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ELECTROSTATIC DIELECTRIC STORAGE

by

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ABSTRACT

The history of electrostatic storage and related devices is briefly reviewed. Three kinds of storage using electrostatic charges on dielectrics at atmospheric pressure are discussed:

(1) Contact brush type with distributed capacitance.
(2) Contact brush type with discrete capacitors.
(3) Non-contact probe type.

Simple calculations from approximate theory are made for each type and results are compared with experimental tests. The first type is found to be impractical on account of abrasion of the dielectric by the brushes. The second type gives reliable operation, but requires frequent replacement of brushes and commutators. The reading, writing, and erasing sections of the third type have been experimentally demonstrated separately. The non-contact system may require operation at reduced atmospheric pressure to obtain satisfactory conditions for both corona writing and erasing. The non-contact reading probe can be utilized in some other storage system such as photoconductive storage.

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1.1 History of Electrostatic Storage and Related Devices

Certain elements of other systems previously developed give some information useful in the evaluation of possible systems for developing a Dielectric Charge Memory Unit.

In Hungary in 1935, Mr. P. Selenyi (1,2) invented an "electrographic" recording system for forming invisible electrical pictures on the surface of an insulating sheet by means of electrostatic charges by use of cathode rays in vacuum or by ion beams in air. He experimentally demonstrated the ion beam in air charging system. The image was developed by sprinkling Lycopodium powder onto the paper. Although this is not a memory [illegible] it shows that an ion stream charging system has been successfully demonstrated.

Xerography, a dry printing system in which the image is formed by projection of ligh onto a charged photoconductor plate, such as selenium, was invented by Chester F. Carlson in 1938,(3) and later developed by Battelle Institute, and produced by Haloid Company. This process offers an alternative method of storing information. The Xerographic process then uses a resin powder which is attracted to the discharged portion of the plate. The image is then transferred to paper and fixed by heating.

Zworykin(4) in 1940 described a storage system using small capacitors in a cathod ray tube in which all the capacitors can be charged and discharged rapidly by a low-inertia electro beam. At the end of World War II extensive research(5) was done on electrostatic storage tubes at Naval Research Laboratory, M.I.T., University of Manchester (England), RCA, and Raytheon Manufacturing Company. In 1949 some systems using capacitors as storage elements were reported by Haddad of IBM.(6) Individual capacitors were used to store digits with a regeneration circuit to restore the charge after it had partially leaked off. In 1950 in the U.S.S.R., Barshchevkii and Lavrenchik(7) reported on electrographic image formation, in which an insulator is touched by a conductor charged to 5kv. Then the conductor is grounded and then removed. The image is then made visible by dusting with powdered resin which can be fixed by warming. The mechanism used in this system utilizes a semi-permanent residual charge similar to the formation of electrets.

At the San Jose IBM Laboratory in 195[illegible] an electrostatic facsimile system was developed using contact wire electrostatic printing(8) which was then made visible by dusting with Xerox powder.

Also in 195[illegible] development was initiated at San Jose on electrostatic storage systems suitable for regenerative storage like a delay line. Three types were investigated and are covered in this report:

(1) Contact Brush Electrostatic Storage with Distributed Capacitance
(2) Contact Brush Electrostatic Storage with Discrete Capacitors
(3) Non-Contact Probe Electrostatic Storage

1.2 Patent Situation

During the course of these investigations, two patents have been issued which may overlap with the electrostatic dielectric storage systems investigated at the San Jose Laboratory during 1952 and 1953.

U. S. Patent 2,620,447. December 2, 1952. J. M. Malpica, Electrostatic Transformer (filed July 30, 1948).

This patent involves a rotating dielectric disc with brushes to act as a voltage transformer and mentions incidentally the transfer of various wave shapes from input and output. Although no mention is made of computer applications, this patent describes a disc with writing, reading and erasing brushes which correspond physically to the electrostatic storage system with distributed capacitance, and also includes description of a discrete capacitor disc.

U. S. Patent 2,629,827. February 24, 1953. Eckert and Mauchly. Memory System (filed October 31, 1947).

This patent applies specifically to a mercury delay line memory system using a recirculating system. The basic idea of recirculation for computer storage is claimed. Among the various specific variations claimed in the patent can be found a dielectric disc with writing, reading and erasing brushes with alternative forms for using corona discharge and contact writing, reading and erasing.

2.1. Contact Reading of Electrostatic Charges on a Dielectric

2.1.1 Electrostatic Writing

If a conducting probe connected to a voltage source is touched to and removed from a dielectric sheet as shown in figure 2.1., a spot of electric charge is left on the surface. The charge can be measured by touching the spot with a probe connected to an electrometer.

2.1.2. Electrometer Reading with Capacitor Multiplier

For example a circuit using a capacitor multiplier with a Cenco electronic electrometer is given in figure 2.2.

$C_A = 10 \mu\mu f$ $\qquad$ $C_C = 514 \mu\mu f$

$C_D = 5 \mu\mu f$ $\qquad$ $R_A = 14 \times 10^{14}$ ohms

The multiplier ratio where C_O is very large is:

$$X = \frac{V_x}{E} = \frac{C_A + C_C + C_D}{C_D} = \frac{10 + 514 + 5}{5} = 106 \qquad (2.1)$$

2.1.3. Effect of Ratio of C_o to Capacity of Measuring System

When the Capacitor C_O is small, the observed voltage Vx to E will be smaller due to the sharing of the charge on C_o with the Capacity of the measuring system. The equipment circuit is shown in figure 2.3.

$$C_D' = C_D \frac{C_A + C_C}{C_A + C_C + C_D} = 0.97 \ C_D$$

When C_D' is touched to C_O, the charge q is shared so that the voltage, $V_x = q/C_o$, drops to $V_x' = \frac{q}{C_D' + C_O}$. (2.2)

For a probe with a point of diameter .020" effective contact and using .001" thick Mylar dielectric:

$$C_o = \epsilon' \frac{\epsilon_0 A}{t} = 3.16 \times 8.85 \times 10^{-12} \frac{\text{farads}}{\text{meter}} \times 2.54 \times 10^{-2} \frac{\text{meter}}{\text{in}} \times \frac{\pi r^2 \ \text{in}^2}{t \ \text{in}} =$$

$$= 2.23 \frac{\mu\mu f}{\text{in}} \frac{r^2 \ \text{in}^2}{t \ \text{in}} = 2.23 \frac{(.010)^2}{.001} = 0.22 \ \mu\mu f \qquad (2.3)$$

Putting this value in equation (22) gives:

$$\frac{V_x'}{V_x} = \frac{0.22}{0.97 \times 5 + 0.22} = 0.044 = \frac{88}{2000}$$

This means that for an .020" diameter probe, a static writing voltage of 2000 volts would give at a maximum of 88 volts read-out.

2.1.4. Effect of Surface Hardness

Experimentally plastic materials give larger read-out voltages than those calculated above, while ceramic surfaces give less than theoretical. This is explained by the deformation of plastics like Mylar to fit the probe-brush point as shown in figure 2.4.A, which increases C_O. On hard surfaces, such as ceramics, the brush rides over small dents and points in the surfaces, making air gaps which decrease C_O as is shown in figure 2.4B. After repeated use, a plastic surface becomes worse than a hard ceramic due to wear as is show in figure 2.4C.

Various alternatives have been considered to avoid these problems. The most promising is a conductive rubber roller. The flexing of the rubber partially destroys the conductive properties so that the resistance through a rubber roller would increase with use. However, it is not known how much resistance in the roller could be tolerated.

