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HIGH ENERGY CAPACITORS FOR MODERATE REPETITION RATE

FINAL REPORT

AUG 1972

BY

Conrad Halberg and Herbert Rice

MAY 1972

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SPRAGUE ELECTRIC COMPANY

NORTH ADAMS, MASSACHUSETTS

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13. ABSTRACT

Capacitors of six designs were designed, constructed and measured for various electrical characteristics. Two designs were chosen for further work in Phase II on the basis of these measurements and 100,000 charge-discharge life test data.

In Phase II, two designs were constructed in three variations and further discharge life tested for a total of 10,000,000 charge-discharge cycles or until failure. The best design was chosen for work in Phase III.

In Phase III, capacitors were constructed and discharge life tested for 50,000,000 charge-discharge cycles or until failure. One capacitor failed at 10,000,000 charge-discharge cycles while the remaining five capacitors completed 50,000,000 charge-discharge cycles. All six capacitors met the contract requirements of delivering 12 joules of energy at 900V and weighing less than six ounces.

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FOR

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Capacitors of six designs were designed, constructed and measured for various electrical characteristics. Two designs were chosen for further work in Phase II on the basis of these measurements and 100,000 charge-discharge life test data.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

1. General

The object of this research effort was the development of high-energy capacitors of minimum weight for moderate repetition rate, non-oscillatory discharge applications, such as target and area illuminators. Specifically, the capacitors, when charged to 900 volts and discharged through a 1 ohm resistor in series with a 30 microhenry inductor, had to deliver not less than 12 joules for the entire temperature range of -40°C to +85°C. The corresponding capacitance for this requirement was 30 μF, minimum. The repetition rate for discharge of the capacitors was to be 10 pulses per second (pps), and the minimum life objective was 5.0×10^7 discharges at ambient temperature of 40°C. The capacitor weight objective was six (6) ounces maximum. Emphasis in the effort was placed on the maximizing of the energy-to-weight ratio.

2. Discussion

There are a number of ways in which the energy-to-weight ratio of capacitors may be increased. The most obvious method is to employ a dielectric and/or impregnant system having a high dielectric constant. More efficient is the use of a dielectric system capable of withstanding high voltage stresses. The energy density increases as the square of the voltage rating, and is also proportional to the dielectric constant.

Still another method involves the use of metallized electrodes. This improves the weight efficiency (energy-to-weight ratio) in two ways. First, metallized electrodes are much thinner than the foil electrodes commonly used. This means a lighter capacitor than obtainable with an energy-comparable foil electrode. Secondly, a metallized capacitor is capable of operating at higher voltage stresses for a given dielectric thickness. This is due to the "self-healing" character of metallized capacitors. In the event of a dielectric failure in a foil type capacitor, high currents flow at the point of rupture, and the adjacent dielectrics and foils are damaged. Thus, the capacitor shorts, and is rendered inoperable. On the other hand, as the case of a dielectric failure in a metallized capacitor, an electric arc is drawn between the two electrodes. This arc vaporizes the metal film from around the area of the breakdown. The vaporized metal and gases released from the dielectric increases the pressure in the area of the breakdown. Both the arc length and the pressure increase until the arc can no longer be sustained. The capacitor, thus, remains operable with little or no change in its electrical properties.

SECTION II

NARRATIVE AND DISCUSSION

1. Objective

The objective of this development effort was the development of a light weight high energy capacitor supplying 12 joules of energy at 900 volts. The energy of a capacitor is described by the equation:

$$E = 1/2\,CV^2 \tag{1}$$

E = Energy
C = Capacity in Farads
V = Voltage in Volts

The capacity is determined by the equation:

$$C = \frac{AK\epsilon}{T} \tag{2}$$

C = Capacity
A = Area of the plates in square meters
K = Constant $8.85 \times 10^{-12}\ \frac{\text{coulombs}^2}{\text{Newton meter}^2}$
ϵ = Dielectric constant
T = Distance between the plates in meters

Since mass is determined by the equation:

$$M = A\,T\,D \tag{3}$$

M = Mass
A = Area in meters
T = Thickness in meters
D = Density in Kg/m^3

Substituting Equation 3 into Equation 2, the result is

$$C = \frac{MK\epsilon}{DT^2} \tag{4}$$

Substituting Equation 4 into Equation 1, the result is

$$E = \frac{1/2 M K \epsilon V^2}{T^2 D} \tag{5}$$

Since in this development effort:

E = 12 joules
V = 900 V

the result is:

$$M = \frac{3.36 \times 10^6 T^2 D}{\epsilon}$$

An equation which relates mass, thickness of the dielectric, density of the dielectric and the dielectric constant results.

From this equation it becomes evident that the mass of a capacitor section excluding margins, extensions and end spray is a balance between the thickness of available material, the density of the material and the dielectric constant. The thickness is the dominant factor. The mass and thickness of the electrodes can be neglected because we are dealing with metallized capacitors. Using this equation a review was made of available dielectric films which would be capable of operating at 900 V. The results of this survey are shown in Table I. As can be seen, the most promising dielectrics were Polyethylene Terephthalate (PETP), Polycarbonate and Polysulfone.

2. Phase I Designs

The designs chosen for Phase I were:

Design A - 0.00027" metallized coated* Polyethylene Terephthalate (PETP)
Design B - 0.00022" metallized coated* Polyethylene Terephthalate
Design C - 0.00026" metallized coated* Polycarbonate
Design D - 0.00027" metallized coated* Polysulfone
Design E - 0.00027" metallized coated* PETP, silicone oil impregnated
Design F - 0.00027" metallized coated* PETP, Bareco wax impregnated

All the dielectric films were coated to aid in the clearing (self healing) of the capacitors. During the clearing the coating helps form

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*Metallizing and Coating are Sprague Proprietary Processes

TABLE I

POLYMER FILM DIELECTRIC SYSTEMS REVIEW

Calculated Section Weight (Grams)	Dielectric Material	Density (gr/cm³)	Dielectric Constant	Thickness	Breakdown Voltage (Volts/mil)	Comments
216	Polyimide Film	1.42	3.6	0.0005"	9,700	Not available in thin gauge
95	PETP	1.25	3.2	0.00025"	10,000	
500	Fluorocarbon Film	2.10	2.2	0.0005"	7,400	Dielectric constant too low; density too high to meet the weight requirement
89	Polycarbonate	1.20	2.99	0.00024"	10,000	
89	Polysulfone	1.25	3.0	0.00024"	10,000	
212	Polyethylene Film	0.93	2.3	0.00025"	9,000	Not available in thin gauges
222	Polypropylene Film	0.92	2.2	0.00025"	11,200	Dielectric constant too low; difficult to handle in thin gauges
80	*Polyvinyl Fluoride Film	1.38	9.3	0.0005"	9,700	Not available in thin gauges; very large change of dielectric constant with temperature
310	Polyvinyl Alcohol Film	1.30	8.8	0.001"	9,600	Not available in thin gauges; soluble in water

*To obtain 12 joules at -40°C weight would have to be 200 grams because of loss of capacitance at low temperature.

(1) $E = \frac{1}{2} CV^2$

C = Capacitance
V = Voltage

(2) $C = \frac{AK\epsilon}{T}$

A = area in meters
K = permeability of free space
T = thickness in meters

(3) $E = \frac{1}{2} \frac{AK\epsilon}{T} V^2$

(4) $M = ATD$

$$E = \frac{1}{2} \frac{MK\epsilon V^2}{T^2 D}$$

$$M = \frac{2E T^2 D}{K\epsilon V^2}$$

(5) $M = \frac{24 T^2 D}{(8.85 \times 10^{-12})\, 81 \times 10^4 \epsilon}$

$$M = \frac{3.36 \times 10^6\, T^2 D}{\epsilon}$$

M = mass
A = area in meters
T = thickness
D = density $Kg/meters^3$

E = 12 joules
K = 8.85×10^{-12} $\frac{Coulombs^2}{Newton\ Meters^2}$
V = 110 volts

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gases and reduces the chances for formation of low resistance deposits. A comparison of clearing for coated and uncoated PETP is shown in Figure 1. All designs utilized film which was 4" wide with 3/16" margins.

After metallizing, coating and slitting, sections were rolled, vacuum dried, end-sprayed and had leads attached in the normal manner. The sections were then cleared at 1000 VDC. Sections of Design B failed to withstand the voltage and shorted between 700 - 800 V. Further work on this design was discontinued.

The sections were then encapsulated in steel cans even though the final units were encapsulated in aluminum cans. There was no advantage to warrant the additional cost of aluminum cans in Phase I. Designs E and F were impregnated using standard impregnation techniques.

3. Capacitance Change

The finished units were read for capacitance, dissipation factor and leakage current at -40°C, +25°C, +40°C and +85°C. The results of these measurements are shown in Tables II - VI. The high leakage current of Design D was due to the base polysulfone film being attacked by the solvents during the coating process. The high dissipation factor reading of Design C was due to the long leads necessary for measuring inside the temperature cycling chamber. The change in capacitance with temperature for Designs A, C, D, E and F are shown in Figures 2 through 6. As shown in Figure 7, Designs A, E and F exhibit approximately the same shape curve for percentage capacitance change versus temperature. Design D exhibits an almost perfectly flat profile from -55°C to +85°C, changing only -.11% over the entire temperature range.

4. Breakdown Test

A sample of each design was tested for breakdown voltage. The results of this testing are shown in Table VII. Because breakdown voltage of Design B was below the contract specified operating voltage, further work on this design was discontinued. The slightly higher breakdown voltages of Designs E and F compared to Design A indicated that little dielectric strength was gained by impregnation of this type of unit.

FAULTS POORLY CLEARED - METALLIZED PETP FILM
(NOTE: Carbon deposit in center of clearing)

COMPLETELY CLEARED FAULTS - METALLIZED COATED PETP FILM
(No carbon deposits)

COMPARISON OF COATED vs UNCOATED PETP FILM

Figure 1

TABLE IIA

PHASE IB - ELECTRICAL EVALUATION (-40°C)
DESIGN A UNITS - 0.00027" METALLIZED COATED* PETP FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1] Factor (%)	Leakage Current[2] (µA)	Leakage Current[3] (µA)
41	35.7	1.75	0.22	0.39
42	31.1	1.56	0.18	0.32
43	30.6	1.62	0.20	0.36
44	31.6	1.54	0.20	0.38
45	31.7	1.46	0.35	0.63
46	31.4	1.72	0.35	0.67
47	32.1	1.48	0.27	0.48
48	31.7	1.48	0.29	0.52
49	31.5	1.62	0.20	0.54
50	31.8	1.40	0.16	0.47
51	31.5	1.46	0.18	0.35
52	30.8	1.54	0.14	0.27
53	29.7	1.68	0.20	0.33
54	31.2	1.49	0.21	0.44

*Metallizing and Coating are Sprague Proprietary Processes
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz
Note 2 - Leakage Current Measured at 500 Volts
Note 3 - Leakage Current Measured at 900 Volts.

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TABLE IIB

PHASE IB - ELECTRICAL EVALUATION (+25°C)
DESIGN A UNITS - 0.00027" METALLIZED COATED* PETP FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
41	37.4	1.05	0.41	0.75
42	32.6	1.05	0.22	0.39
43	31.8	1.10	0.26	0.43
44	33.3	0.95	0.25	0.45
45	33.2	0.94	0.40	0.70
46	32.9	0.96	0.38	0.72
47	33.3	0.97	0.26	0.47
48	33.2	0.97	0.32	0.58
49	32.8	0.96	0.32	0.56
50	33.4	0.97	0.42	0.72
51	32.8	0.96	0.32	0.59
52	32.2	0.97	0.24	0.41
53	31.0	0.96	0.20	0.34
54	32.5	0.96	0.26	0.45

*Metallizing and Coating are Sprague Proprietary Processes
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz
Note 2 - Leakage Current Measured at 500 Volts
Note 3 - Leakage Current Measured at 900 Volts.

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TABLE IIC

PHASE IB - ELECTRICAL EVALUATION (+40°C)
DESIGN A UNITS - 0.00027" METALLIZED COATED* PETP FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
41	37.8	1.05	0.61	1.6
42	32.7	1.08	0.88	1.1
43	31.9	1.10	0.38	0.73
44	33.3	1.09	0.68	0.73
45	33.4	1.12	1.0	2.3
46	32.8	1.00	1.4	2.3
47	33.4	1.09	0.72	1.0
48	33.0	0.97	0.58	1.3
49	32.8	1.05	0.53	1.0
50	33.5	1.05	0.72	1.5
51	33.0	1.06	0.65	1.0
52	32.3	1.06	0.48	0.92
53	31.2	1.04	0.52	0.92
54	32.7	1.09	0.66	0.90

*Metallizing and Coating are Sprague Proprietary Processes
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz
Note 2 - Leakage Current Measured at 500 Volts
Note 3 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IID

PHASE IB - ELECTRICAL EVALUATION (+85°C)
DESIGN A UNITS - 0.00027" METALLIZED COATED* PETP FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
41	39.0	0.34	17	35
42	33.2	0.30	13	27
43	34.8	0.30	10	20
44	34.9	0.26	12	21
45	34.3	0.27	20	35
46	34.7	0.26	17	38
47	34.2	0.25	18	33
48	34.0	0.27	21	40
49	34.5	0.28	13	27
50	34.2	0.29	18	39
51	33.2	0.27	12	25
52	32.2	0.28	12	22
53	33.8	0.29	25	45
54	34.5	0.29	23	43

*Metallizing and Coating are Sprague Proprietary Processes

Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz

Note 2 - Leakage Current Measured at 500 Volts
It is noted that the leakage current is higher than anticipated but it is considered that the values listed are within acceptable design limits.

Note 3 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IIIA

PHASE IB - ELECTRICAL EVALUATION (-40°C)
DESIGN C UNITS - 0.00026" METALLIZED COATED* POLYCARBONATE FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1,3] Factor (%)	Leakage Current[2] (µA)	Leakage Current[4] (µA)
109	Off Scale		0.19	0.36
110	32.95	6.83	0.70	1.40
111	32.38	2.82	0.20	0.53
112	37.78	2.95	0.12	0.30
113	33.60	3.77	0.18	0.35
114	33.00	12.88	0.24	0.40
115	33.68	4.05	0.26	0.50
116	32.65	4.78	0.26	0.60
117	33.68	3.25	0.76	0.90
118	34.45	5.57	0.20	0.36
119	33.57	4.12	0.50	0.98
120	33.30	3.95	0.18	0.36
121	36.74	3.35	0.22	0.40
122	32.82	4.24	0.75	1.00
123	34.15	3.40	0.20	0.46
124	34.78	3.77	0.20	0.36
125	36.70	4.45	0.20	0.34
126	34.70	3.40	0.10	0.30

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - High Dissipation Factor due to long leads necessary for measuring inside the temperature cycling chamber.
Note 4 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IIIB

PHASE IB - ELECTRICAL EVALUATION (+25°C)
DESIGN C UNITS - 0.00026" METALLIZED COATED* POLYCARBONATE FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1,3] Factor (%)	Leakage Current[2] (μA)	Leakage Current[4] (μA)
109	Off Scale		0.32	0.60
110	33.44	5.32	0.36	0.66
111	32.92	3.00	0.14	0.30
112	28.15	3.27	0.18	0.34
113	34.08	4.31	0.28	0.50
114	34.50	9.50	0.22	0.36
115	34.15	4.27	0.11	0.20
116	33.10	5.98	0.30	0.60
117	34.38	3.33	0.44	0.80
118	34.96	6.45	0.35	0.66
119	34.10	4.81	0.48	0.90
120	33.68	4.34	0.17	0.35
121	37.32	3.55	0.20	0.38
122	33.30	4.28	0.25	0.46
123	34.64	3.53	0.28	0.58
124	33.30	3.20	0.16	0.32
125	37.25	3.90	0.36	0.68
126	35.22	3.87	0.36	0.76

*Metallizing and Coating are Sprague Proprietary Processes.

Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.

Note 2 - Leakage Current Measured at 500 Volts.

Note 3 - High Dissipation Factor due to long leads necessary for measuring inside the temperature cycling chamber.

Note 4 - Leakage Current Measured at 900 Volts.

