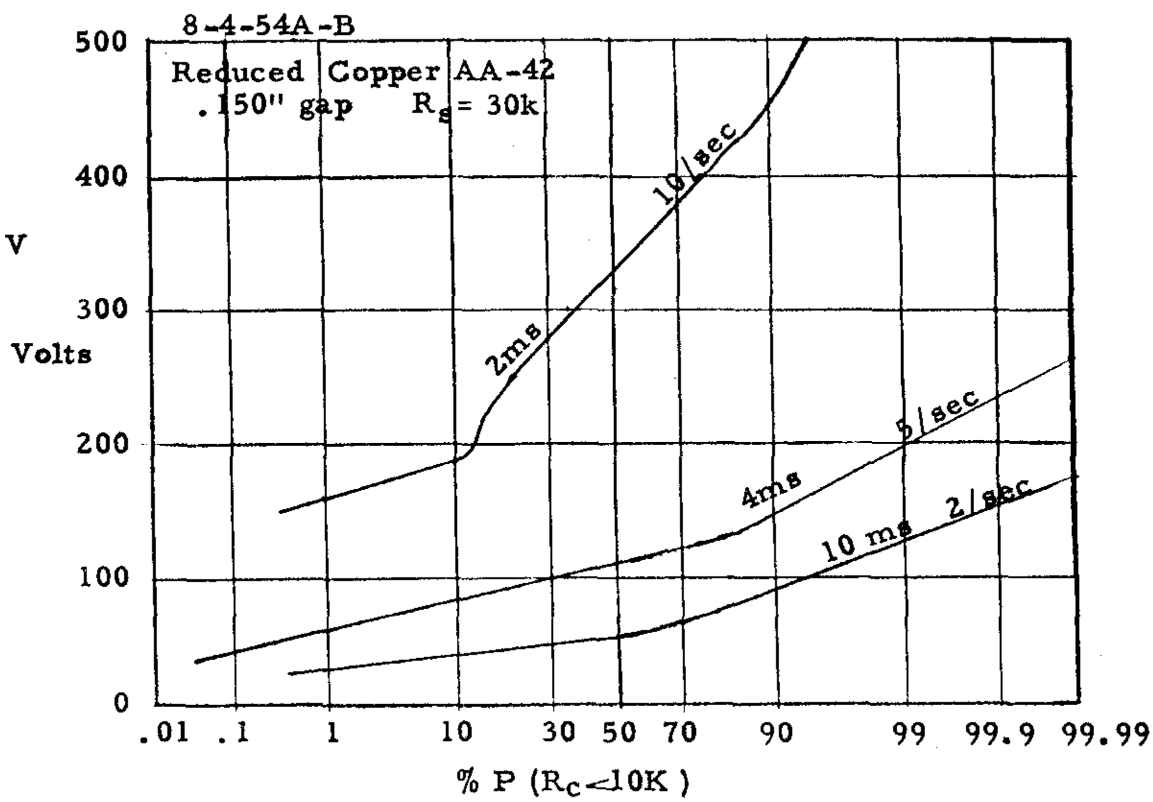


Figure 4-2 Change in Shape of Probability Curve with Change in Pulse Length & Repetition Rate.

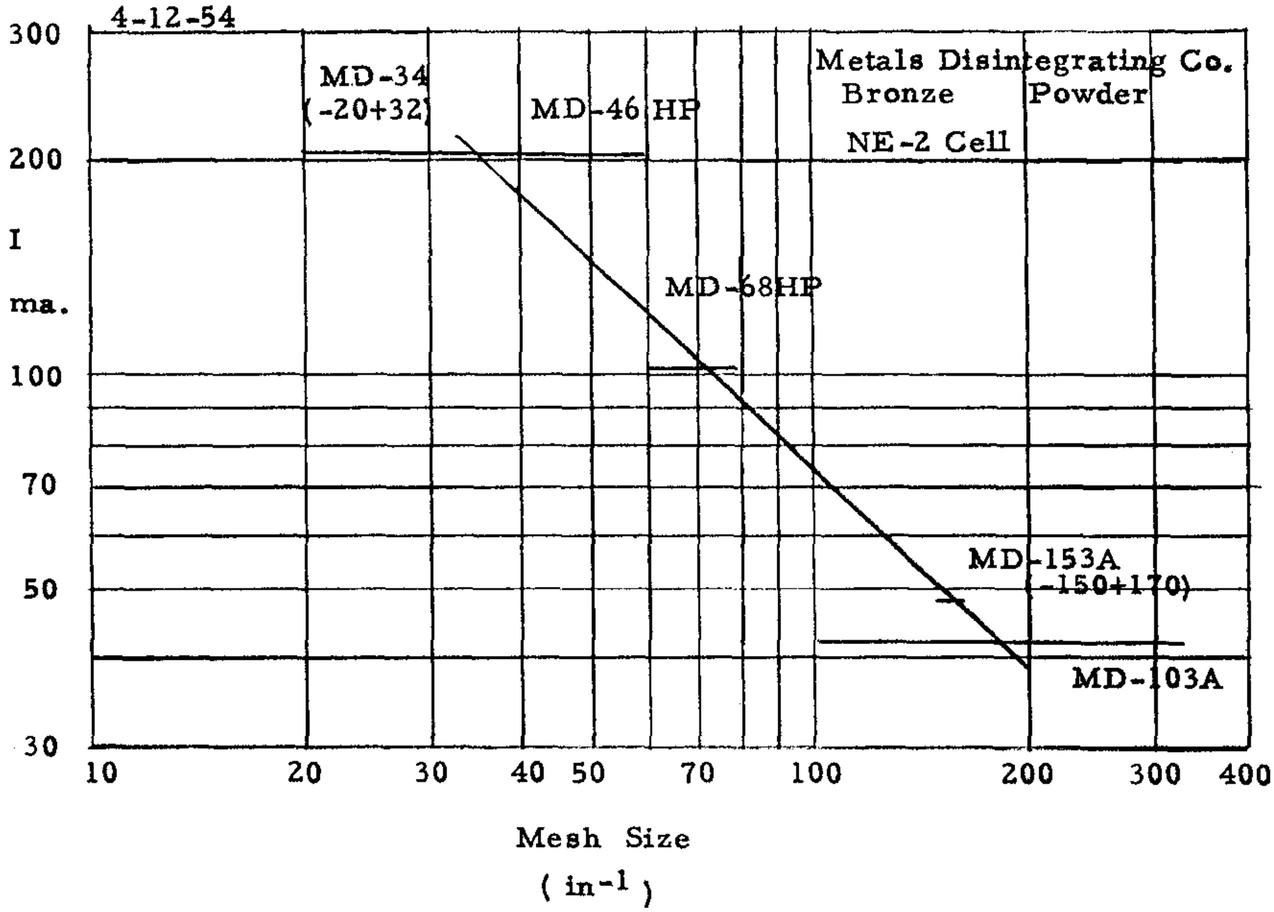


Figure 4-3 Current at Which Bronze Powder Discolors.

