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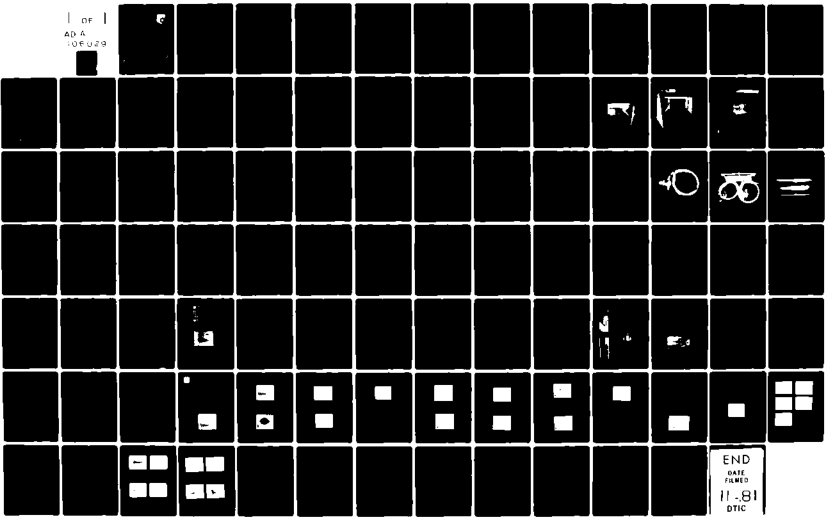

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AFWAL-TR-81-2023

HIGH VOLTAGE TESTING

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P.O. Box 3999
Seattle, Washington 98124

August 1981

Interim Report for Period 24 September 1979 - 20 January 1981

Approved for Public Release; Distribution Unlimited

AERO Propulsion Laboratory
Air Force Wright Aeronautical Laboratories
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

NOTICE

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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Surge Tests
Transformers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The High Voltage Design Guide and High Voltage Specifications and Tests Documents referred to in this report pertain to high voltage/high power airborne equipment. A test plan was designed to evaluate and verify test parameters specified in these documents. This was done by writing detailed test procedures, obtaining representative test samples, and testing the specified parameters. In addition, a standard test fixture and corona-free 150 kV, 400 Hz power supply was specified, evaluated, and delivered for use with a partial discharge test set.

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FOREWORD

Presented herein is the Boeing Aerospace Company's Interim Test Report covering work accomplished on Contract F33615-79-C-2067 for the period of September 24, 1979 through September 30, 1980. This contract is being performed for the U.S. Air Force Wright Aeronautical Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio. The program is under the technical direction of Daniel Schweickart, AFWAL/POOS-2.

Personnel participating in this work for the Boeing Aerospace Company were W. G. Dunbar, the technical leader, and S. W. Silverman, the program manager.

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1.0 PROGRAM OBJECTIVES

The objectives of this program are as follows:

a. Perform high voltage tests on capacitors, cable assemblies and parts, and coils.

b. Design, fabricate, and evaluate a high voltage standard test fixture to be used for measuring the void content in various high voltage insulation systems.

c. Specify and procure a 150 KV, 400 Hz power supply for partial discharge measurements.

d. Update the High Voltage Design Guide completed on U.S. Air Force Contract F33615-76-C-2008 and the Tests and Specifications Criteria Documents completed in U.S. Air Force Contract F33615-77-C-2054.

2.0 SCOPE

The major tasks reported in this Interim Test Report are:

- High voltage power supply verification testing at Hipotronics
- Selection and testing of seven test articles
- High voltage test plans for the seven test articles
- Design and verification testing of the standard test fixture

3.0 BACKGROUND

In previous contracts, high voltage test and specifications criteria *documents* were written for U.S. Air Force airborne power supplies and components which supply megawatts of power at tens of kilovolts to high power/high voltage systems. A generalized power source is shown in Figure 3.0-1 for a turboalternator system. However, the turboalternator can be replaced with a MHD power supply. Emphasis has been placed on minimum weight and volume airborne equipment, which imply compact systems with high density packaging.

The specifications in the criteria documents do not have all the electrical, mechanical, and environmental requirements and test parameters for high voltage and/or high power applications. It is the purpose of this program to evaluate the parameters listed in the applicable criteria documents, written during contract F33615-77-C-2054, by writing detailed test procedures and then test hardware to the specified parameters. Following completion of the test program, the Test and Specification Criteria Documents will be updated to reflect the findings of this test program.

A 150 kilovolt Partial Discharge Detection system was also developed during contract F33615-77-C-2054, and was installed at the U.S. Air Force Wright Aeronautical Laboratory at Wright-Patterson AFB, Ohio. Two new components are being added to this system: a 150 kV, 400 Hz power supply, and a Standard Test Fixture for testing A/C systems, components, and electrical insulation. The addition of these two units to the present direct voltage Partial Discharge Detection System at AFWAL/POOS will give the U.S. Air Force a complete facility for testing electrical properties of materials, components, and systems used in present and future high voltage and/or high power systems.

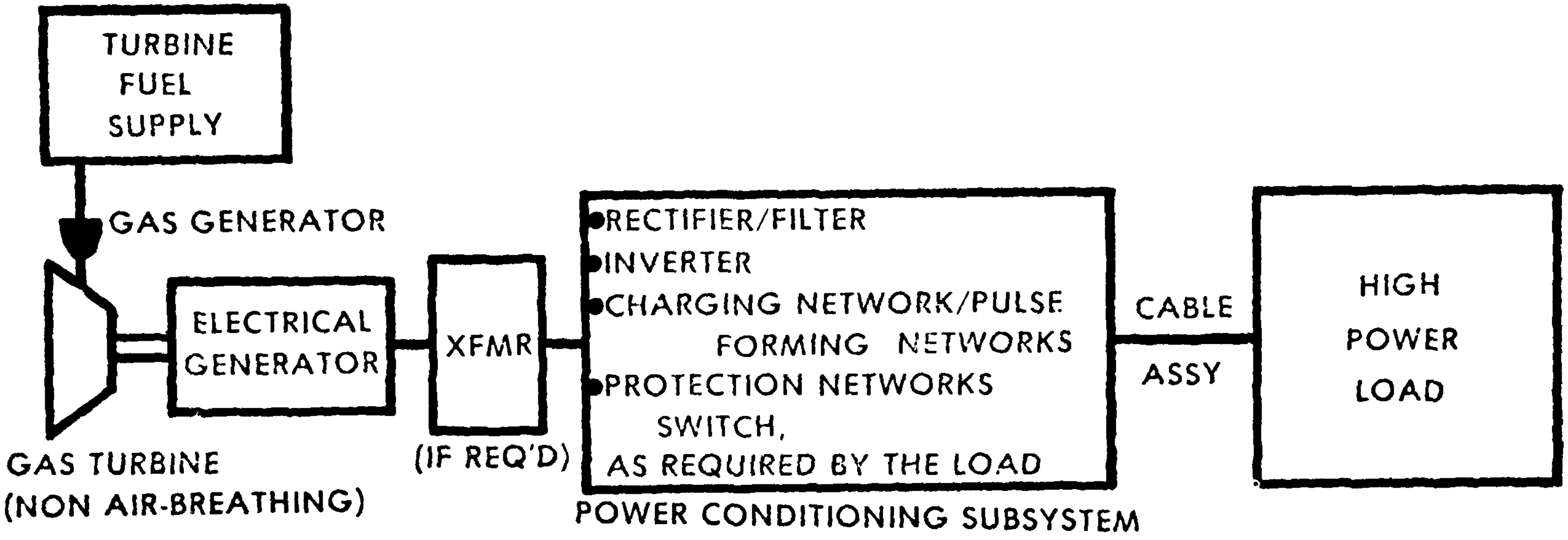

Figure 3.0-1: High Voltage/High Power Airborne System

4.0 HIGH VOLTAGE POWER SUPPLY

4.1 Description. The U.S. Air Force Wright Aeronautical Laboratory purchased a Partial Discharge Detection System capable of detecting 0.1 to 10,000 picocoulombs partial discharges within direct voltage insulation systems. The system is equipped with the following components:

Partial discharge detector
Power separation filter
Calibration Signal Coupler
Voltmeter
Isolation Buffer
Noise Filter
Grounding Wand
Multichannel Analyzer

A system schematic diagram for the facility is shown in Figure 4.1-1.