TABLE IIIC

PHASE IB - ELECTRICAL EVALUATION (+40°C)
DESIGN C UNITS - 0.00026" METALLIZED COATED* POLYCARBONATE FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1,3] Factor (%)	Leakage Current[2] (µA)	Leakage Current[4] (µA)
109	Off Scale		0.60	1.20
110	33.58	6.87	0.20	0.46
111	34.80	2.80	0.92	1.80
112	28.24	4.23	0.72	1.50
113	34.35	7.30	0.84	1.55
114	34.60	9.03	0.72	1.40
115	34.28	5.40	0.26	0.60
116	33.22	5.97	0.20	0.40
117	34.47	5.24	0.30	0.60
118	35.04	7.64	0.50	0.90
119	34.18	5.82	0.90	1.50
120	33.78	6.00	0.28	0.60
121	37.45	5.55	0.18	0.40
122	33.20	9.10	0.26	0.60
123	34.70	5.10	0.40	0.75
124	35.39	5.06	0.50	0.98
125	37.34	6.60	0.58	0.90
126	35.30	4.77	0.42	0.90

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - High Dissipation Factor due to long leads necessary for measuring inside the temperature cycling chamber.
Note 4 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IIID

PHASE IB - ELECTRICAL EVALUATION (+85°C)
DESIGN C UNITS - 0.00026" METALLIZED COATED* POLYCARBONATE FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1,3] Factor (%)	Leakage Current[2] (μA)	Leakage Current[4] (μA)
109	Off Scale		12.0	20.0
110	33.77	4.95	8.0	11.6
111	33.24	4.60	4.0	6.8
112	28.38	2.50	4.0	7.0
113	34.35	7.10	17.0	35.0
114	34.70	4.06	13.0	27.0
115	34.45	5.45	4.8	9.5
116	33.44	5.44	3.6	7.2
117	34.62	5.00	6.2	12.0
118	35.15	5.28	6.2	11.5
119	34.40	5.72	5.8	11.0
120	33.90	6.00	6.4	12.3
121	37.62	5.80	4.2	7.6
122	32.25	10.62	4.2	8.2
123	34.82	5.20	6.2	10.8
124	35.50	3.35	5.6	11.0
125	37.45	5.62	17.0	28.0
126	35.46	5.10	7.2	15.0

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - High Dissipation Factor due to long leads necessary for measuring inside the temperature cycling chamber.
Note 4 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IVA

PHASE IB - ELECTRICAL EVALUATION (-40°C)
DESIGN D UNITS - 0.00026" METALLIZED COATED* POLYSULFONE

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
133	34.54	1.13	4.0	7.8
134	33.08	1.21	4.7	10.2
135	34.43	1.06	5.2	7.4
136	34.54	1.06	3.1	12.0
138	34.62	1.13	4.8	8.3
139	33.82	1.06	3.6	7.4
140	34.87	1.10	3.8	6.9
141	34.84	1.07	4.2	8.3
142	41.38	1.10	2.6	6.6
143	34.35	1.13	3.4	5.9
144	36.68	1.21	2.8	7.1
145	34.68	1.13	2.7	6.4
147	35.18	1.13	2.9	6.3
148	28.27	1.21	2.4	6.0
149	36.44	1.19	2.7	5.8
150	34.13	1.17	2.4	5.7

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IVB

PHASE IB - ELECTRICAL EVALUATION (+25°C)
DESIGN D UNITS - 0.00026" METALLIZED COATED* POLYSULFONE

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
133	34.57	0.75	43	67
134	35.08	0.83	43	67
135	34.46	1.06	41	58
136	34.55	0.83	38	58
138	34.63	0.75	38	56
139	33.78	1.06	36	54
140	34.98	1.06	35	54
141	34.82	0.83	34	50
142	41.38	0.91	40	56
143	34.37	1.05	24	50
144	36.70	0.91	34	52
145	34.55	0.98	36	62
147	35.15	1.06	36	62
148	28.26	1.06	27	48
149	36.50	0.98	33	58
150	34.18	1.06	31	53

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IVC

PHASE IB - ELECTRICAL EVALUATION (+40°C)
DESIGN D UNITS - 0.00026" METALLIZED COATED* POLYSULFONE

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
133	34.58	1.58	48	77
134	35.04	1.73	48	81
135	34.43	2.04	49	84
136	34.51	1.73	42	72
138	34.62	1.81	43	79
139	33.80	1.96	40	68
140	34.97	1.58	40	68
141	34.82	1.57	40	70
142	41.30	2.11	45	77
143	34.38	1.73	27	47
144	36.65	1.96	36	62
145	34.55	1.51	27	81
147	35.15	1.58	30	85
148	28.26	1.13	22	63
149	36.44	1.66	27	82
150	34.17	1.51	24	73

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE IVD

PHASE IB - ELECTRICAL EVALUATION (+85°C)
DESIGN D UNITS - 0.00026" METALLIZED COATED* POLYSULFONE

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current[2] (μA)	Leakage Current[3] (μA)
133	34.62	1.89	82	160
134	35.07	1.81	94	190
135	34.43	1.89	88	140
136	34.57	1.96	82	160
138	34.62	2.04	68	130
139	33.87	2.11	80	145
140	35.04	1.96	76	160
141	34.82	1.81	93	170
142	41.41	1.81	83	180
143	34.42	2.04	43	110
144	36.70	2.11	75	170
145	34.55	2.11	84	160
147	35.14	1.96	98	185
148	38.31	1.96	75	110
149	36.45	2.11	89	170
150	34.21	1.81	70	150

*Metallizing and Coating are Sprague Proprietary Processes.
Note 1 - Capacitance and Dissipation Factor Measured at 1000 Hz.
Note 2 - Leakage Current Measured at 500 Volts.
Note 3 - Leakage Current Measured at 900 Volts.

DAAB07-71-C-0049

TABLE VA

PHASE IB - ELECTRICAL EVALUATION (-40°C)
DESIGN E 0.00027" METALLIZED COATED* PETP SILICONE OIL IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (μA)	Leakage Current at 900 VDC (μA)
77	32.30	1.23	0.14	0.34
78	32.80	1.25	0.14	0.43
79	33.20	1.25	0.13	0.38
80	32.40	1.26	0.12	0.30
81	33.20	1.28	0.13	0.80
82	34.40	1.29	0.13	0.35
83	32.30	1.28	0.11	0.35
84	32.20	1.28	0.11	0.30
85	33.20	1.28	0.10	0.32
86	34.70	1.26	0.12	0.31
87	33.80	1.27	0.13	0.35
88	32.30	1.26	0.14	0.35
89	33.10	1.27	0.14	0.33
90	33.20	1.23	0.15	0.31
91	32.10	1.25	0.15	0.28
92	32.50	1.25	0.14	0.43
93	33.20	1.25	0.13	0.23
94	33.20	1.25	0.12	0.29
95	32.90	1.27	0.13	0.27

*Sprague Proprietary
Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

DAAB07-71-C-0049

TABLE VB

PHASE IB - ELECTRICAL EVALUATION (+25°C)
DESIGN E 0.00027" METALLIZED COATED* PETP SILICONE OIL IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (µA)	Leakage Current at 900 VDC (µA)
77	32.80	0.49	0.58	1.8
78	34.00	0.48	0.54	2.1
79	33.70	0.47	0.50	1.7
80	33.40	0.47	0.48	1.7
81	34.30	0.48	0.48	2.5
82	35.40	0.38	0.46	1.5
83	33.00	1.37	0.43	2.1
84	33.30	0.41	0.40	1.4
85	33.80	0.38	0.59	2.1
86	35.20	0.31	0.49	2.0
87	35.50	0.35	0.41	1.8
88	33.40	0.33	0.43	3.2
89	33.80	0.41	0.44	2.3
90	34.60	0.32	0.40	3.1
91	32.70	0.32	0.39	2.7
92	33.30	0.33	0.37	2.6
93	32.80	0.38	0.37	2.2
94	37.38	0.33	0.36	2.1
95	33.70	0.34	0.35	2.0

*Sprague Proprietary

Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

DAAB07-71-C-0049

TABLE VC

PHASE IB - ELECTRICAL EVALUATION (+40°C)
DESIGN E 0.00027" METALLIZED COATED* PETP SILICONE OIL IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (µA)	Leakage Current at 900 VDC (µA)
77	32.80	0.49	1.3	3.5
78	34.00	0.48	1.2	3.6
79	33.70	0.47	1.2	4.8
80	33.40	0.47	1.2	4.0
81	34.30	0.48	1.2	3.6
82	35.40	0.38	1.0	2.9
83	33.00	0.37	1.1	2.7
84	33.80	0.41	1.0	2.7
85	33.80	0.38	1.0	2.4
86	35.20	0.31	0.9	2.6
87	35.50	0.35	0.9	2.6
88	33.40	0.33	1.1	4.1
89	33.80	0.41	1.0	1.8
90	34.00	0.32	0.7	2.2
91	32.70	0.32	0.8	1.6
92	33.30	0.33	1.0	2.0
93	32.80	0.28	0.9	2.2
94	32.80	0.33	0.7	2.6
95	33.20	0.34	1.2	1.9

*Sprague Proprietary

Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

DAAB07-71-C-0049

TABLE VD

PHASE IB - ELECTRICAL EVALUATION (+85°C)
DESIGN E 0.00027" METALLIZED COATED* PETP SILICONE OIL IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (µA)	Leakage Current at 900 VDC (µA)
77	33.00	0.60	35.0	43.0
78	34.41	0.58	35.0	60.0
79	34.20	0.58	31.0	38.0
80	33.40	0.60	32.0	75.0
81	34.30	0.58	32.0	57.0
82	35.70	0.60	28.0	38.0
83	33.50	0.60	32.0	71.0
84	34.00	0.59	28.0	48.0
85	33.90	0.59	29.0	53.0
86	35.20	0.60	31.0	20.0
87	35.90	0.60	32.0	60.0
88	34.20	0.62	28.0	62.0
89	34.10	0.64	34.0	41.0
90	34.40	0.62	26.0	43.0
91	33.00	0.62	31.0	52.0
92	33.70	0.59	37.0	63.0
93	32.20	0.59	33.0	59.0
94	34.30	0.60	40.0	58.0
95	34.10	0.61	37.0	57.0

*Sprague Proprietary
Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

TABLE VIA

PHASE IB - ELECTRICAL EVALUATION (-40°C)
DESIGN F 0.00027" METALLIZED COATED* PETP WAX IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (µF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (µA)	Leakage Current at 900 VDC (µA)
59	33.30	1.22	0.14	0.39
60	32.60	1.23	0.13	0.37
61	33.20	1.22	0.10	0.43
62	33.10	1.23	0.11	0.41
63	34.00	1.24	0.10	0.43
64	33.60	1.24	0.10	0.44
65	33.50	1.23	0.11	0.38
66	34.30	1.22	0.12	0.36
67	33.20	1.21	0.11	0.28
68	32.80	1.22	0.13	0.31
69	32.70	1.21	0.10	0.34
70	39.40	1.23	0.13	0.29
71	33.80	1.24	0.12	0.34
72	33.30	1.24	0.11	0.33
73	33.50	1.23	0.13	0.38
74	34.70	1.23	0.11	0.36
75	32.70	1.24	0.12	0.33
76	32.80	1.23	0.13	0.34

***Sprague Proprietary**
Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

TABLE VIB

PHASE IB - ELECTRICAL EVALUATION (+25°C)
DESIGN F 0.00027" METALLIZED COATED* PETP WAX IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (μA)	Leakage Current at 900 VDC (μA)
59	34.50	0.42	0.63	2.7
60	33.60	0.50	0.66	2.7
61	34.20	0.50	0.58	2.4
62	34.20	0.49	0.57	2.4
63	35.20	0.50	0.57	2.3
64	34.60	0.48	0.52	2.5
65	34.70	0.50	0.48	2.2
66	35.20	0.48	0.46	2.1
67	34.20	0.49	0.43	2.0
68	34.00	0.48	0.40	1.7
69	33.20	0.51	0.38	1.7
70	35.40	0.50	0.37	1.7
71	35.20	0.50	0.36	1.6
72	34.00	0.48	0.81	2.3
73	34.10	0.47	0.72	2.3
74	34.50	0.47	0.68	2.2
75	33.70	0.47	0.66	2.2
76	33.70	0.49	0.61	1.9

***Sprague Proprietary**
Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

DAAB07-71-C-0049

TABLE VIC

PHASE IB - ELECTRICAL EVALUATION (+40°C)
DESIGN F 0.00027" METALLIZED COATED* PETP WAX IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (μA)	Leakage Current at 900 VDC (μA)
59	34.70	0.43	2.2	3.8
60	33.40	0.46	2.1	3.5
61	34.40	0.47	2.1	3.7
62	34.50	0.47	1.8	3.4
63	35.30	0.47	1.8	3.3
64	34.80	0.47	1.8	3.1
65	34.80	0.49	1.7	3.1
66	35.40	0.47	1.6	2.8
67	34.20	0.46	1.5	2.6
68	34.50	0.48	1.4	2.3
69	33.60	0.49	1.3	2.3
70	35.50	0.50	1.3	2.3
71	35.10	0.48	1.3	2.4
72	34.00	0.48	1.2	3.0
73	34.20	0.48	1.9	5.1
74	34.60	0.49	1.9	4.5
75	33.80	0.49	1.9	5.1
76	33.80	0.50	1.6	4.2

*Sprague Proprietary

Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

TABLE VID

PHASE IB - ELECTRICAL EVALUATION (+85°C)
DESIGN F 0.00027" METALLIZED COATED* PETP WAX IMPREGNATED

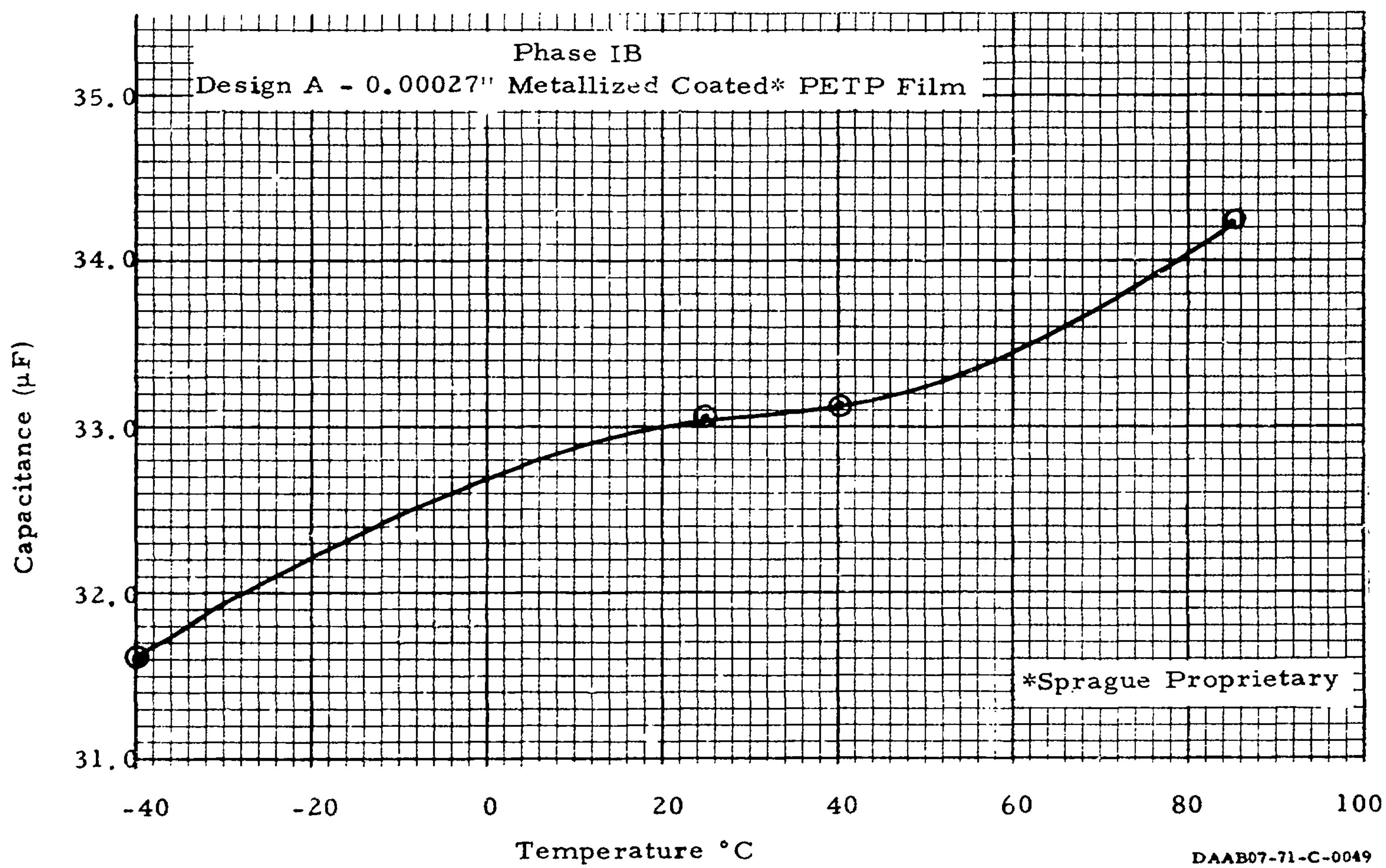
(Encapsulated in Steel Cans)

Unit No.	Capacitance[1] (μF)	Dissipation[1] Factor (%)	Leakage Current at 500 VDC (μA)	Leakage Current at 900 VDC (μA)
59	35.60	0.57	5.0	7.0
60	34.00	0.57	4.4	6.2
61	34.60	0.58	4.3	7.3
62	34.50	0.60	4.1	6.7
63	35.50	0.60	4.0	6.6
64	35.30	0.60	3.8	6.2
65	35.30	0.58	3.8	6.3
66	35.50	0.59	3.3	4.6
67	34.30	0.60	3.2	5.3
68	34.20	0.59	2.8	4.2
69	33.60	0.59	2.8	4.0
70	35.60	0.60	3.0	5.1
71	35.30	0.58	3.2	8.6
72	34.20	0.60	4.7	5.8
73	34.30	0.60	4.8	8.3
74	35.00	0.60	4.3	5.7
75	34.20	0.60	4.5	8.8
76	34.10	0.58	3.8	4.8