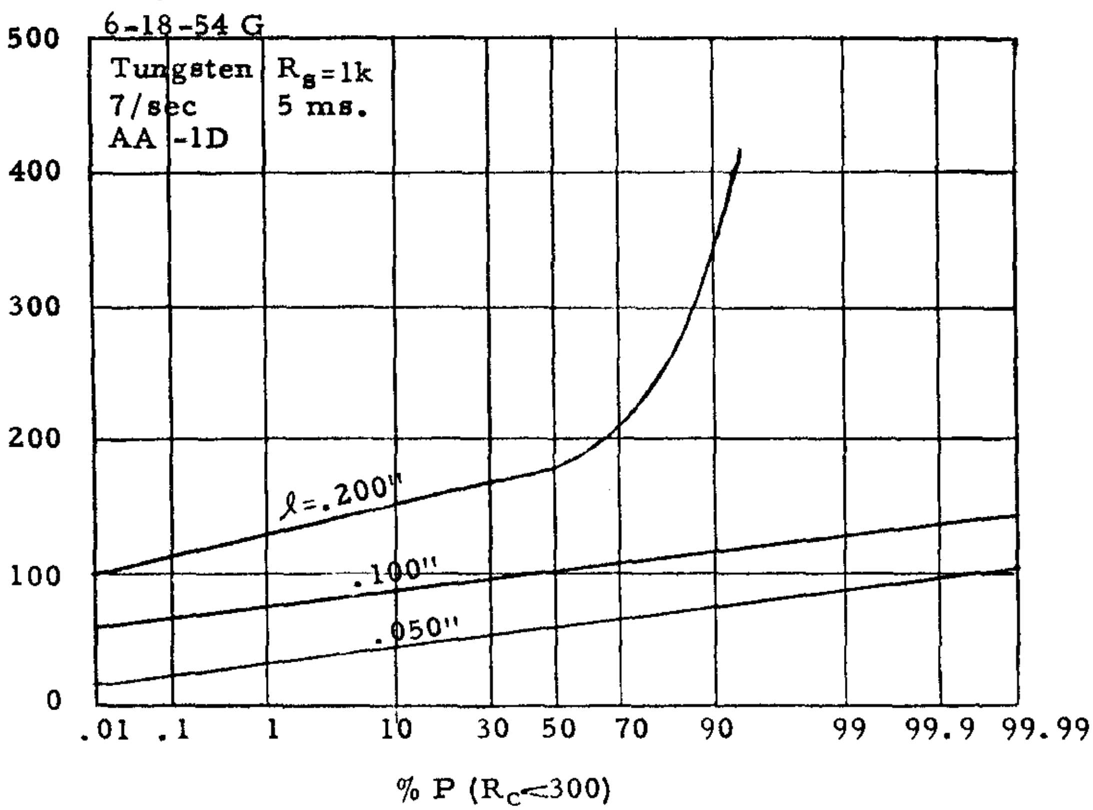


Figure 4-4 Effect of Increasing Coherer Gap Length.

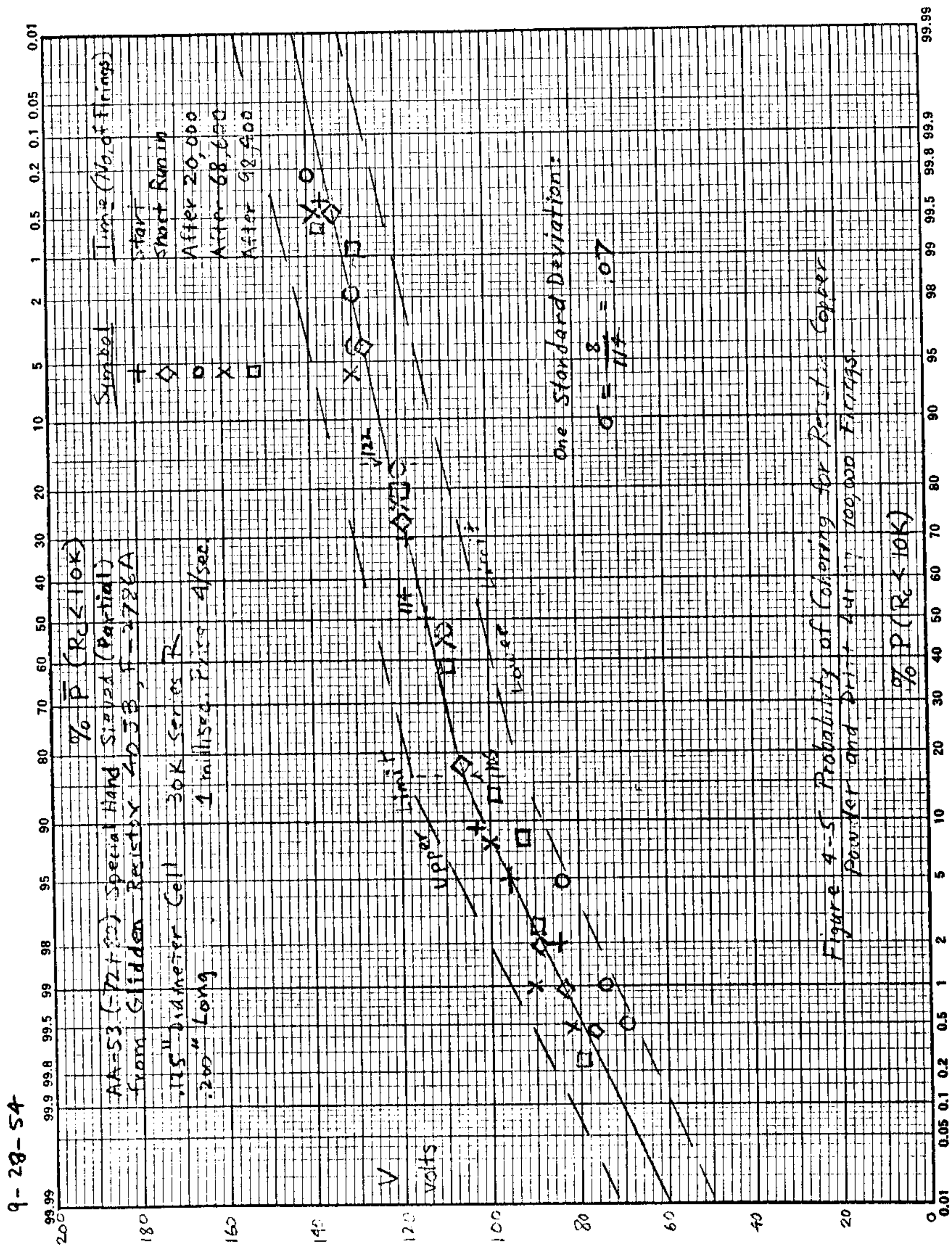


Figure 4-5 Probability of Coloring for Resistor Copper Powder and Print After 100,000 Firings.

