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CONFORMAL COATINGS FOR PRINTED CIRCUIT ASSEMBLIES

REPORT NO. 1

DA 36-039-sc-89136

FIRST QUARTERLY REPORT

JULY 10, 1961 TO OCT. 31, 1961

U. S. ARMY SIGNAL SUPPLY AGENCY
STANDARDIZATION ENGINEERING DIVISION
FT. MONMOUTH, NEW JERSEY

MOTOROLA INC.
Military Electronics Division · Chicago Center
1450 NORTH CICERO AVENUE, CHICAGO 51, ILLINOIS

CONFORMAL COATINGS

FOR

PRINTED CIRCUIT ASSEMBLIES

First Quarterly Report for the period of July 10, 1961 to October 31, 1961.

Signal Corps Contract Number DA-36-039 SC89136

Department of the Army Project Number: 5999-004

Placed by: United States Army Signal Supply Agency
Standards Engineering Division
Materials Section
Fort Monmouth, New Jersey

Contractor: Motorola, Inc.
Chicago Center
1450 N. Cicero Ave.
Chicago 51, Illinois

Signal Corps Contract Number DA-36-039 SC-89136

Technical Requirements for PR & C Number 61-SIMSA-482
dated 22 March 1961.

Dept. of the Army Project Number: 5999-004

Report Submitted by: Anthony Beccasio
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Project Engineer

Approved by: Robert Andreasen
Robert Andreasen
Manager, Engineering Services

CONFORMAL COATINGS FOR

PRINTED CIRCUIT ASSEMBLIES

First Quarterly Report for the period of July 10, 1961 to October 31, 1961

Objective:

Phase A: Evaluate commercially available conformal coating materials used as protective coatings on printed circuit boards in order to obtain data for the preparation of a three services coordinated military specification which will provide sufficient physical, mechanical and electrical properties to assure satisfactory performance of printed circuit assemblies over long storage periods and under high humidity conditions.

Phase B: Investigate a method of removing the coating from the board to permit replacement of parts when necessary without impairing the functional operations of the unit.

Phase C: Evaluate, for possible upgrading purposes, allowable minimum spacings between conductors on uncoated and coated boards as described in paragraphs 5.1.5 of MIL-STD-275A.

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APPENDIX

PURPOSE

The purpose of this project is to evaluate commercially available conformal coating materials used as protective coatings on printed circuit boards in order to obtain data for the preparation of a three services coordinated military specifications which will provide sufficient phy ical, mechanical and electrical properties to assure satisfactory performance of printed circuit assemblies over long storage periods and under high humidity conditions.

In this report, the tasks are defined as follows:

<u>Task A</u>

Investigation of epoxy resin conformal coatings on XXXP glass-epoxy and paper epoxy copper clad laminate series specified in MIL-P-13949B and PR & C-61-SIMSA-482.

<u>Phase 1</u> Two-part epoxy resin coating systems

Part 1 Characteristics of epoxy resin coatings studied

Part 2 Curing Schedule

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<u>Phase 3</u> Precoating Preparation of Surface

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Part 2 Soldering

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<u>Phase 5</u> Physical and Electrical Properties of Epoxy Resin Coating Systems

Part 1 Appearance and adhesion

Part 2 Thickness measurements

Part 3 Dielectric Constant and Dissipation Factor

Part 4 Q Factor

Part 5 Dielectric Withstanding Voltage

Part 6 Insulation resistance under moisture conditions

Part 7 Abrasion Resistance

Part 8 Ruggedization

Part 9 Flexibility

PURPOSE
(Continued)

Task B

Investigation of polyurethane resin conformal coatings on XXXP and glass-epoxy, copper-clad laminate series specified in MIL-P-13949B and PR & C-61-SIMSA-482.

Phases 1 - 5 The same as Task A where application if feasible.

Task C

Investigation of Silicone-based polymer coatings on glass-epoxy and silicone-glass copper-clad laminate series specified in MIL-P-13949B.

Phases 1 - 5 The same as Task A where application is feasible.

Task D

Investigation of fluorinated resin (FEP) based polymers on teflon-glass and FEP copper-clad laminates per MIL-P-13949B and MIL-P-27538 respectively.

Phases 1 - 5 The same as Task A where application is feasible.

Task E

Investigation of melamine coatings on glass-melamine copper-clad laminate.

Phases 1 - 5 The same as Task A where application is feasible.

Task F

Investigation of MIL-V-173 varnishes on glass-epoxy, XXXP and paper-epoxy laminates per MIL-P-13949B.

Phases 1 - 5 The same as Task A where application is feasible.

ABSTRACT

Task A

Investigation of epoxy resin conformal coatings on XXXP, glass-epoxy and paper-epoxy copper-clad laminate series specified in MIL-P-13949B and PR & C-61-SIMSA-482.

Phase 1 Two-part epoxy resin coating systems

Part 1 Characteristics of epoxy resin system studied.

Eight epoxy or modified epoxy resin coatings were obtained from various manufacturers. All the acceptable coatings met the requirements of para. 2b of PR & C-61-SIMSA-482. However, two component systems were evaluated in lieu of one component systems due to unavailability of one component systems.

Part 2 Curing Schedule

All epoxy coatings were cured at maximum temperature of 75°C for 2 hours.

Phase 2 Test Panels Used

The test panels used were: (1) comb pattern fabricated in accordance with Figure I, and paragraph 4.4.1 of SCL-6225 and (2) specimen X fabricated in accordance with Figure I, Note 7 of MIL-P-55110.

Phase 3 Precoating preparation of Surface.

Part 1 Cleaning

To eliminate all corrosion effects other than those from testing or the coating itself, a stepwise cleaning technique for the surface of the specimen panels was devised. Unless otherwise indicated, the complete outlined technique was used.

Phase 4 Method of Coatings Application

All specimen panels were brush coated.

Phase 5 Physical and Electrical Properties of Epoxy Resin Coating System

Part 1 Appearance and Adhesion

A visual check of the coated test panels revealed there was no blistering, wrinkling, cracking and peeling of coating and no corrosion of printed conductors. All coating exhibited good adhesion to specimen test panels.

ABSTRACT
(Continued)

Part 2 Thickness measurements

All specimen test panels were coated to a thickness of 0.012 ± 0.007 inches.

Part 3 Dielectric Constant and Dissipation Factor

Two inch disc specimens were prepared in similar method described in para. 4.3 of MIL-I-16923C. The Dielectric Constant and dissipation factor were measured at 1, 3, 6.25, 30, 50, 75, and 100 mc using the resonance rise-method described in ASTM D-150. It was found that as the frequency increases the dielectric constant decreases. The dissipation factor decreases to a minimum and then increases from 1 mc to 100 mc.

Part 4 Q Factor

The Q value of the coating was measured at 1 megacycle by calculating the relative differences of the coated versus uncoated boards. It has been determined that for the same coating, the Q factor will change depending on what laminate the coating is tested on.

Part 5 Dielectric Withstanding Voltage

All specimen panels passed the initial tests specified in para 4.7.8 of MIL-P-55110 and para 4.4.3.2 of SCL-6225.

Task B

Investigation of polyurethane resin conformal coatings on XXXP, glass-epoxy and paper-epoxy copper-clad laminate series specified in MIL-P-13949B and PR & C-61-SIMSA-482.

Phase 1 Polyurethane resin coating systems

Part 1 Characteristics of polyurethane resin coating systems

Nine polyurethane resin coatings were obtained from various manufacturers. Three of these resin systems were one component and the remainder were two component systems. All the coatings evaluated were clear or transparent when cured. These coatings are repudiated to have better humidity, wear and weather resistance then do the epoxy and vinyl systems. All the systems tested are fungus resistant. All the coatings are solvent based systems.