*Sprague Proprietary

Note 1 - Capacitance and Dissipation Factor measured at 1000 Hz

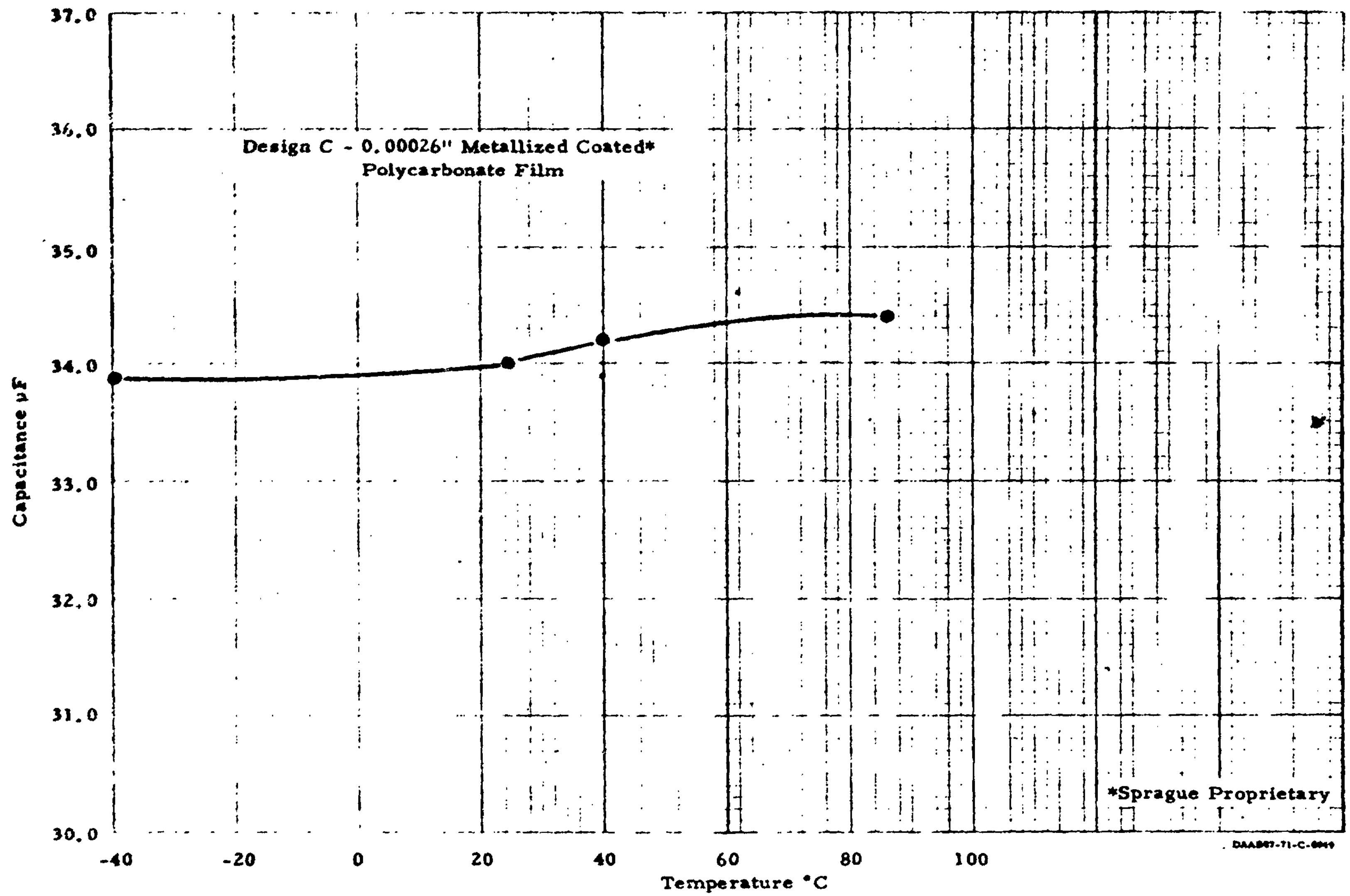
DAAB07-71-C-0049



DAAB07-71-C-0049

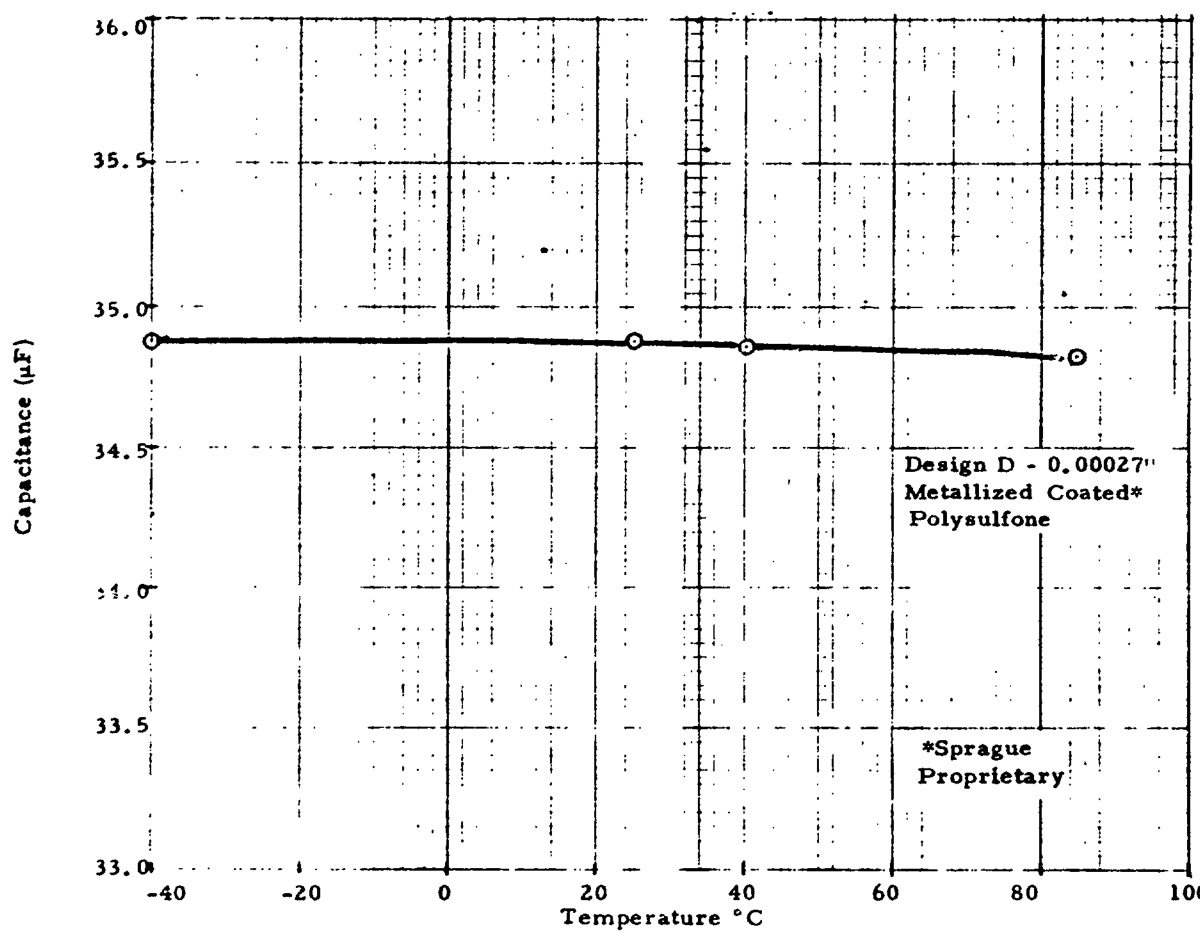
Capacitance Vs. Temperature

Figure 2



Capacitance Versus Temperature

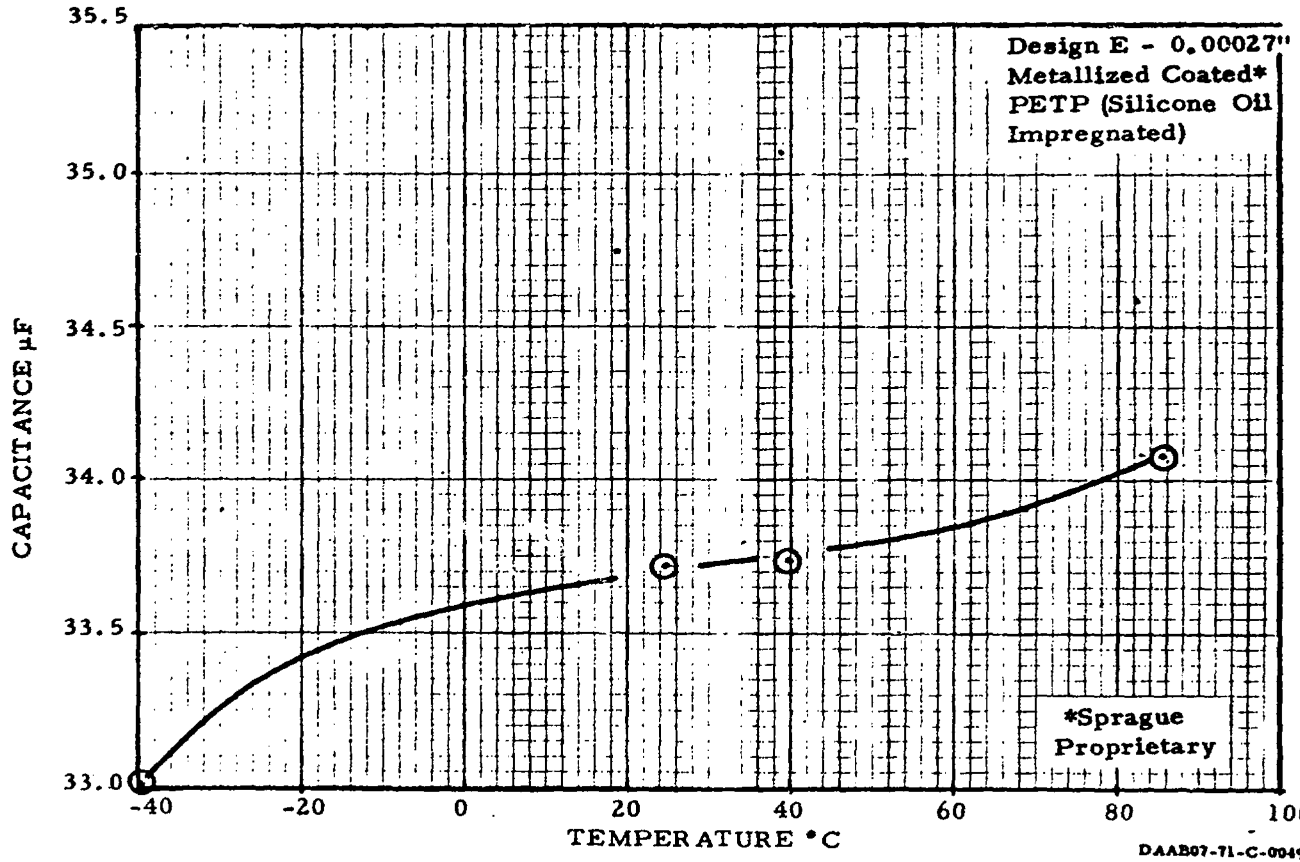
Figure 3



Capacitance vs Temperature For
Metallized Coated* Polysulfone Units

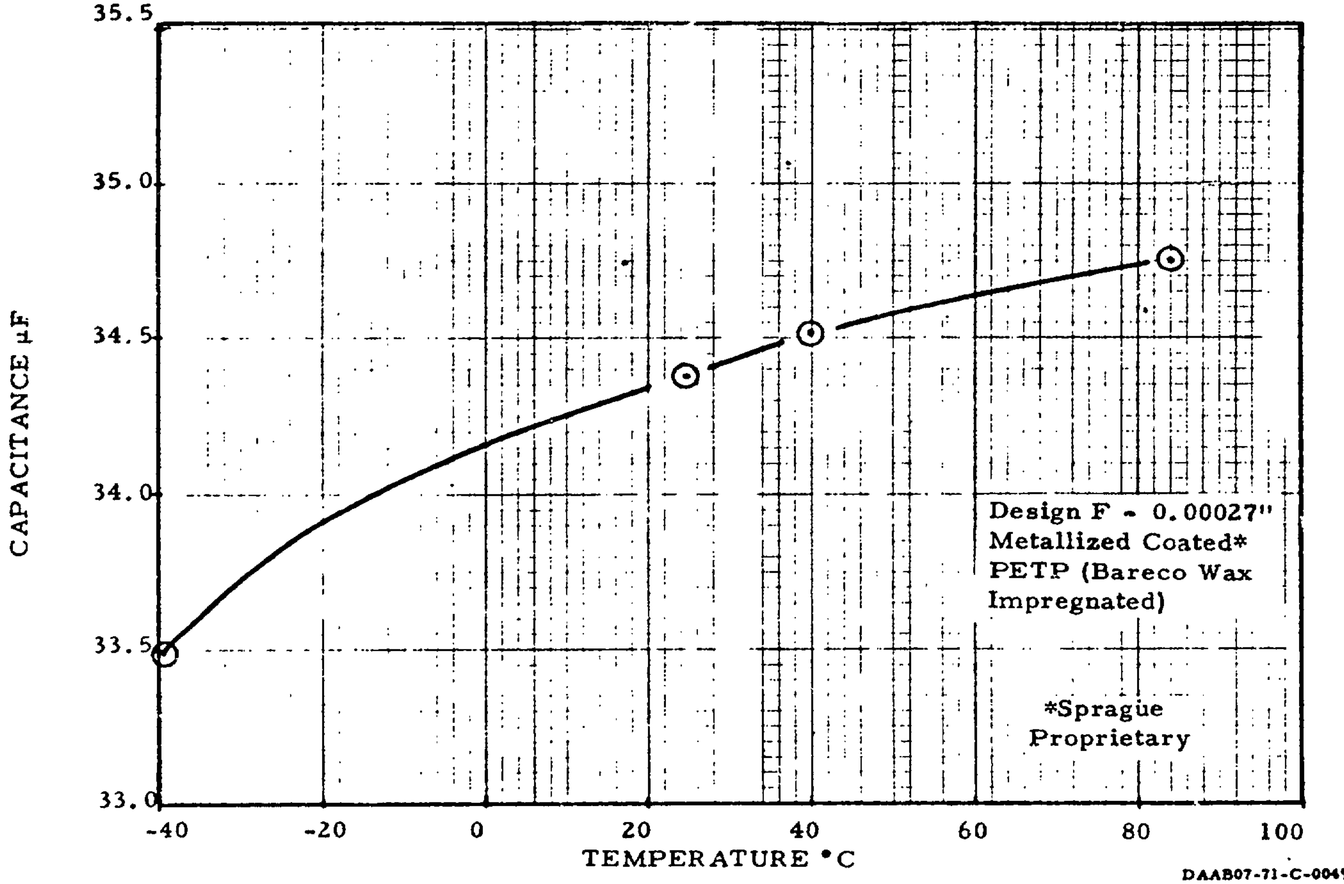
Figure 4

DAAB07-71-C-0049



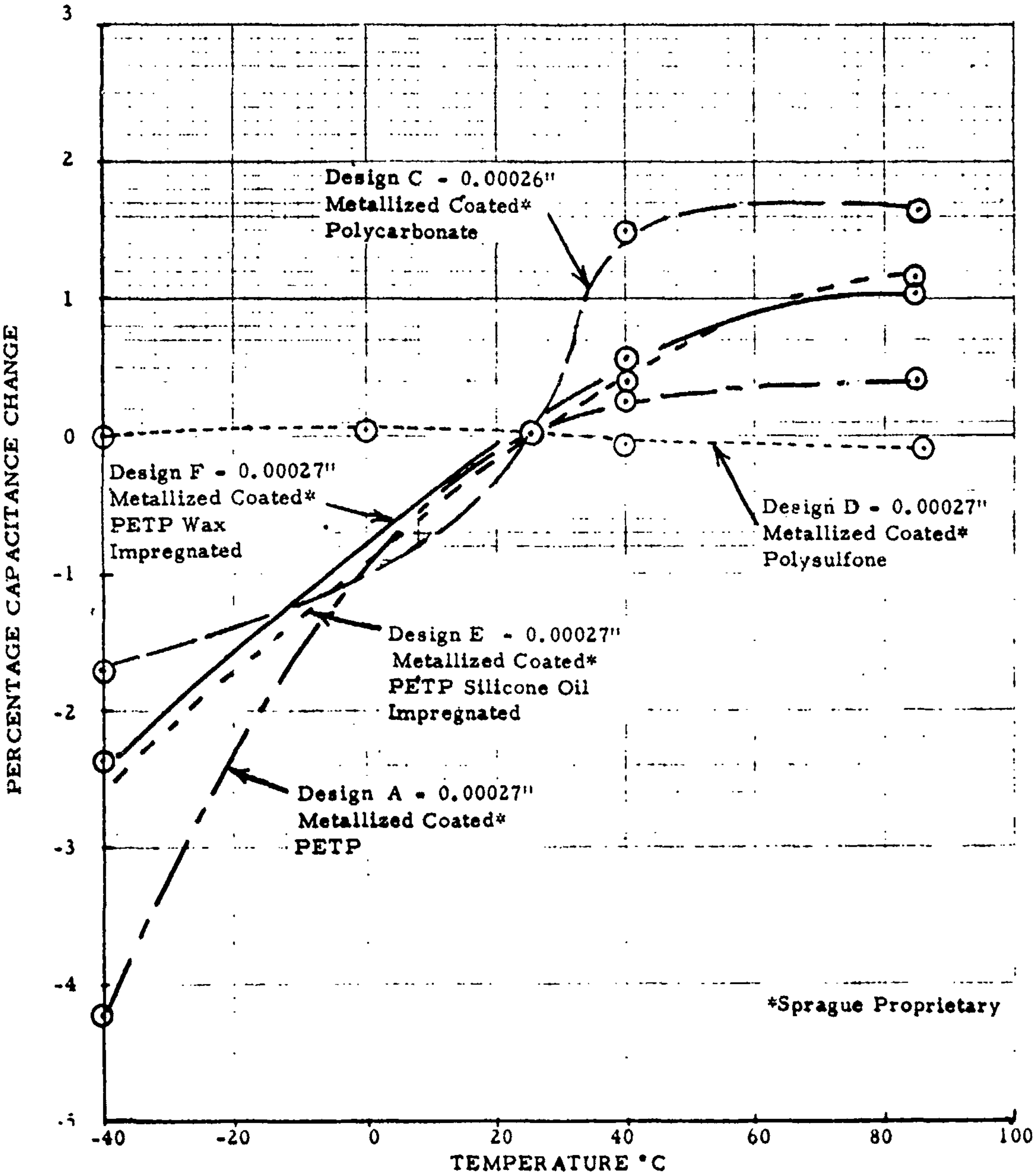
Capacitance vs Temperature For Silicone Oil
Impregnated Metallized Coated* PETP