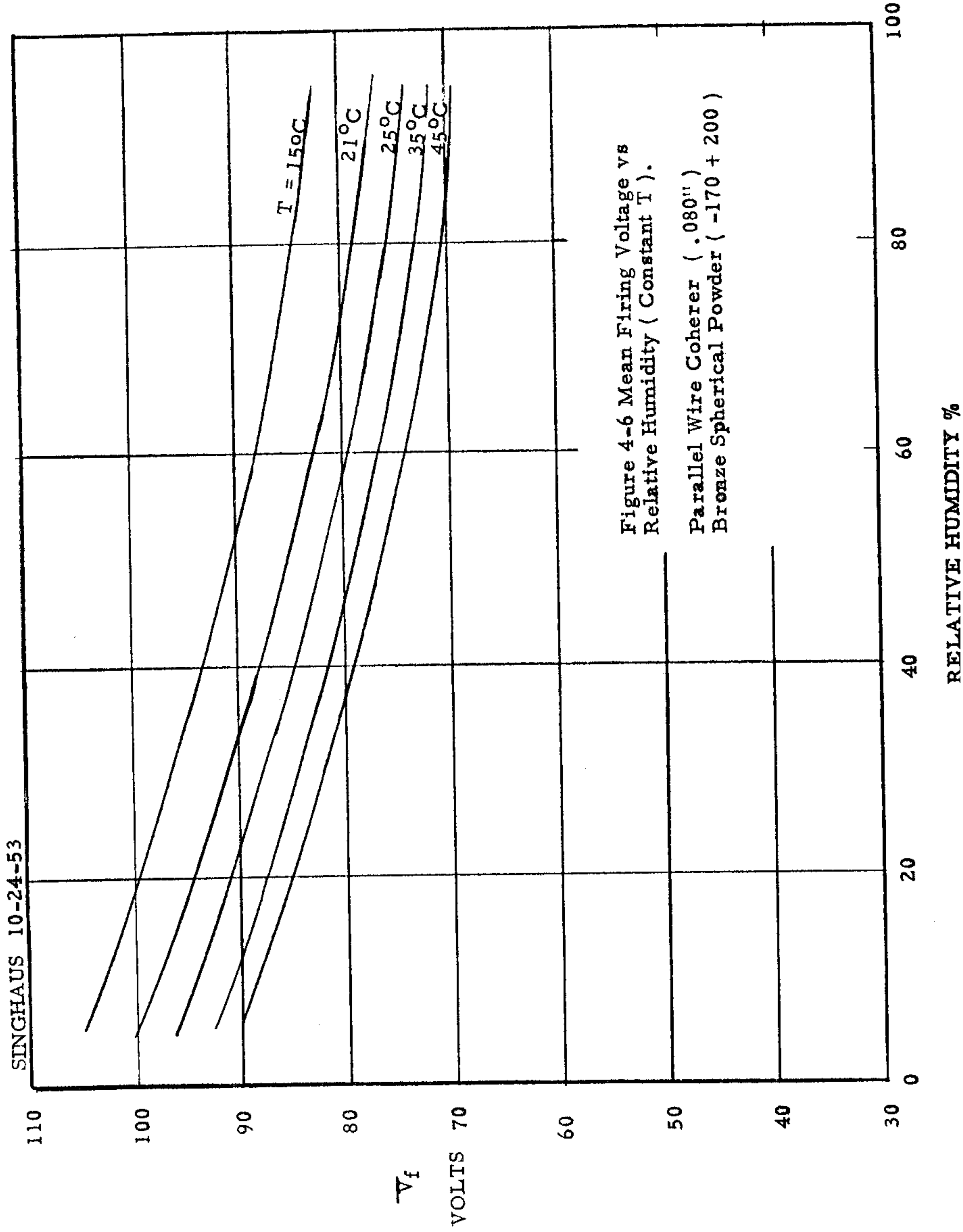


Figure 4-6 Mean Firing Voltage vs Relative Humidity (Constant T).

Parallel Wire Coherer (.080")
Bronze Spherical Powder (-170 + 200)