Part 2 Curing Schedule

All these coatings were cured at room temperature for 24 hours.

ABSTRACT
(Continued)

Phase 2 Test Panels Used

Same as discussed in Phase 2 of Task A of Abstract.

Phase 3 Precoating preparation of surface

Part 1 Cleaning

Same as discussed in Phase 3 of Task A of Abstract.

Phase 4 Method of coating application

All specimen panels were brush coated.

Phase 5 Physical and Electrical Properties of polyurethane resin coating systems

Part 1 Appearance and Adhesion

A visual check of coatings revealed there was no blistering, wrinkling, cracking and peeling of coating and no corrosion of printed conductors. All coatings exhibited good adhesion to specimen test panels.

Part 2 Thickness measurements

All specimen test panels were coated to a thickness of 0.012 ± 0.007 inches.

PUBLICATIONS, LECTURES, REPORTS & CONFERENCES

On July 20, 1961, a representative of Motorola, Inc. visited Mr. A. Orlowski and Miss S. Rosen of the Materials Section of the Standardization Division to discuss and elaborate on the requirements of PR & C 61-SIMSA-482. It was decided at this meeting that Motorola, Inc. investigate polyurethanes and MIL-V-173 varnishes in addition to those coatings described in PR & C 61-SIMSA-482. A ruggedization test for coatings was also decided on and this will be discussed in subsequent paragraphs. It was also decided, at this meeting, that Motorola, Inc. will run flexibility and abrasion tests on the coatings evaluated.

On August 24, 1961, Mr. A. Orlowski, Chief, Materials Section of the Standards Engineering Division visited Motorola, Inc. to discuss the progress of the program. A test plan for Phase A of this program was discussed and a copy of this plan is included in the Appendix Table I.

FACTUAL DATA

Phase 1 Two-part epoxy resin coating systems

Part 1 Characteristics of epoxy resin coating systems

Ten manufacturers of commercially advertised epoxy resin coatings for printed circuit boards were contacted and these manufacturers were carefully screened so that their coatings met the following properties:

(a) Suitability for dip, spray or brush coating application

(b) Transparency of coating when fully cured

(c) Cure time not to exceed 75°C for a two hour period.

(d) One component system, if possible. However in our screening it was discovered that no manufacturer made one component systems that will cure at this low temperature. It was decided then to investigate the two component systems.

(e) Coating formulation shall not support fungus growth.

From our screening evaluation, it was decided that seven manufacturers had coatings which were acceptable for testing. A list of the manufacturers appears in the Appendix Table II.

Part 2 Curing Schedule

The epoxy formulations used were cured at room temperature and when heat cured, the cure cycle did not exceed 75°C for 2 hours.

Phase 2 Test Panels Used

The test panels used for evaluating these coatings were

(a) Comb pattern (Specimen Y) fabricated in accordance with Figure 1 and paragraph 4.4.1 of SCL-6225.

(b) Two parallel lines pattern (Specimen X) fabricated in accordance with Figure 1, note 7 of MIL-P-55110.

A diagram of these test patterns appears in the Appendix, Table III at the end of this report.

The test panels were prepared the following copper-clad laminates, 0.062 inches thick, copper-one side with one and two ounces:

FACTUAL DATA
(Continued)

(a) As specified in MIL-P-13949B

Type PP - Phenolic resin paper base
Type GE - Epoxy resin - glass fabric base
Type GB - Epoxy resin - glass fabric base, general purpose, temperature resistant
Type GF - Epoxy resin - glass fabric, flame retardent
Type GM - Melamine resin - glass fabric
Type GS - Silicone resin - glass fabric.
This laminate is not available commercially due to adhesive system used to bond the copper to the laminate does not meet the minimum peel requirements specified in MIL-P-13949B. Most laminators contacted mentioned that they are working with the Dow Corning Corp. on an adhesive system, but so far a satisfactory product has not been found.

(b) Additional copper clad laminates:

Epoxy resin - paper base
FEP resin - molded form per MIL-P-27538
Teflon resin - glass fabric laminate

For each epoxy coating, six test panels consisting of 1 oz. and 2 oz. copper were prepared from the following laminates:

Laminate	Spec X		Spec Y	
	1 oz. Cu.	2 oz. Cu.	1 oz. Cu.	2 oz. Cu.
Type PP	3	3	3	3
Type GE	3	3	3	3
Type GB	3	3	3	3
Type GF	3	3	3	3
Paper epoxy	3	3	3	3
Uncoated (control pattern each laminate.)	1	1	1	1

Phase 3 Precoating preparation of Surface

Parts 1 & 2 Cleaning and Soldering

The following cleaning technique is outlined to eliminate as nearly as possible all surface contaminates that would tend to cause corrosion. Panels are prepared for testing using the following cleaning methods:

(a) The etched side of the boards are abraded with a fine grade of steel wool.

(b) The leads are soldered to the terminal points using 60 - 40 flux core solder.

(c) The soldered boards are scrubbed in isopropyl alcohol to remove the rosin flux and other contaminants.

FACTUAL DATA
(Continued)

(d) The boards are air dried and then coated.

Phase 4 Method of Application

The epoxy coatings were mixed according to the manufacturers recommendation and deaired for about 10 minutes under vacuum. The coating material was brushed on the etched side of the laminate and was cured in a horizontal position so that an even surface coat is obtained.

Phase 5 Physical and Electrical Properties of epoxy resin coating systems

Part 1 Appearance and Adhesion

After the specimen panels were coated, they were visually examined for blistering, wrinkling, cracking and peeling of the coating and corrosion of the conductors.

Part 2 Thickness measurements

Thickness measurements of the coatings were made in accordance with Method 618.1 of Fed STD-TT-P-141. Three thickness measurements were taken at different areas on the test panel with a dial indicator gage accuracy is ±0.0001 inch. An average thickness reading was calculated from the three measurements. Test panels thickness measurements appears in the Appendix Table III.

Parts 3 & 4 Dielectric Constant and Dissipation Factor & Q Factor

(a) Mold - The epoxy coating specimens were cast in a mold similar to one described in paragraph 4.3.1 of MIL-I-16923C except that glass plates were substituted for highly polished steel plates. The size of the cast sheet made was 5 X 5 inches.

(b) 2 inch disc specimen - The mold described in part 3(a) was heated to 75°C. The epoxy coating was mixed according to the manufacturers recommendations, deaired for 10 minutes and poured into the mold. During the pouring process care was taken to avoid the entrapping of air into the material. The coating material was cured at 75°C for 2 hours. A two inch disc was cut from the cast sheet and the thickness of the specimen was measured with a Micrometer to ensure that the two surfaces were parallel to within ± 0.001 inch. The two inch discs were measured at 1, 3, 6.25, 30, 50, 75 and 100 megacycles.

(c) Procedure - The procedure used for measuring dielectric constant and dissipation factor is similar to the one described in ASTM-D-150. In testing these coatings, the resonance rise method was used in conjunction with a micrometer - electrode system.

For frequencies from 20 to 100 mc, Boonton Radio Co. Model 190-A Q - meter Serial No. 1195 was used.

For frequencies below 20 mc, a Boonton Radio Co. Model 260-A Q - meter Serial No. 159 was used. The micrometer - electrode system used was manufactured by General Radio Co. Type 1690 Dielectric Sample Holder Serial No. 472.