Figure 5



Capacitance vs Temperature For Bareco Wax
Impregnated Metallized Coated* PETP

Figure 6



DAAB07-71-C-0049

Percentage Capacitance Change vs Temperature

Figure 7

TABLE VII

BREAKDOWN VOLTAGE (ROOM TEMPERATURE)

Design A, 0.00027" Metallized Coated* PETP

Unit No.	Breakdown Voltage (VDC)
1	1400
2	1300
3	1500
4	1400
5	1500
6	1300

Design C, 0.00026" Metallized Coated* Polycarbonate

Unit No.	Breakdown Voltage (VDC)
1	1500
2	1400
3	1300
4	1500
5	1400
6	1400

Design D, 0.00027" Metallized Coated* Polysulfone

Unit No.	Breakdown Voltage (VDC)
1	1300
2	1400
3	1200
4	1300
5	1500
6	1200

Design E, 0.00027" Metallized Coated* PETP (Silicone Oil Impregnated)

Unit No.	Breakdown Voltage (VDC)
1	1500
2	1400
3	1500
4	1500
5	1400
6	1600

Design F, 0.00027" Metallized Coated* PETP (Barcco Wax Impregnated)

Unit No.	Breakdown Voltage (VDC)
1	1600
2	1600
3	1500
4	1600
5	1400
6	1600

*Sprague Proprietary

5. Dielectric Absorption

A sample of each design was tested for dielectric absorption. The results of these tests are tabulated in Tables VIII - XII. The dielectric absorption measurements were made in accordance with MIL-C-19978C paragraph 4.7.15. The data indicate that there is a small decrease in dielectric absorption between -40°C and +25°C and a large increase in dielectric absorption between 25°C and 85°C. Another point is that the dielectric absorption of the impregnated coated PETP units is less than that of the dry PETP units. For uncoated PETP the reverse is true.

6. Test Equipment

It was necessary to design and build special test equipment capable of charging and discharging 32 μF at 900 V ten times per second because of the high repetition rate required by this contract. It was decided to build six test units utilizing conventional thyratron tube switching and one test unit employing a special SCR solid state switch. This test equipment is shown in Figure 3.

Safety features of this test equipment included automatic shut-off in case of test capacitor short; pre-setable counter, time delay required for thyratron tubes; and interlock on test chamber door. A three amp fuse was added to the transformer after one of the transformers failed during use.

Each test set was a self-contained unit. The test voltage was variable from zero to 1200 volts peak and the repetition rate was adjustable from one to over ten pulses per second. Because of the high power requirements, special care was taken in the design and winding of the high voltage transformers. The internal discharge circuitry included a 30 μH coil and a one ohm non-inductive resistor. Charging voltage could be monitored on a peak reading voltmeter.

A pulse voltage divider, and pulse current monitoring jacks were provided on the front panel. Controls also included a five digit pre-setable panel-mounted counter to shut down the test station after a predetermined number of charge-discharge cycles.

After completion of Phase II testing, it was decided that certain modifications to the CADET III test equipment were necessary.

TABLE VIII

DIELECTRIC ABSORPTION MEASUREMENTS AT VARIOUS TEMPERATURES DESIGN A 0.00027" METALLIZED COATED* PETP

Unit No.	Dissipation Factor (%)	Recovery Voltage (Volts)	Dielectric Absorption (%)
	-40°C		
47	1.48	7.3	0.81
48	1.48	7.2	0.80
180	1.48	6.4	0.71
	+25°C		
47	0.97	6.1	0.68
48	0.97	5.2	0.58
180		5.0	0.56
	+40°C		
47	1.09	19	2.12
48	1.09	15	1.67
180		12	1.33
	+85°C		
47	0.25	63	7.0
48	0.27	55	6.1
180		66	7.3

Charge Voltage 900 VDC
Discharge Resistor 5 Ω
Discharge Time 10 sec.
Recovery Time 15 min.
Dissipation Factor at 1000 Hz
*Sprague Proprietary

DAAB07-71-C-0041

TABLE IX

DIELECTRIC ABSORPTION MEASUREMENTS AT VARIOUS TEMPERATURES
DESIGN C 0.00026" METALLIZED COATED* POLYCARBONATE

Unit No.	Dissipation Factor (%)	Recovery Voltage (Volts)	Dielectric Absorption (%)
		-40°C	
121	0.48	5.7	0.63
125	0.43	5.5	0.61
126	0.48	5.6	0.62
		+25°C	
121	0.48	3.4	0.38
125	0.45	5.4	0.60
126	0.47	5.7	0.63
		+40°C	
121	0.45	5.5	0.61
125	0.42	16	1.78
126	0.45	15	1.67
		+85°C	
121	0.40	38	4.2
125	0.41	30	3.3
126	0.42	30	3.3

Charge Voltage 900 VDC
Discharge Resistor 5Ω
Discharge Time 10 sec.
Recovery Time 15 min.
Dissipation Factor at 1000 Hz

*Sprague Proprietary

DAAB07-71-C-0049

TABLE X

DIELECTRIC ABSORPTION MEASUREMENTS AT VARIOUS TEMPERATURES DESIGN D 0.00026" METALLIZED COATED* POLYSULFONE

Unit No.	Dissipation Factor (%)	Recovery Voltage (Volts)	Dielectric Absorption (%)
	-40°C		
140	1.10		
141	1.07	Unable to read	Unable to read
145	1.13		
	+25°C		
140	1.06	>10	>1.1
141	0.83	>10	>1.1
145	1.98	>10	>1.1
	+40°C		
140	1.58		
141	1.57	Unable to read	Unable to read
145	1.51		
	+85°C		
140	1.96		
141	1.81	Unable to read	Unable to read
145	2.11		

Charge Voltage 900 VDC
Discharge Resistor 5Ω
Discharge Time 10 sec.
Recovery Time 15 min.
Dissipation Factor at 1000 Hz
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XI

DIELECTRIC ABSORPTION MEASUREMENTS AT VARIOUS TEMPERATURES
DESIGN E 0.00027" METALLIZED COATED* PETP
SILICONE OIL IMPREGNATED

Unit No.	Dissipation Factor (%)	Recovery Voltage (Volts)	Dielectric Absorption (%)
		-40°C	
77	1.23	6.6	0.73
84	1.28	6.7	0.75
85	1.28	6.8	0.75
		+25°C	
77	0.49	3.8	0.42
84	0.41	4.6	0.51
85	0.35	4.2	0.47
		+40°C	
77	0.49	5.0	0.56
84	0.41	9.3	1.03
85	0.38	7.7	0.85
		+85°C	
77	0.60	54	6.0
84	0.59	64	7.1
85	0.59	60	6.7

Charge Voltage 900 VDC
Discharge Resistor 5Ω
Discharge Time 10 sec.
Recovery Time 15 min.
Dissipation Factor at 1000 Hz
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XII

DIELECTRIC ABSORPTION MEASUREMENTS AT VARIOUS TEMPERATURES
DESIGN F 0.00027" METALLIZED COATED* PETP
WAX IMPREGNATED

Unit No.	Dissipation Factor (%)	Recovery Voltage (Volts)	Dielectric Absorption (%)
		-40°C	
66	1.22	6.2	0.69
69	1.21	7.1	0.79
72	1.24	7.0	0.78
		+25°C	
66	0.48	3.4	0.38
69	0.51	3.6	0.40
72	0.48	3.7	0.41
		+40°C	
66	0.47	4.8	0.53
69	0.49	4.6	0.51
72	0.48	5.0	0.56
		+85°C	
66	0.59	63	7.0
69	0.59	55	6.1
72	0.60	66	7.3

Charge Voltage 900 VDC
Discharge Resistor 5Ω
Discharge Time 10 sec.
Recovery Time 15 min.
Dissipation Factor at 1000 Hz
*Sprague Proprietary

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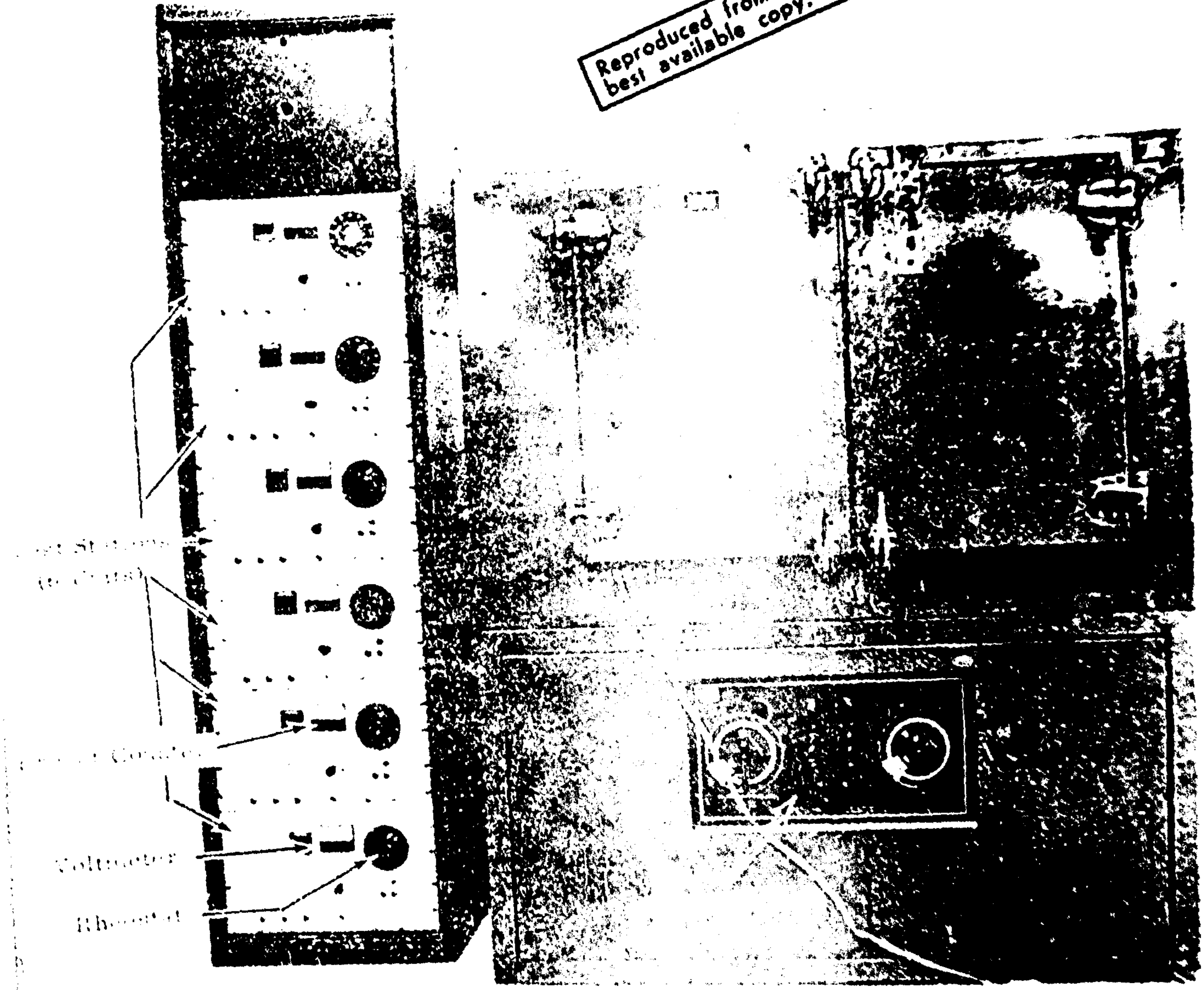


Figure 8

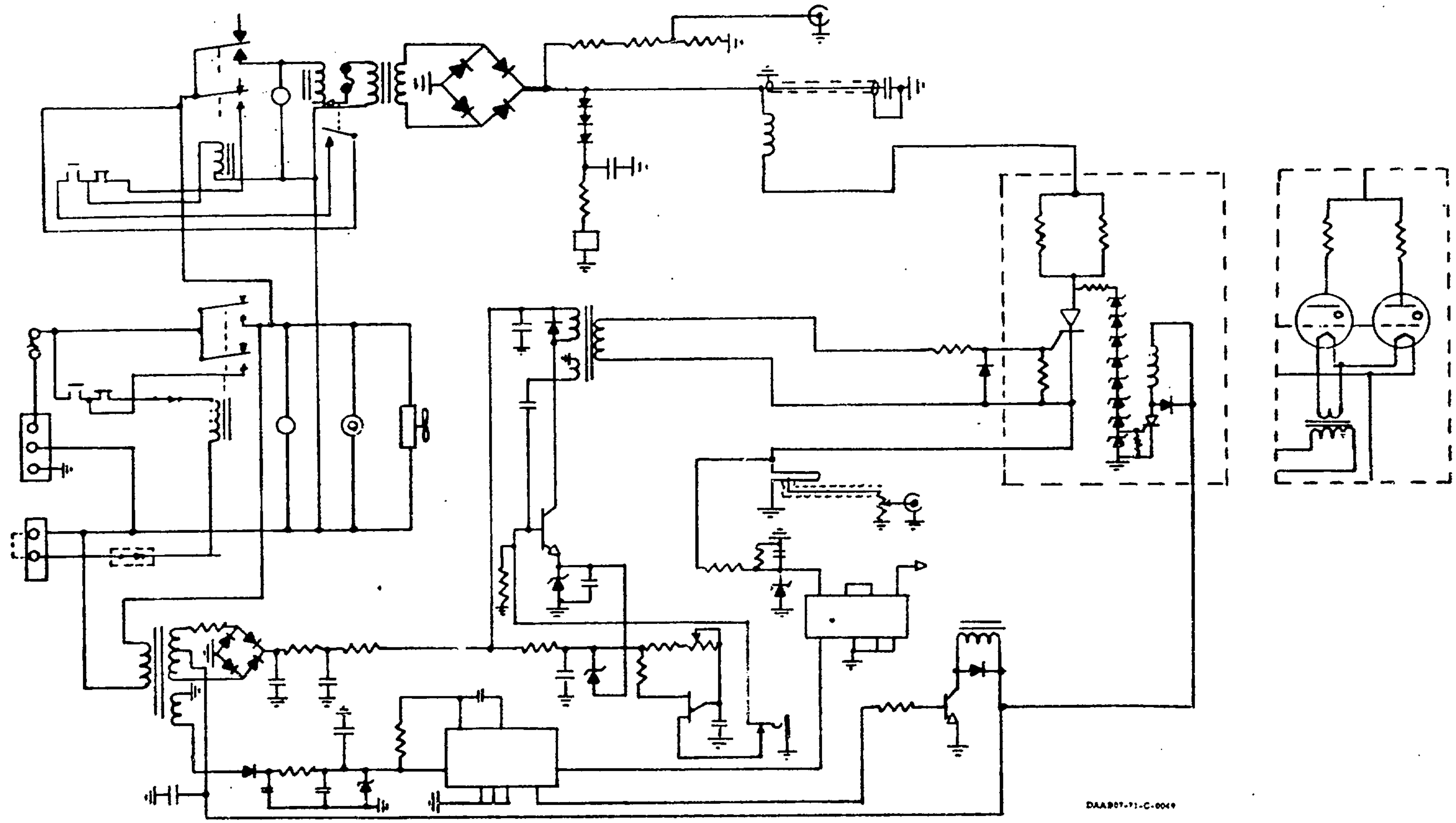
After approximately 20 million charge-discharge cycles, the thyratron tubes had aged to the extent that replacement was necessary. Since the test station of solid state design had performed flawlessly for more than 20 million charge-discharge cycles, and this was the second set of thyratron tubes, it was decided to convert the conventional test stations to solid state switching. This was accomplished on a one-at-a-time basis, so that the testing schedule was not disrupted. It was also decided at this time to increase the range of the counters by a factor of ten. Additional circuitry was added to the basic counter circuit to accomplish this extension.

A schematic drawing of one of the test sets is shown in Figure 9. Figure 10 shows the CADET III test equipment and test oven.

An eighth test station was constructed in an effort to provide backup capabilities in case of equipment failure, and to gain additional information at higher repetition rates. This test station had capabilities of from 1 - 30 pps at voltages ranging from 200 - 1200 volts. A much larger transformer was required because of the much higher power requirements necessitated by the higher repetition rate. Also, a change in basic design was required by the high repetition rate and resonant charging utilized. This test station also utilized solid state switching and all the safety features included in stations one through seven as well as extended counter range. A drawing of the circuit is shown in Figure 11.