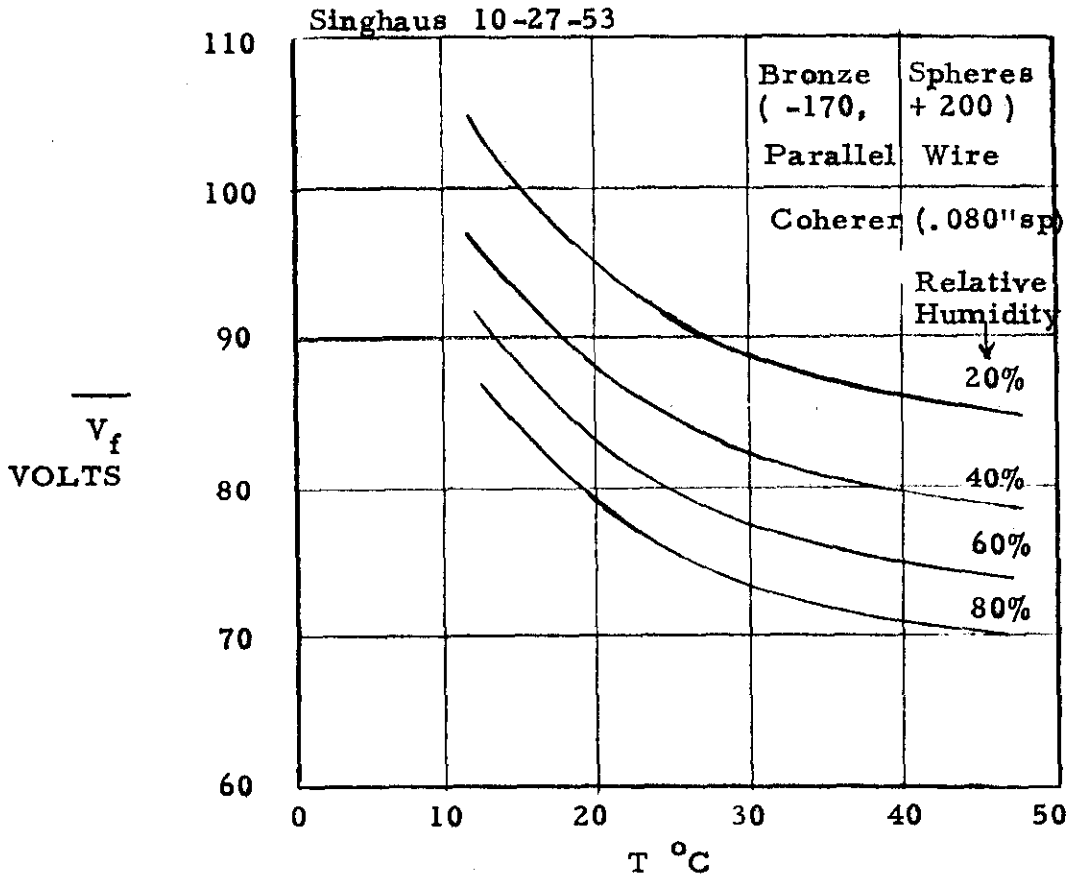


Figure 4-7. Firing Voltage vs Temperature for Constant Relative Humidity

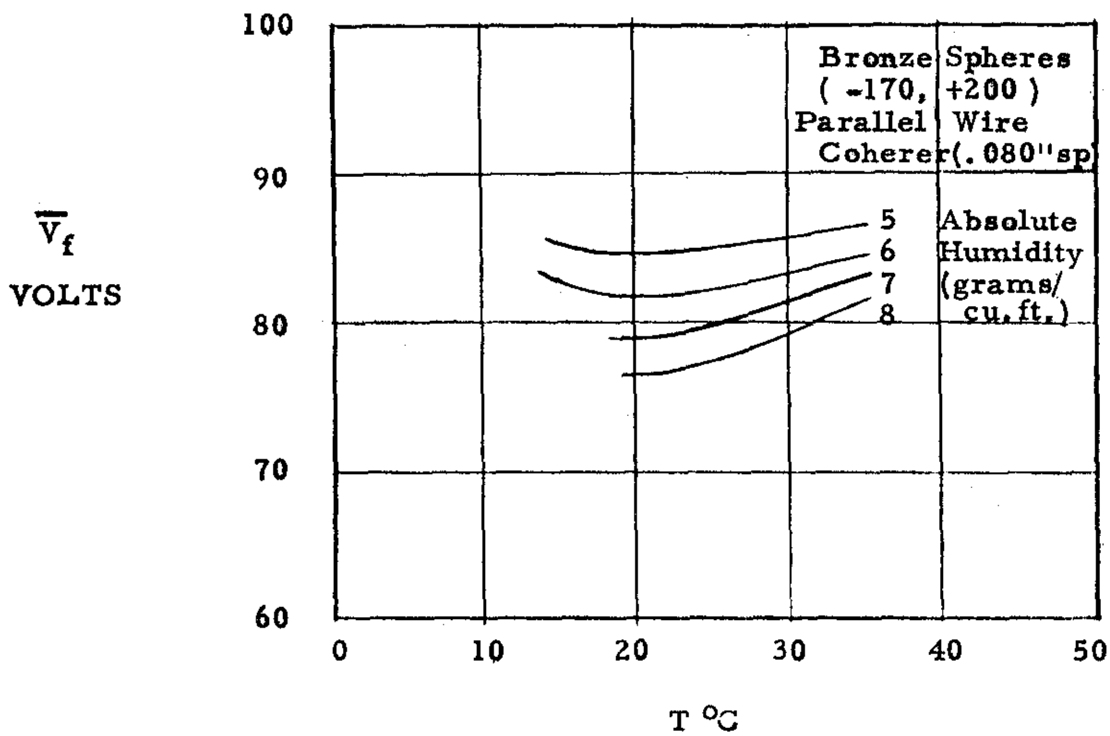


Figure 4-8 Firing Voltage vs Temperature for Constant Absolute Humidity.

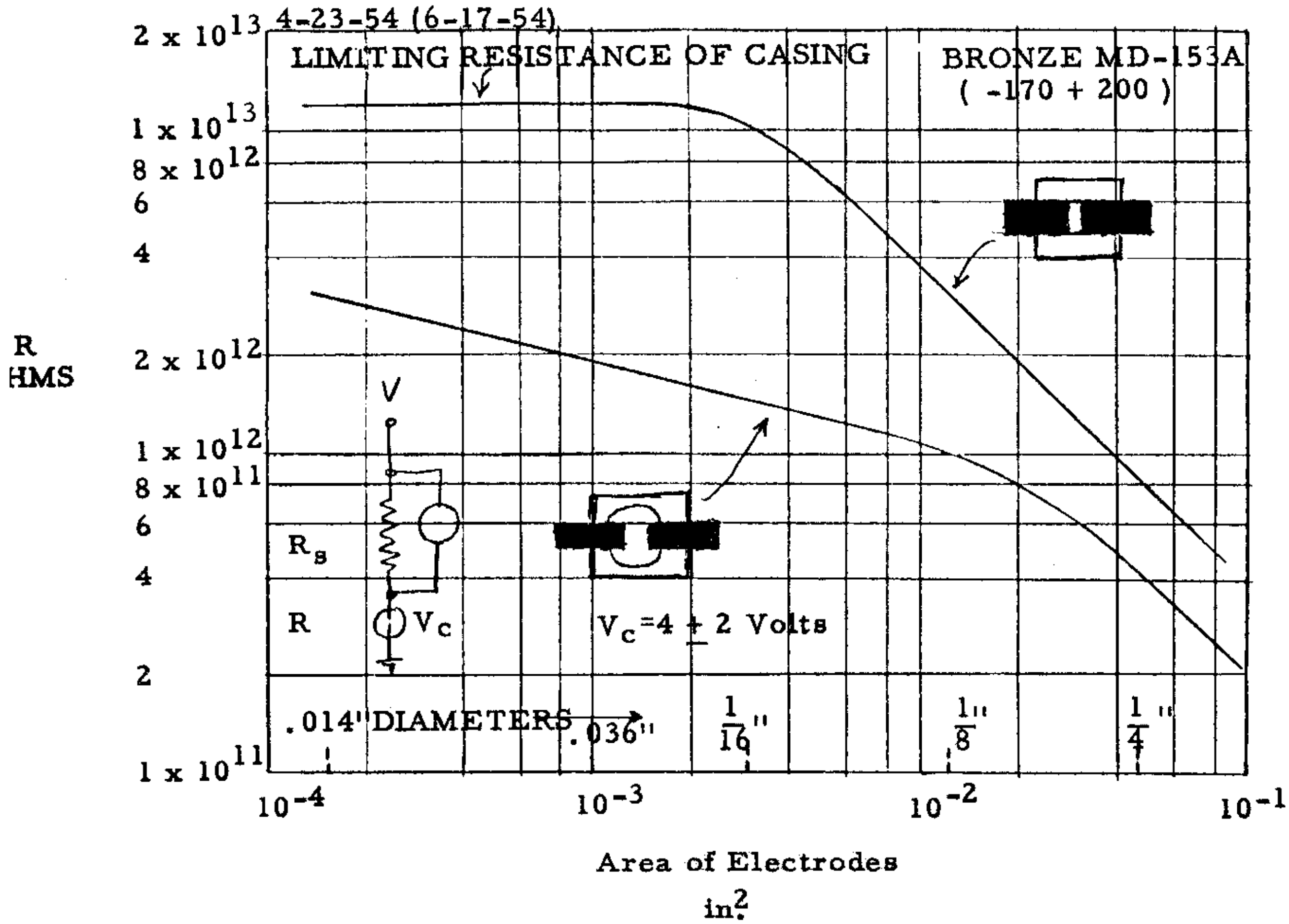


Figure 4-9 Variation of Coherer Resistance with Electrode Size and Cell Shape

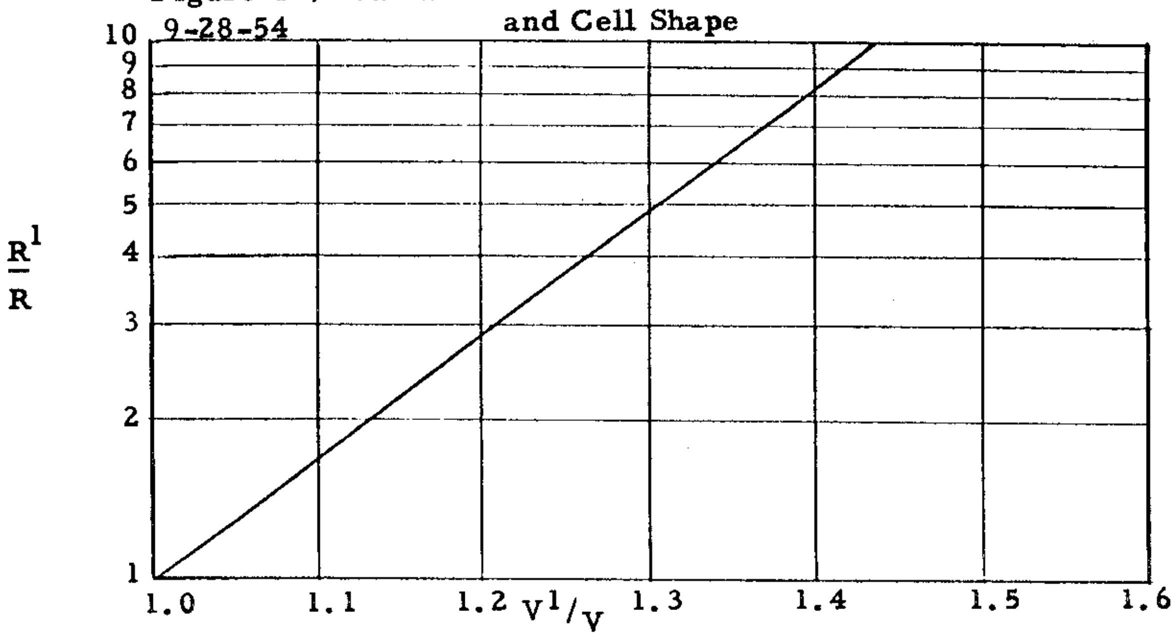


Figure 4-10 Change in Firing Voltage as a Function of Change in Prefiring Resistance of a Coherer.