The dc noise filter is designed to operate with dc applied. The power separation filter/detector is designed to operate with either high voltage ac or dc. To broaden system capability, a high voltage ac power supply (not shown in Figure 4.1-1) was purchased with the following specified electrical parameters and components:

HIGH VOLTAGE TRANSFORMER
Input Voltage: 208 Volts, 400 Hz, 1 Phase
Output: 150 KV, 20 KVA, 400 Hz, 1 Phase, 1 hour duty cycle
        150 KV, 15 KVA, 400 Hz, 1 Phase, continuous
Corona Detector: 20 Picofarads
Oil Filled - Texaco #55 uninhibited transformer oil or equivalent
Life: 10,000 hours in 10 years
      1 year guaranteed
Noise level shall be less than 5 PC at 150 KV

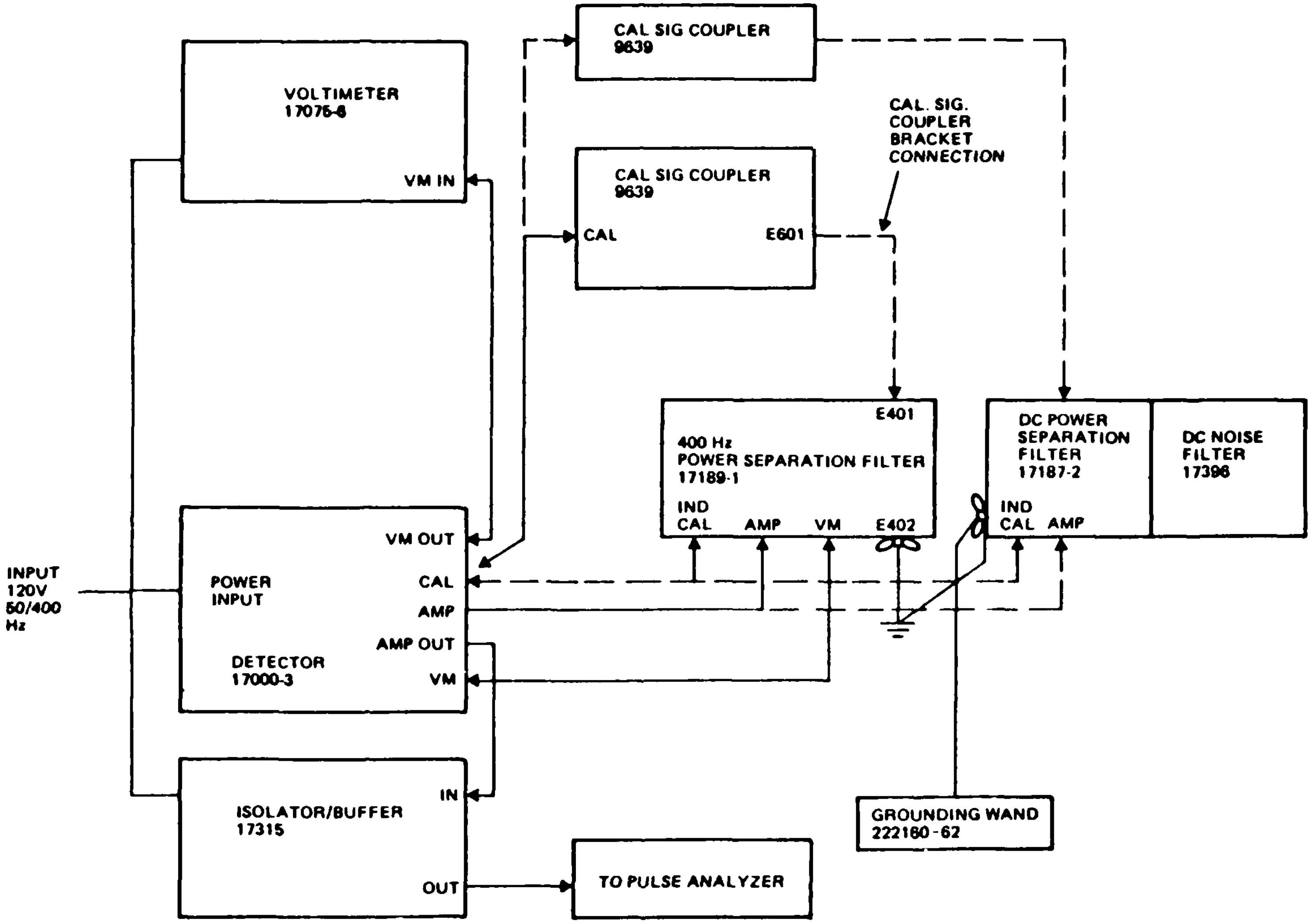

Figure 4.1-1 *Corona Test System Schematic*

CONTROLLER

Input: Controls: 120 Volts, 60 Hz, 1 Phase,
Power: 208 Volts, 400 Hz, 1 Phase, 120 Amperes

Overcurrent protection
Meter relay to preset output voltage

Voltage rise:	30 seconds and/or 300 seconds
Voltage vernier:	10 KV at voltages between 10KV and 140KV

Power line filter
Console writing shelf
Interconnect cables
Power cables

Instruction manuals

Manufacturer: Hipotronics

4.2 Qualification Test. A qualification test was made at the Manufacturer's facility (Hipotronics). Following qualification and inspection, the unit was packaged and shipped to AFWAL where it will become a part of the Partial Discharge Detection System.

4.2.1 Test. The high voltage power supply and controller were connected to the output of a 400 Hz generator. As the controller voltage was increased from 95 kV to 150 kV, corona readings, input voltage, and current readings were taken. The test results are shown in Table 4.2-1.

TABLE 4.2-1: HV POWER SUPPLY TEST DATA

Transformer Output kV	Corona PC (max.)	Controller Input 400 HZ Volts	Amperes
96	1.0	217	33
124	2.0	208	57
145	4.0	218	85
150	4.5	215	84

A check of the voltage vernier was made with the output set at 100 kV.

Boost	100 to 129 kV
Buck	100 to 78 kV

The Controller includes the following operational instruments and controls.

Voltmeter: ac multirange
Ammeter: Primary (transformer) current
Rate of rise control:
  28 seconds (maximum) to full voltage
  300 seconds (minimum) to full voltage
Corona output impedance: 4700 ohms

4.2.2 Auxiliary Components. A three-phase, 400 Hz, 25 Kva, 208/115 volt, ac generator will be used to supply the low voltage input ac energy requirements for the high voltage power supply. This power source should be operated with 0.8 lag to 0.8 leading power factor. The high voltage power supply is a capacitive (leading power factor) load due to the capacitance of the bushing and windings. Therefore it is necessary to 1) decrease the capacitive current demand and 2) balance the generator output (current). To do this, capacitors and resistors must be added to the non-connected phases and an inductor added to the connected phase as shown in Figure 4.2-1. In addition, a delta-connected, balanced resistor network is connected to the primary of the transformer to correct the generator power factor. The component values were calculated as shown below.

Data collected during the qualification test are shown in Figure 4.2-2 and Table 4.2-2.

TABLE 4.2-2: POWER LINE REQUIREMENTS

Voltage kV	Line Current Amperes	Line Volts	Impedance Ohms
96	33	217	6.56
124	57	218	3.82
145	85	218	2.565
150	84	215	2.56