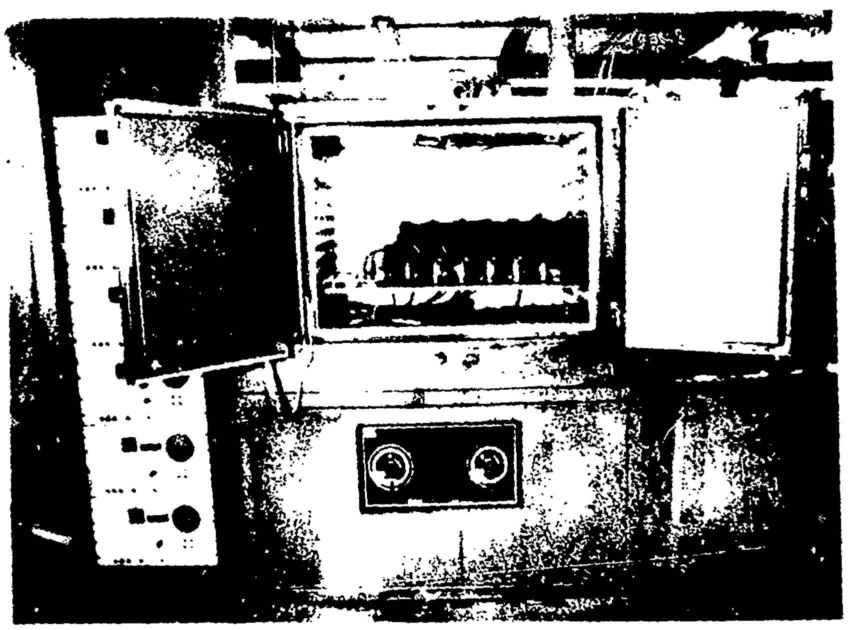
7. Testing and Evaluation

A six-piece sample of Designs A, C, D, E and F were charge-discharge life tested utilizing CADET III test equipment at 10 pps and 40°C. Design C was partially tested on CADET II because CADET III had not been completed. Design A was tested on both CADETS II and III. Photographs showing a typical discharge current wave for both CADETS II and III are shown in Figure 12. It is interesting to note that while the duration of the current wave from CADETS II and III are about equal, the amplitude is considerably higher for CADET III. Because of differences in the circuitry, there is no undershoot on CADET III. The results of the initial charge-discharge testing are tabulated in Tables XIII - XVII. Tables XIII and XIIIA indicate that there is little difference in the results between the two pieces of test equipment. Each group of capacitors had one failure. The unit (#51) which shorted on CADET III was a catastrophic failure caused by a rapid rise in the dissipation factor (DF). This caused the unit



Wiring Diagram for CADET III

Figure 9



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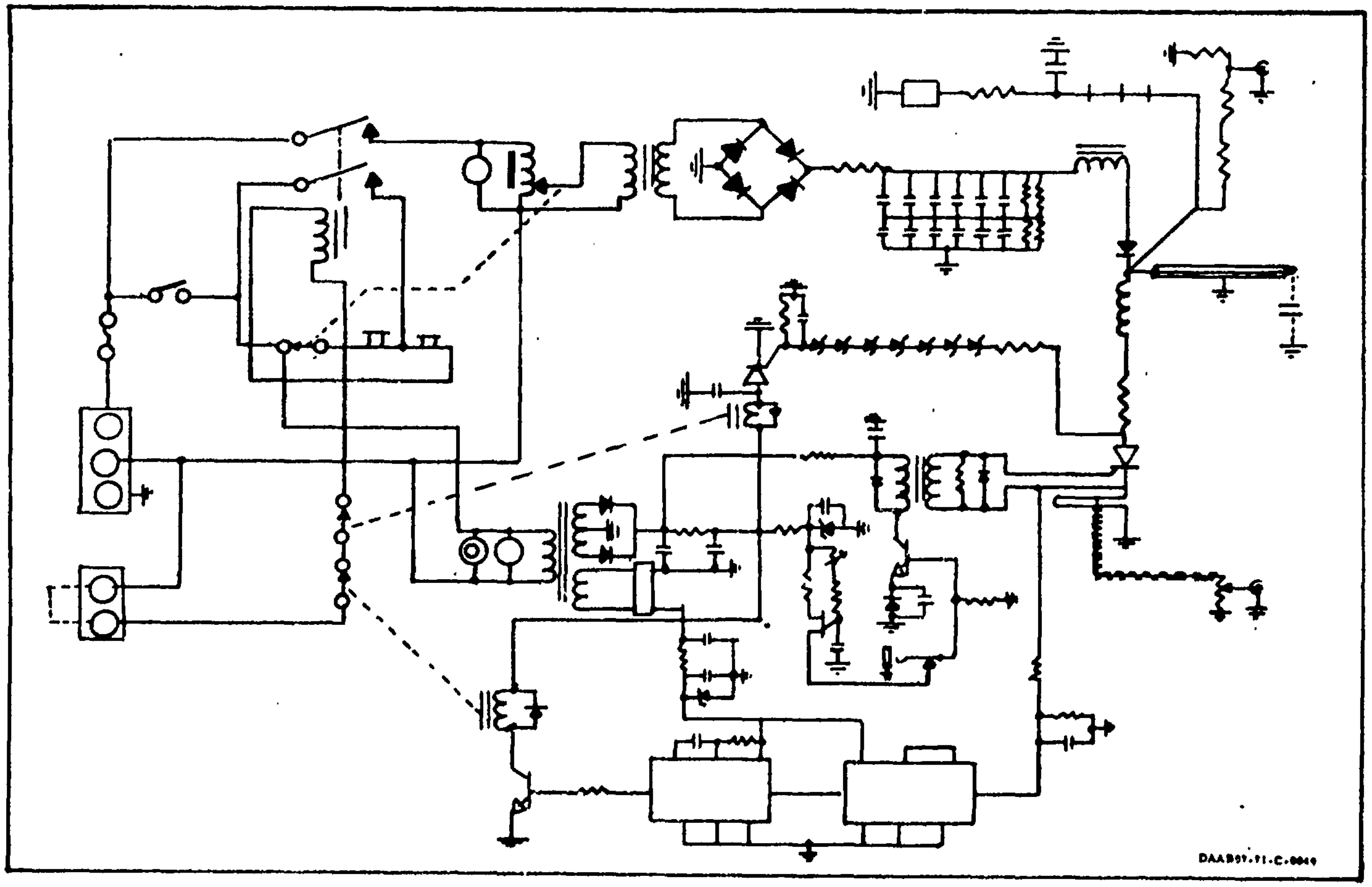
CADET III With Oven Door Open

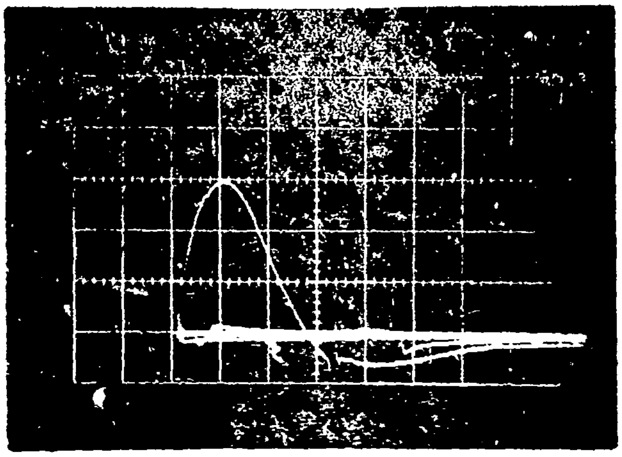
Figure 10



CADET III Test Equipment 1-30 pps Test Station

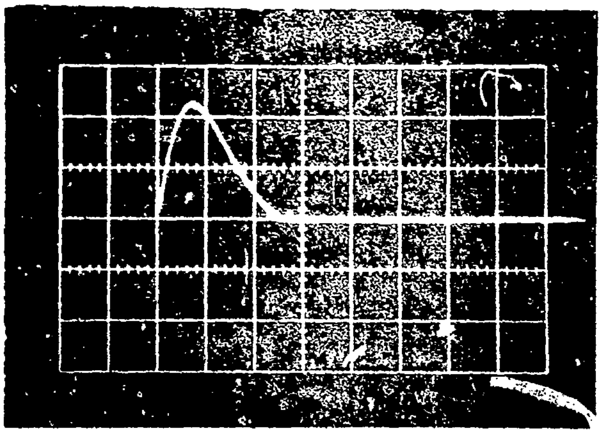
Figure 11

100 A/cm



CADET II (50μ sec/cm)

200 A/cm



CADET III (50μ sec/cm)

Typical Wave Shapes Of Discharge Current

Figure 12

(The circuitry of these two pieces of equipment is entirely different CADET II has two 32 μH inductors together while CADET III has only a single 30 μH inductor. Also the discharge devices are different. CADET II uses spark gaps while CADET III uses SCR switching).

TABLE XIII

PHASE IB - CHARGE-DISCHARGE LIFE TEST**
DESIGN A 0.00027" METALLIZED COATED* PETP FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		0 Cycles	
41	37.40	0.86	0.41
42	32.60	0.73	0.22
43	31.80	0.80	0.26
44	33.30	0.95	0.25
45	33.20	0.94	0.40
46	32.90	0.96	0.26
		5000 Cycles	
41	38.53	0.94	2.0
42	33.77	0.84	1.3
43	33.58	0.84	0.25
44	34.34	0.94	0.22
45	34.38	0.84	1.0
46	33.83	0.84	1.25
		10,000 Cycles	
41	38.54	0.84	2.3
42	33.77	0.74	2.0
43	33.60	0.84	0.27
44	34.36	0.94	0.27
45	34.38	0.74	1.1
46	33.84	0.84	1.5
		25,000 Cycles	
41	38.53	1.04	3.7
42	38.77	0.84	2.35
43	33.51	0.94	0.60
44	34.35	0.94	0.38
45	34.36	0.94	1.5
46	33.81	0.94	1.9
		50,000 Cycles	
41	38.50	1.04	0.16
42	33.80	0.74	1.9
43	29.28	5.34	0.75
44	34.31	0.94	0.3
45	34.37	0.84	1.25
46	33.77	0.84	1.65
		100,000 Cycles	
41	38.57	1.04	0.25
42	33.94	0.94	1.8
43	29.28	5.34	0.80
44	34.28	1.04	2.5
45	34.38	0.84	1.7
46	33.83	0.84	1.8

*Metallizing and Coating are Sprague Proprietary Processes.

**Test Conditions: Capacitance and Dissipation Factor at 1000 Hz.
Leakage Current at 500 VDC
Test Temperature 40°C
Measurement Temperature 25°C.
Load 30μH plus 1 ohm resistor.
Repetition Rate 0.1 pps.+
Test Voltage 900 VDC.
Peak Current 300 amps.

+CADET II test equipment used in accordance with proposal. This equipment is limited to 0.1pps for capacitors in the 30-35μF range.

TABLE XIIIA

PHASE IB - CHARGE-DISCHARGE LIFE TEST**
DESIGN A 0.00027" METALLIZED COATED* PETP FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance (µF)	Dissipation Factor (%)	Leakage Current (µA)
		0 Cycles	
49	32.82	0.97	0.32
50	33.43	0.97	0.42
51	32.81	0.96	0.32
52	32.24	0.97	0.24
53	31.05	0.96	0.20
54	32.53	0.96	0.26
		100,000 Cycles	
49	33.87	0.94	1.0
50	34.42	0.94	1.25
51	34.00	0.65	1.35
52	failed 37,000 cycles.		
53	32.19	0.94	1.3
54	33.69	1.24	1.25
		200,000 Cycles	
49	33.85	0.94	0.0022
50	34.43	0.92	2.05
51	34.00	0.94	1.61
53	32.22	0.94	1.45
54	33.68	1.24	2.05
		500,000 Cycles	
49	33.82	0.94	0.08
50	34.37	1.04	0.08
51	33.97	0.61	0.10
53*	0.0019	3.64	0.125
54	33.72	1.34	0.08
Unit No. 53 failed to charge after 241,000 cycles.			
		1,000,000 Cycles	
49	33.82	0.94	0.0026
50	34.30	0.94	2.5
51*	34.04	0.94	8.6
54	33.50	2.44	1.75
Unit No. 51 removed from test 901,000 cycles.			
		1,500,000 Cycles	
49	33.85	0.49	2.55
50	34.30	1.04	2.9
54	Off scale, removed from test 1,028,402 cycles.		
		2,000,000 Cycles	
49	33.82	0.94	1.85
50	34.31	0.94	1.90

*Metallizing and Coating are Sprague Proprietary Processes.
**Test Conditions: Capacitance and Dissipation Factor at 1000 Hz.
Leakage Current at 500 VDC.
Test Temperature 40°C.
Measurement Temperature 25°C.
Load 30µH plus 1 ohm resistor.
Repetition Rate 10 pps. +
Test Voltage 900 VDC.
Peak Current 450 amps.
+CADET III Test equipment used. (Designed to run 10 pps repetition rate)

TABLE XIV

PHASE IB - CHARGE-DISCHARGE LIFE TEST**
DESIGN C 0.00026" METALLIZED COATED* POLYCARBONATE FILM

(Encapsulated in Steel Cans)

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		0 Cycles	
109	34.65	0.70	0.38
110	33.45	0.47	0.18
111	32.90	0.45	0.16
112	28.15	0.45	0.16
113	34.45	0.56	0.30
114	34.08	0.61	0.20
		1000 Cycles	
109	33.18	6.94	0.36
110	33.39	0.32	0.12
111	32.92	0.51	0.105
112	28.18	1.04	0.11
113	34.43	0.53	0.235
114	34.04	0.45	0.22
		10,000 Cycles	
109***	Off Scale (High DF)		
110	33.41	0.62	0.20
111	32.88	0.62	0.17
112	28.18	0.62	0.17
113	34.04	1.04	0.32
114	34.45	0.62	0.23
		25,000 Cycles**	
110	33.40	0.39	0.24
111	32.91	0.45	0.22
112	28.16	0.32	0.25
113	34.05	1.24	0.50
114	34.41	0.57	0.38
		50,000 Cycles**	
110	33.41	0.42	0.24
111	33.90	0.45	0.23
112	28.11	0.40	0.25
113	34.04	1.30	0.60
114	34.43	0.6	0.45
		100,000 Cycles**	
110	33.40	0.36	0.265
111	32.97	0.41	0.22
112	28.14	0.54	0.30
113	34.08	1.04	2.0
114	34.40	0.62	0.32

*Metallizing and Coating are Sprague Proprietary Processes.

**Test Conditions: Capacitance and Dissipation Factor at 1000 Hz.
Leakage Current at 500 VDC.
Test Temperature 40°C.
Measurement Temperature 25°C.
Load 30μH plus 1 chm resistor.
+Repetition Rate 0.1 pps up to and including 10,000 cycles
10 pps from 10,000 cycles upward.
Test Voltage 900 VDC.
Peak Current 450 amps.

***109 Failed 6469 Cycles.

****CADET III test equipment used from 10,001 to 100,000 cycles. Repetition rate increased from 0.1 pps to 10 pps.

+CADET II test equipment was limited to 0.1pps and CADET III test equipment designed to run test at 10pps in accordance with proposal.

TABLE XV

PHASE IB - CHARGE-DISCHARGE LIFE TEST**
DESIGN F 0.00027" METALLIZED COATED* PETP WAX IMPREGNANT

(Encapsulated in Steel Cans)

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		0 Cycles	
59	34.50	0.42	0.63
62	34.20	0.49	0.57
63	35.20	0.50	0.57
67	34.20	0.49	0.43
68	34.00	0.48	0.40
71	35.20	0.50	0.36
		5000 Cycles	
59***	25.54	6.14	Short
62	34.00	0.94	0.475
63	34.84	1.04	0.28
67	34.03	1.04	0.165
68	33.68	1.04	0.15
71	34.75	1.04	0.35
		10,000 Cycles	
62	33.99	0.94	0.50
63	34.81	1.04	0.28
67	34.01	0.94	0.195
68	33.69	0.94	0.0045
71	34.76	0.94	0.31
		20,000 Cycles	
62	34.00	0.94	0.285
63	34.82	0.94	0.245
67	34.00	0.94	0.15
68	33.62	0.94	0.145
71	34.73	0.94	0.335
		40,000 Cycles	
62	34.01	0.94	0.26
63	34.82	0.94	0.235
67	33.99	0.94	0.135
68	33.69	0.94	0.125
71****	Cannot Read (Short)		
		100,000 Cycles	
62	34.03	0.94	0.49
63	34.87	1.04	0.50
67	34.02	0.94	0.23
68	33.68	0.94	0.25

*Metallizing and Coating are Sprague Proprietary Processes.
**Test Conditions: Capacitance and Dissipation Factor at 1000 Hz.
Leakage Current at 500 VDC.
Test Temperature 40°C.
Measurement Temperature 25°C.
Load 30μH plus 1 ohm resistor.
+Repetition Rate 10pps.
Test Voltage 900 VDC.
Peak Current 450 amps.
+CADET III test equipment used. (Designed to run 10pps repetition rate.)
***59 Failed 3200 Cycles.
****71 Failed 33,800 Cycles.