FACTUAL DATA
(Continued)

The procedure for determining the dielectric constant dissipation factor and Q factor of the coatings is as follows: -

(1) Insert 2 inch disc specimen in between electrode plates of Dielectric Sample Holder and screw top electrode down until it is in contact with specimen.

(2) Resonate Q-meter circuit and note readings C, on capacitance dial and Q_1 reading on voltmeter scale and spacing of electrodes (t_1).

(3) Remove specimen from holder and resonate Q-meter circuit again by bringing electrodes closer together. Record new spacing (t_2) and new Q_2 reading.

For a 2 inch specimen the unknown capacity (C_x) is

$$C_x = C_2 + \Delta C_2 - \Delta C_1 \quad \text{(Eq. 1)}$$

where C_2 = geometric air capacitance for spacing (t_2)

C_1 = geometric air capacitance for spacing (t_1)

ΔC_2 = correction for setting (t_2) (correction factor for dielectric sample holder)

ΔC_1 = correction for setting (t_1) (correction factor for dielectric sample holder)

The geometric air capacitance (C) for 2 inch disc specimen is obtained from the following formula:

$$C = \frac{706.5}{t} \quad \text{(t = mils or thousands of an inch)}$$

The dielectric constant (K) is calculated as follows: -

$$K = \frac{C_x}{C_1} \quad \text{(Eq. 2)}$$

The Q factor of the coating (Q_x) is calculated as follows: -

$$Q_x = \frac{Q_1 Q_2 C_x}{(Q_2 - Q_1) C} \quad \text{(Eq. 3)}$$

From this the dissipation factor (D_x) is: -

$$D_x = \frac{1}{Q_x} = \frac{C}{C_x}\left(\frac{1}{Q_1} - \frac{1}{Q_2}\right) \quad \text{(Eq. 4)}$$

The dielectric constant and dissipation factor data and graphs for epoxy coating systems appear in the Appendix Table V thru Table VIII.

(d) Coated boards

The Q factor and dissipation factor was determined on the control specimen and coated panels at 1, 50 and 100 mc. These tests were run on Specimen X in lieu of Specimen Y because at higher frequencies, the lead length begins to introduce appreciable error due to lead inductance. Because of this effect, we wanted to keep our lead length from the specimen to the measuring instrument as short as possible so as to reduce this measurement error.

The procedure used for determining these factors is as follows: -

(1) Resonate Q meter without specimen and note Q_2 (Voltmeter readings) and C_2 readings.

(2) Place test specimen in Q meter circuit and resonate circuit again and note Q_1 and C_1 readings.

(3) Calculate Q_x of coating as follows: -

$$Q_x = \frac{Q_1 Q_2 (C_2 - C_1)}{(Q_2 - Q_1) C_1} \quad \text{(Eq. 5)}$$

The dissipation factor can be calculated by using (Eq. 4).

The relative change in the Q of the coating is calculated as follows: -

$$Q_x \begin{pmatrix}\text{of coating}\\ \text{on panel}\end{pmatrix} = \left(Q_x \begin{pmatrix}\text{of uncoated}\\ \text{board}\end{pmatrix} - Q_x \begin{pmatrix}\text{coated}\\ \text{board}\end{pmatrix} \right) \quad \text{(Eq. 6)}$$

The data for these above mentioned readings is listed in Appendix, Table IX.

Part 5 Dielectric Withstanding Voltage

All dielectric withstanding voltage tests were made on a Motorola built - Breakdown tester TE-8359 with output from 0 to 3000 v AC at 60 cps. Specimen X was electrified at 1500 V AC for 30 seconds and Specimen Y electrified at 1000 V AC for 1 minute.

Task B

Investigation of polyurethane resin conformal coatings on XXXP, glass-epoxy and paper-epoxy copper-clad laminate series specified in MIL-P-13949B.

Phase 1 Polyurethane resin coating systems

Part 1 Characteristics of polyurethane resins coating systems

The polyurethane coatings evaluated were of two types: - (1) those coatings that have high moisture and humidity resistance and (2) those coatings which have good abrasion resistance. The manufacturers evaluated appears in the Appendix, Table II

FACTUAL DATA
(Continued)

Polyurethane coatings have some properties which are somewhat better then epoxies and vinyls. A few of the outstanding properties of urethane coatings are as follows: -

(a) Resistance to chemicals and solvents.

(b) Resistance to moisture, water immersion.

(c) Resistance to weathering and wear.

(d) Resistance to elevated temperatures.

(e) Toughness with flexibility.

(f) Very high gloss finish.

(g) High fungus and mildew resistance.

The types of urethanes coatings investigated were of the one component and two component system types. The one component system coating depends on free oxygen and humidity of the atmosphere to set. This type of coating usually dries from 1/2 hour to 3.0 hours. This type of coating does not yield films of the highly resistant character of which the two package urethane system is capable. The two component system types are packaged as a prepolymer (part A) and catalyst (part B). In our studies, we will investigate whether both systems can be used for coatings on printed circuit assemblies.

Part 2 Curing Schedule

All coatings were cured at room temperature for 24 hours. However electrical tests were not performed on these coatings until a seven day period elapsed so that these coatings had reached the full cure stage.

Phase 2 Test panels used

Same as described in phase 2 of Task A of Factual data.

Phase 3 Precoating Preparation of Surface

Parts 1 and 2 Cleaning and Soldering

Same procedure described in phase 3 of Task A of Factual Data.

Phase 4 Method of coating application

All tests panels were brush coated.

Phase 5 Physical and Electrical Properties of Epoxy Resin Coating Systems

Part 1 Appearance and Adhesion

After the specimen panels were coated, they were visually examined for blistering, wrinkling, cracking and peeling of the coating and corrosion of the conductors.

Part 2 Thickness measurements

Same procedure as described in part 2, phase 5 of Task A. Thickness measurements data are listed in the Appendix Table IV.

Parts 3 and 4 Dielectric Constant, Dissipation Factor and Q Factor

(a) Mold

Since the urethane coating systems investigated are of the solvent type, the apparatus discussed in paragraph 4.3.1 of MIL-I-16923C could not be used. We cast films of these coatings, using an apparatus described below and pictured in the Appendix Table V.

A teflon sheet which had one side etched was bonded to a sheet of lucite to ensure flatness of the teflon. The edges were built up with layers of masking tape so as to confine the liquid urethane into a certain area. In this manner a film having a thickness of 0.015 to 0.020 inches could be obtained.

(b) Two inch disc specimen

The coating material was mixed according to the manufacturers instruction and poured into the mold described above. The resultant coated was cured for seven days prior to cutting of two inch discs.

(c) Procedure

The procedure for measuring the dissipation factor, dielectric constant and Q factor is similar to one described in section c of Parts 3 & 4, Phase 5 of Task A in the Factual Data.

(d) Coated boards

The Q factor and dissipation factor was determined using the same procedure outlined in section d of parts 3 & 4, Phase 5 of Task A in the Factual Data.

Part 5 Dielectric Withstanding Voltage

Procedure is similar to one outlined in part 5 of phase 5, Task A of the Factual Data.

CONCLUSION

Task A and B

Investigation of epoxy resin and polyurethane conformal coatings on XXXP, glass-epoxy and paper-epoxy copper-clad laminate series specified in MIL-P-13949B and PR & C 61-SIMSA-482.

Phase 1 Epoxy and Polyurethane systems

Part 1 Characteristics of epoxy and polyurethane resin systems studied

All the epoxy and polyurethane coatings studied met the following characteristics:

(a) Suitability for dip, spray or brush coat application.

(b) Transparency when fully cured.

(c) Cure time not to exceed two hours at 75°C.