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

Firing Voltage (and $\Delta = \sigma V$)

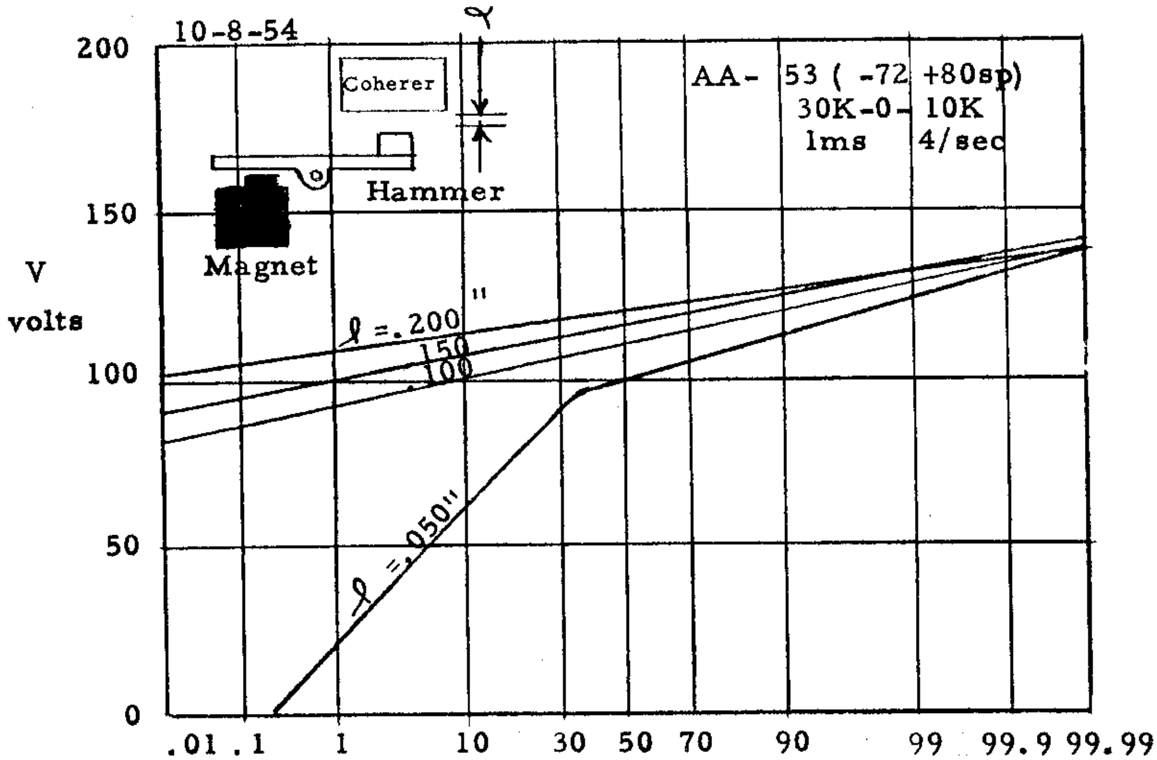
Number of Cycles	Cell A	Cell B	Cell G
START	71	92	140 (13)
220,000	71 (6)	81 (11)	
370,000	74 (7)	81 (9)	
480,000			140
605,000			117 (11)
660,000	78	83	
760,000 *	81	88	120 (12)
870,000	71	86	
915,000			
950,000	76	86	
1,000,000			122
1,100,000			133
Powder	AA-50X Red Copper -60+80	AA-53 -72+80SP Resistox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

* Decohering Hammer Broke
And Was Reparied.

Table V - 2:

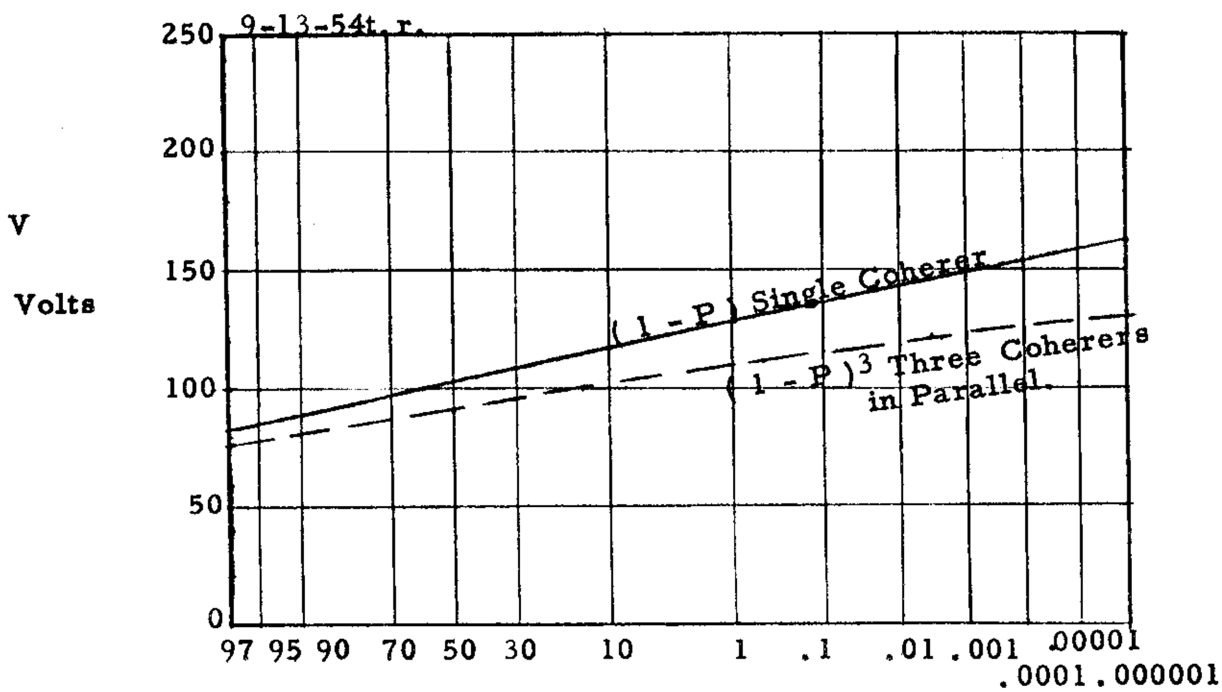
11-10-54D Effect of Changing The
Amount of Powder in Cell

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



% P (R_c 10K)

Figure 5-1 Effect of Increasing the Decohering Energy



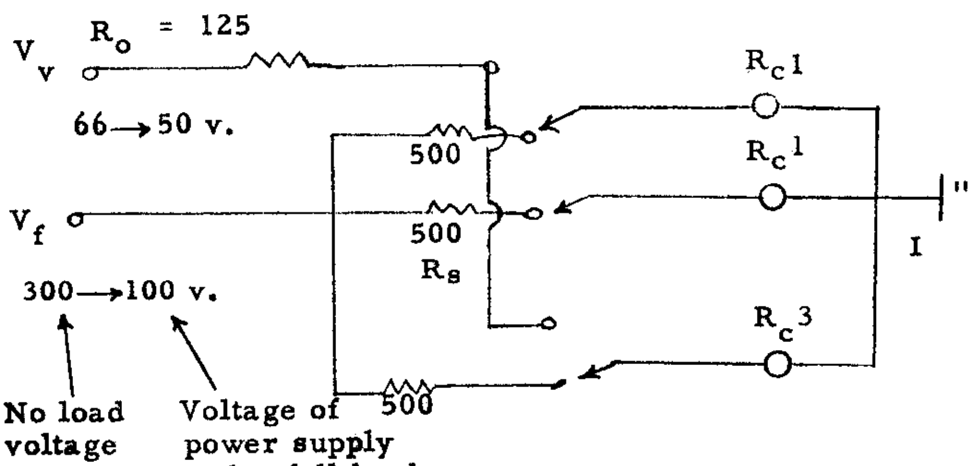
% (1-P) = % $\overline{P}$ (R_c R')

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

5 - 4 - 54
Data of 5-3-54
F. B. W

Parallel Coheres

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 ∿	.170	.210
# 2	1700 ∿	.028	.060
# 3	130 ∿	.195	.210
All Three	80 ∿	.256	.280

* —est #5

R_s	V_f
500	250 v.
125	140 v.