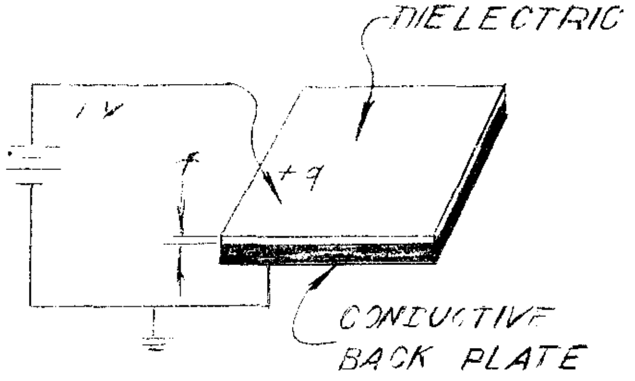


Figure 2.1

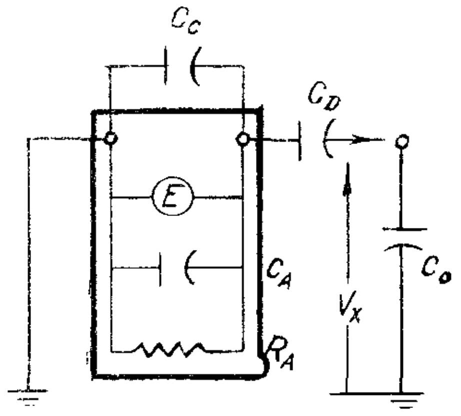


FIGURE 2.2

FIGURE 2.3

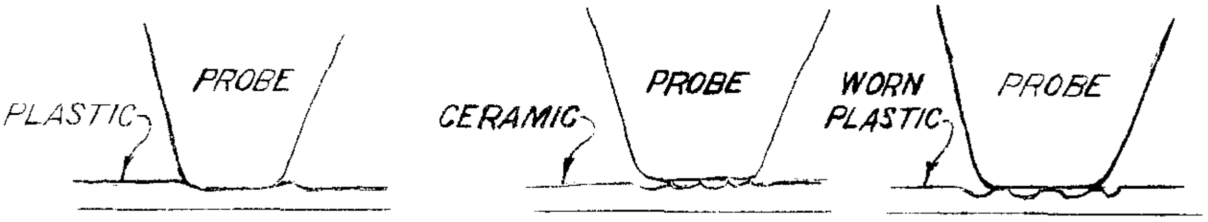


FIGURE 2.4A

FIGURE 2.4B

FIGURE 2.4C

FIGURE 2.4

2. 2. Rotating Drum, Contact Dielectric Storage

2. 2. 1. A Sample Storage Drum

Speed 6000 r. p. m. 100 c. p. s.
628 inches / sec.

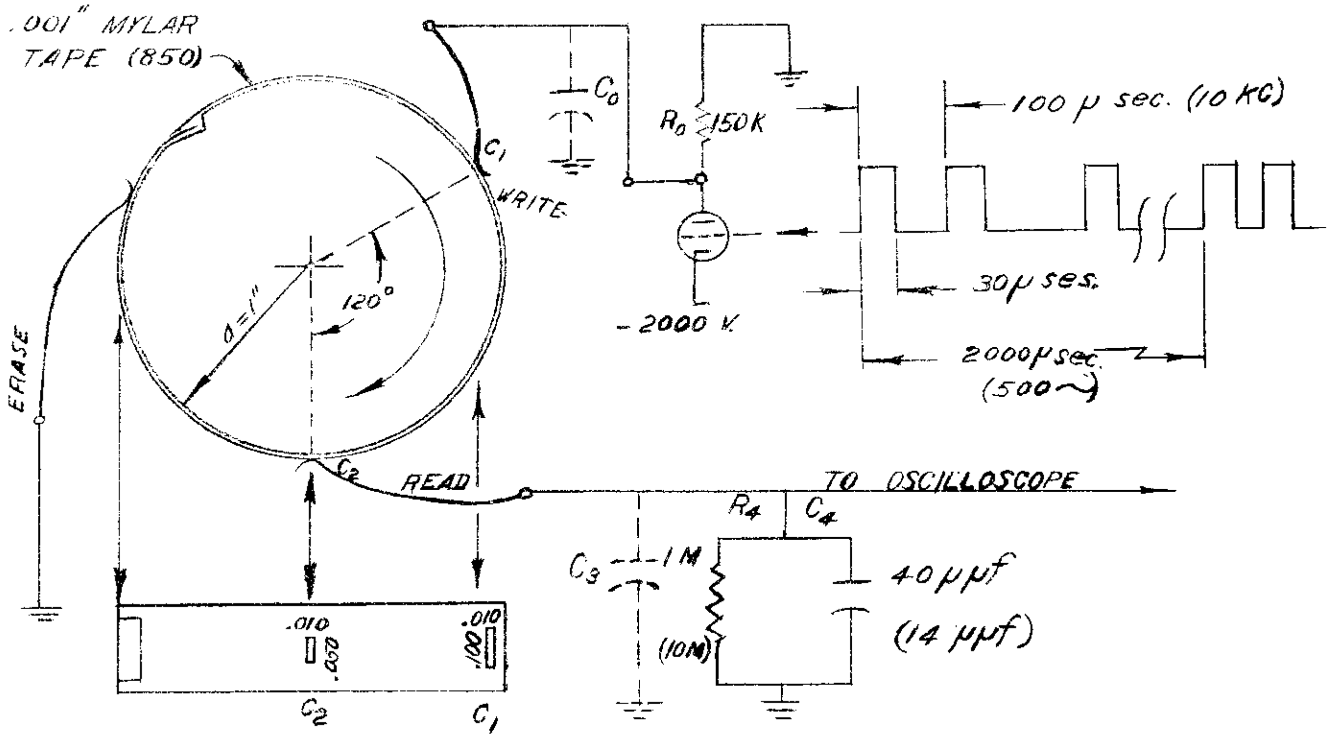


Figure 2.5 Experimental Storage System

The delay time is: $\frac{120^0 \text{ rev.}}{360^0 \times 100 \text{ r.p.s.}} = 3.33 \times 10^{-3}$ seconds

The time that a spot on the dielectric is under a writing or reading brush is:

.010 in. / 628 in. per sec. = 16 μ sec.
The capacities at the brushes are:

$$C_1 = \frac{2.23}{\pi} \frac{\mu\mu f}{in} \frac{A \ in^2}{t \ in} = \frac{0.71 \times 0.100 \times 0.010}{0.001} = 0.71 \ \mu\mu f$$

[illegible]

Using equation (2.2) the maximum theoretical read-out voltages are: The leakage capacitance C_3 is not known and is omitted:

$$C_4 = 40\,\mu\mu f: \quad V_{out} \leq \frac{C_2}{C_2 + \cancel{C_3} + C_4} V_{in} = \frac{0.36}{40 + 0.36} 1800 = 16.1 \text{ volts}$$

$$\text{or when } C_4 = 14\,\mu\mu f: \quad V_{out} \leq \frac{0.36}{14 + 0.36} 1800 = 45 \text{ volt.}$$

The experimentally observed voltages are about 6 and 25 volts respectively. Capacitances C_2 and C_3 have been measured with a Q-meter at 5 mc/sec.

$C_2 \cong 0.4\,\mu\mu f$ (theory 0.36) reading brush

$C_3 \simeq 2.1\,\mu\mu f$ Capacity of brush and leads less C_2.

This gives a revised output voltage as follows:

$$C_4 = 40\,\mu\mu f: \quad V_{out} \leq \frac{C_2}{C_2 + C_3 + C_4} V_{in} = \frac{0.36}{40 + 2.1 + 0.36} 1800 = 15.3 \text{ volts}$$

$$\text{or when } C_4 = 14\,\mu\mu f: \quad V_{out} \leq \frac{0.36}{14 + 2.1 + 0.36} 1800 = 39.3 \text{ volt}$$

The experimental read-out voltages of one-half of theoretical is about the discrepancy expected due to following factors omitted in the calculations:

(1) decreased capacity due to adhesive on back of Mylar
(2) additional capacitance of leads
(3) uncertainty as to actual contact area of brushes

2.2.2. Charging of Dielectric in Writing

A strip is charged on the dielectric that has a length equal to the sum of the brush width plus the electrical pulse length. At the end of the pulse, the tail of charge under the brush is erased. This is illustrated in figure 2.6 where time, angle of rotation of drum, and distance on the drum are plotted in a triangular coordinate system.

The input pulse (v) and the charge density (q/A) are also shown in the diagram.