(d) Coating formulation shall not support fungus.

(e) One component system preferred.

For the epoxies, two component systems were studied due to the unavailability of one component systems to meet the curing requirements outlined above.

Two component as well as one component polyurethane systems were investigated, because two component systems will give better properties than the one component systems.

Part 2 Curing Schedule

All epoxy coatings were cured at a maximum of 2 hours at 75°C.

All polyurethane coatings were cured at room temperature for 24 hours.

Phase 4 Method of Coating Application

All coatings were brush coated on the specimen test panels.

Phase 5 Physical and Electrical Properties of Epoxy and Polyurethane resin coating systems

Part 1 Appearance and Adhesion of coatings

All test panels coated with both types of coatings exhibited no blistering, wrinkling, cracking or peeling of coating and no corrosion of printed conductors. All coatings exhibited good adhesion to test panels.

CONCLUSION
(Continued)

Part 2 Thickness measurements

All specimen test panels were coated to a thickness of 0.012 ± 0.007 inches.

Part 3 Dielectric Constant and Dissipation Factor

The dielectric constant drops as the frequency increases from 1 to 100 mc. On the other hand, the dissipation factor at 1 mc begins at one value and then drops until the frequency reaches 30 mc. and then begins to rise to 100 mc. This observation agrees with Murphy and Morgan (1).

The changes in the dielectric constant and dissipation factor with frequency are produced by the dielectric polarization which exist in the material. The two most important polarizations, caused by various constituents which make up the particular formulation, are (1) dipole polarization due to polar molecules - this effect becomes more noticeable in the higher frequency ranges and (2) interfacial polarization - this effect is seen at the lower frequency spectrum. Each polarization furnishes a maximum of value of dissipation factor. The frequency at which this maximum loss occurs is called the relaxation frequency for that polarization. It is also the frequency at which the dielectric constant is increasing at its greatest rate. From Table VI and VIII as the frequency approaches 1 mc, the dielectric constant and dissipation factor begin to increase in value. This means that below 1 mc, there is a relaxation frequency for epoxy materials.

Part 4 Q Factor

All epoxy coated boards measured indicates that the Q factor dropped in comparison to their uncoated relatives. The relative percentage loss is dependent on what laminate the particular coating was placed. We have not fully interpreted these results as yet.

Part 5 Dielectric Withstanding Voltage

All coated specimens passed the initial dielectric withstanding voltage before thermal cycling. Coated Specimen X patterns withstood 1500 V AC for 30 seconds while coated Specimen Y withstood 1000 V AC for 1 minute.

(1) Murphy and Morgan, "The Dielectric Properties of Insulating Materials Bell System Technical Journal Vol 16, October 1937 p.p. 493 - 512.

PROGRAM FOR NEXT INTERVAL (QUARTER)

(1) Complete Tasks A through F, Phases 1 - 5 where application is feasible.

IDENTIFICATION OF KEY PERSONNEL

	Time Spent - Hours
Mr. Anthony Beccasio Project Engineer	330
Mr. Ernest Colon Technician	139
Mr. John Kwiatkowski Technician	16
Mr. Lester Powell Senior Component Engineer	*
Mr. Arthur Bethke Chemist	*
TOTAL	485

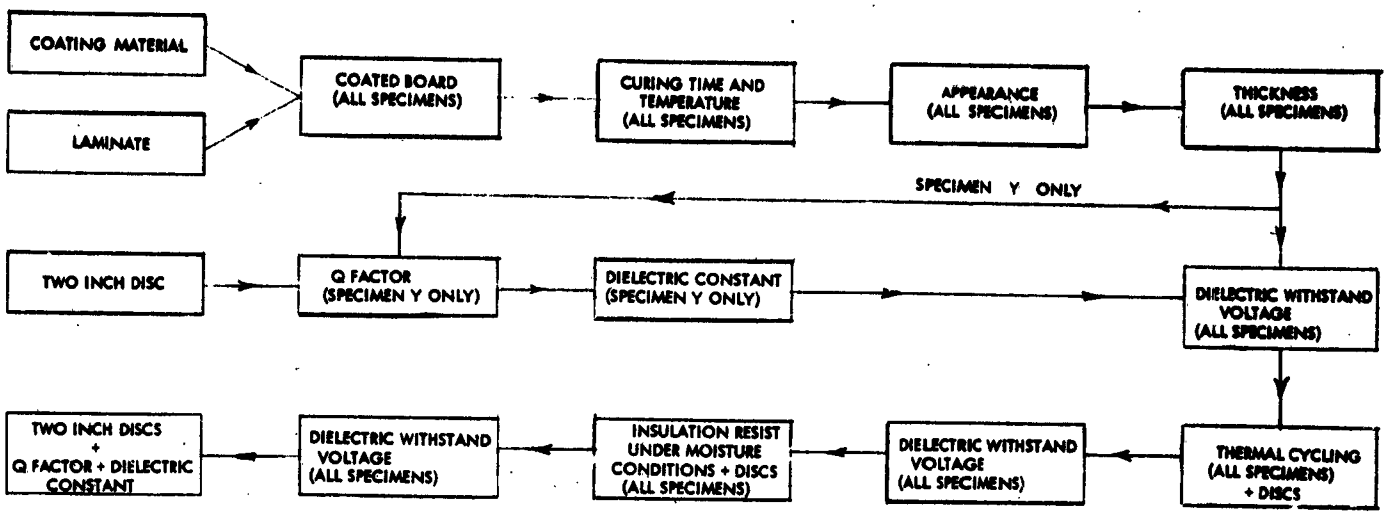
* Mr. Powell and Mr. Bethke are available at no cost to the project.

A P P E N D I X

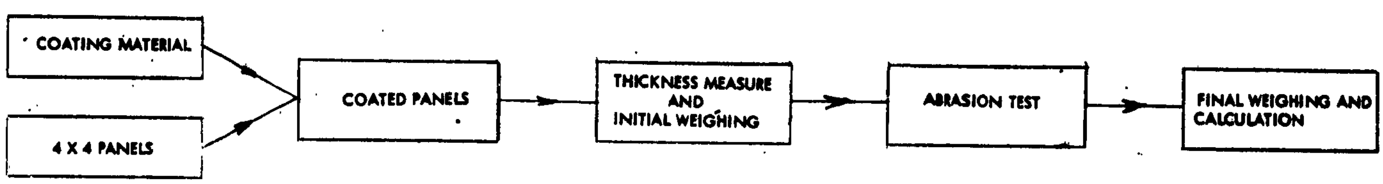
FLOW CHART FOR PHASE A TESTING

Table I

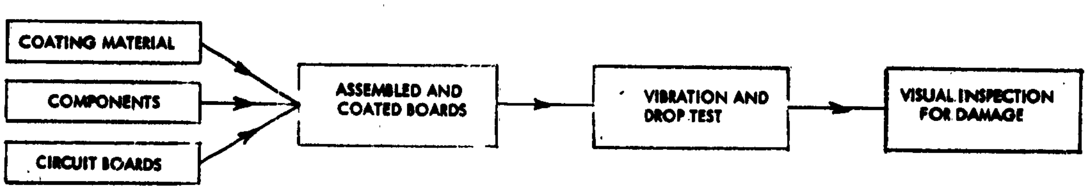
A. ELECTRICAL TESTING



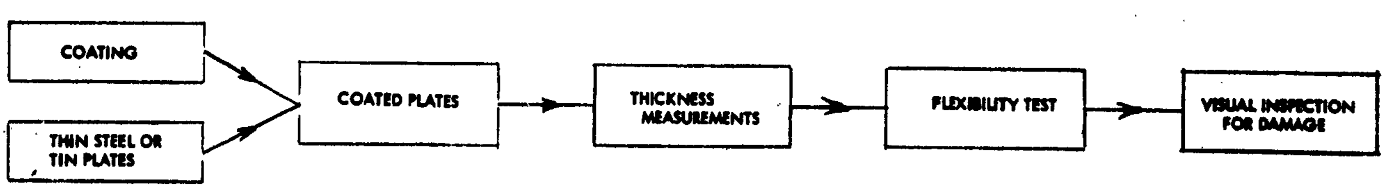
B. ABRASION TEST



C. RUGGEDIZATION TEST



D. FLEXIBILITY TEST



PREPARED BY A.J.B. AUG.22,1961

TABLE II

This table has been purposely omitted.