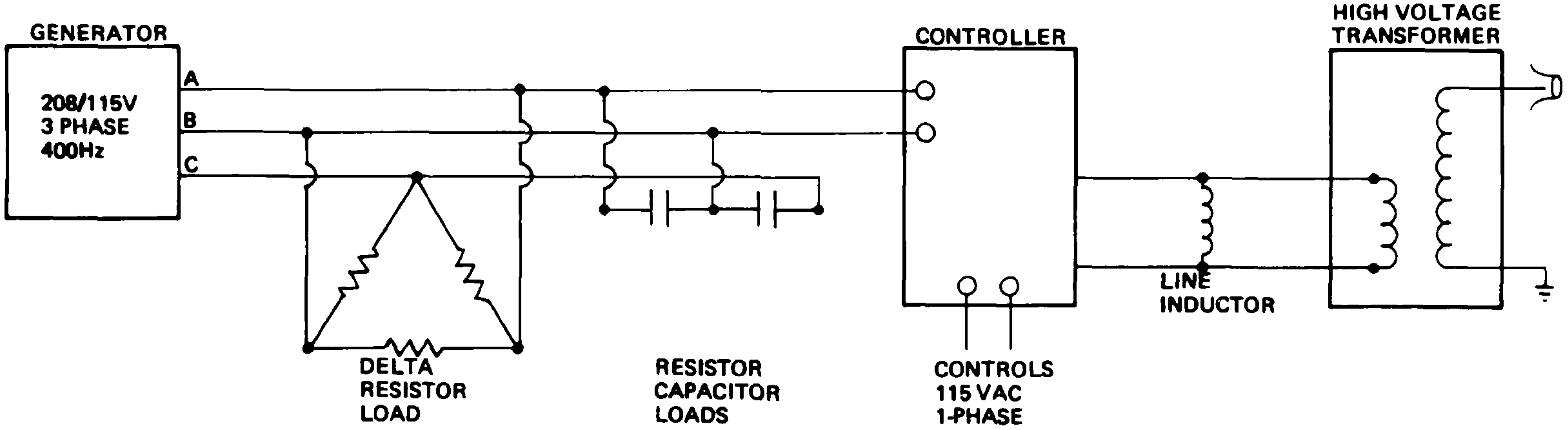

Figure 4.2-1: Power Supply and Auxiliary Components

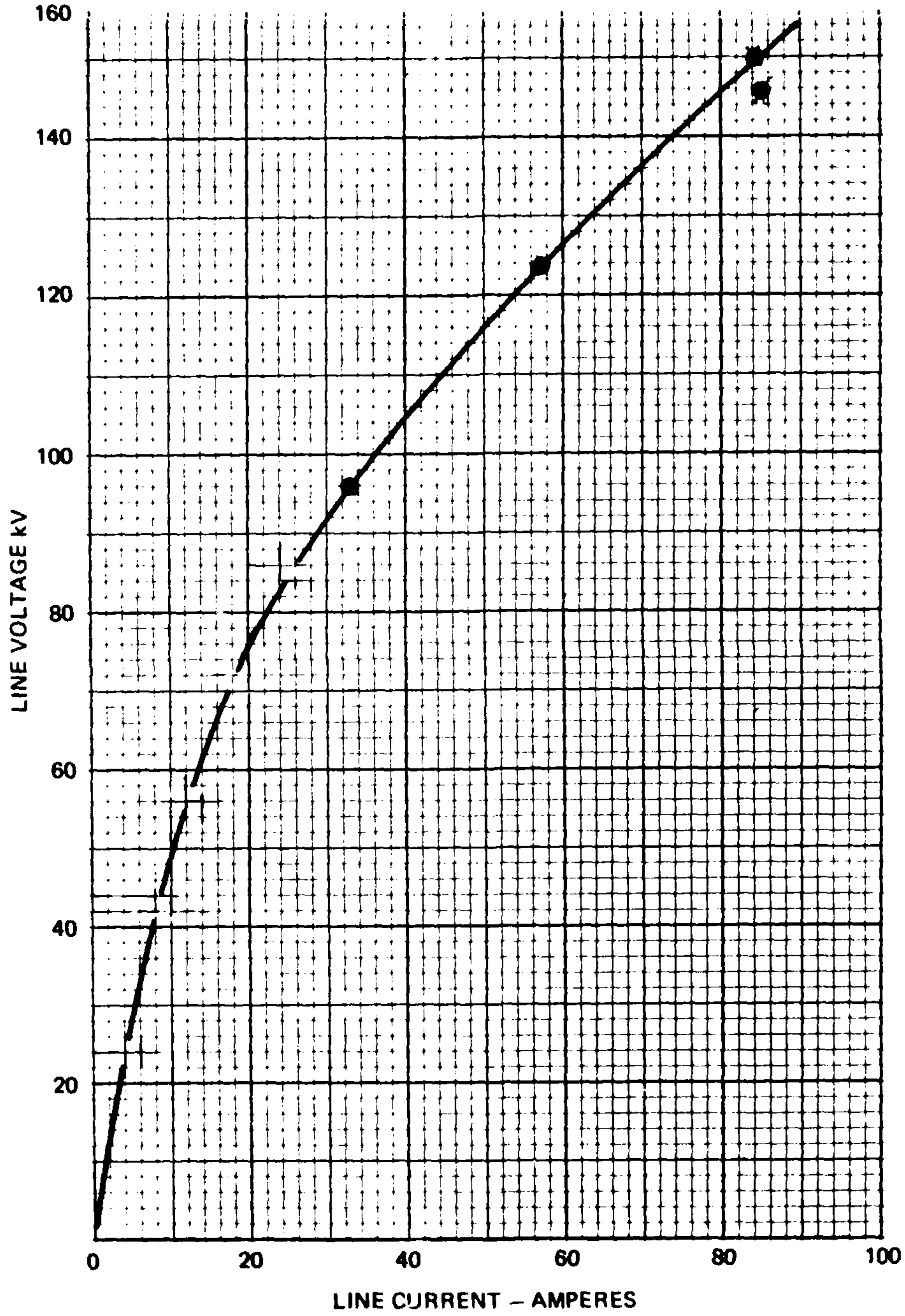

Figure 4.2-2: Power Supply Electrical Input Requirement

A 400Hz, high-voltage transformer reflects a capacitive reactance into the power line rather than an inductive reactance like most low voltage transformers. This capacitance comes from the high voltage bushings and winding capacitances.

The capacitive reactance based on the data shown in Figure 4.2-2 is calculated as follows:

Using the impedance shown in Table 4.2-2, the inductance required for resonance with an unloaded transformer at 140 to 150 kV is

$$Z = X_c = X_l = 2.56 \text{ ohms}$$

To maintain the capacitive reactance status the $X_l > X_c$ or approximately 2.6 ohms

Therefore,

$$L = \frac{X_L}{2\pi f} = 1.03 \text{ millihenry}$$

An inductor of 1.0 to 1.25 millihenry is required. Its rating should be:

Inductance:	0.3 to 1.19 Millihenry
Voltage:	250 volts, ac, continuous
Current:	100 amperes, ac, continuous

5.0 STANDARD TEST FIXTURE

5.1 General. The information and procedures contained within this instruction manual have been prepared to assist the user in connecting, operating, and maintaining the high voltage Standard Test Fixture. The Standard Test Fixture is to be used as a part of the Partial Discharge Detection System at the Wright-Patterson AFB, Oh., Area B, Building 450, Room D109. Care has been taken to include an electrical interlock for safety and specify standard ASTM-D149 electrodes for dielectric strength, breakdown, and partial discharge measurements.

Measurements may be taken with the specimen either submerged in a liquid, encapsulated, or in air. The test fixture was fully tested before shipping. Proper use and maintenance of the test fixture, as outlined herein, will aid in keeping the test fixture at peak performance and prolong its useful life. A safety practices paragraph is included as part of the operators instruction manual to be followed when using this equipment.

5.2 Description. The test fixture is designed to comply with the latest requirements set forth in ASTM-D149 and ASTM-D3382 for standard test methods of testing electrical insulating materials for breakdown, dielectric strength, and partial discharges.

Two plug-in test fixtures, purchased from Associated Research, Inc., Skokie, Illinois are available for testing electrical materials. These fixtures are designed so that they can be easily and quickly changed.

Standard electrodes per ASTM-D149 were also purchased for these fixtures. The fixture part numbers and descriptions are shown in Table 5.2-1.

Table 5.2-1: Test Fixtures and Electrodes

Description	Associated Research, Inc. Part Number
Test Fixture	31550
Test Chamber	31560
2-inch electrode, upper	31867
2-inch electrode, lower	31884
1-inch electrode, upper	31873
1-inch electrode, lower	31883
1/4-inch electrode, upper	31870
1/4-inch electrode, lower	31876

All three electrode sizes are designed to fit into the test fixture. A test sample may be tested either in a gas between the electrodes or in a liquid by inserting the test fixture in the test chamber as shown in Figures 5.2-1, 5.2-2, and 5.2-3. The test fixture and chamber are housed in a bench-mounted steel cabinet measuring 25½ inches high, 21½ inches wide, and 18½ inches deep. A built-in test compartment in the upper part of the cabinet has inside dimensions of 12½ inches high, 17½ inches wide, and 16 inches deep. Hinged double doors are made of clear plexiglass for full view of the test article under test, and to provide access to the test compartment. A double interlock system attached to the two doors can be series-connected to the partial discharge detection system interlock system. High voltage and ground leads are connected to the bottom of the test compartment. These leads will be connected to the Partial Discharge Detection System. Test fixtures, purchased in the future, may be connected to the two high voltage receptacles mounted through the bottom of the test compartment. A photograph of the Test Fixture Assembly, with the test fixture installed, is shown in Figure 5.2-1.