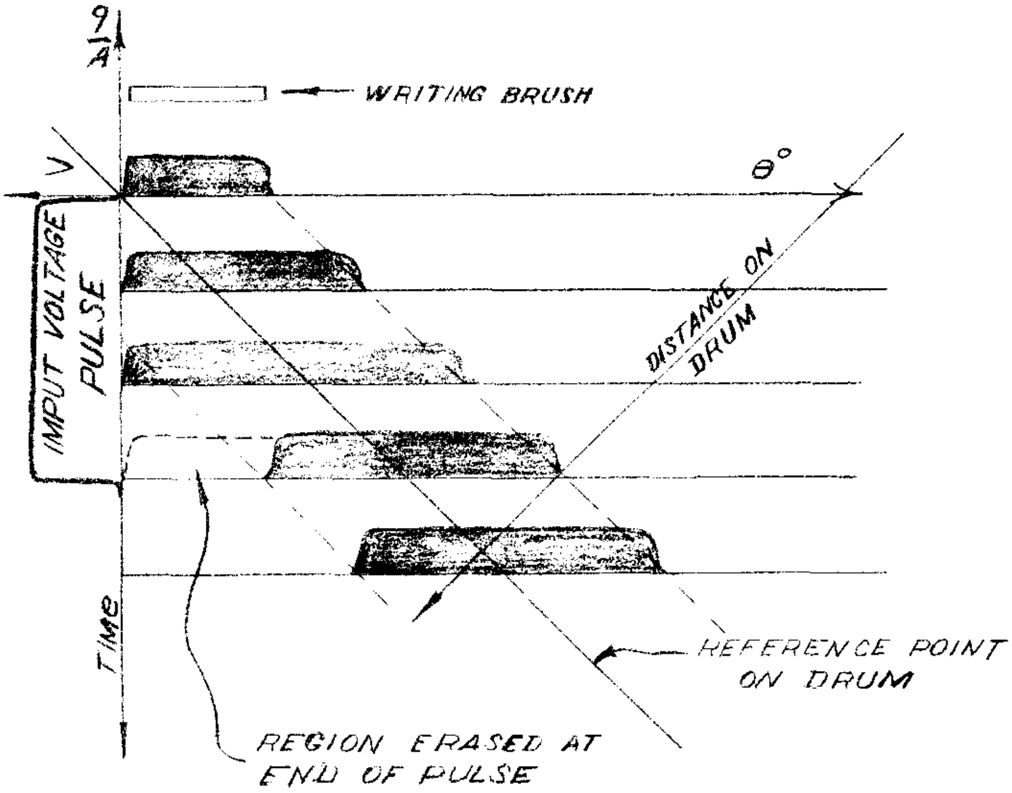


Figure 2.6 Writing Charge Distribution

2.2.3. Discharge of Dielectric in Reading

As is shown in figure 2.7, the discharge of the electric charge at the reading brush is incomplete, requiring an erasing brush to complete the erasing.
At the beginning of the pulse at the reading brush, charge is transferred ahead on the dielectric by the conducting path of the brush. At the end of the pulse when R_4C4 is large, a tail is added to the charge distribution on the Mylar due to the transfer of charge from C_4 to the dielectric.

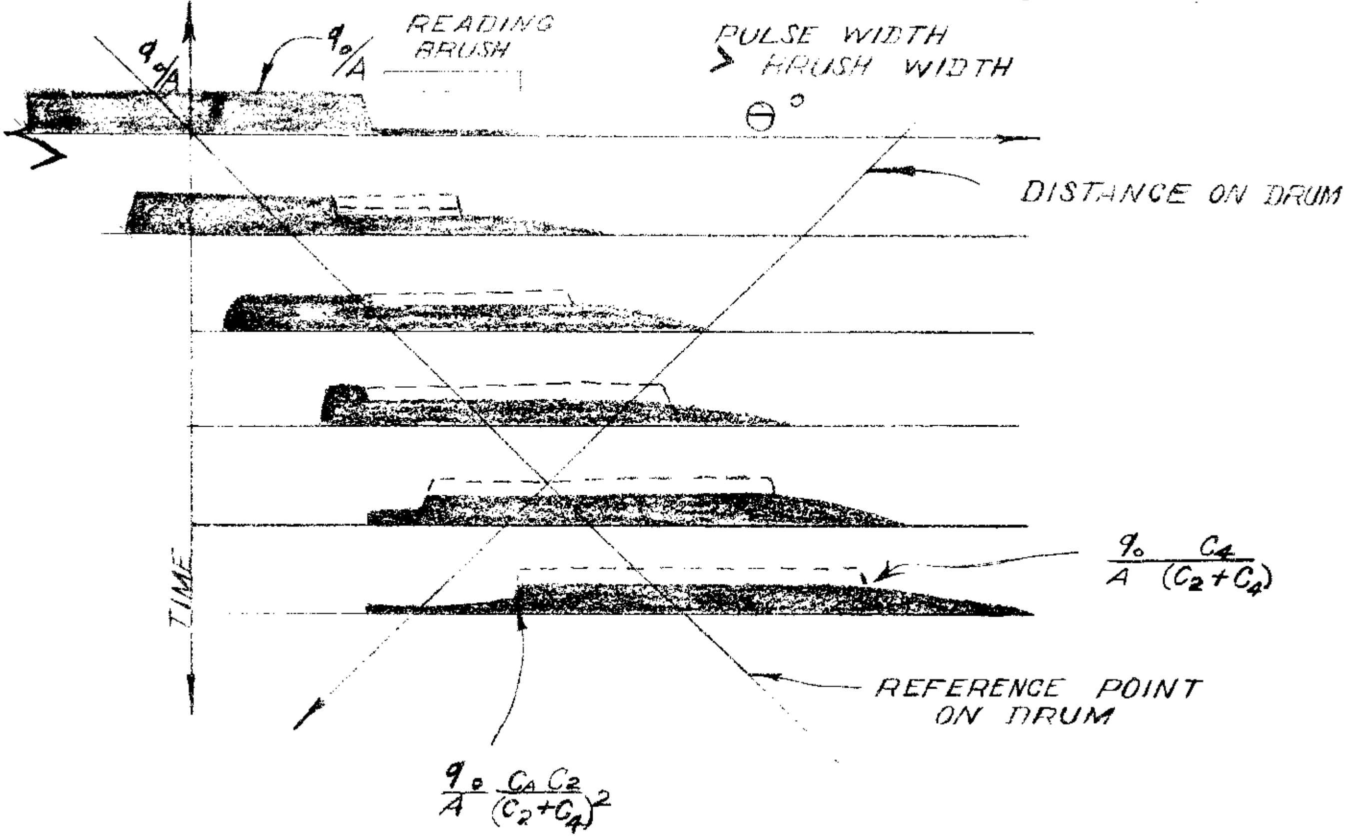


Figure 2.7. Discharge by Reading Brush

The charge distribution curves of figure 2.7 are constructed with the assumption that the time a spot is in contact with the reading brush is small compared to the time constant RC. For slow speeds the voltage would approach a distribution between the storage drum and oscilloscope in the ratio of the resistances instead of the ratios of the inverses of the capacitances.

The approximate theoretical output voltage and the experimentally observed wave shapes are shown in figure 2.8. The discrepancy in shape during the charging has nc been analyzed.

