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ELECTRICAL PROPERTIES OF SOLARAMIC COATINGS

BY

F. B. WOOD

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ABSTRACT

Ceramic coatings on metal have been investigated as possible dielectrics for electrostatic capacitor storage and for electrostatic printing. Measurements were made of the dielectric constant, dielectric strength, insulation resistance, surface resistivity, and volume resistivity for different types of Solaramic coatings. Electrostatic printing was demonstrated on these coatings, using Xerox developer to make the latent image visible. Storage times of from eleven seconds to thirty minutes were obtained with a standard capacitor using different types of Solaramic coatings.

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1. Introduction

Samples of ceramic coatings for potential use in dielectric electrostatic storage and printing have been supplied to IBM for test by Solar Aircraft Co. of San Diego. They selected four coatings out of some four thousand formulas which had been investigated in the development of ceramic coatings for metal parts of jet engines. The four were selected as possibilities for meeting the following requirements:

Volume resistivity:	10^{16} ohm-centimeters
Surface resistivity:	10^{14} ohms per square
Dielectric strength:	(a) 2000 volts per mil (storage)
or	(b) 600 volts per mil (printing)

The results of tests are summarized in this report. The best sample was found to have the values of 4.3×10^{16} ohm-cm., 4×10^{12} ohms per square, and 900 volts per mil.

2. Dielectric Constant and Dielectric Strength

The samples were prepared for measurement of the dielectric constant by cleaning with toluene, drying, and then rolling a square piece of lead foil onto the center of the surface as shown in Figure 1. The capacity was then measured with a Cenco electronic electrometer (71010B). The procedure given by par. VI E 1 and figure 4 of the electrometer manual[1] was used. The coating thickness was calculated from the gauge of the metal and the average of measured total thickness.

The specific inductive capacity is:

$$K = \frac{\epsilon}{\epsilon_o} = \frac{t\,C}{\epsilon_o A} \qquad (1)$$

where ϵ is the dielectric constant, ϵ_o the dielectric constant in free space, and t, A, and C are the thickness, area, and capacity respectively in M.K.S. units.

The dielectric strength was tested by moving a high voltage wire probe across the surface. The voltage was increased in steps until breakdown occurred at some points on the surface. Some portions of each sample were excluded where obvious defects, such as points and holes, reduced the dielectric strength.

	White NTF-4	Brown S 5210-3C	Blue S 5210-5	Green S 521-3C DHT
Coating Thickness	.005"	.002"	.006"	.0045"
Specific Inductive Capacity: $K = \varepsilon/\varepsilon_0$	10.6	3.9	3.8	6.9
Dielectric Strength volts/mil.	400	1000	500	900

TABLE I

3. Insulation Resistance

a. Wet Insulation Resistance (Test for Holes)

The insulation resistance between an electrode touching a wet sponge on the surface and the metal back plate was measured with a Simpson 260 ohmmeter. The results are tabulated in Table II. ("s.s." means at some spots; "o.s." means at one spot.)

b. Dry Insulation Resistance

This is the total resistance of the samples with electrodes as shown in Figure 1, with coating thicknesses as indicated in Table I. The insulation resistance consists of a volume resistance and a surface resistance in parallel.

	White NTF-4	Brown S 5210-3C	Blue S 5210-5	Green S 521-3C DHT
Wet Insulation Resistance - ohms	$> 10^6$ except 10K s.s.	$> 10^6$ except 22K o.s.	$> 10^6$ except 10K s.s.	$> 10^6$ except 10^6 o.s.
Dry Insulation Resistance - ohms, 26% r.h., 25° C.	4.7×10^{11}	4.3×10^{10}	3.5×10^{12}	8.9×10^{12}
Equivalent Volume Resistivity ohm-cm. (Surface effects neglected in calculations)	1.4×10^{14} *	3.3×10^{13} *	9.4×10^{14} *	3×10^{15} *

TABLE II.

*For the geometry of the electrode used, the surface resistance cannot be neglected. However, these values, which are not true volume resistivities, are included for comparison of the different materials.