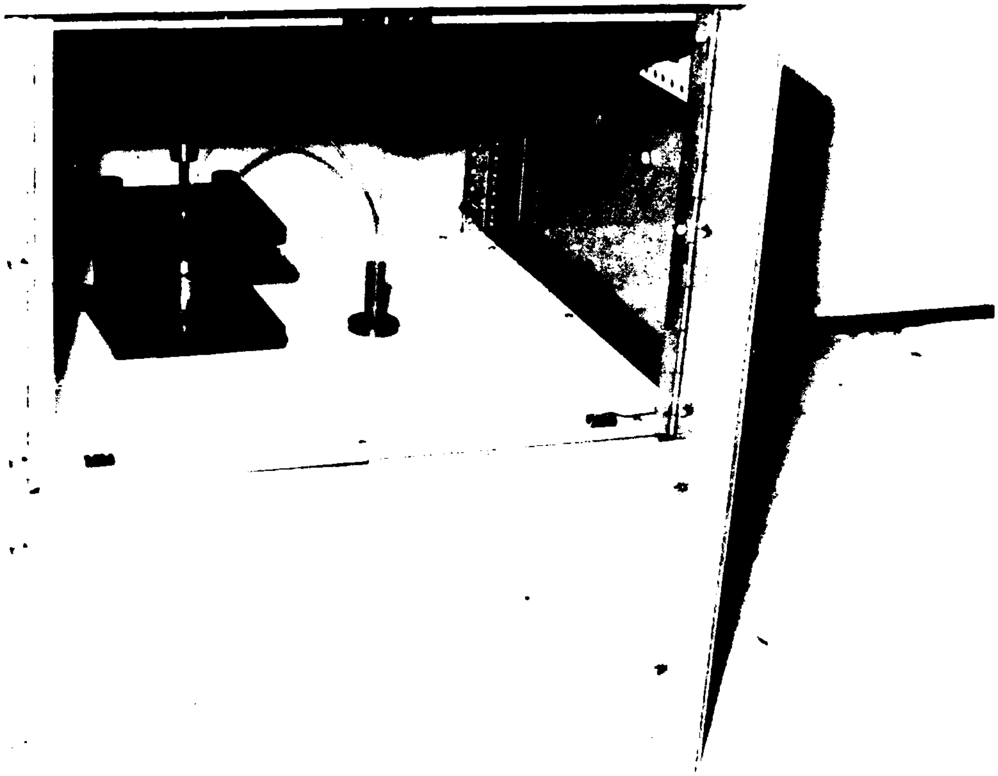

Figure 5.2-1: High Voltage Test Fixture

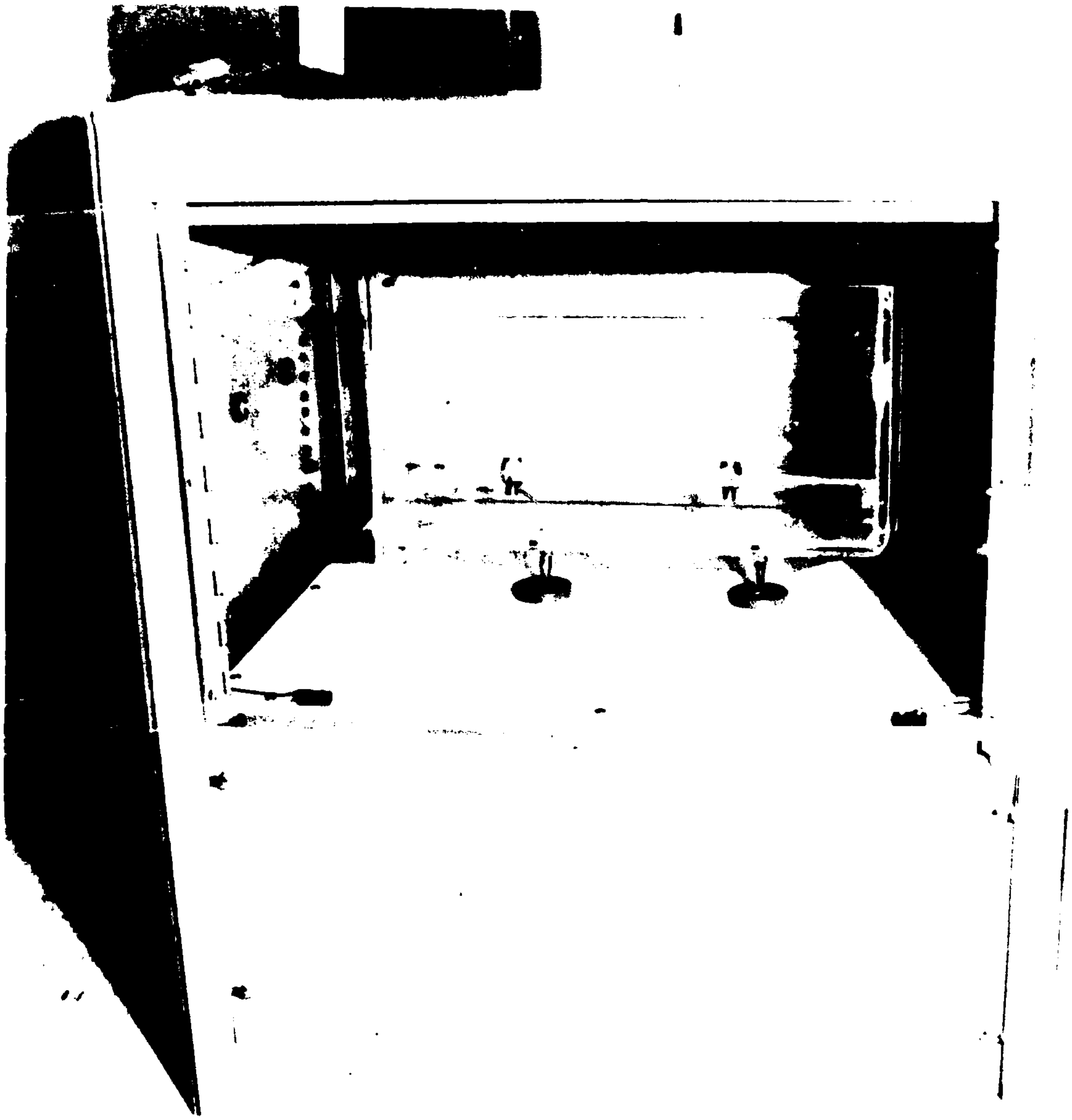

Figure 5.2-2: Test Chamber

Figure 5.2-3: Electrodes Installed in the Test Chamber

5.2.1 Test Compartment. The test compartment houses the high voltage terminations, materials test fixture, and material being tested, augmenting safety for the operator and other personnel. This safety feature permits the instrument to be used in the laboratory, without the need for roping off the area or erecting a test cell.

Two, hinged, clear plexiglass doors provide access to the test chamber. Both doors are equipped with safety interlock switches that can be connected in series with the Partial Discharge Detection System interlock system to disable the High Voltage control circuit when one or both doors are open. The doors are held in the closed position by magnetic latches.

High Voltage terminations are made of two large banana jacks mounted on the bottom plate of the Test Chamber. These jacks receive the banana plug terminations on the materials test fixtures, providing high voltage connection to the fixture electrodes.

5.2.2 Cables. A flexible copper braid ground return is connected to the left terminal. This ground return must be connected to the Partial Discharge Detection System Separation Filter ground. The insulated high voltage lead connected to the right terminal must be connected to the high voltage termination of the Separation Filter. Care must be taken to centrally locate the high voltage wire between all frame edges on the back side of the Test Fixture, to prevent corona and arcing to the frame.

5.3 Principles of Operation.

CAUTION

TO INSURE PERSONNEL SAFETY, THE INTERLOCK SWITCHES MUST BE INCORPORATED INTO THE EXTERNAL PARTIAL DISCHARGE DETECTION SYSTEM CIRCUITRY, AND THE HIGH VOLTAGE LEAD MUST BE GROUNDED AT ALL TIMES THAT THE TEST FIXTURE IS INACTIVE.

5.3.1 General. The following procedure has been prepared to acquaint the user with the fundamental operating procedure of the Test Fixture and to assist in obtaining the maximum performance from the system which includes the Partial Discharge Detection System. For best results ASTM or military specified procedures must be adhered to.

5.3.2 Preliminary Preparation.

CAUTION
THE VOLTAGES PRESENT IN THIS SYSTEM ARE DANGEROUS TO LIFE. USE EXTREME CARE WHEN OPERATING.

a. Clean the Test Fixture high voltage test compartment with alcohol to eliminate all grease, oils and debris. Remove the test fixture electrodes and test chamber.

b. Ground the Partial Discharge Detection System, (PDDS) Power Separation filter high voltage terminal.

c. Connect the Test Fixture interlock in series with the PDDS interlocks.

d. Connect the Test Fixture ground to the PDDS power separation filter ground terminal.

e. Connect the Test Fixture high voltage lead to the PDDS power separation filter high voltage terminal. Adjust the high voltage lead to exit through the center of the Test Fixture rear opening.

f. Close the Test Fixture doors. Check operation of interlock system.

g. Do not remove the PDDS power separation filter ground until the system is ready for checkout.

5.3.3 Checkout. Remove the PDDS power separation filter ground. Slowly increase the voltage in 10 kv steps to 60 kv. Monitor the PDDS output detector and MCS and record any partial discharges at each step. Slowly decrease the voltage to 0 voltage. Open the Test Fixture doors. Ground the PDDS power separation filter high voltage terminals.