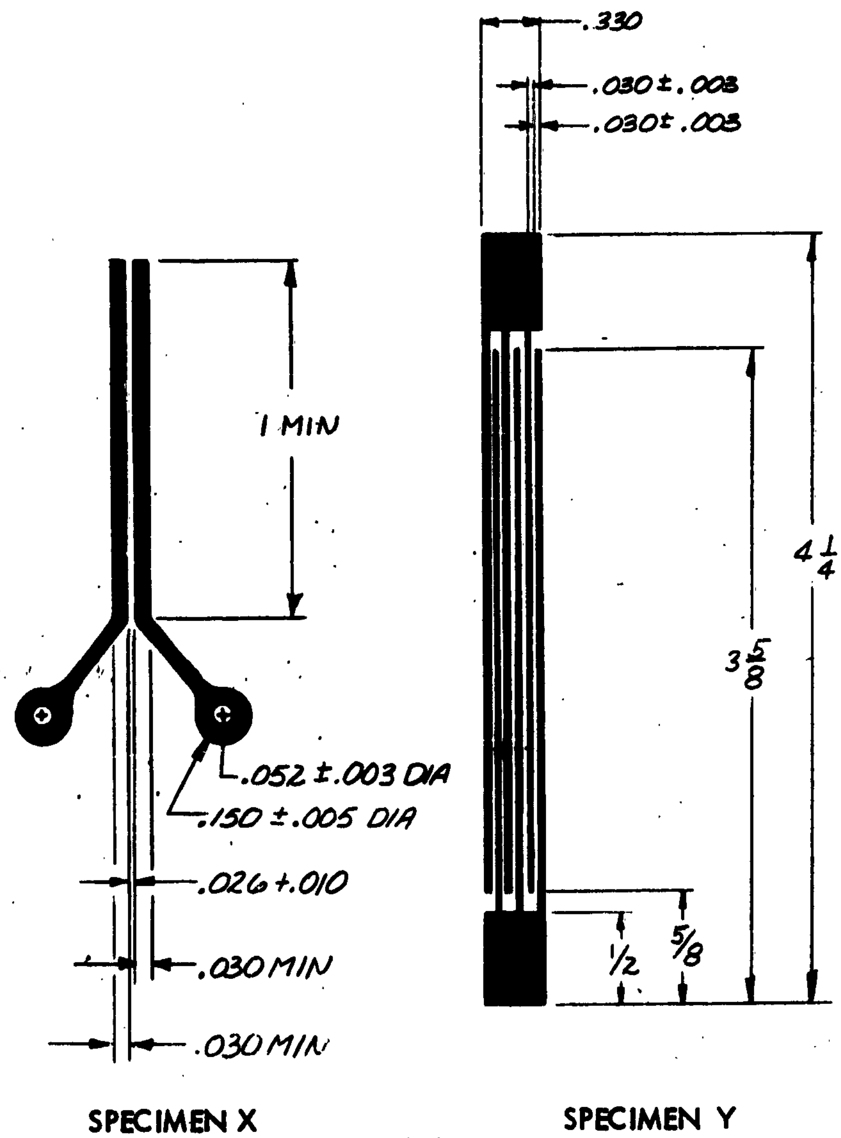


TABLE III
TEST PANELS

TABLE IV

THICKNESS MEASUREMENTS OF COATED EPOXY TEST PANELS

Mfr. code no.	Laminate	Test panel	Average thickness (inches)		
			Patt. 1	Patt. 2	Patt. 3
A	XXXP	Y	0.013	0.014	0.008
		X	0.013	0.013	0.010
	GE	Y	0.012	0.014	0.007
		X	0.010	0.008	0.009
	paper epoxy	Y	0.010	0.014	0.019
		X	0.019	0.017	0.012
	GB	Y	0.010	0.010	0.009
		X	0.014	0.011	0.007
	GF	Y	0.019	0.012	0.008
		X	0.019	0.017	0.013
B	paper epoxy	Y	0.009	0.012	0.012
		X	0.007	0.006	0.007
	GB	Y	0.013	0.011	0.012
		X	0.013	0.019	0.018
	GE	Y	0.005	0.004	0.007
		X	0.006	0.006	0.007
	GF	Y	0.005	0.006	0.005
		X	0.006	0.010	0.010
	XXXP	Y	0.006	0.008	0.015
		X	0.004	0.006	0.008
C	GE	Y	0.011	0.012	0.009
		X	0.020	0.018	0.014
	GF	Y	0.004	0.003	0.005
		X	0.012	0.009	0.009
	paper epoxy	Y	0.012	0.016	0.009
		X	0.006	0.008	0.009
	XXXP	Y	0.012	0.008	0.013
		X	0.010	0.012	0.013
	GB	Y	0.019	0.014	0.010
		X	0.015	0.013	0.009
D	GB	Y	0.005	0.009	0.004
		X	0.011	0.011	0.009
	GE	Y	0.011	0.009	0.009
		X	0.010	0.007	0.008
	paper epoxy	Y	0.013	0.019	0.013
		X	0.012	0.010	0.008
	XXXP	Y	0.011	0.011	0.008
		X	0.009	0.013	0.012
	GF	Y	0.016	0.011	0.010
		X	0.015	0.011	0.010
E	GF	Y	0.009	0.016	0.008
		X	0.020	0.022	0.020
	GB	Y	0.016	0.013	0.016
		X	0.016	0.014	0.017
	GE	Y	0.018	0.017	0.012
		X	0.019	0.014	0.015
	XXXP	Y	0.024	0.014	0.013
		X	0.016	0.013	0.014

TABLE IV (CONT.)

Mfr. code no.	Laminate	Test panel	Average thickness (inches)		
			Patt. 1	Patt. 2	Patt. 3
E	paper epoxy	Y	0.017	0.020	0.019
		X	0.013	0.010	0.017
F	paper epoxy	Y	0.003	0.005	0.005
		X	0.003	0.004	0.005
	GE	Y	0.004	0.003	0.003
		X	0.003	0.005	0.005
	GF	Y	0.004	0.006	0.005
		X	0.002	0.003	0.004
	XXXP	Y	0.004	0.004	0.005
		X	0.004	0.002	0.006
	GB	Y	0.007	0.006	0.003
		X	0.005	0.005	0.006
G	GB	Y	0.007	0.009	0.011
		X	0.008	0.007	0.007
	GE	Y	0.009	0.007	0.008
		X	0.008	0.011	0.008
	XXXP	Y	0.008	0.008	0.010
		X	0.012	0.007	0.008
	GF	Y	0.010	0.006	0.008
		X	0.007	0.009	0.007
	paper epoxy	Y	0.007	0.010	0.011
		X	0.008	0.009	0.009
H	paper epoxy	Y	0.019	0.014	0.005
		X	0.020	0.019	0.019
	XXXP	Y	0.007	0.007	0.005
		X	0.012	0.014	0.017
	GB	Y	0.010	0.009	0.013
		X	0.013	0.009	0.011
	GE	Y	0.011	0.009	0.014
		X	0.014	0.013	0.013
	GF	Y	0.007	0.009	0.007
I	GB	Y	0.006	0.007	0.005
		X	0.007	0.005	0.008
	GE	Y	0.008	0.006	0.007
		X	0.004	0.006	0.008
	GF	Y	0.006	0.007	0.010
		X	0.009	0.005	0.011
	paper epoxy	Y	0.006	0.005	0.007
		X	0.005	0.006	0.007
	XXXP	Y	0.005	0.007	0.007
		X	0.004	0.006	0.010

TABLE IV (CONT.)