To avoid complicated electrostatic shielding problems encountered in high resistance measurements, the dry insulation resistance was measured indirectly from the capacity and the decay time constant, $T = RC$. The capacitor of Figure 1 was charged to -300 volts, and then after a measured time interval the voltage was measured with a Cenco electrometer, using the resistance multiplier circuit of figure 5 of the instruction manual. From repeated charging and reading, curves like that of Figure 4 were obtained. The initial absorption of charge caused the point B' to range from 30 to 55% of the charging voltage A. The slope of the curve BC was used to obtain the time constant T, from which:

$$R = T/C \qquad (2)$$

4. Surface Resistivity

The surface resistivity was measured, using a conductive silver paint grid like that shown in Figure 2, except that for the brown sample an evaporated grid of $P/g = 2120$ instead of 612 was used. The surface resistance was measured with a Cenco electron electrometer, using the circuit of figure 5 in the manual and the ratio scale (VI D 1) with a 5-volt bias supply. The sample being tested was discharged before each measurement. RPC type HBF resistors were used as comparison standards.

Sample calculation: 98% relative humidity, green solaramic.
$R = 10^8$, meter reads $K = 4.2$, so $R_x = KR = 4.2\times10^8$ ohms.

With sample disconnected, the leakage resistance of the plexiglass humidity box is: $R_x' = 50\times10^8$

$$R_s = \frac{R_x R_x'}{R_x' - R_x} = 4.6\times10^8 \qquad \sigma = (P/g)R_s = 612\times4.6\times10^8 = 2.8\times10^{11} \text{ ohms/sq.}$$

The results are plotted in Figure 5. The green, white, and blue samples were given the following heat treatment to dry the silver paint: one hour bake up to 350°F, raise to 750°F, raise to 1000°F for 20 minutes, and cool slowly. Spots where silver paint spilled on the surface were scraped with a knife blade and cleaned with toluene. The brown sample was not heat treated since an evaporated grid was used on it.

The green sample was found to be relatively insensitive to changes of relative humidity.

5. Volume Resistivity

The volume resistivity was measured as defined by ASTM[2] method D247-52T with the modified test circuit shown in Figure 6.

Material: Green solaramic coating S 521-3C DHT, Solar Aircraft Co., San Diego, California.

Shape: 4" square .050" ASI Type 321 stainless steel with .0045" coating, heat treated.
Electrode: Rectangular silver print, 22x25 mm, with guard ring separated by 0.5 mm as shown in Figure 3.
Test conditions: R.T. 25°- 28°C, 45 to 55% relative humidity.
Method: Voltmeter-Ammeter method, using electronic electrometer in place of ammeter, as shown in Figure 6. Modification of D 257 (Figure 7) to balance electrometer shunt with resistance in series with the guard electrode.
Applied voltage: -300 volts.
Time of electrification: One minute.
Measured results: $E_2 = 3.3$ volts, $R_x = \frac{RB(E_1 - E_2)}{E_2(R+B)} = 9 \times 10^{13}$ ohms

Computed Results: $\rho = \frac{A}{t} R_x = 481 \times 9 \times 10^{13} = 4.3 \times 10^{16}$ ohm.cm.

6. Application to Storage and Printing

Storage time: The time it takes the charge on a capacitor of Figure 1 to decay to $^1/_e$ of its value (B) after the absorption effect has occurred is tabulated in Table III.

25 C 26% r.h.	White	Brown	Blue	Green
Storage Time	135 sec.	11.5 sec.	310 sec. (5 min.)	1800 sec. (30 min.)

TABLE III - Storage Time

Printing test (Test for usefulness in electrostatic facsimile system[3]): Clear writing was obtained, using a .006" diameter wire with plus 350 volts, using Haloid developer.

7. Evaluation

The Solaramic coatings, particularly S 521-3C (DHT), are potentially useful for electrostatic storage. The difficulty which prevents immediate use in a storage system is the lack of uniform contact area with writing and reading brushes.

Although the surface resistivity is lower than the 10^{14} ohms originally requested, systems could be designed to utilize the lower values. The fact that the green sample has a surface resistivity almost independent of relative humidity is of particular importance.

Solaramic coatings appear to be particularly useful for electrostatic printing where the uniformity of brush contact is not a serious problem.