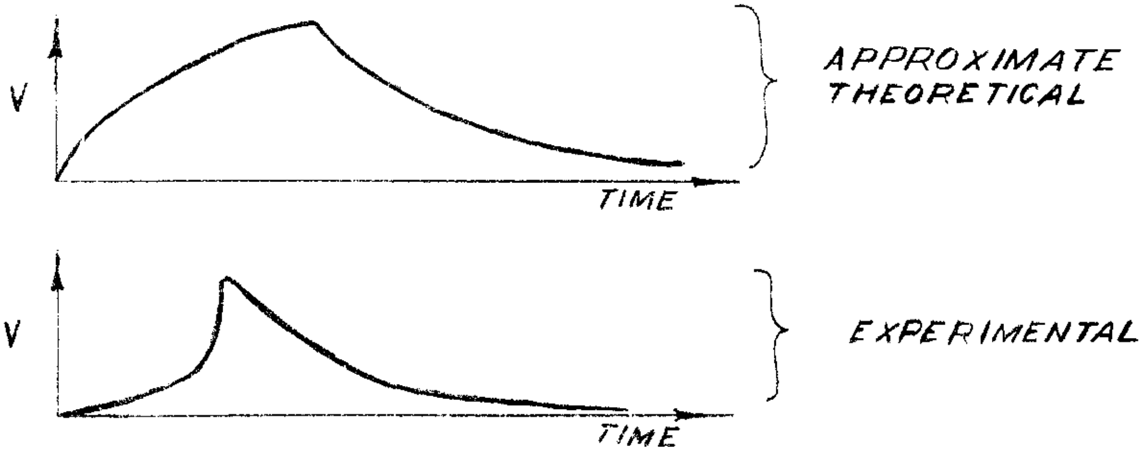


Figure 2.8 Reading Wave Form on Oscilloscope

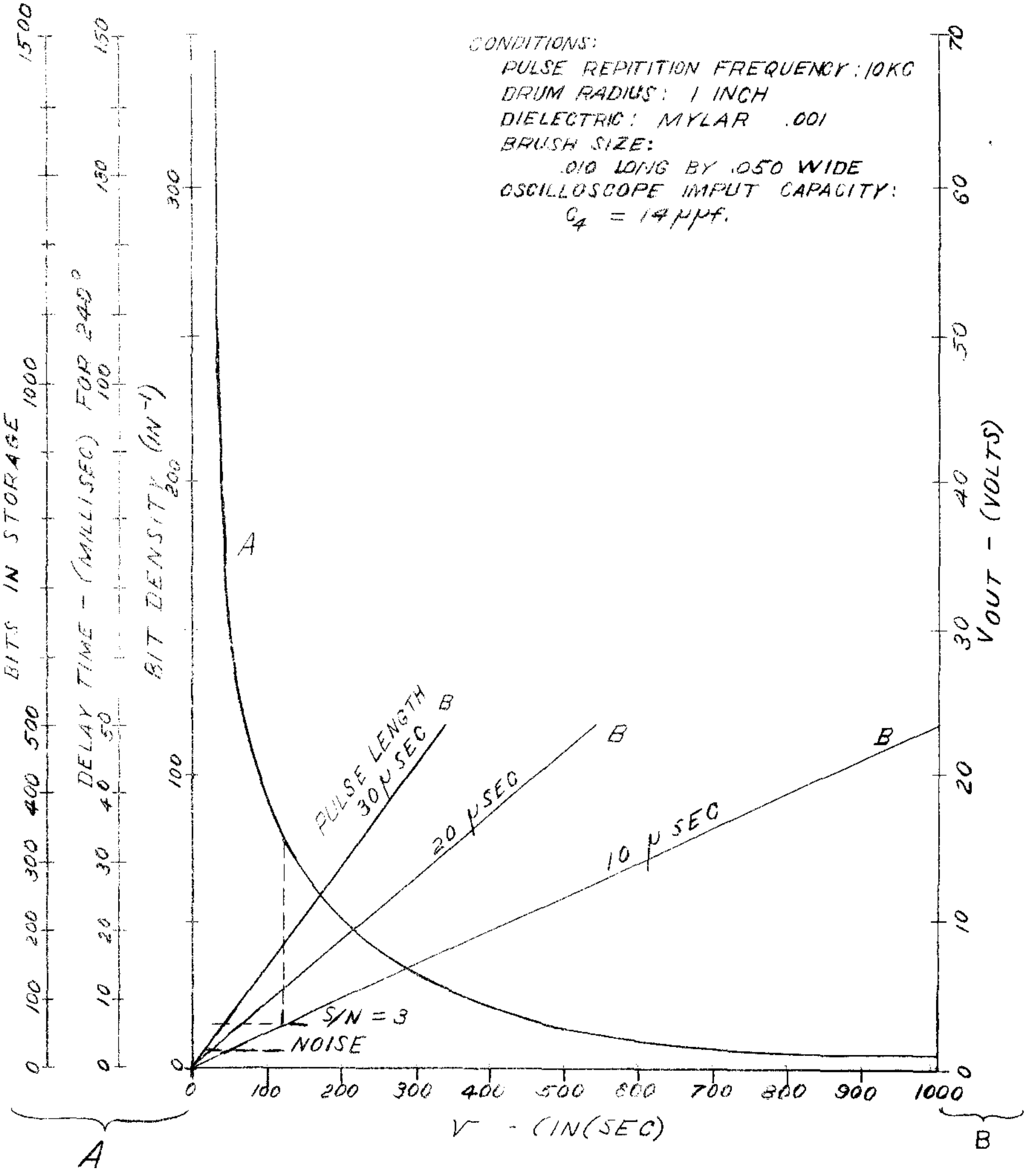


Figure 2.9 - Bit Density and Read Out Voltage vs. Speed.

2.2.4. Storage Density

The bit storage density in the example of paragraph 2.2.1. is 10,000/628 = 16 bits/inch. Tests have been run at a slower speed of 13.8 in./sec. at 1.6 kc with 20 μ sec. pulses giving 1,600/13.8 = 116 pulses/ inch.

When the brush width, $w_b \text{ (seconds)} = \dfrac{W \text{ (in)}}{V \text{ (in/sec)}}$,

is greater than the electrical pulse length T (sec), the incoming charge is distributed over the remaining brush contact area, reducing the voltage by:

$$\frac{V'_{out}}{V_{out}} = \frac{T}{w_b} = \frac{T\,V}{W}$$

Curves of V' out vs v are plotted in figure 2.9 along with curves of bit density. Lines for a noise level of one volt and signal to noise level of three are drawn in to show what information density limits correspond to various pulse lengths.

2.3. Conclusions

Reasonable output voltages and information density can be obtained with contact-distributed-capacity-dielectric-storage. However, the most serious difficulty is the abrasion and dust problem. Even if a good dielectric can be found which is resistant to abrasion, occasional dust particles may raise brushes to miss a 9
digit. The investigation of ceramic coatings is described in a separate report. The output voltage can be raised by use of a low input capacity cathode follower. The information acquired in the study of contact distributed capacitance storage will be useful in investigating the other alternatives.

3. Contact Brush Electrostatic Storage with Discrete Capacitor

3.1. Introduction

A discrete capacitor dielectric storage disc was constructed and tested to avoid the effect of the dielectric wearing out under the brushes. The use of a printed circuit technique or embedded commutator bar technique would insure a uniform capacity per spot, even though the brush contact area is irregular.

3.2. Equipment

A storage disc was made of brass commutator bars embedded in castolite thermosetting plastic, as shown in figure 3.1. The outer ring is the timing track for generating pulses. The second ring is a set of ninety commutator bars which form the top sides of the discrete capacitors. The third ring is a second set of commutator bars. The test circuit using a 45 volt battery for generating charging pulses with the timing track is shown in figure 3.2. The bars have a surface area of 13 x 2.2 = 28.6 mm., which makes a capacity of 31.5 $\mu\mu f$ with .001" thick Mylar clamped between the commutator disc and the supporting metal disc. At a speed of 3000 r.p.m. with 90 pulses per revolution, the pulse rate is 4.5 kc.

The theoretical capacity per bar was not realized, because the warping and cracking of the castolite on setting left air gaps. These were filled with Dow Corning 200 Fluid (Silicone), 350 viscosity, to eliminate the air from the gaps.

IBM No. 163789 wire brushes were used as modified, by clipping off part of the wires, so that the brushes would not contact two bars at a time.

3.3. Experimental Results

Tests were run at 3000 r.p.m. A Tektronex 514 D oscilloscope was used to observe the writing and reading voltages which are shown in figure 2.3. The theoretical voltage available for reading out is:

$$V_{out} \leq \frac{C_{bar}}{C_{bar} + C_{leads} + C_{amplifier}} V_{in} = \frac{9.25}{9.25 + 46.5 + 40} = 4.3 \text{ volts}$$

The observed output voltage averaged 3 volts.

The experimentally measured capacity per bar averaged 9.25 $\mu\mu f$.