TABLE XVI

PHASE IB - CHARGE-DISCHARGE LIFE TEST**
DESIGN E 0.00027" METALLIZED COATED* PETP SILICONE OIL IMPREGNATED

(Encapsulated in Steel Cans)

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		0 Cycles	
78	34.00	0.67	0.54
80	33.40	0.97	0.48
83	33.00	0.67	0.43
90	34.00	0.80	0.40
92	33.30	0.77	0.37
94	33.38	0.66	0.36
		5000 Cycles	
78	33.85	1.04	0.25
80	34.20	0.32	0.0016
83	33.11	0.65	5.0
90	34.19	0.94	0.14
92	33.51	0.94	0.245
94	34.15	0.94	0.29
		10,000 Cycles	
78	33.87	0.94	0.1
80	34.18	0.94	0.7
83	33.11	0.94	0.8
90	34.18	0.96	0.07
92	33.57	0.94	0.13
94	34.13	0.94	0.17
		25,000 Cycles	
78	33.87	0.94	0.14
80	34.23	1.04	0.10
83	33.15	0.94	1.35
90	34.25	0.94	0.175
92	35.61	0.94	0.25
94	34.17	0.57	0.315
		50,000 Cycles	
78	33.88	0.65	0.25
80	34.19	0.94	0.002
83	33.15	0.84	0.90
90	34.21	0.57	0.15
92	33.58	0.84	0.20
94	34.14	0.94	0.265
		100,000 Cycles	
78	33.88	0.65	0.24
80	34.18	0.94	0.0015
83	33.15	0.84	0.95
90	34.22	0.74	0.16
92	33.59	0.84	0.24
94	34.14	0.94	0.25

*Metallizing and Coating are Sprague Proprietary Processes.

**Test Conditions: Capacitance and Dissipation Factor at 1000 Hz.
Leakage Current at 500 VDC.
Test Temperature 40°C.
Measurement Temperature 25°C.
Load 30μH plus 1 ohm resistor.
Repetition Rate 10 pps.
Test Voltage 900 VDC.
Peak Current 450 amps.
CADET III test equipment used.

TABLE XVII

PHASE IB - CHARGE-DISCHARGE LIFE TEST**
DESIGN D UNITS - 0.00026" METALLIZED COATED*POLYSULFONE

0 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
134	34.95	0.56	2.5
135	34.30	0.52	3 [illegible]
136	34.38	0.68	2.4
138	34.78	0.49	1.8
139	33.62	0.32	1.2
140	34.80	0.55	3.0

100 Cycles

134	Shorted 42 cycles
135	Shorted 86 cycles
136	Shorted 56 cycles
138	Shorted 95 cycles
139	Shorted 36 cycles
140	Shorted 50 cycles

*Metallizing and Coating are Sprague Proprietary Processes.

**Test Conditions: Capacitance and Dissipation Factor at 1000 Hz.
Leakage Current at 500 VDC.
Test Temperature 40°C.
Measurement Temperature 25°C.
Load 30μH plus 1 ohm resistor.
Repetition Rate 10 pps. +
Test Voltage 900 VDC.
Peak Current 450 amps.

+CADET III test equipment used. (Designed to run 10pps repetition rate).

to heat which eventually caused the dielectric to melt. For the type of units tested, the higher repetition rate of CADET III only seems to accelerate the rate of failures. The higher repetition rate of CADET III quickens the loss of connection between the electrode and end spray, thus raising the DF and causing the unit to heat. This heat rise can become so high that the dielectric can no longer withstand the voltage and the unit fails. A photograph showing loss of metal along the end connection edge of the film is shown in Figure 13.

After this limited testing the discharge life test data indicate that Design E performed the best with no failure after 100,000 charge-discharge cycles. Designs A, C and F exhibited life test results of approximately the same level of performance. This level was only slightly lower than that exhibited by Design E. Units of Design D failed before 100 cycles, again indicating dielectric of poor quality.

8. Design Selection

Design A was chosen over Design C for use in Phase II because the PETP is much easier to coat and metallize with consistently good results than the polycarbonate. The lower DF of the coated polycarbonate compared to the coated PETP would not be a distinct advantage at a 10 pps repetition rate. At higher repetition rates, the coated polycarbonate should perform better than coated PETP. Design F was not chosen because the wax impregnation did not improve the breakdown voltage significantly and increased the weight. Also wax would not conduct the heat out of the section as well as the silicone oil.

Design D was eliminated because of the extremely poor discharge life test results. Design B had previously been eliminated when units of this design would not withstand the necessary voltage.

9. End Connection

Considerable time was spent in an effort to develop better mechanical and electrical connections between the electrode and the metal end spray. Sections were rolled using 2" wide 0.00052" metallized coated* PETP film. The sections were processed in the normal manner with the exception of the end spray - lead

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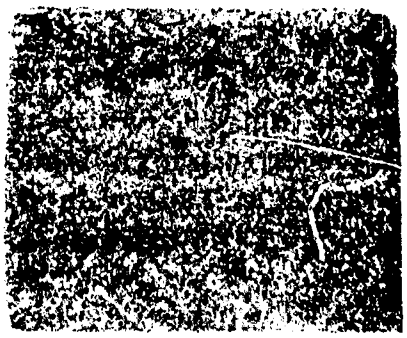
*Metallizing and Coating are Sprague Proprietary Processes

LOSS OF METAL AND END CONNECTION



NO LOSS OF END CONNECTION

COMPARISON OF FILM

WITH AND WITHOUT LOSS OF END CONNECTION

Figure 13

attachment method. All the experimental groups received 10,000 charge-discharge cycles at 2500 volts and 40°C or were removed from test due to excessive failures. The result of this testing is shown in Table XVIII. The data indicate that Spray Process C, control solder method gave the best results. Table XVIII also indicates a slight advantage using Spray Process A and lead attachment using Solder Process I.

10. Phase I Extension

It was decided to extend the testing on Design E units because of the extremely good initial results achieved with this design. This was easily done because test equipment would be idle during the initial stages of Phase II.

The extended life test data on Design E is shown in Table XIX. As the extended data indicate, Design E performed extremely well.

11. Phase II

A decision was made to include three end-connection g[illegible]etric variations for both Design A (0.00027" metallized coated*PE[illegible] [illegible]nd Design E (0.00027" metallized coated*PETP, silicone oil im[illegible]ated) in the Phase II program. The three variations were:

Variation 1 - A different geometry with a longer electrode length terminated with Spray Process C, Solder Process I. The purpose of these units was that the longer electrode length would reduce the peak current per linear inch and extend the life of the end connection.

Variation 2 - Standard design with Spray Process C, Solder Process I. This experimental group used the best spray process from the end spray evaluation.

Variation 3 - Standard design with Spray Process A, Solder Process I. This was the second best spray process of the end evaluation.

These capacitors were rolled and processed using the same techniques as in Phase I. The only deviation from the processes used in Phase I was the variations in end spray. The 4" long units were encapsulated in aluminum cans while shorter units were encapsulated in steel cans because aluminum cans were not available at that time and the delay required to secure the cans was unnecessary.

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*Metallizing and Coating are Sprague Proprietary Processes

TABLE XVIIIA

END SPRAY EVALUATION
of
0.00052 METALLIZED COATED* PETP FILM

No.	0 Cycles Cap(μF)	0 Cycles DF(%)	100 Cycles Cap(μF)	100 Cycles DF(%)	500 Cycles Cap(μF)	500 Cycles DF(%)	1000 Cycles Cap(μF)	1000 Cycles DF(%)	2000 Cycles Cap(μF)	2000 Cycles DF(%)	5000 Cycles Cap(μF)	5000 Cycles DF(%)	10,000 Cycles Cap(μF)	10,000 Cycles DF(%)
CONTROL SPRAY AND SOLDER PROCESS														
1	9.075	0.47	9.064	0.46	9.059	0.49	9.050	1.65	9.043	0.49	9.023	0.48	8.895	0.56
2	9.440	0.51	9.428	0.50	9.430	0.49	9.420	0.65	9.411	0.49	9.385	0.48	7.951	6.01
3	8.990	0.61	8.962	0.63	6.111	10.91	3.125	14.91	removed from test endspray loose from electrode					
4	8.880	0.55	8.854	0.53	8.845	0.54	8.828	0.65	8.826	0.49	8.793	0.79	removed from test	
5	8.895	0.55	8.852	0.73	8.885	0.54	8.874	0.62	8.899	0.49	8.868	0.49	8.847	0.48
SPRAY PROCESS A, CONTROL SOLDER														
6	8.857	0.48	8.852	0.74	8.834	0.54	8.822	0.62	8.815	0.48	8.871	0.44	6.885	0.48
7	8.892	0.72	8.879	0.95	8.875	0.69	8.861	0.70	8.835	1.41	8.807	1.30	8.646	1.51
8	8.880	0.47	8.865	0.47	8.851	0.49	8.843	0.65	8.849	0.49	8.809	0.48	8.463	0.46
9	8.887	0.47	8.870	0.46	8.869	0.49	8.854	0.65	8.858	0.49	8.851	0.44	8.725	0.46
10	8.840	1.38	8.807	3.24	8.700	17.91	1.330	5.21	removed from test loss of connection between endspray and electrode					
CONTROL SPRAY PROCESS, SOLDER PROCESS 1														
11	8.830	0.62	8.810	0.56	8.805	0.48	8.871	0.49	8.802	0.53	8.802	0.48	8.706	0.48
12	8.695	0.62	8.674	0.49	8.655	0.55	8.655	0.49	8.649	0.53	8.609	0.48	2.877	0.45
13	8.765	0.73	8.752	0.49	8.736	0.55	8.734	0.49	8.690	0.53	8.688	0.47	3.905	5.00
14	8.715	0.71	8.705	0.49	8.697	0.53	8.693	0.49	8.693	0.53	8.693	0.58	8.581	0.54
15	8.796	0.65	8.753	0.49	8.741	0.53	8.796	0.99	8.740	0.53	8.742	0.47	8.177	0.54
SPRAY PROCESS B, CONTROL SOLDER														
16	8.972	0.60	8.943	0.45	8.922	0.53	8.918	0.49	8.883	0.53	8.899	0.47	8.975	2.80
17	8.950	0.57	8.897	0.45	8.885	0.82	8.060	5.31	6.644	6.73	3.689	2.10	removed from test	
18	11.230	0.70	11.250	0.64	11.140	1.91	10.270	3.21	7.873	0.54	7.837	0.48	7.351	1.61
19	8.958	0.55	8.941	0.49	8.928	0.53	8.924	0.53	8.918	0.54	8.911	0.48	8.283	3.11
20	8.896	0.60	8.881	0.49	8.367	0.49	8.861	0.53	8.853	0.54	8.851	0.48	4.806	8.11

Tested at 2500 volts, 500 amps, 40°C, and 32μH load
Cap & DF measured at 1000 Hz
*Sprague Proprietary

DAAB07-71-[illegible]

TABLE XVIIIB

END SPRAY EVALUATION
of
0.00052" METALLIZED COATED* PETP FILM

SPRAY PROCESS E, CONTROL SOLDER

No.	0 Cycles Cap(µF)	0 Cycles DF(%)	100 Cycles Cap(µF)	100 Cycles DF(%)	500 Cycles Cap(µF)	500 Cycles DF(%)	1000 Cycles Cap(µF)	1000 Cycles DF(%)	2000 Cycles Cap(µF)	2000 Cycles DF(%)	5000 Cycles Cap(µF)	5000 Cycles DF(%)	10,000 Cycles Cap(µF)	10,000 Cycles DF(%)
21	8.796	0.70	8.802	0.50	8.769	0.48	off scale - removed from test							
22	9.180	0.74	9.181	0.50	9.160	0.49	(off scale - removed from test)							
23	8.830	0.74	8.812	1.04	2.888	15.91	2.467	27.91	removed from test					
24	8.864	0.74	8.962	0.49	8.925	0.49	8.920	0.49	8.884	0.45	8.881	0.44	8.880	0.49
25	8.883	0.73	8.886	0.49	6.675	6.81	5.770	7.61	8.33	6.61	4.786	7.21	4.762	7.21
SPRAY PROCESS D, CONTROL SOLDER														
26	9.030	0.71	9.021	0.75	9.025	0.56	9.031	0.56	9.015	0.49	7.799	0.79	8.603	1.71
27	8.990	0.76	8.997	0.78	8.989	0.56	9.000	0.53	7.932	0.49	9.005	0.64	off scale	
28	8.895	0.65	8.897	0.75	8.903	0.56	8.907	0.56	8.980	0.49	8.900	0.44	off scale	
29	8.974	0.75	8.872	0.75	8.945	0.56	8.883	1.01	7.613	0.49	7.504	0.44	7.450	0.49
30	8.930	0.75	8.920	0.75	8.928	0.56	8.940	0.49	8.907	0.45	8.339	0.44	8.376	0.490

Tested at 2500 volts, 500 amps, 40°C, and 32µH load
Cap & DF measured at 1000 Hz
*Sprague Proprietary

DAAB07-71-C-0069

TABLE XVIIIC

END SPRAY EVALUATION
of
0.00052" METALLIZED COATED* PETP FILM

No.	0 Cycles Cap(µF)	0 Cycles DF(%)	100 Cycles Cap(µF)	100 Cycles DF(%)	500 Cycles Cap(µF)	500 Cycles DF(%)	1000 Cycles Cap(µF)	1000 Cycles DF(%)	2000 Cycles Cap(µF)	2000 Cycles DF(%)	5000 Cycles Cap(µF)	5000 Cycles DF(%)	10,000 Cycles Cap(µF)	10,000 Cycles DF(%)
SPRAY PROCESS C, CONTROL SOLDER														
36	8.730	0.45	8.714	0.45	8.715	0.49	8.709	0.65	No Data Available		8.702	0.47	8.708	0.45
37	8.470	0.45	8.479	0.45	8.480	0.49	8.479	0.47			8.466	0.46	8.433	0.45
38	8.802	0.45	8.785	0.45	8.783	0.49	8.779	0.47			8.762	0.46	8.737	0.45
39	8.573	0.45	8.556	0.45	8.556	0.49	8.148	0.47			8.533	0.46	8.527	0.45
40	8.174	0.45	8.161	0.45	8.158	0.49	8.551	0.47			8.141	0.46	8.094	0.45
CONTROL SPRAY, SOLDER PROCESS 2														
41	9.228	0.54	9.223	0.54	9.209	0.55	9.192	0.76	No Data Available		2.718	16.91	Removed From Test	
42	9.325	0.53	9.310	0.54	9.253	0.54	9.246	0.62			4.169	21.91		
43	9.032	0.5[illegible]	9.035	0.54	9.019	0.54	9.005	0.62			4.151	8.21		
44	8.959	0.49	8.959	0.54	8.955	0.48	8.930	0.62			8.513	2.71		
45	9.030	0.70	9.039	0.54	8.725	1.71	8.685	2.51			Off Scale			
SPRAY PROCESS F, CONTROL SOLDER														
46	8.920	0.55	8.915	0.54	8.904	0.49	8.897	0.50	Test Continuing		Off Scale			
47	8.388	0.56	8.384	0.54	9.355	0.49	Cannot Read							
48	8.935	0.55	8.926	0.54	8.921	0.49	8.900	0.50	No [illegible]ailable		6.280	0.74	Removed From Test	
49	9.049	0.57	9.038	0.54	7.334	0.49	8.330	0.50			4.510	0.96		
50	8.815	0.55	8.804	2.91	7.430	6.31	7.337	6.61			1.224	1.31		

Tested at 2500 volts, 500 amps, 40°C, and 32µH load
Cap & DF measured at 1000 Hz
*Sprague Proprietary

LEGEND FOR TABLES XVIIIA - XVIIIC

Report Heading	Actual Description
Control Spray	Endspray applied in conventional state-of-the-art manner.
Spray Process A	Endspray was applied at a distance of approximately 8" between the spray nozzle and the top of the section.
Spray Process B	Capacitor chilled to -55°C temperature before spraying to prevent shrinkage of the film due to end spray heat.
Spray Process C	Pure tin metal used as endspray material.
Spray Process D	Four coats (approximately 1-3 mils each) of normal endspray formulation per end.
Spray Process E	State-of-the-art vacuum deposition of aluminum precoat prior to standard endspray.
Spray Process F	A 45° angle was used in applying the spray to obtain maximum theoretical contact of spray and electrode.
Control Solder	Leads attached onto endspray using 60/40 tin/lead solder with electric soldering iron (state-of-the-art soldering procedure).
Solder Process 1	Pre-tinned leads attached to endspray using carbon tip resistance soldering (no added solder).
Solder Process 2	Pre-tinned leads attached to endspray during the endspraying process using the heat of the melting endspray to solder the lead to the endspray.