THICKNESS MEASUREMENTS OF POLYURETHANE COATED PANELS

Mfr. code no.	Laminate	Test panel	Average thickness (inches)		
			Patt. 1	Patt. 2	Patt. 3
AA	GE	Y	0.008	0.009	0.003
		X	0.009	0.010	0.010
	GE	Y	0.010	0.010	0.011
		X	0.010	0.008	0.013
	GF	Y	0.011	0.012	0.015
		X	0.009	0.008	0.008
	paper epoxy	Y	0.010	0.010	0.008
		X	0.012	0.009	0.007
	XXXP	Y	0.010	0.005	0.006
		X	0.008	0.009	0.011
BB	GF	Y	0.010	0.008	0.008
		X	0.005	0.003	0.008
	GB	Y	0.005	0.012	0.011
		X	0.006	0.009	0.008
	XXXP	Y	0.010	0.009	0.008
		X	0.008	0.006	0.007
	GE	Y	0.008	0.008	0.008
		X	0.005	0.008	0.012
	paper epoxy	Y	0.008	0.009	0.012
		X	0.004	0.005	0.008
CC	paper epoxy	X	0.005	0.005	0.005
		Y	0.006	0.006	0.006
	GF	Y	0.004	0.004	0.004
		X	0.006	0.004	0.005
	GE	Y	0.006	0.004	0.005
		X	0.009	0.008	0.006
	GB	Y	0.006	0.007	0.005
		X	0.006	0.006	0.005
	XXXP	Y	0.003	0.004	0.004
		X	0.004	0.005	0.006
DD	GB	Y	0.009	0.007	0.009
		X	0.006	0.008	0.006
	GF	Y	0.004	0.005	0.012
		X	0.008	0.009	0.007
	GE	Y	0.008	0.007	0.008
		X	0.009	0.009	0.010
	paper epoxy	Y	0.003	0.014	0.015
		X	0.005	0.005	0.009
	XXXP	Y	0.005	0.008	0.009
		X	0.007	0.004	0.006
GG	paper epoxy	Y	0.020	0.006	0.008
		X	0.005	0.011	0.008
	GE	Y	0.007	0.008	0.006
		X	0.007	0.007	0.017
	XXXP	Y	0.005	0.007	0.005
		X	0.010	0.006	0.006
	GF	Y	0.008	0.010	0.007
		X	0.015	0.011	0.006

TABLE IV (CONT.)

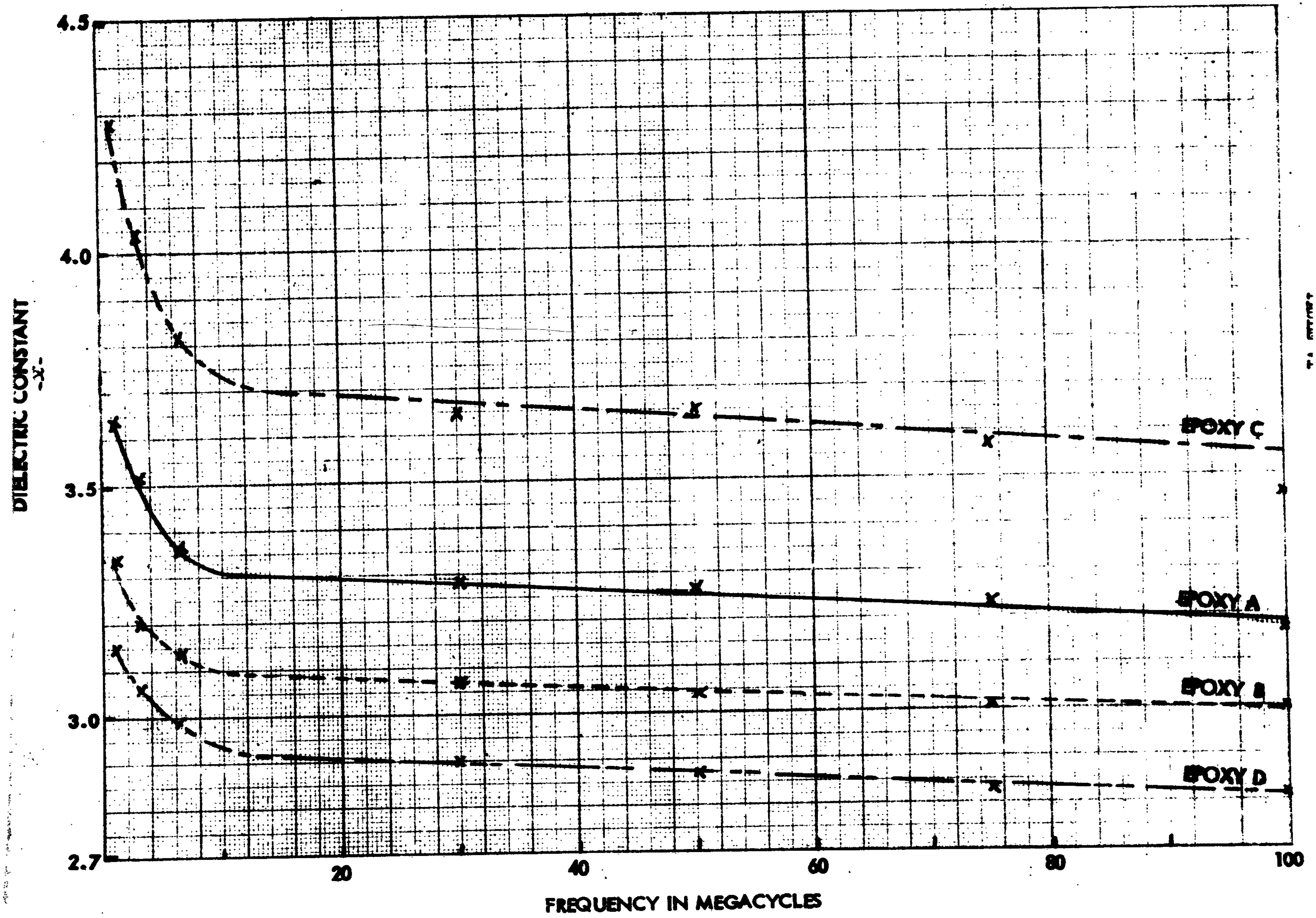
Mfr. code no.	Laminate	Test panel	Average thickness (inches)		
			Patt. 1	Patt. 2	Patt. 3
GG	GB	Y	0.010	0.011	0.006
		X	0.013	0.006	0.006
HH	paper epoxy	Y	0.007	0.008	0.005
		X	0.005	0.006	0.014
	GF	Y	0.014	0.005	0.006
		X	0.005	0.012	0.010
	XXXP	Y	0.006	0.007	0.006
		X	0.007	0.006	0.009
	GB	Y	0.006	0.008	0.011
		X	0.011	0.009	0.008
	GE	Y	0.004	0.007	0.007
		X	0.010	0.009	0.009
II	GE	Y	0.010	0.007	0.005
		X	0.009	0.007	0.008
	paper epoxy	Y	0.004	0.007	0.010
		X	0.007	0.009	0.009
	GF	Y	0.007	0.009	0.010
		X	0.010	0.007	0.006
	XXXP	Y	0.007	0.005	0.005
		X	0.007	0.006	0.009
	GB	Y	0.005	0.005	0.011
		X	0.007	0.008	0.006