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 successsul 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 cohered 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.

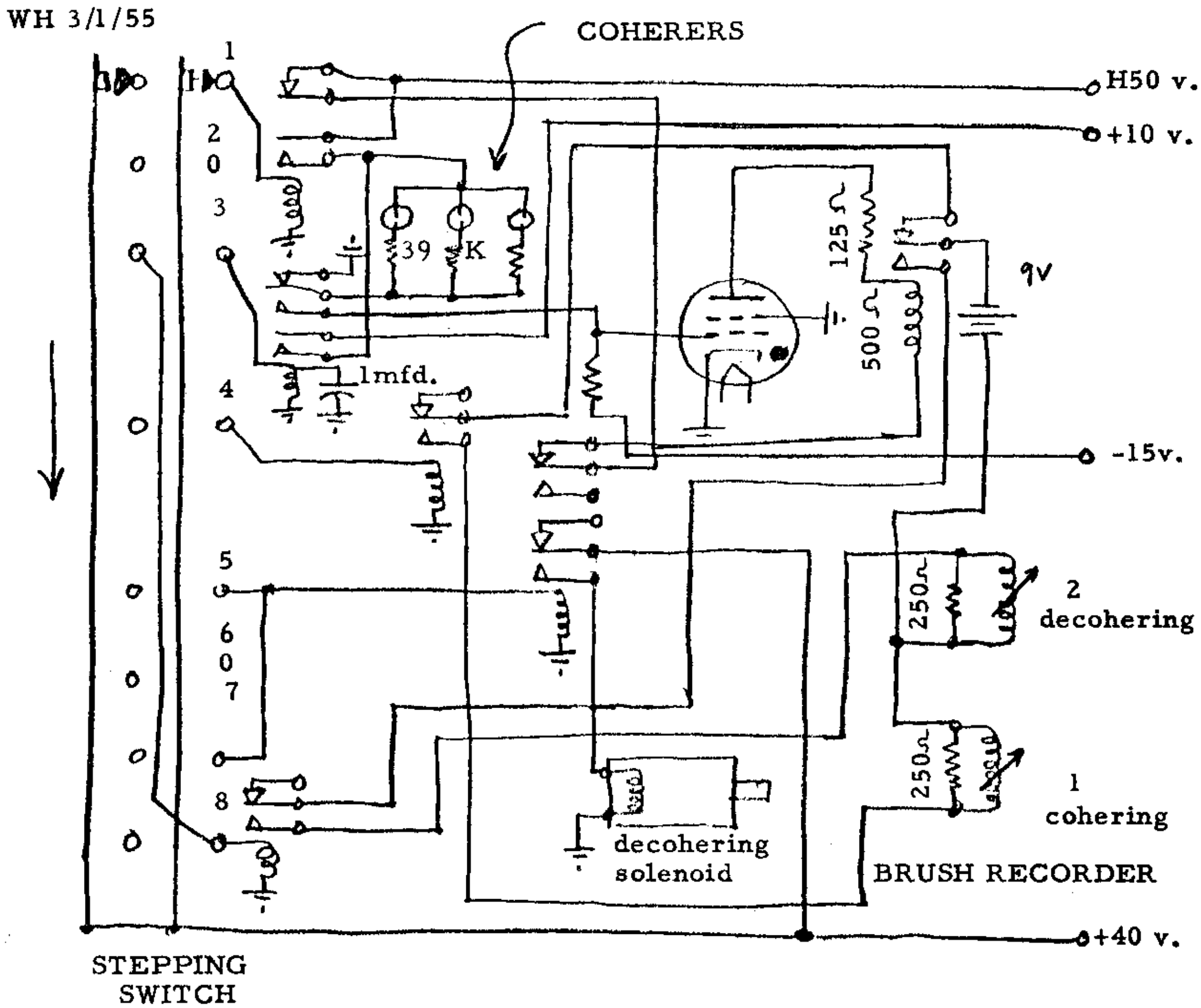


Figure 6-1 Readout of Coherer Through Thyratron

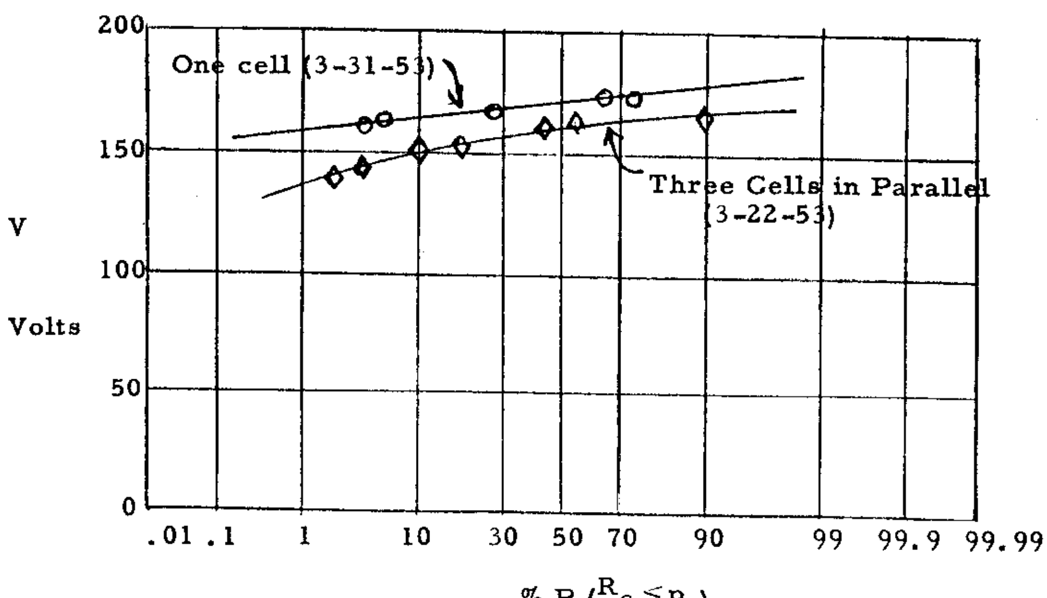


Figure 6-2 Probability Curves for One and Three Cells in Parallel, Read Out Through Thyratron

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 information the rows are changed to $\frac{-V}{2}$ in sequence while the columns are raised to +V if there is a punch at the point on the card. This puts 3/2V across the coherer to be fired and $\pm$ V/2 on the remainder. Instead of back current circuit eliminators such as diodes or neon tubes, the separate series resistors permit any previously cohered cells to carry current without interfering with the firing of the rest of the matrix. This requires extra current carrying capacity in the power supply.