TABLE XIX

CONTINUATION OF PHASE IB CHARGE-DISCHARGE LIFE TESTING DESIGN E - 0.00027" METALLIZED COATED* PETP SILICONE OIL IMPREGNATED

Unit No.	Capacitance (µF)	Dissipation Factor (%)	Leakage Current (µA)
		0 Cycles	
78	34.00	0.67	0.54
80	33.40	0.97	0.48
83	33.00	0.67	0.43
90	34.00	0.80	0.40
92	33.30	0.77	0.37
94	33.38	0.66	0.36
		5,000 Cycles	
78	33.85	1.04	0.25
80	34.20	0.32+	0.0016+
83	33.11	0.65	5.0
90	34.19	0.94	0.14
92	33.51	0.94	0.245
94	34.15	0.94	0.29
		10,000 Cycles	
78	33.87	0.94	0.1
80	34.18	0.94	0.7
83	33.11	0.94	0.8
90	34.18	0.96	0.07
92	33.57	0.94	0.13
94	34.13	0.94	0.17
		25,000 Cycles	
78	33.87	0.94	0.14
80	34.23	1.04	0.10
83	33.15	0.94	1.35
90	34.25	0.94	0.175
92	35.61	0.94	0.25
94	34.17	0.57	0.315
		50,000 Cycles	
78	33.88	0.65	0.25
80	34.19	0.94	0.002+
83	33.15	0.84	0.90
90	34.21	0.57	0.15
92	33.58	0.84	0.20
94	34.14	0.94	0.265
		100,000 Cycles	
78	33.88	0.65	0.24
80	34.18	0.94	0.0015+
83	33.15	0.84	0.95
90	34.22	0.74	0.16
92	33.59	0.84	0.24
94	34.14	0.94	0.25

Contract No. DAAB07-71-C-0049

TABLE XIX (CONTINUED)

CONTINUATION OF PHASE IB CHARGE-DISCHARGE LIFE TESTED
DESIGN E - 0.00027" METALLIZED COATED*PETP SILICONE OIL IMPREGNATED

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		500,000 Cycles	
78	34.05	0.84	0.32
80	34.20	0.99	0.70
83	33.30	0.94	1.30
90	34.55	0.84	0.22
92	33.66	0.94	0.80
94	34.10	0.94	0.55
		1,000,000 Cycles	
78	33.88	0.79	0.32
80	34.10	0.70	0.75
83	33.10	0.76	1.80
90	34.10	0.70	0.25
92	33.48	0.72	0.98
94	34.04	0.70	0.50
		2,000,000 Cycles	
78	33.80	0.84	0.28
80	34.00	0.84	0.68
83	33.00	0.75	0.90
90	34.00	0.79	0.22
92	33.25	0.79	0.80
94	‡34.20	0.84	0.50
		5,000,000 Cycles	
78	33.75	0.74	0.34
80	34.09	0.74	0.92
83	34.12	0.74	1.40
90	34.06	0.74	1.30
92	33.90	0.74	0.26
94	36.04	0.74	0.88
		10,000,000 Cycles	
78	33.65	0.94	0.48
80	33.84	0.84	0.98
83	32.85	0.74	0.27
90	33.78	0.65	0.22
92	33.27	0.76	0.94
94	35.68	0.74	0.68

*Sprague Proprietary
Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 V
Test Temperature 40°C up to 100,000 cycles 25°C after 100,000 cycles
Measuring Temperature 25°C
Repetition Rate 10 pps
Load 32 μH + 1Ω resistor
Current = 450 amp.
‡Reading error

The finished encapsulated units were cleared at 1000 volts at 70°C. The number of audible clearings was recorded. These data are recorded in Table XX.

A sample of each design was measured for inductance. The readings are shown in Table XXI. The inductance measurements were in the range of values expected for capacitors of this size and construction.

12. Testing and Evaluation

A sample of six units of each design variation was discharge life tested for 10,000,000 charge-discharge cycles (at 10 pps and 40°C) or until failure. The results of this testing are shown in Tables XXII - XXVII.

Two things are evident from these data:

Silicone oil impregnated units performed better than their dry (unimpregnated) counterparts.

Variation 1 units performed better than standard design units.

The reason that the silicone oil impregnated units performed better than the unimpregnated ones was not due to any appreciable increase in dielectric strength caused by the impregnant, but rather from the silicone oil acting as a heat transfer medium to conduct heat away from the end connections and windings to be dissipated by the can.

The probable reason for the greater success of Variation 1 capacitors was that the longer electrode length of these units lowered the peak discharge current per unit of length to a value at which a connection between the metallized electrode and end spray metal could be maintained.

On the basis of the discharge life test data, silicone oil impregnated units of Variation 1 design were selected for use in Phase III.

TABLE XXA

AUDIBLE MOMENTARY BREAKDOWN
AT ELEVATED TEMPERATURE AT 1 kV
DESIGN A VARIATION 1
(0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	No. of Breakdowns
151	26
152	20
153	21
154	26
155	33
156	17
157	17
158	22

Test Voltage 1000 VDC
Test Temperature 70°C
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXB

AUDIBLE MOMENTARY BREAKDOWN
AT ELEVATED TEMPERATURE AT 1 kV
DESIGN A VARIATION 2
(0.00027" METALLIZED COATED* PETP, STANDARD DESIGN)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	No. of Breakdowns
200	10
201	12
202	18
203	20
204	15
205	22
206	18
207	16

Test Voltage 1000 VDC
Test Temperature 70°C
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXC

AUDIBLE MOMENTARY BREAKDOWN AT ELEVATED TEMPERATURE AT 1 kV DESIGN A VARIATION 3 (0.00027" METALLIZED COATED* PETP, STANDARD DESIGN) SPRAY PROCESS A, SOLDER PROCESS I

Unit No.	No. of Breakdowns
174	18
175	22
176	17
177	15
178	10
179	19

Test Voltage 1000 VDC
Test Temperature 70°C
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXD

AUDIBLE MOMENTARY BREAKDOWN
AT ELEVATED TEMPERATURE AT 1 kV
DESIGN E VARIATION 1
(0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY,
SILICONE OIL IMPREGNATED)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	No. of Breakdowns
180	10
181	12
182	16
183	9
184	11
185	18

Test Voltage 1000 VDC
Test Temperature 70°C
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXE

AUDIBLE MOMENTARY BREAKDOWN
AT ELEVATED TEMPERATURE AT 1 kV
DESIGN E VARIATION 2
(0.00027" METALLIZED COATED* PETP, STANDARD DESIGN, SILICONE OIL IMPREGNATED)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	No. of Breakdowns
193	20
194	18
195	14
196	22
197	17
198	19

Test Voltage 1000 VDC
Test Temperature 70°C
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXF

AUDIBLE MOMENTARY BREAKDOWN
AT ELEVATED TEMPERATURE AT 1 kV
DESIGN A VARIATION 3
(0.00027" METALLIZED COATED* PETP, STANDARD DESIGN,
SILICONE OIL IMPREGNATED)
SPRAY PROCESS A, SOLDER PROCESS I

Unit No.	No. of Breakdowns
186	10
187	15
188	16
189	19
190	27
191	18
192	22

Test Voltage 1000 VDC
Test Temperature 70°C
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXI

EFFECTIVE SERIES INDUCTANCE

Unit No.	Effective Series Inductance (μH)
Design A Variation 1 (0.00027" Metallized Coated* PETP, Different Geometry) Spray Process C, Solder Process I	
151	0.0326
152	0.0324
153	0.0310
154	0.0355
155	0.0311
156	0.0325
157	0.0331
158	0.0332
Design A Variation 2 (0.00027" Metallized Coated* PETP, Standard Design) Spray Process C, Solder Process I	
200	0.0320
201	0.0310
202	0.0298
203	0.0290
204	0.0310
205	0.0300
206	0.0306
207	0.0308
Design A Variation 3 (0.00027" Metallized Coated* PETP, Standard Design) Spray Process A, Solder Process I	
174	0.0327
175	0.0319
176	0.0368
177	0.0325
178	0.0334
179	0.0312

Unit No.	Effective Series Inductance (μH)
Design E Variation 1 (0.00027" Metallized Coated* PETP, Different Geometry, Silicone Oil Impregnated) Spray Process C, Solder Process I	
180	0.0364
181	0.0338
182	0.0401
183	0.0404
184	0.0380
185	0.0363
Design E Variation 2 (0.00027" Metallized Coated* PETP, Standard Design, Silicone Oil Impregnated) Spray Process C, Solder Process I	
159	0.0381
160	0.0454
161	0.0362
162	0.0336
163	0.0414
164	0.0380
165	0.0380
Design E Variation 3 (0.00027" Metallized Coated* PETP, Standard Design, Silicone Oil Impregnated) Spray Process A, Solder Process I	
186	0.0363
187	0.0322
188	0.0324
189	0.0311
190	0.0314
191	0.0360
192	0.0401

DAAB07-71-C-0049

*Sprague Proprietary

TABLE XXII

CHARGE-DISCHARGE LIFE TESTING
DESIGN A VARIATION 1
(0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		0 Cycles	
153	32.65	0.69	2.00
154	31.40	0.71	1.00
155	33.35	0.74	0.82
156	33.58	0.71	1.40
157	31.90	0.66	0.68
158	31.43	0.66	0.30
		1,000,000 Cycles	
153	32.25	0.75	1.82
154	31.72	0.57	0.60
155	33.16	0.70	0 32
156	34.16	0.74	1.30
157	30.40	0.74	0.68
158	31.28	0.57	0.40
		5,000,000 Cycles	
153 *SHORT			
154	31.22	0.62	1.90
155	32.97	0.62	2.50
156	32.85	0.64	1.60
157	27.70	0.65	0.92
158	31.10	0.56	2.00

*Failed 2,433,283

*Sprague Proprietary
Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 V
Repetition Rate 10 pps
Test Temperature 40°C
Measuring Temperature 25°C
Load 30μH + 1Ω resistor
Test Voltage 900 V
Peak current = 450 Amps

DAAB07-71-C-0049

TABLE XXII (CONT'D)

CHARGE-DISCHARGE LIFE TESTING
DESIGN A VARIATION 1
(0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
	10,000,000 Cycles		
154	30.15	0.66	0.80
155	32.77	0.64	0.44
156	31.62	0.81	3.50
157	24.50	0.62	0.70
158	30.80	0.63	0.85

*Sprague Proprietary
Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 V
Repetition Rate 10 pps
Test Temperature 40°C
Measuring Temperature 25°C
Load 30 μH + 1Ω resistor
Test Voltage 900 V
Peak current ≈ 450 Amps.

DAAB07-71-C-0049

TABLE XXIII

CHARGE-DISCHARGE LIFE TESTING
DESIGN A VARIATION 2
(0.00027" METALLIZED COATED* PETP STANDARD DESIGN)
SPRAY PROCESS C, SOLDER PROCESS I

0 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
200	30.40	0.54	0.50
201	29.00	0.64	0.80
202	28.65	0.64	0.60
203	29.98	0.64	0.80
204	29.38	0.64	0.78
205	30.45	0.66	0.90

1,000,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
200	Failed 238,950		
201	28.65	0.75	0.98
202	28.50	0.85	0.75
203	Failed 938,652		
204	29.00	0.82	0.95
205	Failed 256,322		

5,000,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
201	Failed 1,098,506		
202	Failed 2,568,300		
204	Failed 1,687,352		

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 V
Test Temperature 40°C
Measuring Temperature 25°C
Repetition Rate 10 pps
Load 30 μH + 1 Ω resistor
Test Voltage 900 V
Peak Current ≈ 450 A.
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXIV

CHARGE-DISCHARGE LIFE TESTING
DESIGN A VARIATION 3
(0.00027" METALLIZED COATED* PETP, STANDARD DESIGN)
SPRAY PROCESS A, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
	0 Cycles		
200	30.40	0.54	0.50
201	29.00	0.64	0.80
202	28.65	0.64	0.60
203	29.98	0.64	0.80
204	29.38	0.64	0.78
205	30.45	0.66	0.90
	1,000,000 Cycles		
200*	Short		
201	26.65	0.75	0.98
202	28.50	0.82	0.75
203+	Open		
204	29.00	0.82	0.95
205#	Open		

*Failed 238,950
+Failed 938,652
#Failed 256,322

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
	5,000,000 Cycles		
201**	Short		
202++	Open		
204##	Short		

**Failed 1,098,506
++Failed 2,568,300
##Failed 1,681,352

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 V
Test Temperature 40°C
Measuring Temperature 25°C
Repetition Rate 10 pps
Load 30μH + 1Ω resistor
Test Voltage 900 V
Peak Current = 450 A.
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXV

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 1
(0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY, SILICONE OIL IMPREGNATED)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
	0 Cycles		
180	32.13	0.61	0.32
181	31.78	0.57	0.76
182	32.30	0.53	0.38
183	31.20	0.57	0.75
184	32.29	0.54	0.70
185	30.60	0.53	0.90
	1,000,000 Cycles		
180	32.10	0.65	0.25
181	31.70	0.61	0.25
182	32.30	0.63	0.18
183	31.10	0.65	0.68
184	32.35	0.63	0.70
185	30.90	0.63	0.25
	5,000,000 Cycles		
180	32.30	0.62	0.15
181	31.74	0.62	0.12
182	32.45	0.65	0.24
183	31.40	0.61	0.25
184	32.37	0.62	0.78
185	30.95	0.62	0.72
	10,000,000 Cycles		
180	32.25	0.57	0.18
181	31.65	0.57	0.16
182	32.44	0.53	0.22
183	31.35	0.57	2.00
184	32.32	0.53	0.32
185	30.94	0.53	0.98

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500V
Test Temperature 40°C
Measuring Temperature 25°C
Repetition Rate 10 pps
Load 30μH + 1Ω resistor
Test Voltage 900 V
Peak Current * 450 A.
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXVI

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 2
(0.00027" METALLIZED COATED* PETP STANDARD DESIGN
SILICONE OIL IMPREGNATED)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current 500 V (μA)
	0 Cycles		
193	34.17	0.69	0.40
194	34.09	0.74	0.38
195	35.75	0.74	0.38
196	34.35	0.74	0.95
197	34.14	0.74	0.95
198	33.74	0.74	0.40
	5,000,000 Cycles		
193	34.10	0.70	0.30
194	Open 2,567,323		
195	35.79	0.70	0.40
196	34.29	0.70	1.60
197	34.10	0.70	0.30
198	33.70	0.70	0.34
	10,000,000 Cycles		
193	34.08	0.73	0.98
195	35.70	0.73	0.48
196	34.35	0.74	0.38
197	34.06	0.74	0.52
198	33.67	0.74	0.28

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 VDC
Repetition Rate 10 pps
Test Temperature 40°C
Measuring Temperature 25°C
Load 30μH plus 1 ohm resistor
Test Voltage 900 VDC
Peak Current ≈ 450 amps.
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXVII

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 3
(0.00027" METALLIZED COATED* PETP, STANDARD DESIGN, SILICONE OIL IMPREGNATED)
SPRAY PROCESS A, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
	0 Cycles		
186	33.56	0.76	0.68
187	39.43	0.74	1.50
188	34.05	0.71	0.80
190	33.71	0.74	0.40
191	33.55	0.69	0.98
192	35.22	0.74	0.40
	1,000,000 Cycles		
186	33.50	0.70	0.46
187	34.40	0.71	0.30
188	34.10	0.70	0.40
190	33.65	0.73	0.60
191	33.50	0.71	0.40
192	35.20	0.69	0.60
	5,000,000 Cycles		
186	33.72	0.70	0.28
187	34.42	0.71	0.38
188	34.88	0.69	0.35
190*	Open		
191	33.62	0.69	0.30
192	35.25	0.69	0.45
*Failed 3,226,368			
	10,000,000 Cycles		
186	33.56	0.68	0.26
187	34.30	0.74	0.20
188	33.95	0.74	0.50
191	33.70	0.80	0.30
192	35.15	0.81	0.24

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 V
Test Temperature 40°C
Repetition Rate 10 pps
Measuring Temperature 25°C
Load 30μH + 1Ω resistor
Peak Current* 450 A
Peak Voltage 900 V.
*Sprague Proprietary

DAAB07-71-C-0049

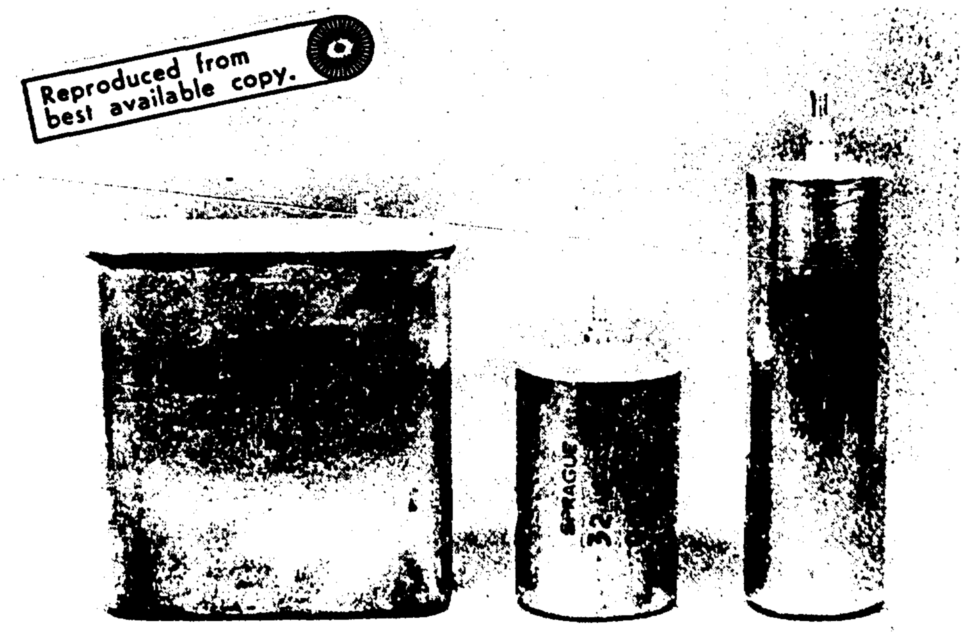
13. Phase III

Units of Design E Variation 1 were produced in the same manner as in Phase II with the exception that plated aluminum cans and covers were used. The cans and covers were plated with electroless nickel followed by a hot tin dip. With the plating, the units could be hermetically encapsulated using standard tin-lead solder. A comparison among the state-of-the-art metallized paper capacitor, the initial contract design units and the final design is shown in Figure 14.