TABLE V

DIELECTRIC CONSTANT OF

EPOXY COATING TWO INCH DISCS

MFR. Code #	Dielectric Constant at 1 mc	3 mc	6.25 mc	30	50	75	100
A	3.63	3.51	3.36	3.28	3.26	3.23	3.17
B	3.34	3.20	3.14	3.07	3.04	3.01	3.00
C	4.28	4.04	3.81	3.65	3.65	3.57	3.46
D	3.15	3.06	2.99	2.90	2.87	2.83	2.81



4.5
4.0
3.5
3.0
2.7
20
40
60
80
100
DIELECTRIC CONSTANT
-K-
FREQUENCY IN MEGACYCLES
EPOXY C
EPOXY A
EPOXY B
EPOXY D

TABLE VII

DISSIPATION FACTOR OF

EPOXY COATINGS TWO INCH

DISC SPECIMENS

MFR. Code #	DISSIPATION FACTOR AT 1 mc	3 mc	6.25 mc	30 mc	50 mc	75 mc	100 mc
A	0.054	0.049	0.044	0.040	0.042	0.047	0.049
B	0.047	0.030	0.035	0.030	0.030	0.033	0.034
C	0.076	0.075	0.077	0.065	0.078	0.070	0.080
D	0.056	0.047	0.052	0.034	0.030	0.031	0.034

DISSIPATION FACTOR VS. FREQUENCY

FIGURE VIII

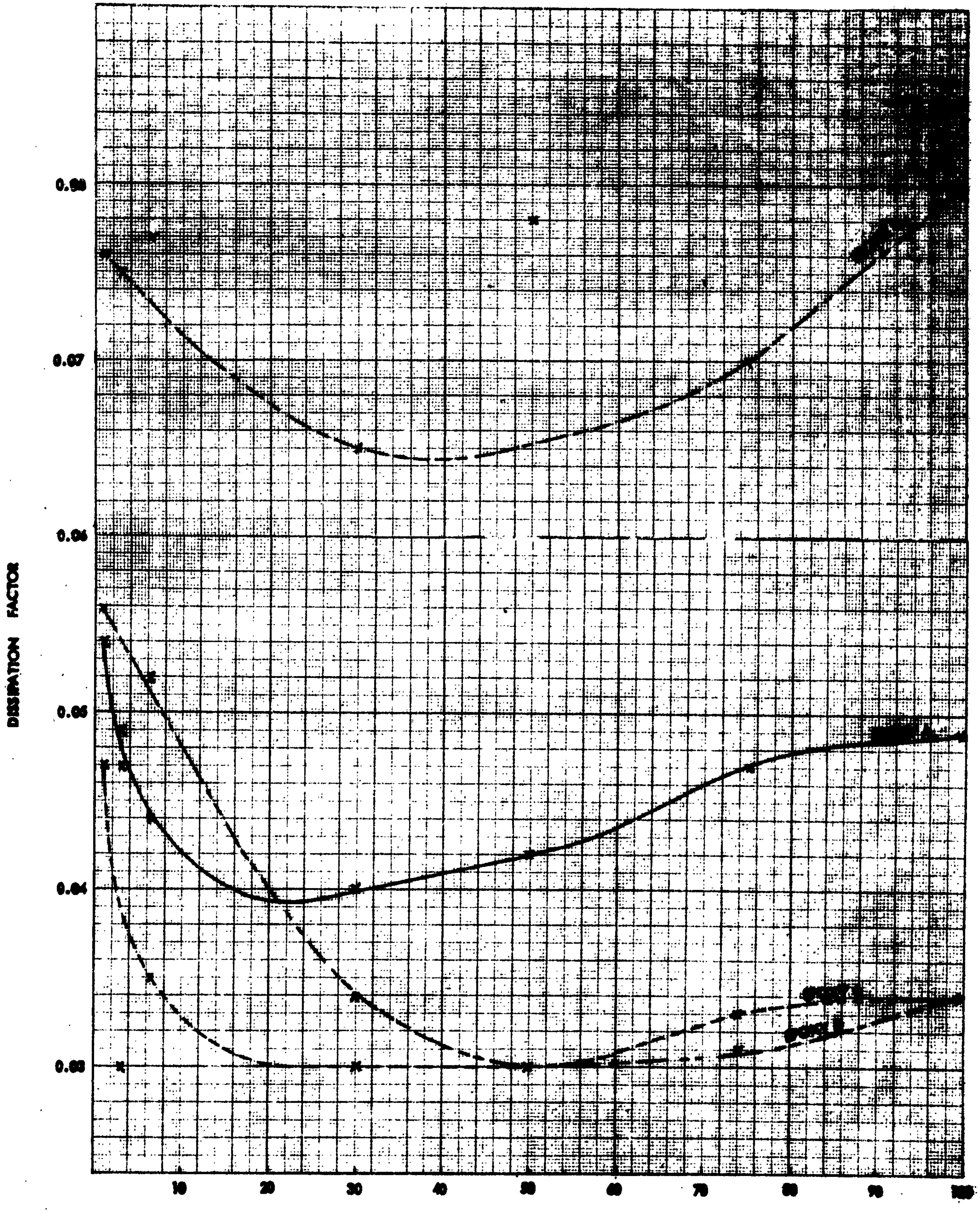


TABLE IX

Q FACTOR AND DISSIPATION FACTOR MEASUREMENTS OF EPOXY COATED

SPECIMEN X TEST PANELS

Mfr. code No.	Laminate and weight of copper	Test specimen	Average thick. of panels	1mc.		50mc.		100 mc.	
				Av. Q	Av. DF	Av. Q	Av. D.F.	Av. Q	Av. D.F.
[redacted]	paper epoxy 2oz.	control	--	43.8	0.023				
		Coated	0.017	33.9	0.029				
[redacted]	XXXP 2oz.	control	--	59.2	0.017				
		coated	0.012	43.0	0.023				
[redacted]	GF 2oz.	control	--	107.9	0.009				
		coated	0.013	58.4	0.017				
[redacted]	GE 2oz.	control	--	82.2	0.012				
		coated	0.009	67.7	0.014				
[redacted]	GB 2oz.	control	--	148.1	0.007				
		coated	0.011	68.0	0.015				
[redacted]	paper epoxy 1oz.	control	--	45.7	0.022				
		coated	0.007	44.0	0.023				
[redacted]	GF 1oz.	control	--	130.2	0.008				
		coated	0.009	98.4	0.010				
[redacted]	GB 1oz.	control	--	176.7	0.006				
		coated	0.015	103.6	0.010				
[redacted]	GE 1oz.	control	--	83.4	0.012				
		coated	0.006	59.9	0.017				
[redacted]	XXXP 1oz.	control	--	62.8	0.016				
		coated	0.006	55.7	0.018				
[redacted]	GB 1oz.	control	--	130.0	0.008				
		coated	0.012	86.3	0.012				
[redacted]	XXXP 1oz.	control	--	57.1	0.018				
		coated	0.011	49.0	0.020				
[redacted]	paper epoxy 1oz.	control	--	86.6	0.012				
		coated	0.008	49.0	0.020				
[redacted]	GF 1oz.	control	--	85.6	0.012				
		coated	0.010	80.4	0.012				
[redacted]	GB 1oz.	control	--	118.4	0.008				
		coated	0.010	66.9	0.015				
[redacted]	GE 1oz.	control	--	75.1	0.013				
		coated	0.008	60.0	0.017				
[redacted]	paper epoxy 1oz.	control	--	48.9	0.020				
		coated	0.010	41.5	0.024				
[redacted]	XXXP 1oz.	control	--	66.5	0.015				
		coated	0.011	45.6	0.022				
[redacted]	GF 1oz.	control	--	89.6	0.011				
		coated	0.012	64.4	0.016				
[redacted]	paper epoxy 1oz.	control	--	54.3	0.018				
		coated	0.013	41.1	0.024				
[redacted]	XXXP 1oz.	control	--	58.1	0.017				
		coated	0.013	47.1	0.021				
[redacted]	GF 1oz.	control	--	111.2	0.009				
		coated	0.022	66.5	0.015				
[redacted]	GB 1oz.	control	--	133.7	0.007				
		coated	0.016	73.3	0.014				