If it is required that the accuracy be less than one failure in one million operations, then for a three-element coherer, the resultant probability curves should go through the points A and B where $P(V/2) = 10^{-6}$ at point A and $(1-P) = \overline{P}(3V/2) = 10^{-6}$ at point B.

Since a coherer bank to be used as a buffer storage will have the voltage V/2 applied at each step in the 12 x 80 = 960 cycles, it has an effectively different pulse length for determining the error of failing to fire on writing and misfiring on reading.

Extrapolating from figure 3-6, shows that the firing voltage is increased by a factor of 1.66 for an increase of pulse length by a factor of 960. Multiplying the V/2 of point A by 1.66 gives point C in figure 7-2.

Curve CB is the theoretical probability curve for three coherers in parallel. The curve for each single coherer is obtained as follows:

At point B: $(1-P)^3 = 10^{-6}$, so $(1-P) = 10^{-2}$, which puts B' at $V = 1.5$, $\overline{P} = 0.01$

At point C: $(1-P)^3 = 1-3P = 1-(10^{-6})$, so $P = 3.3 \times 10^{-7}$

Correcting point C' for the different effective pulse length:

At point A': $\overline{P} = 3.3 \times 10^{-7}$, $V = \frac{0.83}{1.66} = 0.5$

The straight line AB' in Figure 7-2 is a required characteristic for each cohering path. As shown in Figure 7-1 the voltages are removed from the rows of wires for reading. The read out is through connection to amplifiers on the right. The column wires are grounded except the one being read, which has a fractional voltage applied such as $\frac{V}{5}$ for reading. Each fired coherer unit has a resistance of between 10K and 30K if 30K series resistors are used. If all 79 coherers other than the ones being read have been fired and all three elements have been fired, the shunt resistance across 100 ohm output would be 127 ohms. This gives an output voltage of 0.0056 volts as shown in figure 7-3 (b). When no other cells in the row are fired, the read-out voltage is 0.3 volts as shown in figure 7-3 (a).

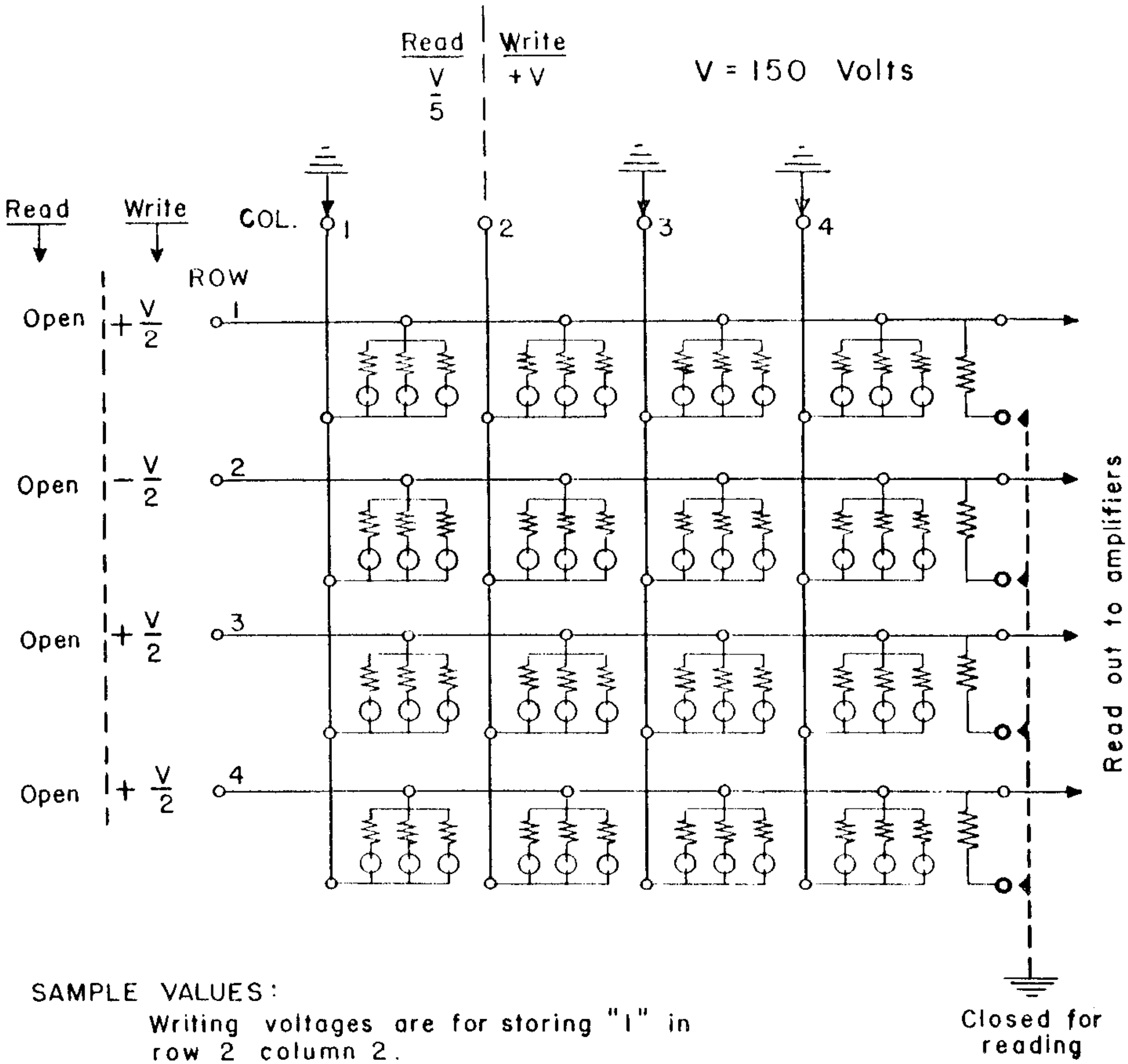
The circuit parameters will have to be adjusted if this output voltage range is too close to noise from the switching circuit. A coherer matrix circuit like this has been tried and set up in a circuit in which information is keyed in and transferred by stepping switch from the coherer cell through an amplifier.

This experimental matrix system gave an accuracy of one error in 2,100 coherer cell firings. The following factors have been found to be of significance accuracy:

1. The firing voltage for different columns of the matrix have been slightly different even though the cells have the same physical dimensions and the same amount of powder put in each cell by use of the standard dispenser. It may be that the slight variation in powder size and oxide thickness is enough to upset the delicate balance of the firing voltages so that to realize this system with no back circuit eliminators the powder must be more accurately controlled.

2. Another factor is the pulse length from relays are long compared to the pulses that are needed for accurate control of matrix firing of coherers. It may be that an electronic pulsing circuit system would be a better test of the procedure. It was found that many of the pulse

lengths on the cells were considerably longer than desired. Another factor is that some of the pulses had reverse spikes at the beginning and/or the ends of the pulses which may have contributed to misfiring. The general conclusion from this matrix test system is that it is potentially realizable but requires more careful control of the voltage pulses applied to the row and the columns. More attention must be paid to eliminating transients. Also, better uniformity in particle size and quantity of powder in each cell will have to be established to make the coherer matrix function satisfactorily without back circuit eliminators.



SAMPLE VALUES:

Writing voltages are for storing "1" in row 2 column 2.

Reading voltages are for reading column 2.

FIGURE 7-1 – MATRIX STORAGE USING THREE COHERERS IN PARALLEL PER ELEMENT.