References:

1. Central Scientific Co., "Operating Manual, Cat. No. 71010 Cenco Electronic Electrometer, Model B."

2. American Society for Testing Materials, "Tentative Methods of Test for Electrical Resistance of Insulating Materials", D257-52T.

3. L. W. Allen, "Electrostatic Facsimile System", IBM Code: 210.043.027, June 8, 1953.

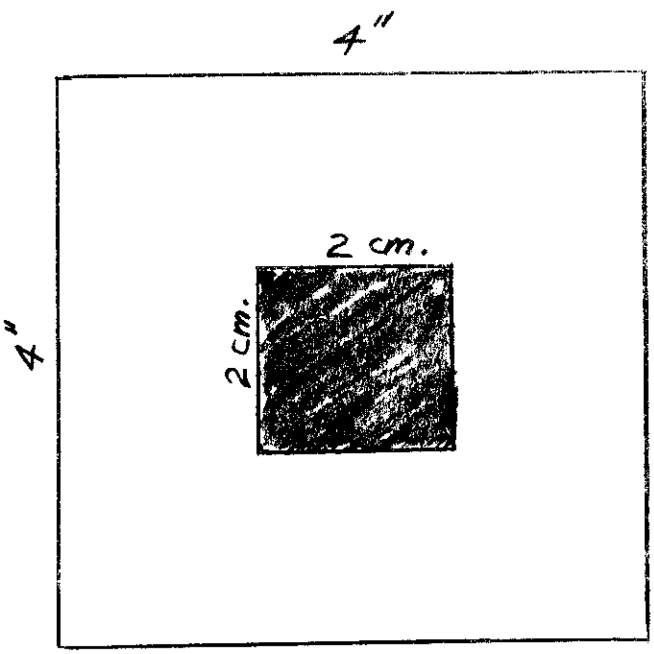

FIGURE 1 - Capacitor
Test Electrode

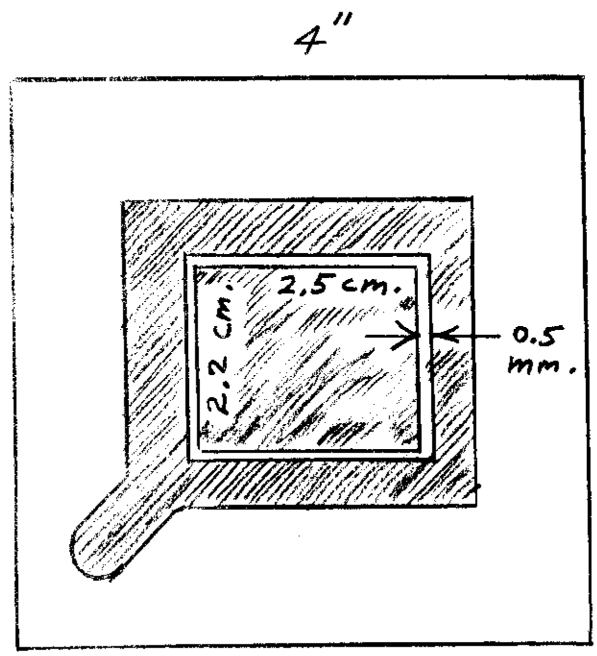

FIGURE 3 - Volume
Resistor with Guard Ring

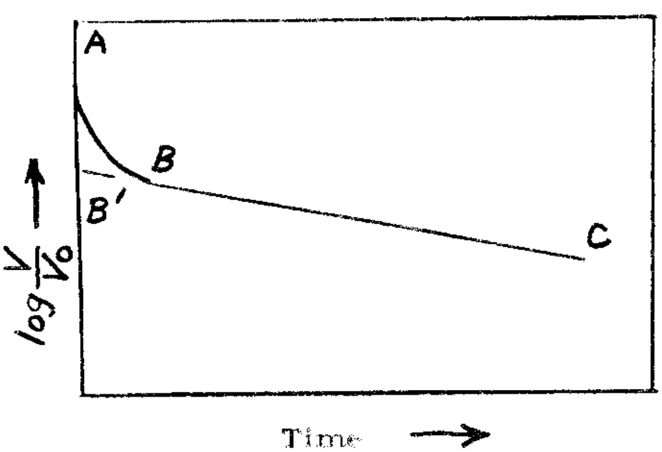

FIGURE 4 - Typical
Discharge Curve

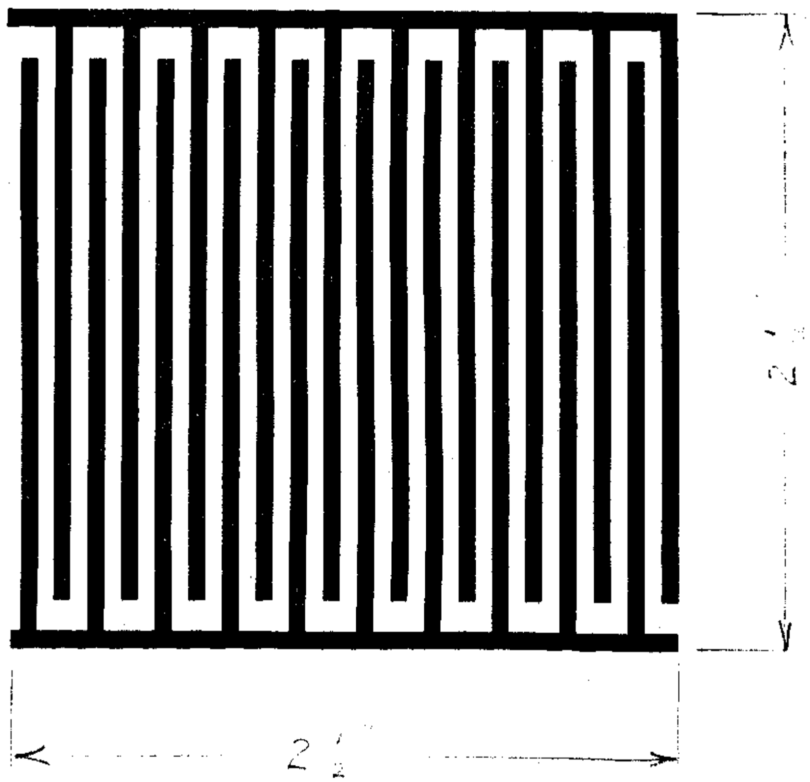

Figure 2 - Sur[illegible] Resistor

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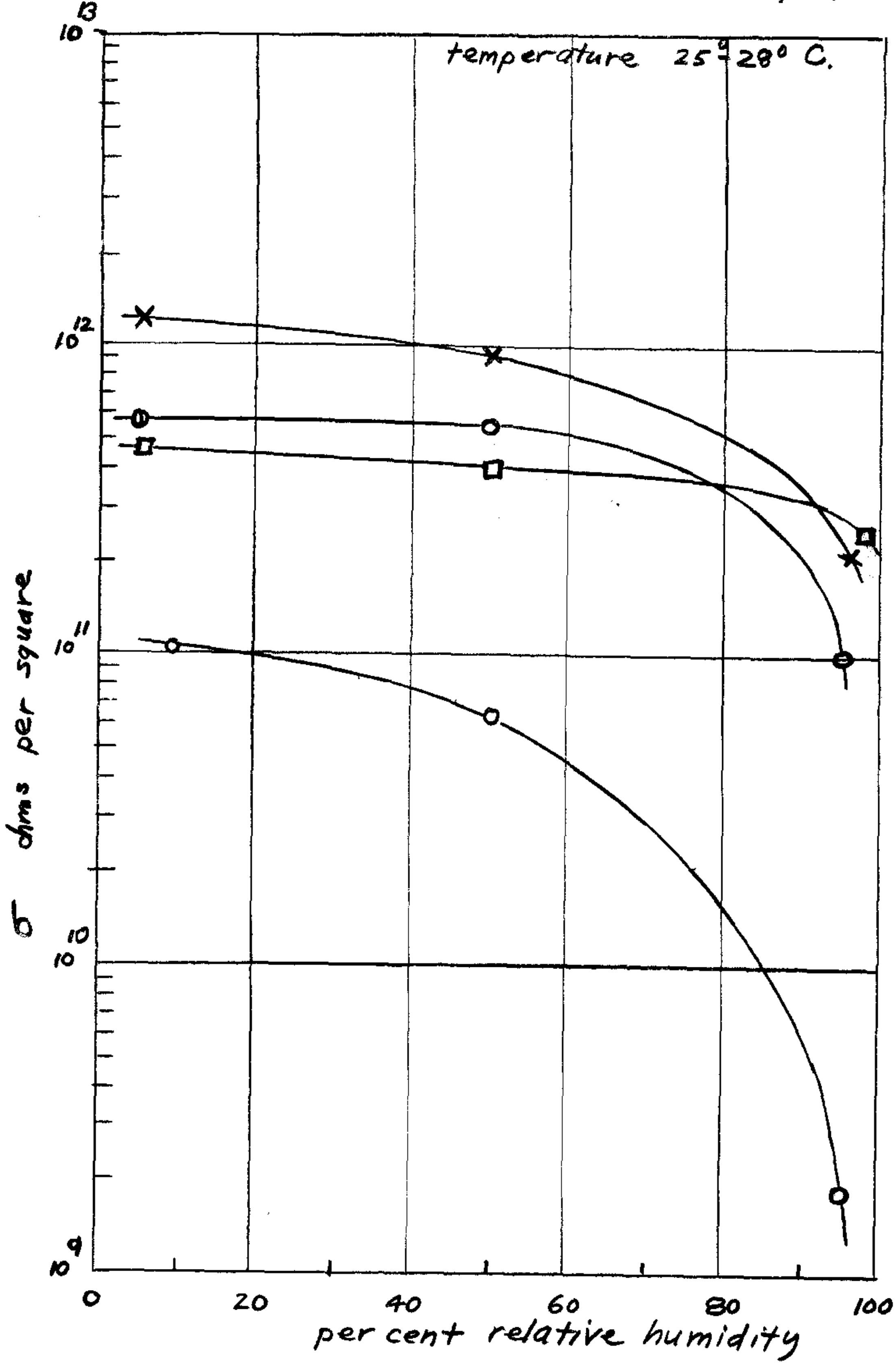