TABLE IX (CONT.)

Mfr. code	Laminate and weight of copper	Test specimen	Average thick. of panels	1mc.		50 mc.		100 mc.	
				Av. Q	Av. D.F.	Av. Q	Av. D.F.	Av. Q	Av. D.F.
E	GE 1oz.	control	--	78.9	0.013				
		coated	0.016	63.2	0.016				
F	GE 1oz.	control	--	97.0	0.010				
		coated	0.003	70.4	0.014				
	GF 1oz.	control	--	123.8	0.008				
		coated	0.005	109.1	0.009				
	XXXP 1oz.	control	--	68.2	0.015				
		coated	0.005	63.9	0.016				
	paper epoxy 1oz.	control	--	66.4	0.015				
		coated	0.004	65.0	0.015				
	GB 1oz.	control	--	171.6	0.006				
		coated	0.005	131.6	0.008				
G	GB 1oz.	control	--	164.8	0.006				
		coated	0.007	84.7	0.012				
	GE 1oz.	control	--	93.9	0.011				
		coated	0.009	57.0	0.018				
	XXXP 1oz.	control	--	70.2	0.014				
		coated	0.009	50.4	0.020				
	GF 1oz.	control	--	156.2	0.006				
		coated	0.008	61.0	0.016				
	paper epoxy 1oz.	control	--	66.9	0.015				
		coated	0.008	47.2	0.021				
H	XXXP 2oz.	control	--	80.4	0.012				
		coated	0.014	65.6	0.015				
	GB 2oz.	control	--	156.7	0.006				
		coated	0.011	124.6	0.008				
	GE 2oz.	control	--	127.5	0.008				
		coated	0.013	95.8	0.010				
	GF 2oz.	control	--	124.6	0.008				
		coated	0.015	102.8	0.010				
	paper epoxy 2oz.	control	--	59.1	0.017				
		coated	0.020	58.1	0.017				
I	GB 2oz.	control	--	136.1	0.007				
		coated	0.006	124.8	0.008				
	GF 2oz.	control	--	127.6	0.008				
		coated	0.008	99.1	0.010				
	paper epoxy 2oz.	control	--	60.3	0.017				
		coated	0.006	54.1	0.018				
	GE 2oz.	control	--	100.0	0.010				
		coated	0.006	75.0	0.013				
	XXXP 2oz.	control	--	72.6	0.014				
		coated	0.007	64.6	0.015				

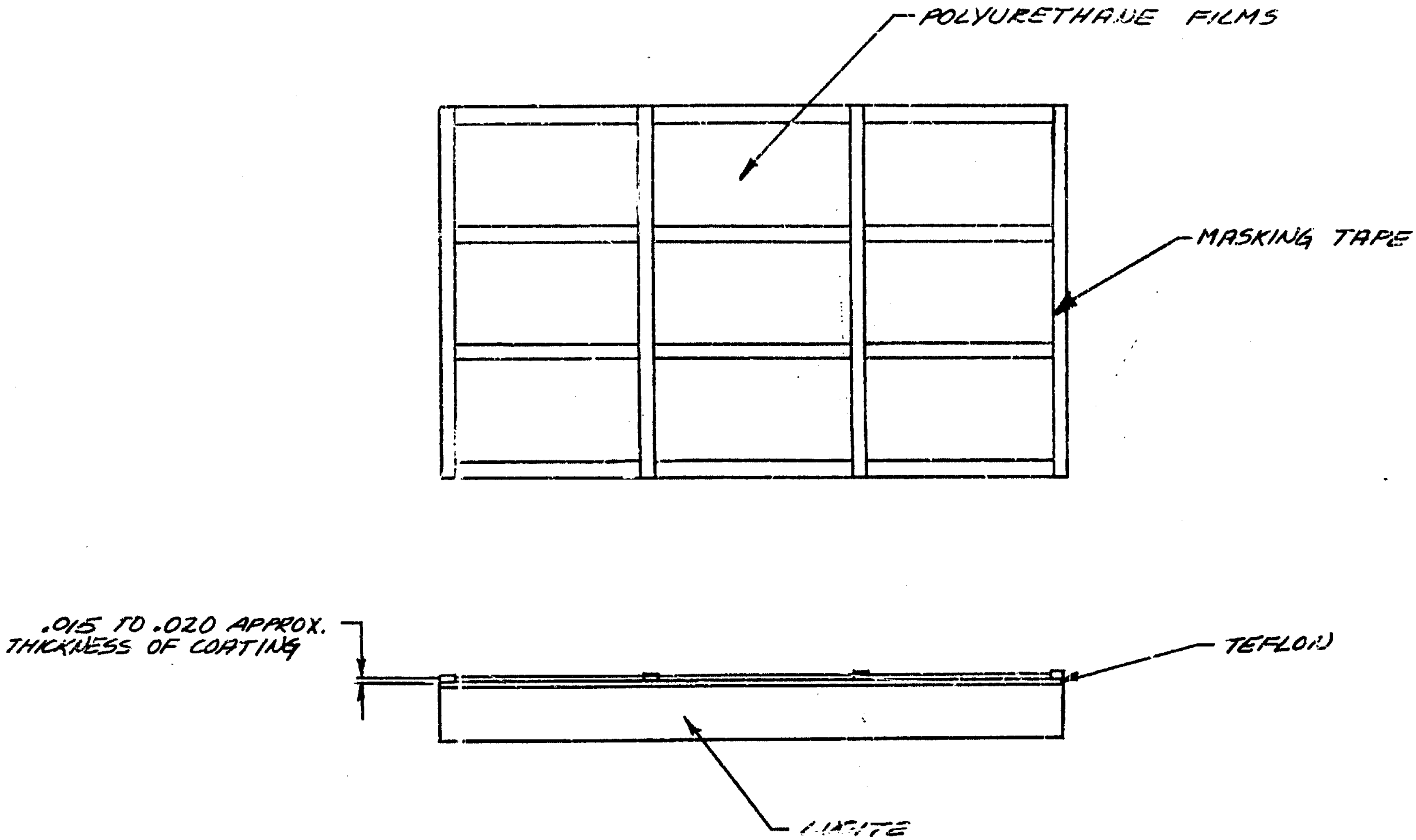


FIGURE X
POLYURETHANE CASTING MOLD

DRAWN BY: E.H. [illegible]
26 OCT 61