9-13-54

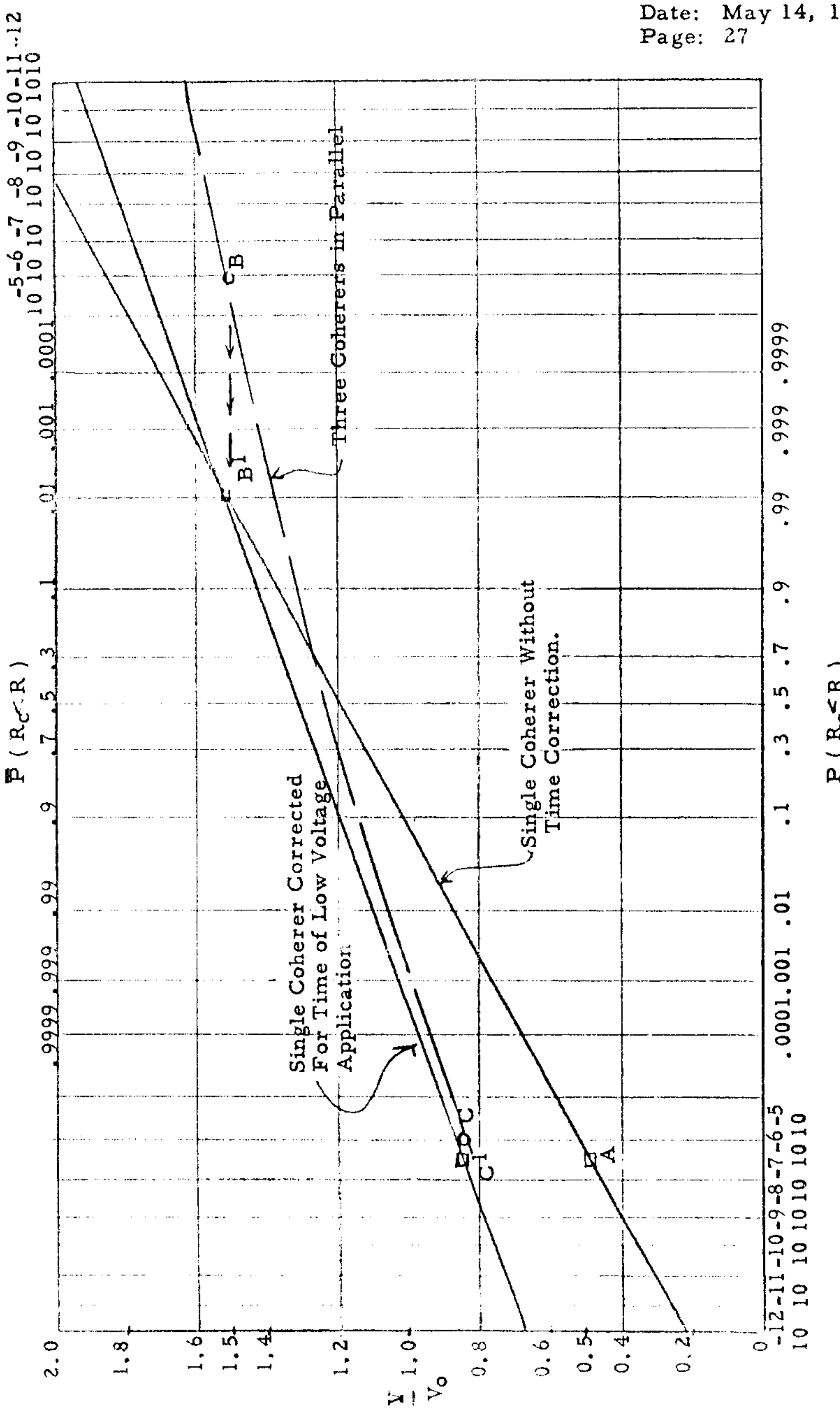
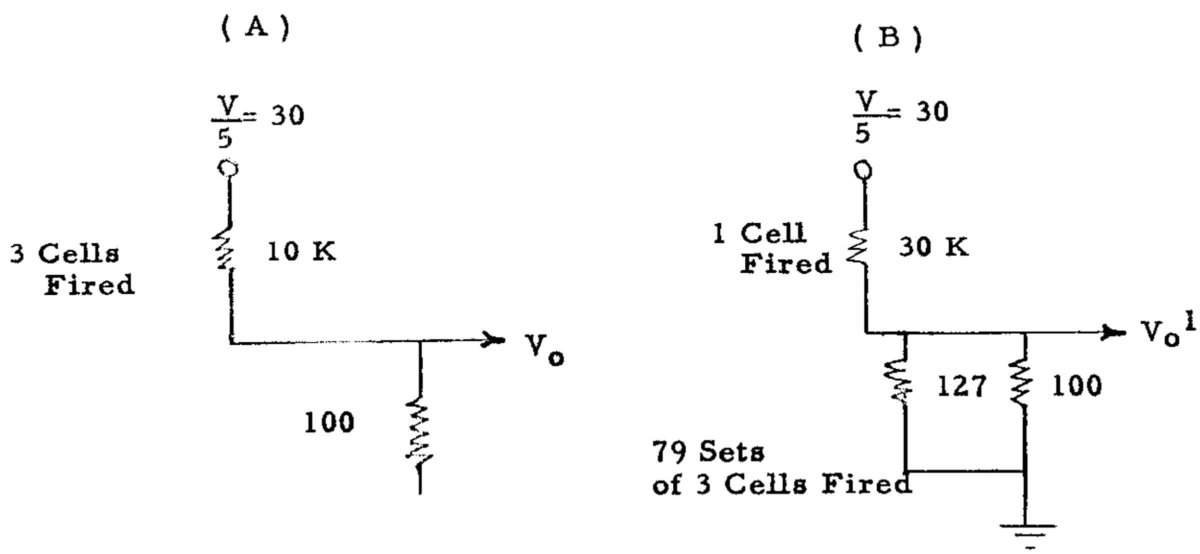


Figure 7-2 Theoretical Probability Curves for Parallel Coherers in Matrix



$$V_o = \frac{100}{10,000}\ 30 = 0.3$$

$$V_o^1 = \frac{100 \times 127}{227}\ \frac{30}{30,000} = 0.0056$$

Figure 7-3 Maximum and Minimum Read-Out Voltages

VIII Conclusions

The operation of a coherer as a storage element is definitely a statistical phenomena involving a time delay and a statistical variation superimposed on the initial time delay. This requires that the voltage and pulse length be carefully checked and probability curves obtained on any elementary design. With the use of parallel cells it is possible to greatly increase the accuracy, that is, to decrease the probability of misfiring, so that coherers can be designed for reliable operation. There is a problem of getting both a good design in respect to firing voltage and pulse length required with a suitable standard devitation that will also last for 10^7 cycles. The Resistox-treated hydrogen-reduced copper powder has given the best performance. Although in some form, it has appeared that the heat developed in the cells tends to evaporate off the coating so that the oxide layer gradually increases, thus pushing the firing voltage up. Some samples of Resistox-treated powder have given fairly flat curves of firing voltage with time for as many as a million cycles.

Separately connected coherer cells can be used for buffer storage provided the temperature rise during operation is kept low enough to prevent deterioration of the Resistox-treatment of the oxide-coated powder. The variation of the voltage for a 50 per cent probability of firing prevents a practical utilization of coherers in matrices without back circuit eliminators. If closer tolerances on the thickness of the oxide layers, the mesh size of the powder, and the number of grains of powder per cell, it should be simple to make successful coherer matrices. Before coherers can be used as reliable storage devices, more specific knowledge of the Resistox treatment or an equivalent treatment of the powder surface is required.