5.3.4 Operation.

a. Install the test chamber in the test compartment, insert the banana plugs into the high voltage and low voltage terminals in the base of the test compartment.

b. Install the Test Fixture in the test chamber, insert the banana plug on the base of the test fixture into the high voltage terminal in the test chamber. Insert the banana plug attached to the upper electrode lead into the ground terminal banana plug in the base of the test chamber.

c. Insert the test specimen into the fixture.

d. Fill the test chamber with liquid until the liquid covers the top side of the upper Test Fixture electrode.

e. For test specimens not requiring oil, the Test Fixture may be installed in the test compartment without the test chamber. Connect the two terminals as though the test chamber were used.

f. Remove the ground from the PDDS power separation filter.

g. Close the Test Fixture doors. The insulation system is ready to test.

h. Starting at the low kv range on the PDDS, adjust the high voltage output as specified in the PDDS test procedure.

i. At the conclusion of each test the PDDS voltage shall be reduced to 0 kv, the PDDS power separation filter high voltage terminal grounded, and the Test Fixture interlocked doors opened.

j. Remove the test specimen and prepare for the next test.

5.4 Partial Discharge Verification Tests. Partial discharge tests were performed to verify the high voltage merit of the Test Fixture, not the test article. Evaluation tests were made using 1) a sheet of silicone rubber immersed in flurocarbon, and 2) a multilayered polyimide test article immersed in fluro carbon.

5.4.1 Test Requirements. The following requirements apply:

a. Atmospheric pressure: 100 ± 20 kilopascals.

b. Temperature: $25^{\circ} \pm 5^{\circ}$ C.

c. Relative humidity: 50% to 90%.

d. The test articles shall be immersed in flurocarbon, FC - 77. The flurocarbon shall cover the test article and upper electrode.

e. Test voltage. The test voltage shall be 0 to 20 kv, at dc, 60 Hz or 400 Hz.

f. Rate of application - the test voltage shall be raised uniformly from zero to 50 percent of test specimen rated voltage in not less than 5 seconds; from 50 percent to maximum rated voltage the rate of rise shall not exceed 500 volts per second.

5.4.2 Test Specimen. The test specimens used in the verification test program are described in this paragraph.

5.4.2.1 Polyimide Film. One test specimen part is made of polyimide film measuring 7.5 cm on each side and 0.00254 cm thick. The polyimide film is perforated with 0.0625 cm holes spaced 0.625 cm apart as shown in Figure 5.4-1. The small holes represent voids within the dielectric system. By using three or more film sections, the voids may be located at either electrode surface or in the center of the dielectric system.

5.4.2.2 Silastic Sheet. The second type specimen are made of silastic sheets. The silastic sheets are 0.01524 cm (0.060 in.) thick and 7.5 cm square. The silastic material is a silicone crosslinked demethyl siloxane resin system with titanium dioxide filler manufactured by Dow Corning called Silastic E. Tests may be made using one or more sheets of material.

5.4.2.3 Test Specimen. By placing the perforated polyimide sheet between the electrodes in between silastic sheets or polymide sheets, the effect of voids can be studied.

5.4.3 Tests. Evaluation tests are described in this paragraph. The first set of eval-uation tests were made at the Boeing Aerospace Company. They were: 1) a single one-hole perforated sheet of one-mil (0.00254 cm) polyimide in air with continuous partial discharges, 2) an insulation system sandwich of two sheets silastic E and one sheet poly-imide perforated with one hole, see Figure 5.4-1, sheet No. 2, described in paragraph 5.4.2.1 immersed in fluorocarbon with partial discharges confined to the perforated void, and 3) one sheet of silicone rubber over a perforated polimide sheet immersed in FC-77 with the partial discharges confined to the perforated voids.

The second set of evaluation tests were made at the WPAFB using the Partial Discharge Detection system described in paragraph 4.1. The three test samples tested included the following configurations: Sample 4) three sheets polyimide; one sheet had a single perforation, Sample 5) a silicone/polyimide/silicone sandwich with a single hole in the polyimide sheet, and Sample 6) a silicone/polyimide/silicone sandwich with seven holes in the polyimide sheet.

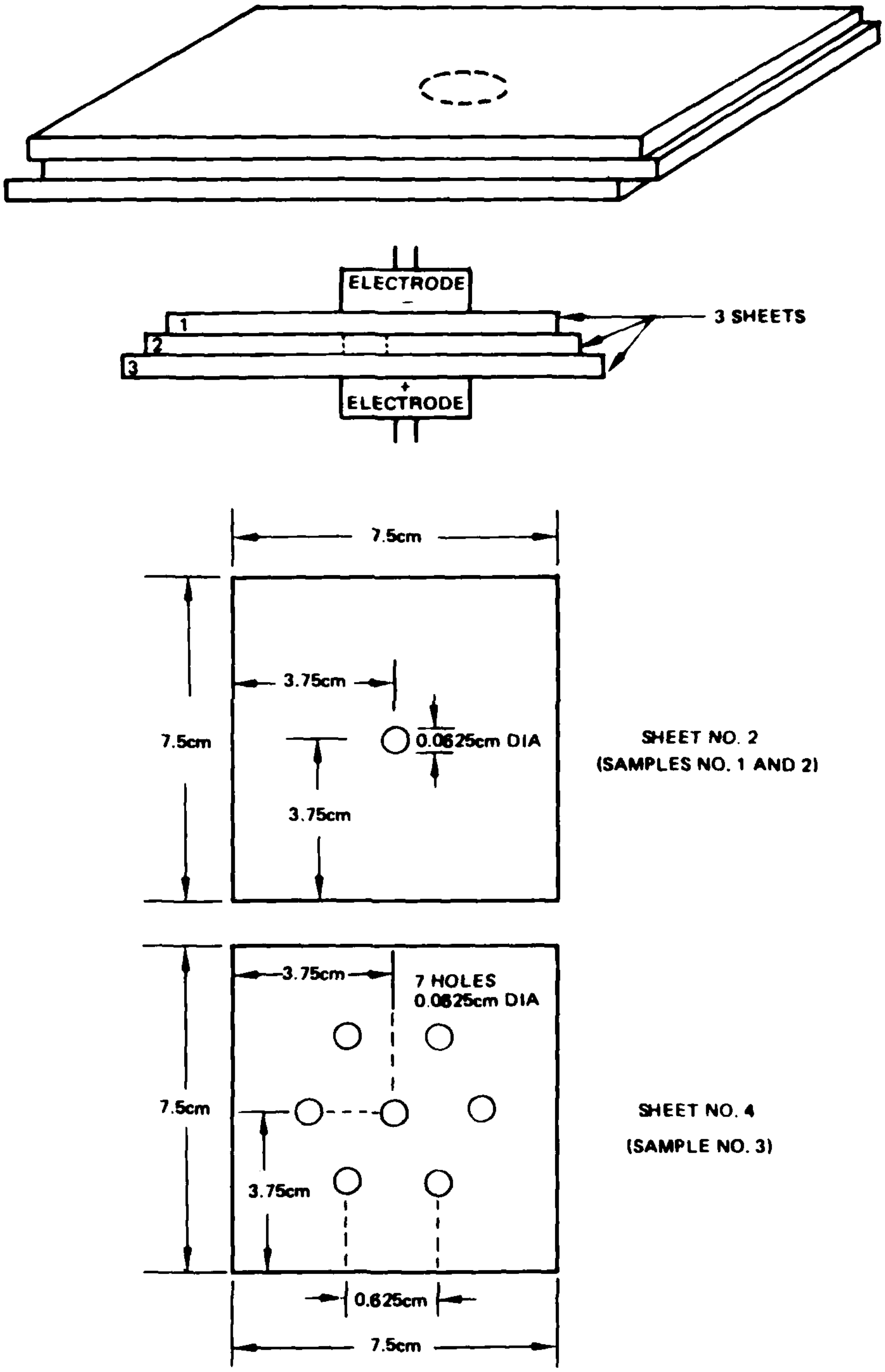

Figure 5.4-1: Insulation System Test Samples

5.4.4 Test Results. The test samples tested at Boeing consisted of the materials shown in Table 5.4-1.

TABLE 5.4-1: INSULATION SYSTEM TEST SAMPLES

Sample Number	Next to Positive Electrode Surface	Next to Negative Electrode Surface	Between Electrode Surface Dielectrics
Tested at Boeing			
1	Perforated Polyimide-one hole	Perforated Polyimide-one hole	None
2	Silastic E	Silastic E	Perforated Polyimide-one hole
3	Silastic E	Perforated Polyimide-7 holes	None
Tested at AFWAL/POOS-2			
4	Solid Polyimide	Solid Polyimide	Perforated Polyimide-one hole
5	Silastic E	Silastic E	Perforated Polyimide-one hole
6	Silastic E	Silastic E	Perforated Polyimide-7 holes

The first three tests were conducted using 60 Hz, 10 kv output power supply. Sample numbers 4, 5 and 6 were tested with 60 Hz and direct voltage power supplies. Sample numbers 4, 5 and 6 were immersed in FC-77. The test results are shown in Table 5.4-2.