3.4. Potential Developments

Tests at high speed were not run, because the particular disc was cracked. If further work is to be pursued on this project, an etched printed circuit technique on semi-cured plastic would be a good procedure. Then the metal bars could be pressed flush in the final curing.

By increasing the speed from 3000 r.p.m. to 6000 r.p.m. and increasing the number of bars per track from 90 to 250, the frequency would be increased to 25 kc. This would give about 1 $\mu\mu f$ per bar on the outer track. With a cathode follower as a read out probe, the amplifier and lead capacitance could be reduced to 5 $\mu\mu f$ so that 8 volts output could be obtained or the input voltage could be reduced in proportion. It would be difficult to increase the density of commutator bars over 25 per track, because the lower limit on brush size would be reached. Increasing the speed or diameter of the discs would result in serious balancing problems.

The potential life of a disc and set of brushes can be estimated from the advertized results of a fabricator of printed circuit commutators.

Their copper with nickel plate and flash of rhodium commutators are reported to be still as satisfactory after 10^7 operations (here interpreted to be revolutions). At 6000 r.p.m., this would be 27 hours. For eight hours of operation per day, the discs and/or brushes might have to be charged twice a week. Tests at Endicott on commutator discs for printed circuit emitters operating at slower speeds have satisfactorily lasted for 7.5×10^7 operations. Therefore, it may be possible to develop a brush and commutator for 10^8 operations.