After initial electrical measurements shown in Table XXVIII, six capacitors were discharge life tested. Twelve additional capacitors were shipped to the U. S. Army Electronics Command, Fort Monmouth, New Jersey. The results of this testing are shown in Table XXIX. It can be seen that only one unit of the six which were tested failed to meet the 50,000,000 charge-discharge cycles objective. This unit was removed from test after 10,000,000 charge-discharge cycles because of loss of capacitance from an initial reading of 31.65µF to 19.25µF after 10,000,000 charge-discharge cycles. It should be pointed out that this was not a catastrophic failure such as a short or open but was still operable. The dissipation factor had also risen to 3.30%. It is interesting to note that the large loss of capacitance and rise in dissipation factor occurred between 5,000,000 and 10,000,000 discharge cycles. It should be noted that the capacitance on this unit dropped about 6% between 0 and 2.5 million cycles. This is a considerably higher capacitance drop than was exhibited by the other units. Because of this capacitance change, it may be possible to screen out infant mortalities such as this unit by use of a burn-in. It appears that a burn-in of less than 10% of the expected life could eliminate possible early failures.

Apparently, new methods of measurements will have to be devised to screen out early failures. However, on the basis of present state-of-the-art capacitors, a failure at 10,000,000 charge-discharge cycles could not be considered an early failure, especially when the repetition rate of 10 pps is considered.

Late in Phase III, a new film (Polyvinylidene Fluoride) became available in engineering sample quantities. This is an extruded biaxially oriented film with a dielectric constant of 11.0. A sample of the film was processed and capacitors were rolled. Because of the limited amount of film available, it was decided to roll capacitors of only approximately 5µF. The initial electrical measurements on



(Left to Right) State-of-the-Art, Final Design and Initial Design Capacitors

Figure 14

TABLE XXVIII

INITIAL MEASUREMENTS OF DESIGN E VARIATION 1
0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY
SILICONE OIL IMPREGNATED

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)	Weight in Grams
208	30.65	0.72	0.38	164
209	31.10	0.62	0.72	162
210	31.65	0.62	0.50	162
211	36.25	0.75	0.54	165
212	35.22	0.62	0.84	166
213	36.68	0.62	0.84	169
214	31.96	0.69	2.5	174
215	32.60	0.55	14.0	176
216	32.85	0.59	3.2	175
217	32.41	0.55	2.6	176
218	32.41	0.57	3.0	176
219	32.27	0.60	2.8	172
220	31.24	0.54	2.3	175
221	33.51	0.64	3.0	173
222	32.48	0.65	1.2	171
223	32.32	0.62	3.0	174
224	31.63	0.42	3.0	178
225	32.90	0.52	1.3	181
226	31.67	0.59	2.4	176
227	32.26	0.56	2.7	175
228	32.37	0.56	3.6	175
229	32.11	0.55	4.2	177
230	32.39	0.53	6.0	177
231	31.04	0.53	2.5	178
232	32.99	0.55	7.4	175
233	32.67	0.59	0.15	175

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 VDC
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXIX

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 1
0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY,
SILICONE OIL IMPREGNATED

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		0 Cycles	
208	30.65	0.72	0.38
209	31.10	0.62	0.72
210	31.65	0.62	0.50
211	36.25	0.75	0.54
212	35.22	0.62	0.84
213	36.58	0.62	0.98
		2,500,000 Cycles	
208	31.75	0.68	0.40
209	31.00	0.75	0.68
210	30.66	0.68	0.75
211	36.00	0.75	0.54
212	35.20	0.60	0.80
213	36.60	0.61	0.85
		5,000,000 Cycles	
208	31.50	0.66	0.45
209	30.90	0.76	0.75
210	30.00	0.75	0.70
211	36.50	0.76	0.60
212	34.90	0.72	0.76
213	36.50	0.69	0.85
		10,000,000 Cycles	
208	31.15	0.61	0.32
209	30.62	0.61	0.18
210	19.25	3.30	0.54
211	36.00	0.75	0.68
212	34.75	0.70	0.70
213	36.40	0.69	0.80

DAAB07-71-C-0049

TABLE XXIX (CONT'D)

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 1
0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY,
SILICONE OIL IMPREGNATED

12,500,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.18	0.62	0.40
209	30.55	0.65	0.25
210	Removed from test		
211	36.08	0.75	0.70
212	34.70	0.70	0.65
213	36.00	0.76	0.75

15,000,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.10	0.60	0.45
209	30.25	0.70	0.38
211	35.95	0.69	0.60
212	34.15	0.65	0.45
213	36.05	0.71	0.65

17,500,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.15	0.57	0.96
209	29.65	0.75	0.36
211	35.90	0.69	0.58
212	34.45	0.65	0.40
213	36.05	0.71	0.65

20,000,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.05	0.60	0.75
209	29.95	0.70	0.45
211	35.95	0.65	0.58
212	34.55	0.60	0.42
213	36.10	0.70	0.68

DAAB07-71-C-0049

TABLE XXIX (CONT'D)

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 1
0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY,
SILICONE OIL IMPREGNATED

22,500,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.00	0.70	0.65
209	29.75	0.69	0.80
211	35.70	0.65	0.60
212	35.50	0.70	0.45
213	36.08	0.69	0.70
25,000,000 Cycles			
208	31.05	0.70	0.70
209	29.65	0.65	0.70
211	35.10	0.75	0.60
212	39.50	0.70	0.68
213	35.95	0.75	0.80
27,500,000 Cycles			
208	31.08	0.70	0.65
209	29.60	0.70	0.80
210	35.10	0.70	0.60
212	34.48	0.70	0.80
213	35.60	0.80	0.65
30,000,000 Cycles			
208	31.10	0.70	0.80
209	29.55	1.70	0.80
211	35.06	0.53	0.25
212	34.40	0.71	1.00
213	35.50	0.90	6.80

DAAB07-71-C-0049

TABLE XXIX (CONT'D)

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 1
0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY, SILICONE OIL IMPREGNATED

32,500,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.09	0.65	0.75
209	29.05	1.60	0.60
211	34.68	0.60	0.58
212	34.00	0.63	0.60
213	35.55	0.65	0.80

35,000,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.00	0.60	0.80
209	29.60	0.60	0.70
211	34.75	0.62	0.65
212	33.60	0.60	0.70
213	35.50	0.60	0.85

37,500,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.08	0.56	0.80
209	29.50	0.66	0.88
211	35.08	0.70	0.90
212	32.56	0.66	0.74
213	35.60	0.50	0.80

40,000,000 Cycles

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
208	31.07	0.57	0.12
209	29.44	1.75	0.82
211	35.00	0.57	0.62
212	35.25	0.57	0.62
213	28.86	0.57	0.50

DAAB07-71-C-0049

TABLE XXIX (CONT'D)

CHARGE-DISCHARGE LIFE TESTING
DESIGN E VARIATION 1
0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY,
SILICONE OIL IMPREGNATED

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
		42,500,000 Cycles	
208	31.05	0.52	0.26
209	29.35	1.60	0.80
210	35.08	0.66	0.70
211	35.30	0.60	0.68
212	35.30	0.60	0.68
213	27.65	0.60	0.58
		45,000,000 Cycles	
208	31.00	0.58	0.60
209	29.30	1.50	0.85
211	35.05	0.60	0.76
212	35.50	0.58	0.46
213	27.00	0.66	0.44
		47,500,000 Cycles	
208	31.00	0.58	0.25
209	29.28	1.60	0.75
211	35.30	0.60	0.80
212	33.40	0.68	0.40
213	26.08	0.58	0.60
		50,000,000 Cycles	
208	31.05	1.56	0.20
209	29.25	1.74	0.82
211	35.23	0.56	0.84
212	33.35	0.66	0.22
213	24.82	0.59	0.40

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 VDC
Repetition Rate 10 pps
Test Temperature 40°C
Measuring Temperature 25°C
Load 30 μH plus 1 ohm resistor
Peak Current ≈ 450 amps.
*Sprague Proprietary

DAAB07-71-C-0049

these units are shown in Table XXX. The leakage currents and dissipation factors are much higher for these capacitors than for any of the designs used in Phase I. This is due to the basic nature of the film and not because of any degrading of the film's properties due to coating.

The electrical characteristics were measured at various temperatures. There was a tremendous capacitance loss at the lower temperatures which would necessitate a much larger size unit at room temperature to maintain a constant amount of energy at the lower temperature. Capacitance change vs. temperature is shown in Figure 15.

These units failed before 500 charge-discharge cycles because of the high DF and high leakage currents on discharge life testing at 10 pps.

Very late in Phase III the eighth test station of CADET III was received. Because of the lack of time very little data was gathered with this unit. The results of the discharge life test at 30 pps are shown in Table XXXI. It is interesting to note that the Design E Variation 1 type units performed well with only 1 failure in six units tested for 10,000,000 charge-discharge cycles.

TABLE XXXA

INITIAL ELECTRICAL RESULTS
0.00036" METALLIZED COATED*POLYVINYLIDENE FLUORIDE

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
1	4.957	1.20	4.0
2	4.995	1.20	3.6
3	4.993	1.20	Short
4	5.001	1.20	Short
5	4.993	1.2	3.0
6	4.956	1.2	4.6
7	5.318	1.2	3.2
8	4.986	1.2	3.2
9	5.236	1.2	3.0
10	4.981	1.2	2.8
11	5.015	1.2	3.0
12	4.970	1.2	3.2
13	5.149	1.3	4.2
14	5.076	1.2	3.0
15	5.040	1.2	3.2
16	4.980	1.2	3.6
17	5.047	1.2	3.4
18	5.106	1.5	4.4
19	5.082	1.2	4.4
20	5.164	1.2	3.8

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 VDC
*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXXB

BREAKDOWN VOLTAGE
0.00036" METALLIZED COATED*POLYVINYLIDENE FLUORIDE

Unit No.	Breakdown Voltage (Volts)
1	1400
2	2100
3	1800
4	1300

*Sprague Proprietary

DAAB07-71-C-0049

TABLE XXXC

CAPACITANCE AND DISSIPATION FACTOR FOR VARIOUS FREQUENCY
0.00036" METALLIZED COATED*POLYVINYLIDENE FLUORIDE

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Capacitance (μF)	Dissipation Factor (%)
	.1 Hz		1. kHz	
5	5.017	0.95	4.9516	1.16
9	Cannot Read		5.2040	12.90
16	4.9892	0.93	4.9282	1.14
19	5.0920	0.95	5.0316	1.21
	2 kHz		5 kHz	
5	4.9373	1.37	4.9214	2.084
9	5.1972	16.10	5.2167	29.405
16	4.9260	1.34	4.8980	1.94
19	5.0173	1.51	5.0008	2.33
	10 kHz			
5	4.9362	3.08		
9	5.3001	58.6		
16	4.9094	2.96		
19	5.0162	2.03		

*Sprague Proprietary

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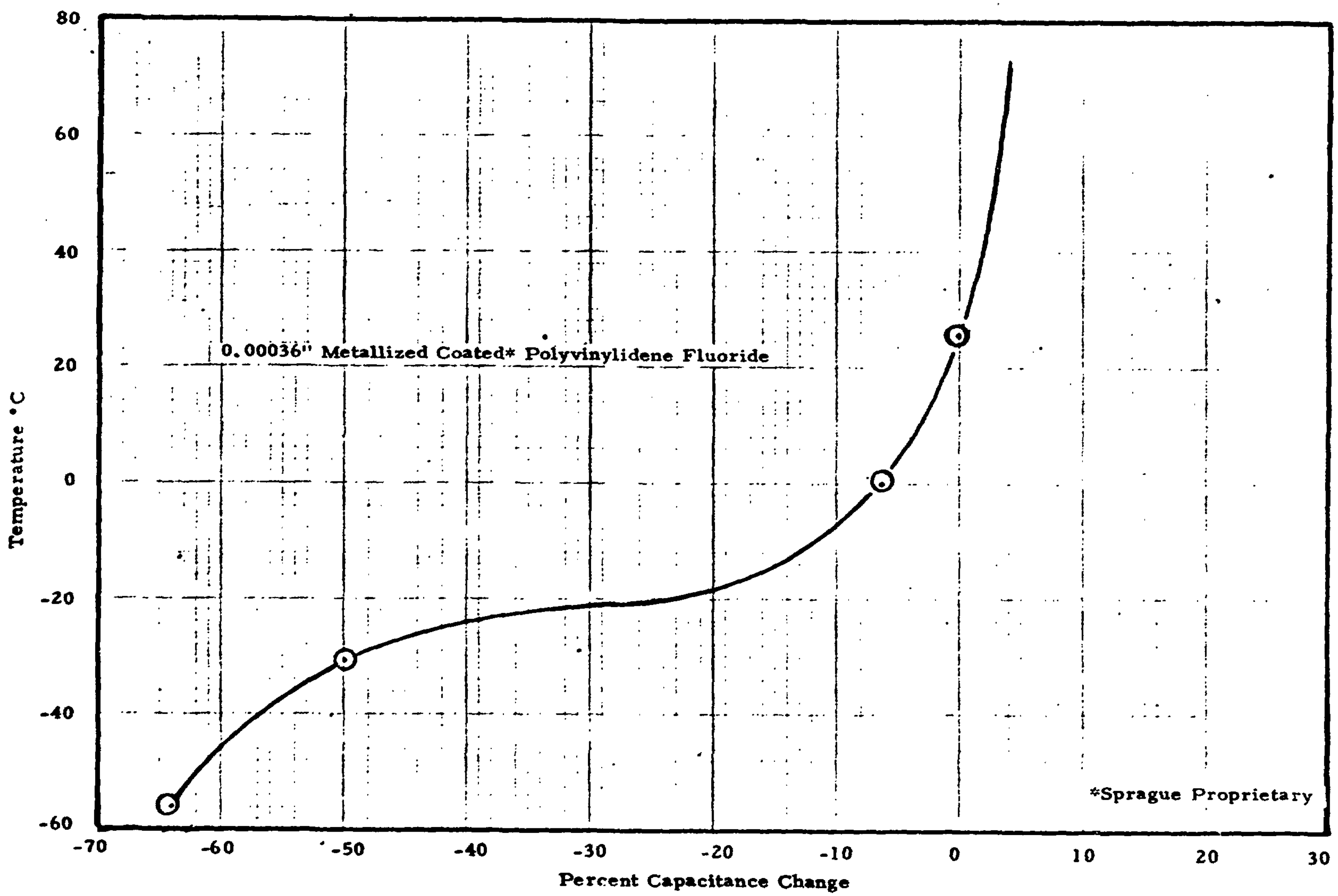

Capacitance Change vs Temperature

Figure 15

TABLE XXXI

CHARGE-DISCHARGE TESTING 30 pps DESIGN E VARIATION 1
(0.00027" METALLIZED COATED* PETP, DIFFERENT GEOMETRY, SILICONE OIL IMPREGNATED)
SPRAY PROCESS C, SOLDER PROCESS I

Unit No.	Capacitance (μF)	Dissipation Factor (%)	Leakage Current (μA)
0 Cycles			
234	30.94	0.53	0.98
235	31.35	0.57	0.20
236	32.25	0.87	0.18
237	32.36	0.55	0.26
238	32.55	0.65	0.53
239	31.82	0.77	0.65
10,000,000 Cycles			
234	30.80	0.75	0.88
235	31.00	0.64	0.20
236	31.32	0.70	0.80
237	Shorted 7,860,553		
238	31.62	0.85	0.75
239	31.60	C.79	0.70

Capacitance and Dissipation Factor at 1000 Hz
Leakage Current at 500 VDC
Test Voltage 900 VDC
Test Temperature 40°C
Measurement Temperature 25°C
Load 32 μH plus 1 ohm resistor
Pulse Rate 30 pps
Peak Current ≈ 400 amps.
*Sprague Proprietary

DAAB07-71-C-0049

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

1. Capacitors weighing approximately six ounces, and capable of supplying 12 joules of energy for 50,000,000 charge-discharge cycles at 10 pps can be produced using metallized coated* 0.00027" PETP and silicone oil as an impregnant. The design objectives of the contract were accomplished.

2. At a repetition rate of 10 pps, silicone oil impregnated units exhibit longer life than do dry unimpregnated units of the same construction.

3. Silicone oil acts more as a heat transfer medium to conduct heat away from the capacitor windings and end connectors rather than increase the dielectric strength of the unit.

4. By increasing the length of the electrode, the life of a metallized coated energy storage capacitor is increased due to the reduction in current per length of electrode.

5. Polysulfone with the present coating system is not a satisfactory dielectric for high repetition rate energy storage capacitors.

6. Coated polycarbonate performed satisfactorily as a dielectric for energy storage capacitors and it may be superior to coated PETP at higher repetition rates.

7. Additional work may prove coated Polyvinylidene Fluoride to be a good dielectric at low repetition rates and where loss of capacitance at low temperatures is not a critical factor.

8. A coated PETP silicone oil impregnated capacitor will operate satisfactorily at 30 pps for at least 10,000,000 charge-discharge cycles.

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*Metallizing and Coating are Sprague Proprietary Processes

9. Additional work should be conducted at higher temperatures and repetition rates on metallized coated capacitors.

10. Additional work should be conducted in an effort to measure the determining factors of the life of a capacitor.