TABLE 5.4-2: INSULATION SYSTEM TEST RESULTS

	Insulation System		Partial Discharge		
Sample Number	Layers Silastic E	Perforated Polyimide	Initiation Voltage	Extinction Voltage	Pico Coulombs
1	0	1	320 Vac	315 Vac	0.5
2	2	1	2,300 Vac	2,200 Vac	2.0
3	1	1	2,100 Vac	2,000 Vac	1.5
4	0	1 (2 Solid)	2,350 Vdc 950 Vac	2,300 Vdc 770 Vac	
5	2	1	2,300 Vdc 1,400 Vac	1,800 Vdc 1,200 Vac	
6	2	1	2,150 Vdc 1,700 Vac	2,050 Vdc 1,500 Vac	

5.4.5 Analysis. The above tests were conducted with the voids air-filled at normal temperature and pressure. That is, 23°C and 100 kilo pascals (760 Torr). Using these data and the Paschen law curve shown in Figure 5.4-2, the calculated partial discharge initiation values are as follows for the six test samples.

Sample 1. The partial discharge initiation voltage for the 0.001 inch (0.00254 cm) voids in the polyimide sheets is:

Pressure (P) = 760 Torr
Temperature = 23°C
Spacing (S) (void length) = 0.00254 cm

P x S = 760 x 0.00254 = 1.93 torr-cm
Initiation Voltage (Figure 5.4-2) = 313 volts ac
= 443 volts dc

Voltage breakdown of air is the same value at 60 Hz and 400 Hz.

Sample 2. The air filled void is sandwiched between two silastic E wafers. The physical dimensions and characteristics of the sandwich are:

Silastic E
Dielectric Constant (ε_1) = 3.7
Thickness (T_1) = 0.1524 cm per wafer

Air
Dielectric Constant (ε_2) = 1.0
Thickness (T_2) = 0.0025 cm per wafer

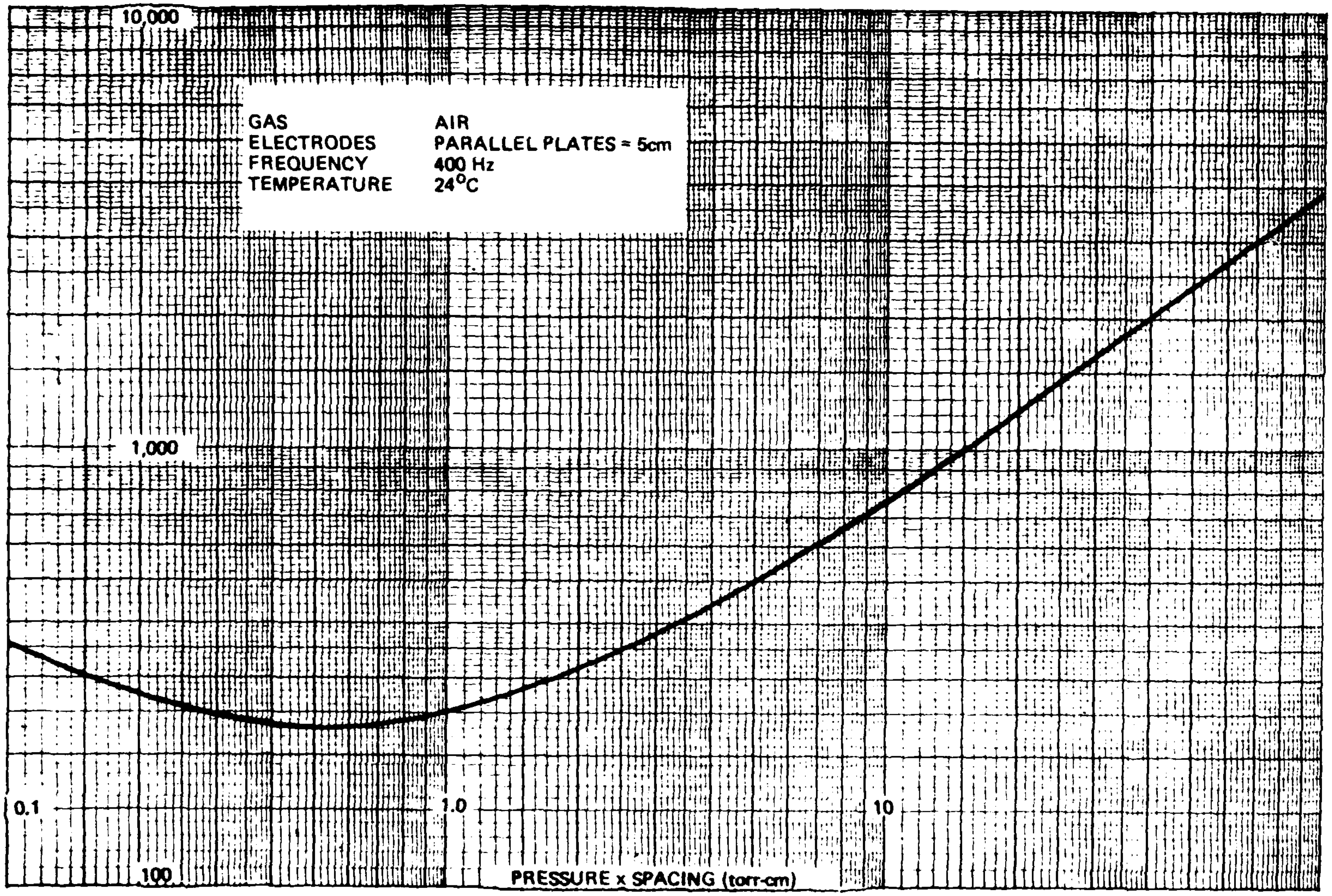

Figure 5.4-2: Paschen's Law Curve

The applied voltage (V^1) required to obtain partial discharges across the polyimide void (V_2) is (Reference 1)

$$V = V_2 \left\{ \frac{t_1}{t_2} \frac{\mathcal{E}_2}{\mathcal{E}_1} + 1 \right\}$$

$$= 313 \left\{ \frac{0.1524}{0.00254} \cdot \frac{1.0}{2.9} + 1 \right\}$$

$$= 313 \times 21.7$$

$$= 6792 \text{ volts}$$

In sample 1 calculations show the partial discharges within the single polyimide sheet are accurate. In samples 2 and 3 voids or bubbles existed in the gas at the silastic sheet electrode interface generating partial discharge at much lower value than anticipated within the polyimide sheet. This test will be re-run at a later date with the sandwiched parts next to the metalized electrodes.

Reference 1. "High Voltage Design Guide for Airborne Equipment," AFAPL-TR-76-41, Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433.

6.0 TEST ARTICLES

6.1 Introduction. Engineering criteria documents were developed for eight components for high-power high-voltage airborne systems on contract F33615-77-C-2054, "High Voltage Specifications and Tests (Airborne Equipment)" in 1977 and 1978. The eight criteria documents were written in accordance with military specifications for: cables, cable assemblies, capacitors, connectors, converters, power characteristics, power sources, and transformers and inductors.

Included in each criteria document were high voltage tests and test parameters based on insulation design parameters and engineering judgment. In this program eight test articles were selected which represented components or component parts for the components discussed in the criteria documents. The selected test articles are:

Cable
Cable Assembly
Connector
Alternator Coil (Section)
Transformer Coil
Capacitors (3 Kinds)

Each test article was tested for:

Insulation Resistance
Dielectric Withstanding Voltage
Surge Voltage
Partial Discharges (Corona)

In most cases, the test article was tested for capacitance to determine the loading for the partial discharge test facility. Section 6.2 of the document is devoted to the description of the test articles. Section 6.3 is devoted to the test plan, including the test parameters. The test data is in Section 6.4 and a correlation of the test results and parameters set forth for similar test articles in the criteria documents, and changes to the criteria document test procedures and parameters.

6.2 Test Articles. The eight test articles were either purchased from or supplied by manufacturers of high-voltage high-power components for high-voltage high-power equipment.