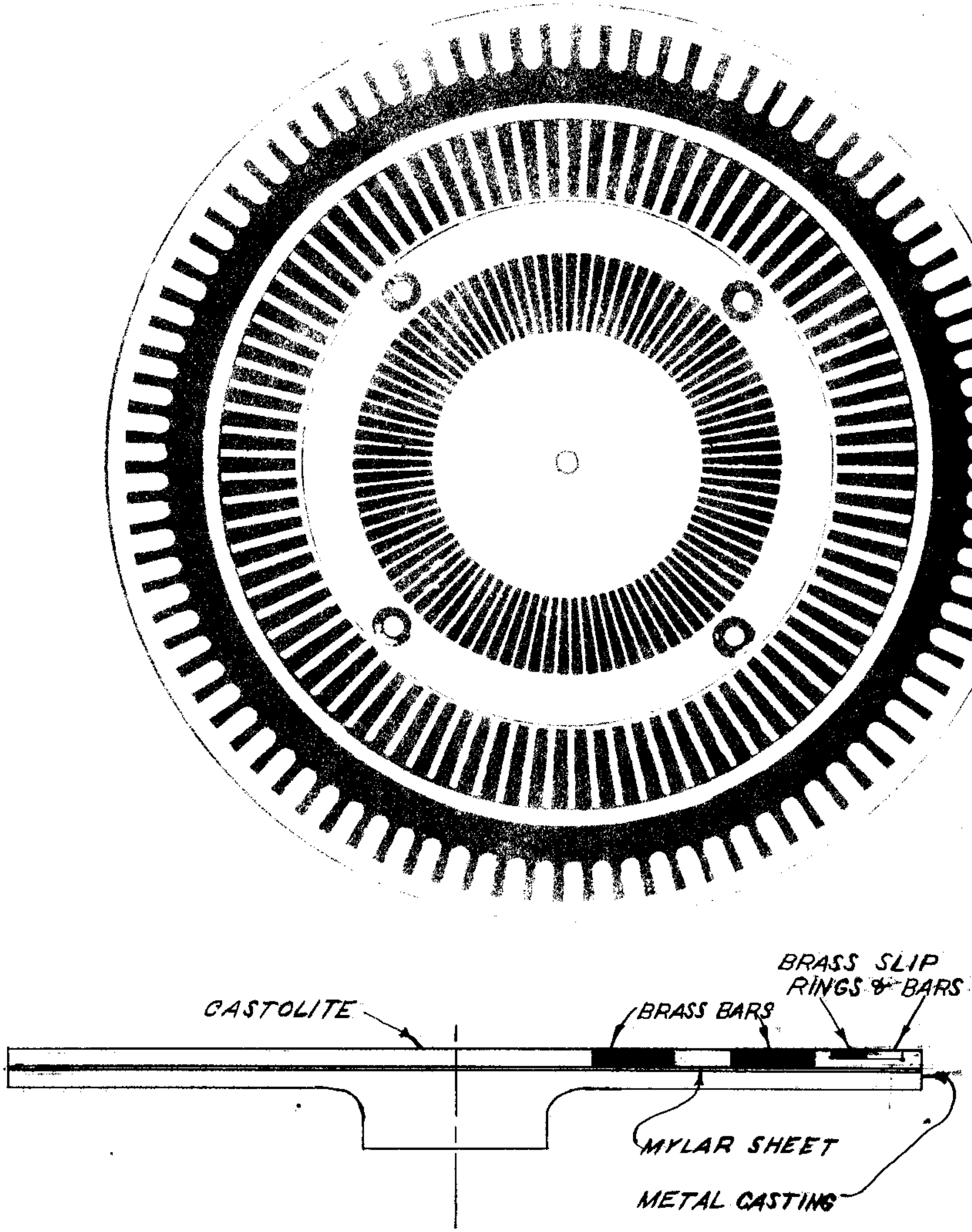


FIGURE 3.1 DISCRETE CAPACITOR DISC

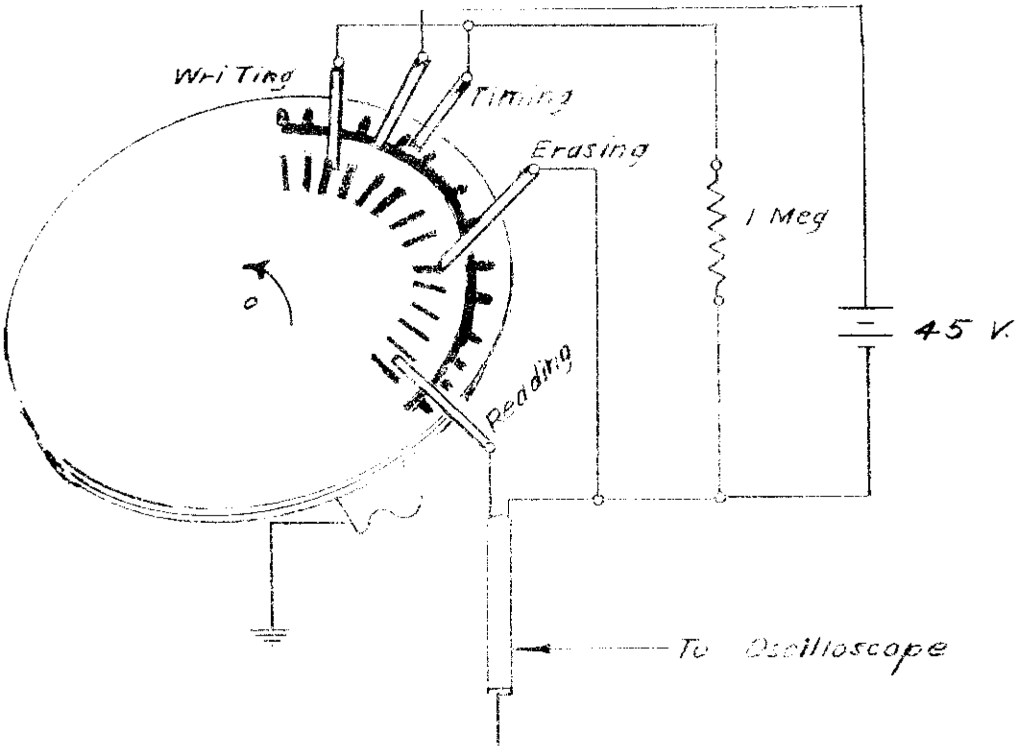


FIGURE 3.2 DISCRETE CAPACITOR STORAGE SYSTEM

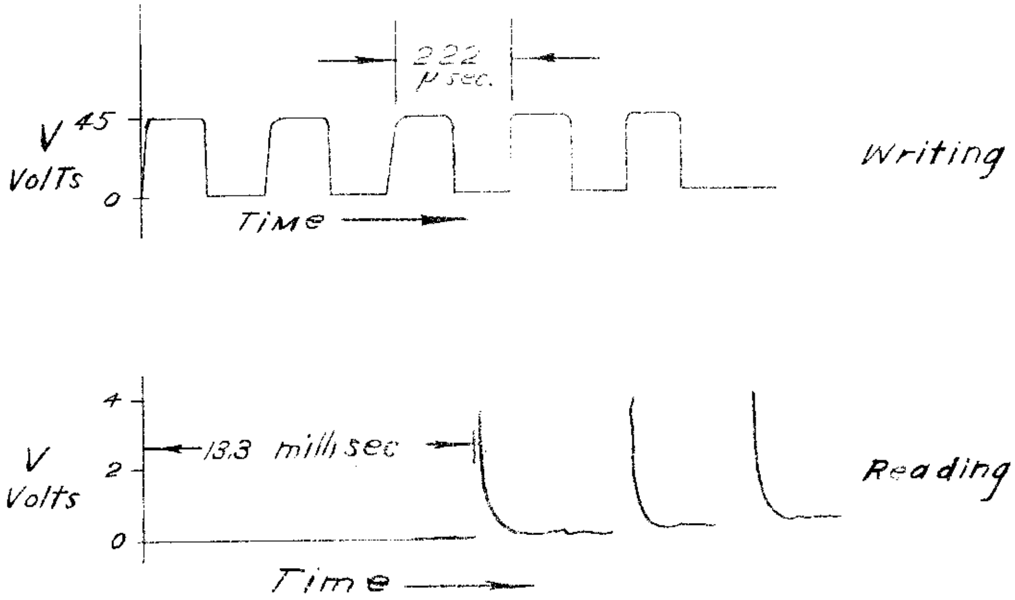


FIGURE 3.3 WRITING AND READING WAVEFORMS

3.5. Evaluation

The discrete capacitor storage system is a definite advance over the present state of distributed capacitance storage, where the wear of the Mylar can cause irregular contact within a few minutes. Although the commutator disc and brushes could possibly be made cheaper than magnetic storage heads and drums, the frequent replacement costs make dielectric storage impractical at present. There are potential slow speed sorting systems where this system of storage might be useful without requiring a recirculating system. Making the printed circuit disc out of Teflon with the capacitor formed by Mylar sheet between a portion of the commutator bars and a grounding ring could result in a storage time sufficient for some sorting operations.

4. Non-Contact Probe Electrostatic Storage

4.1. Introduction

The wear versus uniform area of contact dilemma of contact distributed capacitance storage leads to the consideration of discrete capacitor storage. Then the wearing of brushes and/or commutator discs which requires replacement every three days leads to a review of the possibility of developing a non-contact system to avoid the abrasion problem. The basic system is shown in figure 4.1. Charges are deposited on a dielectric coating over a grounded metal disc. The charges are then read-out by electrostatic induction at the reading electrode, and are erased at the erasing electrode.

Although non-contact reading is satisfactory, there are difficulties in obtaining reliable writing and erasing.

4.2. Writing

4.2.1. Corona Discharge

Charges are satisfactorily transferred to the disc at slow speeds at atmospheric pressure. At high speeds, such as 1000 inches per second, the corona discharge is irregular. The discharge tends to be carried by the moving air and the breaks and reforms. The corona discharge could probably be made more stable by enclosing the disc or drum in an air tight chamber. Then the air pressure could be reduced, or the air could be replaced by a more readily ionizable gas.

Radioactive sources near the electrode have been tried to make tons more readily available, but no appreciable improvement was observed. A curve of the experimental static read-out voltage versus corona gap length for a needle point electrode is given in figure 4.2. The static measurements were made with a cenco electronic electrometer.

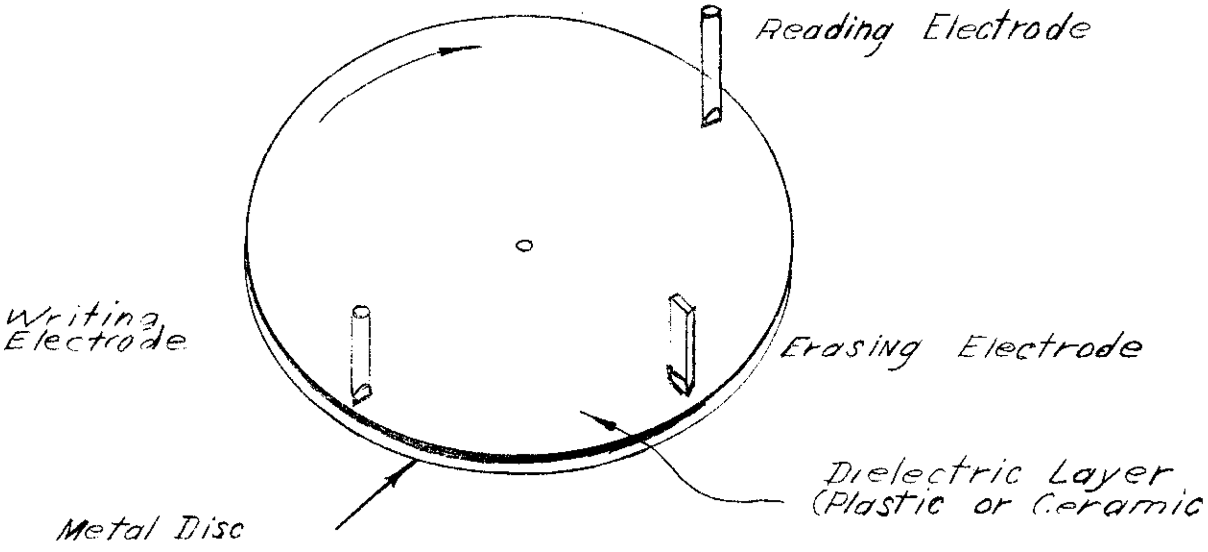


FIGURE 4.1 ELEMENTS OF NON-CONTACT STORAGE.