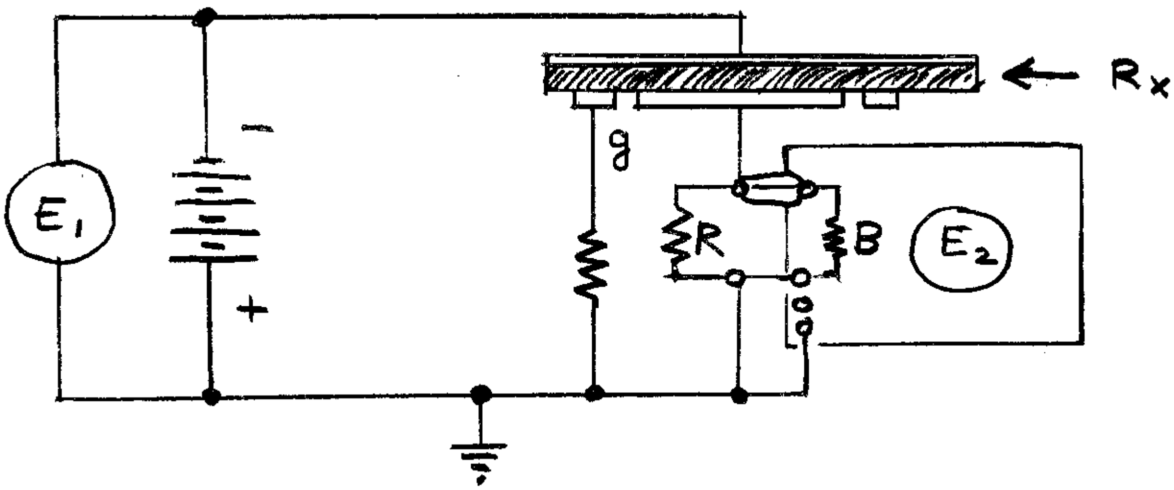


FIGURE 5 - Surface Resistivity of Solaramic Coatings



$$R_x = \frac{RB(E_1 - E_2)}{E_2(R + B)}$$

R_x is approximately equal to R, and was adjusted to make the potential across g zero, so that no surface current would flow across the gap.

FIGURE 6 - Volume Resistor Circuit