6.2.1 Cables, Cable Assembly and Connector. One connector assembly and one cable assembly were purchased from Contractor A. The cables were constructed with a semicon layer extruded over the inner conductor, the primary insulation extruded over the inner semicon layer and an outer semicon layer extruded over the primary insulation next to the shield as described in the cable criteria document, AFAPL-TR-79-20R4, High Voltage Specifications and tests. The connector and shield termination was molded onto the cable as described for the connector in the connector criteria document. The primary insulation was EPR, the semicon layers carbon-filled EPR, and the outer jacket neoprene. The 90kV cable assembly is designed to be tested as a cable when the connector mating half is disconnected. Test configurations are described in Table 6.2-1. Photographs of the cable assemblies and connectors are shown in Figure 6.2-1 and 6.2.2.

TABLE 6.2-1: TEST CONFIGURATION

Configuration	Part Designation	Test Article	Voltage Rating K Vdc
Cable	A-1	Cable Only	90
Cable Assembly	A-2	Cable and Connector	90
Connector	A-3	Connector with High Voltage Lead	60
Cable Assembly	A-4	Cable with two Connectors	60

6.2.2 Capacitors. Three cylindrical plastic-cased high-voltage capacitors were purchased from Contractor B and one rectangular metal-cased capacitor was supplied by the U.S. Air Force from Contractor C. The electrical and physical parameters of the capacitors from Contractor B are listed in Tables 6.2-2 and 6.2-3. A photograph of the capacitors is shown in Figure 6.2-3.

Figure 6.2-1: Cable Assembly and Connector

Figure 6.2-2: Test Articles

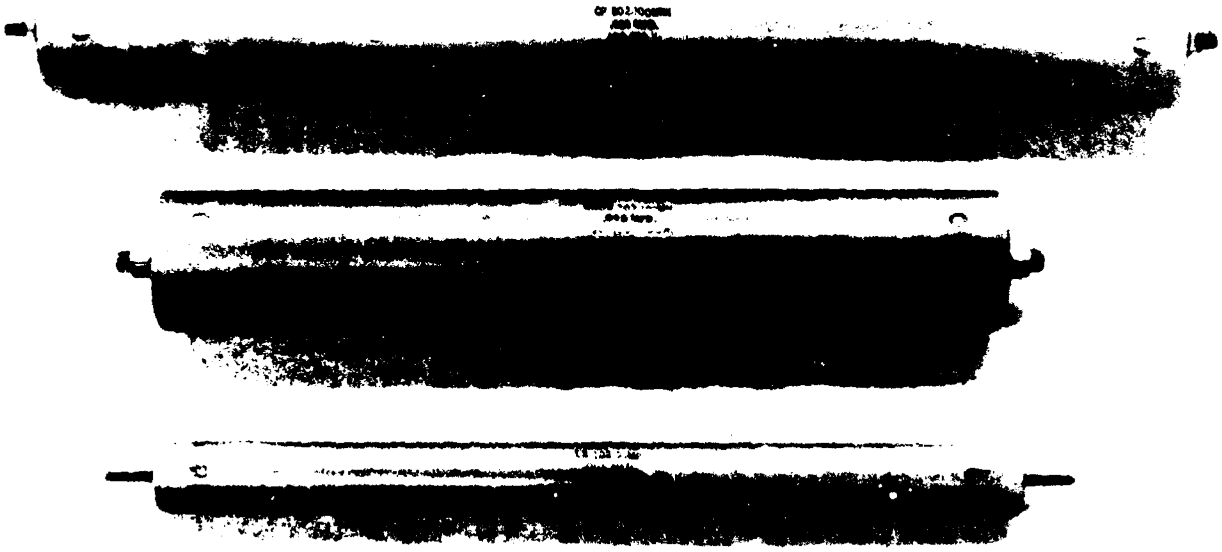

Figure 6.2.3: Capacitors

Table 6.2-2: Electrical Parameters Of Capacitors

Unit	Contractor	Part Designation	Capacitance, Microfarads	Voltage Rating, kV	Use
1	B	B-1	0.005	100	Filters with low-inductance and high-peak current capacity.
2	B	B-2	0.005	100	Low inductance and dissipation factor for high current, high rep-rate, fast pulse discharge operation.
3	B	B-3	0.001	80	Low inductance, high peak operation up to 10^5 shots with rep-rates to 100 PPS.
4	C	C-1	2.2	15	High energy density for use in PFN with repitition rates to 300 PPS.

Table 6.2-3: Physical Characteristics Of Capacitors

Unit	Part Designation	Length, Inches	Width, Inches	Diameter, Inches	Height, Inches	Configuration	Coating	Terminals
1	B-1	17½	-	2¼	-	Round	Phenolic	2
2	B-2	25	-	3¼	-	Round	Phenolic	2
3	B-3	13½	-	1	-	Round	Phenolic	2
4	C-1	6	4	-	6	Rectangular	Metal	2

6.2.3 Alternator Coil. Three straight sections of an alternator coil were obtained from Contractor D for test. Each section is insulated as in the final alternator configuration consisting of six square tubular copper coils sections as shown in Figure 6.2-4, without the 0.039 to 0.056 inch taper conductor insulation is double glass, nominal 10-mil build. The coil is half-lap wrapped, nominal 6-mil Fusa-Fab^R polyester and glass tape. The wedge adjacent to the coil in Figure 6.2-4 is not part of the coil. Wedges are cut to fit the actual gaps between coils: the wedge will be simulated by placing strips of 6 -mil Fusa-Fab^R polyester between adjacent coils during test.

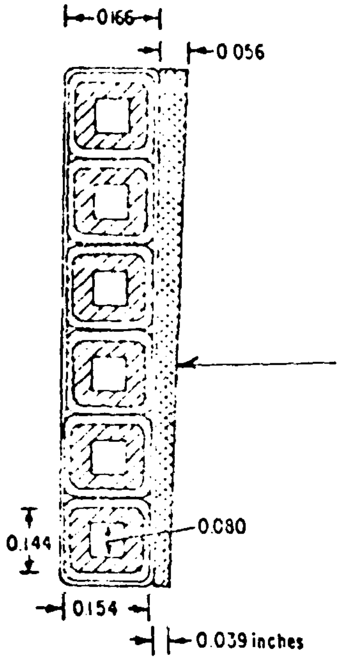

Figure 6.2-4. Coil Cross Section

6.2.4 <u>Transformer Coil</u>. (To be delivered in 1981.)

6.3 Test Procedure. Each test article was tested in accordance with the test procedures outlined in the High Voltage Criteria documents using test equipment delineated in either the appropriate Military Standards, Military Specifications, ASTM Standards, or the High Voltage Criteria Document. The specific test procedure and test equipment are detailed for each test.

6.3.1 <u>Insulation Resistance</u>. When tested for insulation resistance at a potential of 500 ± 50 Vdc, the minimum insulation resistance shall be greater than 1000 megohms.

6.3.1.1 Procedure. Each component identified in paragraph 6.2, in turn, shall be attached to an electrical circuit and a potential of 500 ± 50 Vdc shall be applied between the high voltage terminal and ground or for the generator coils between adjacent coil groups. The potential shall be applied for a period of one minute, minimum. However, if a stable reading is obtained in less than one minute and the results are in excess of 1000 megohms, the minimum allowable, the test may be terminated.

During the energization period, the insulation resistance shall be measured and shall be 1000 megohms, minimum.

6.3.1.2 Connections. Electrical connections shall be made to the test article terminals as described in Table 6.3-1.

TABLE 6.3-1: ELECTRICAL CONNECTIONS

TEST ARTICLE		CONNECTIONS	
CONFIGURATION	PART DESIGNATION	POSTIVE	NEGATIVE
Cable	A-1	Center Conductor	Shield
Cable Assembly	A-2	Center Conductor	Shield
Connector	A-3	Center Conductor	Shield
Cable Assembly	A-4	Center Conductor	Shield
Capacitor	B-1	(+)Terminal	(-)Terminal
Capacitor	B-2	(+)Terminal	(-)Terminal
Capacitor	B-3	(+)Terminal	(-)Terminal
Capacitor	C-1	(+)Terminal	(-)Terminal
Generator Coil	D-1	Conductor #1	Conductor #2
Transformer Coil	-	To be determined	To be determined

6.3.1.3 Instruments. Insulation resistance shall be measured with certified calibrated instruments. Approved instruments or equivalent are listed in Table 6.3-2.

TABLE 6.3-2: INSTRUMENT FOR MEASURING INSULATION RESISTANCE

Instrument Function	Manufacturer	Model
Insulation Resistivity	General Radio	GR 1862C

6.3.2 Capacitance. When test aritcles are tested for capacitance, the capacitance shall be within ± 1.0% of the specified value.

6.3.2.1 Procedure. Each component identified in Paragraph 6.2, in turn, shall be attached to an electrical circuit and tested for capacitance as specified in MIL-STD-202, Method 305. A frequency of 100 Hz shall be applied between the active terminals or parts.