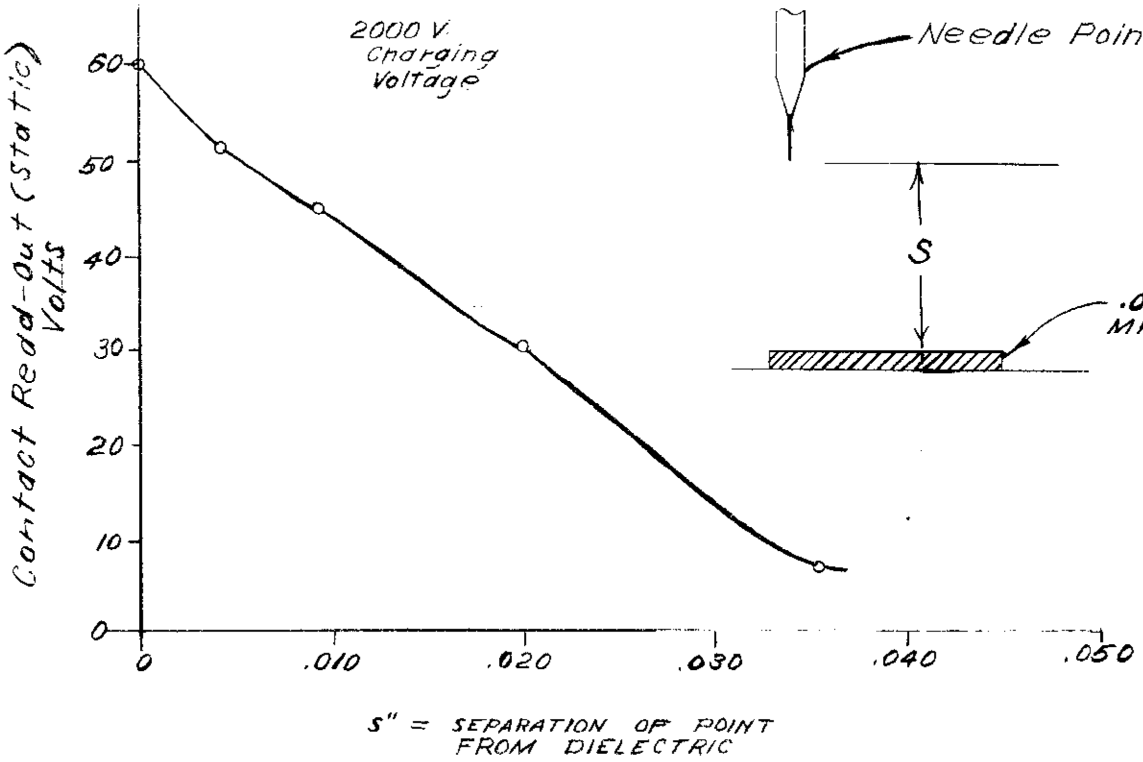


FIGURE 4.2 STATIC READ-OUT VOLTAGE VS. CORONA CHARGING GAP LENGTH

4.2.2. Selenyi Ion Gun

Although no work has been done currently on this type of writing, it is mentioned because it might lead to a satisfactory non-contact writing system. P. Selenyi[1] in 1935 described an ion gun system for writing on dielectrics at atmospheric pressure. He used a hot cathode of platinum wire coated with barrium oxide. The cathode was biased from 500 to 1500 volts negative with respect to the dielectric surface. A grid with a slit was located between the hot cathode and the dielectric. The electrons emitted by the cathode attach themselves to gas molecules, which are then driven through the slit in the grid. The width of the line of charges deposited upon the dielectric can be controlled to 100 per cent modulation by a grid voltage of from 5 to 10 volts.

The work mentioned above has not been checked experimentally here. The only recent work[11] on ion guns in air known to the author is a recent thesis at Stanford University.

4.3. Reading -Electrostatic Induction

4.3.1. Distributed Capacitance Reading

When a charge is placed on a moving dielectric as in figures 4.1 and 4.4A, the induced voltage can be approximated by a charge moving past a probe as is shown in figure 4.3. Shockley (12) has derived an equation for the current induced in a conductor by a moving charge as follows: By utilization of Green's reciprocation theorem it can be shown that the current,

$$I = A\ \overline{E} \cdot \overline{V}$$

where A is a constant, $\overline{E}$ is the electric field at the probe due to the charge and $\overline{V}$ is the velocity of the charge.

The formula is derived for a grounded probe, while any useable probe must have a resistance to ground in order to observe the induced current. Although this formula does not yield a useful numerical value for the induced current or voltage, it does show the proportionality of the induced current to the velocity. A limiting value of the induced voltage can be obtained by estimating the capacity of the probe to the charged spot and calculating the voltage from the capacity divider formed by this capacity and the input capacity of the amplifier.

The electric field lines of a point charge on the surface of a dielectric sheet which is backed by a conducting sheet are shown in figure 4.4A. The fact that the induced current is the vector product of $\overline{E}$ and $\overline{V}$ which are at right angles when the probe is opposite the charge, means that non-contact reading gives a voltage proportional to the derivative of the charge density opposite the probe. This makes a negative and positive pulse for each spot of charge. If only one of the two pulses is desired, the second can be eliminated by a diode. The fact that non-contact readir is a differentiation process limits the bit density. If two spots of charge are close to each other the leading and trailing pulses of adjacent charges can cancel. Therefc the bit length is effectively at least three times the length of the space occupied by the charge, to which must be added a clear space.

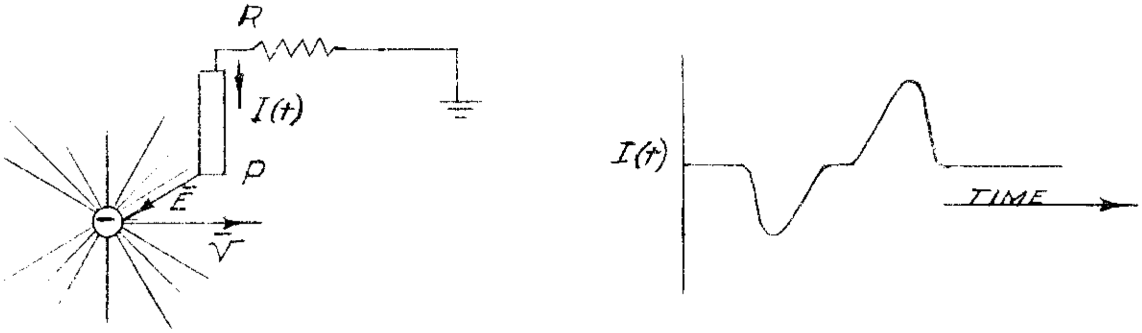


FIGURE 4.3 VOITAGE INDUCED IN PROBE BY MOVING CHARGE

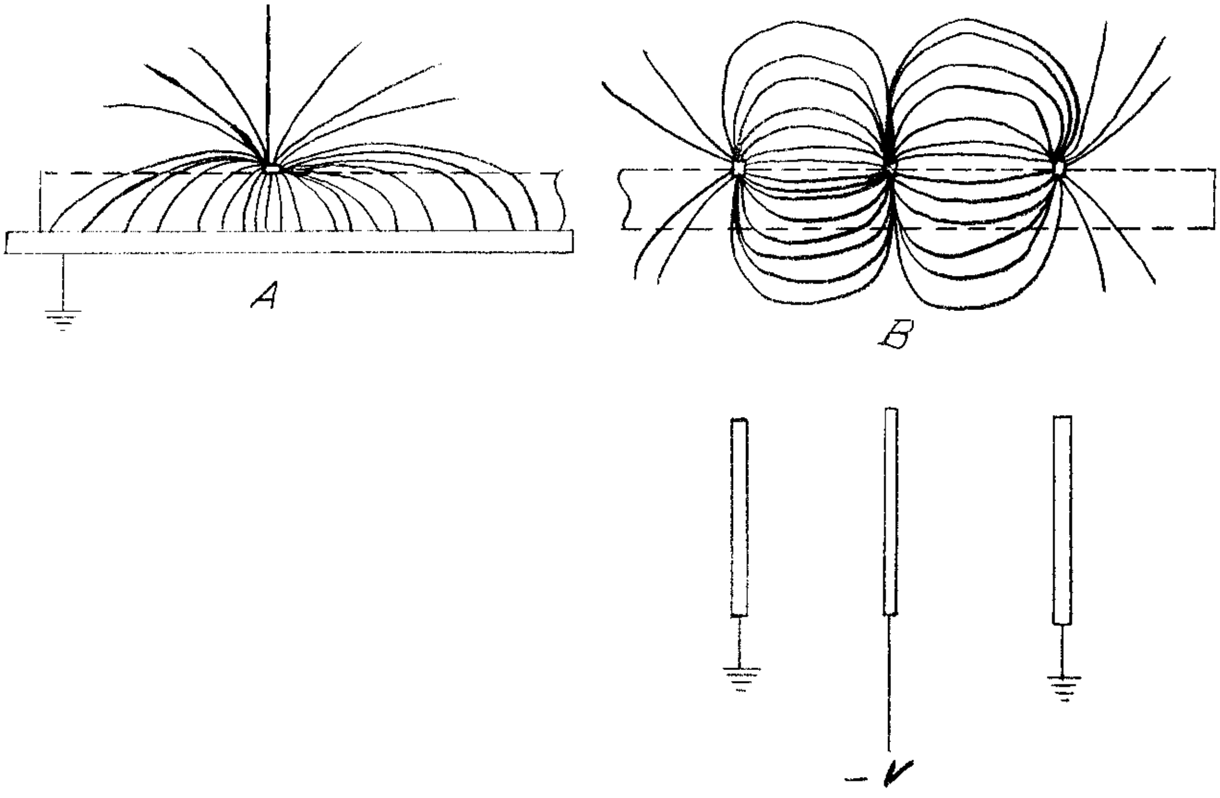


FIGURE 4.4 - COMPARISON OF FIELDS OF DISTRIBUTED CAPACITANCE CHARGING AND DISCRETE CAPACITORS WITH GROUND BARS.

A typical value for non-contact reading is: For 5/32" knife edge probe, 0.015" gap to dielectric, 2000 volts contact charging, 168 inches/second: 0.5 volts read out

4.3.2. Discrete Capacitor Reading

Theoretically the output voltage can be increased by a factor of two or three for the same width of charge and same capacity, by using the field orientation of figure 4.4 The discrete bars with alternate ones grounded make a further reduction of the bit density. The increase in read out voltage come from $\overline{E}$ and $\overline{V}$ vectors being almost parallel in the region where $\overline{E}$ is still high. A non-contact telephone line voltage sensing commutator using this principle has been developed by Bell Telephone Laboratories.

4.4. Erasing

4.4.1. Corona Erasing

The erasing in one sweep past a corona discharge is incomplete as is shown by figure 4.5. Increasing the erasing voltage results in the curve of figure 6 which shows that the signals can only be reduced to forty per cent in one revolution with reasonable erasing voltages. Using a different gas and/or pressure might make some improvement.

4.4.2. Moisture Spray

The electric charge on a Mylar disc has been successfully erased by a spray of water vapor, which makes the surface temporarily conducting. This is not very practical because a drying air blast must follow the erasing so that the surface is dry for writing again.

4.4.3. Flame

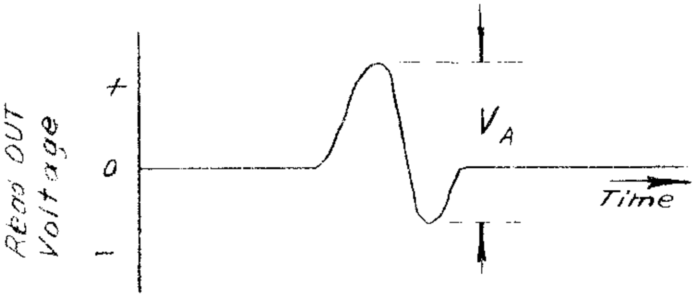
Selenyi used a bunsen burner flame to erase his electrographic images. However an open flame is not a safe device for use in a computer.

4.4.4. Hot Anode

Selenyi suggests using a Kunsman hot anode for erasing with positive ions. This method has not been investigated here. The advantages of hot ions over corona erasing might possibly be a turbulence of the ion gas which might do a better job of destroying the information on the disc.

4.5. Evaluation

The part of electrostatic storage that is reliable is the induced reading of electric charges. Non-contact electrostatic reading can be used with other systems such as photoconductive storage.



Reading Speed:
36 r.p.s. 168 Inches/sec.
$V_A \sim$ 0.5 Volts
Erasing Speed:
Slow motion by hand

Figure 4.5A

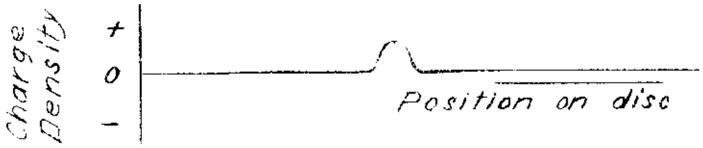


Figure 4.5B

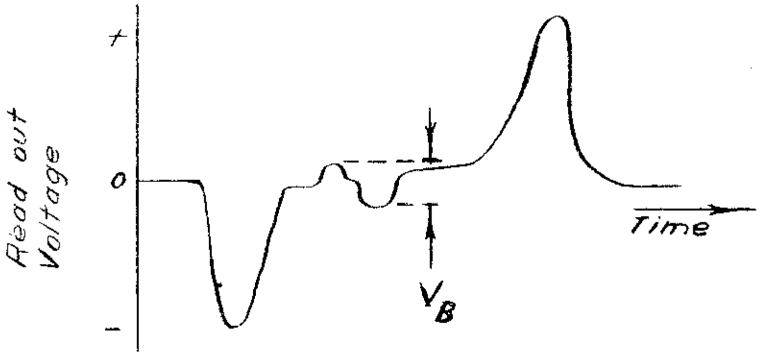
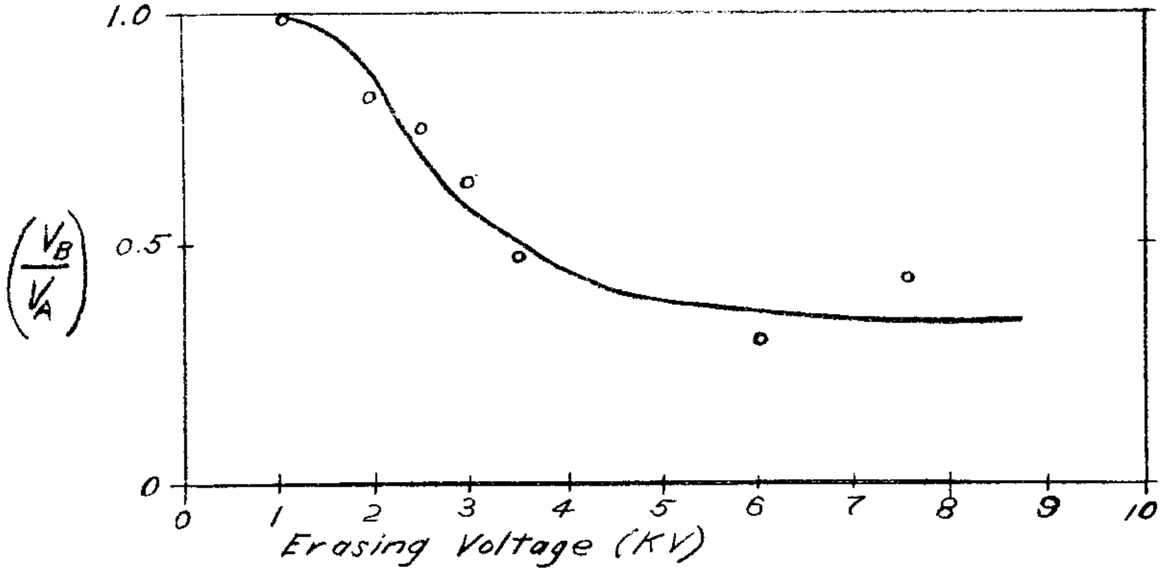


Figure 4.5C

Figure 4.5D

FIGURE 4.5

TYPICAL READ OUT VOLTAGE (EXPERIMENTAL) AND CHARGE DENSITY (THEORETICAL) BEFORE AND AFTER ERASING.



Pressure 1 atm. 82° F
Rel. Hum. 48% .015" Gap

FIGURE 4.6

Signal Voltage vs. Erasing Voltage

A system using corona writing, electrostatic induction reading, and corona erasing could be developed. However, it might require a sealed off container to insure a correct gas pressure for production of ions. The high voltages required for partial erasing would complicate the shielding problems. The absence of complete erasing complicates the electronic circuits required to provide proper discrimination levels.

The development of ion guns for operation at atmospheric pressure could be conducted as a separate project. If satisfactory ion guns and hot anodes were developed, then the development on non-contact electrostatic storage might be worth resuming.

5. Conclusions

Contact brush electrostatic storage is impractical on account of brush wear and abrasion of the dielectric. Discrete capacitor electrostatic storage with contact brushes could be used for low speed application by use of one of the following printed circuit techniques:

(1) Etching away copper from bonded plastic sheets.
(2) Fusing of silver paint on glass or ceramic coated metal
(3) Chemical deposition of nickel on plastics

Non-contact probe storage has been experimentally demonstrated but it may involve a sealed off container to maintain the optimum gas pressure for the corona discharge. The following alternative systems for limited application utilizin new materials such a solaramic ceramic coatings could be considered:

(1) Multiple brush distributed capacity ceramic storage.
(2) Multiple brush discrete capacity storage.
(3) Multiple brush writing on ceramic with non-contact reading, and contact erasing.
(4) Photo conductive writing by light beam with non-contact electrostatic reading.
(5) Discrete capacitor writing by contact, with BTL dyad style non-contact reading, and contact erasing.
(6) Selenyi ion gun writing, non-contact electrostatic reading, hot anode or flame erasing.

In addition to the specific systems of electrostatic storage covered by non-IBM owned patents, 2,620,447 and 2,629,827, the latter claims the basic concept of recirculating information in a delay line or rotating disc storage system. Therefore the patent situation is not favorable for further development of electrostatic dielectric storage, except for possible special applications.

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