6.3.2.2 Connections. Electrical connections shall be made to the applicable test articles terminals as described in Table 6.3-1.

6.3.2.3 Instruments. Capacitance shall be measured with the certified calibrated instrument or equivalent, as shown in Table 6.3-3.

TABLE 6.3-3: CAPACITANCE MEASURING INSTRUMENT

Instrument	Manufacturer	Model
Capacitance Bridge	ESI	ESI 270

6.3.3 Dissipation Factor. The three capacitors listed in Table 6.2-2 shall be tested for dissipation factor. The dissipation factor shall be less than 0.050 ± 2 percent instrumentation error.

6.3.3.1 Procedure. Each component identified in Table 6.2-2 shall be connected to an electrical circuit and tested for dissipation factor per AFAPL-TR-79-2024, (Appendix C, Paragraph 6.7.11). A frequency of 100 ± 10 Hz at a voltage not to exceed 20 percent of the capacitor rated voltage shall be applied between the active terminals listed in Table 6.3-1.

6.3.3.2 Connections. Connections shall be made to the capacitor terminals as described in Table 6.3-1.

6.3.3.3 Instruments. The dissipation factor shall be measured with the certified calibrated instruments or equivalent, as shown in Table 6.3-4.

Table 6.3-4: DISSIPATION FACTOR MEASURING INSTRUMENT

Instruments	Manufacturer	Model
Capacitance Bridge	ESI	ESI-270

6.3.4 Dielectric Absorption. The three capacitors listed in Table 6.2-2 shall be tested for dielectric absorption. The dielectric absorption time shall be within 15 minutes.

6.3.4.1 Procedure. Each component identified in Table 6.2-2, in turn shall be attached to the electrical circuit of Figure 6.3-1.

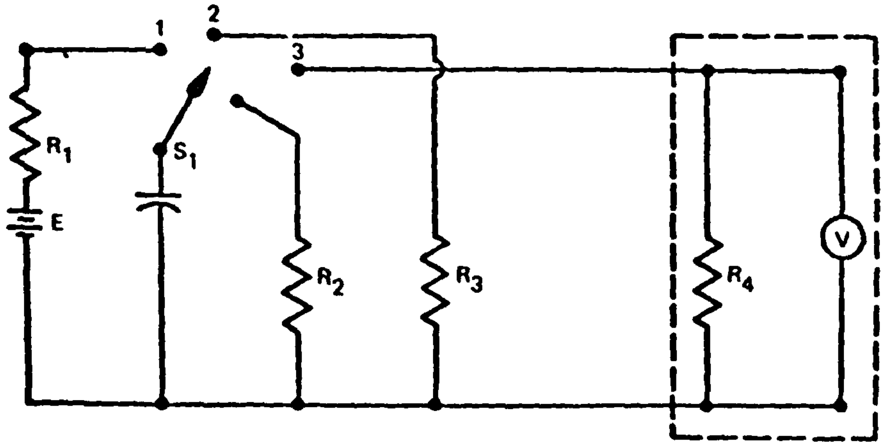

Figure 6.3-1 Typical Production Dielectric Absorption Test Method

The capacitor shall be charged at 50 percent of the dc voltage rating for 2 hours ± 1 minute. The initial surge current shall not exceed 50 milliamperes. At the end of this period, the capacitor shall be disconnected from the power source and discharged through a 5 ohm ± 2 percent resistor for 10 ± 1 seconds. The discharge resistor shall be disconnected from the capacitor and the recovery voltage shall be measured with an electrometer or other suitable device having an input resistance of 10,000 megohms, or greater. Recovery voltage shall be read at the maximum voltage within a 15 minute period. The dielectric absorption shall be computed from the following formula:

$$d = \frac{V_1}{V_2} \times 100$$

Where:

d = Percent dielectric absorption
V_1 = Maximum recovery voltage
V_2 = Charging voltage

6.3.4.2 Capacitor Connections. Connections shall be made to the capacitor terminals as described in Table 6.3-1.

6.3.4.3 Instruments. Dielectric absorption shall be measured using the certified calibrated instruments or equivalent listed in Table 6.3-5.

TABLE 6.3-5: DIELECTRIC ABSORPTION MEASURING INSTRUMENTS

Instrument	Manufacturer	Model
Power Supply	TRYGON	M160-5A
Electrometer	Keithly	610BR
Timer	Graylab	167

6.3.5 Dielectric Withstanding Voltage (DWV). The test articles tested in Paragraph 6.2 shall be tested for DWV. When tested to the specified test parameter for one minute, there shall be no evidence of breakdown, arcing, or other visible damage to the test article.

6.3.5.1 Procedure. Each test article listed in Paragraph 6.2, in turn, shall be connected to a high voltage electrical circuit per MIL-STD-202, Method 301. The component shall be tested in accordance with MIL-STD-202, Method 301, with the test parameters listed in Table 6.3-6. The duration of the test shall be one minute ± 5 seconds. Leakage current shall be measured and plotted for each coil insulation configuration. Coils shall be tested with 1, 2, and 3 strips of insulation between coils. Connections shall be as shown in Table 6.3-1.

6.3.5.2 Instruments. DWV shall be measured using the certified calibrated instrument, or equivalent, listed in Table 6.3-7.

TABLE 6.3-6: DIELECTRIC WITHSTANDING VOLTAGE PARAMETERS

Test Article	Part Designation	Test Freq.	Test #1	Voltage, kV #2	#3
Cable (90kV)	A-1	DC	108	125	144
Cable Assembly	A-2	DC	108	125	144
Connector	A-3	DC	72	86	100
Cable Assembly	A-4	DC	Not Tested	-	-
Capacitor (100kV)	B-1	DC	160	180	200
Capacitor (100kV)	B-2	DC	160	180	200
Capacitor (80kV)	B-3	DC	130	145	160
Capacitor	C-1	DC	Not Tested	-	-
Generator Coil	D-1	60Hz	2.8	3.2	3.6
Transformer Coil	-	60Hz		TBD	

TABLE 6.3-7: DIELECTRIC WITHSTANDING VOLTAGE INSTRUMENT

Instrument	Manufacturer	Model
250Kv Power Supply	Universal Voltronics	BAL200-18

6.3.6 Surge Test. Each component identified in Paragraph 6.2 shall be subjected to surge tests separated a minimum of 20 seconds apart. Testing shall be discontinued if there is evidence of breakdown, arcing, or other physical damage to the test articles.

6.3.6.1 Procedure. Each test article listed in Paragraph 6.2, in turn, shall be connected to an electrical circuit as specified in IEEE Publication, Number 4, 1978, ANSI C-57, or ANSI C-93. Test points shall be as shown in Table 6.3-1. The surge voltage levels shall be as shown in Table 6.3-8. The surge voltage profile shall be as specified in the above mentioned IEEE Publication Standard and similar to that shown in Figure 6.3-2, using an instrument such as that described in Table 6.3-9.

TABLE 6.3-8: SURGE VOLTAGE PARAMETERS

Test Article	Part Designation	Peak Voltage Minimum kV	Peak Voltage Maximum kV
Cable (90kV)	A-1	120	200
Cable Assembly	A-2	120	200
Connector	A-3	80	120
Cable Assembly	A-4	80	120
Capacitor	B-1	120	200
Capacitor	B-2	120	200
Capacitor	B-3	100	160
Capacitor	C-1	10	15
Generator Coil	D-1	4	10
Transformer Coil		TBD	TBD

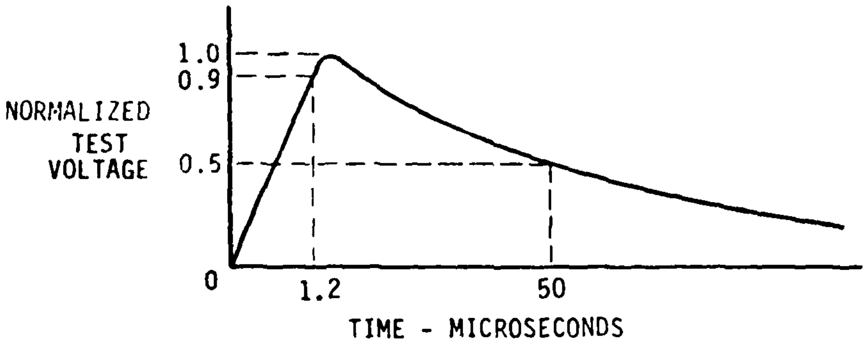

Figure 6.3-2 Basic Insulation Level Test Voltage Profile

TABLE 6.3-9: SURGE TEST INSTRUMENTS

INSTRUMENT	MANUFACTURER	MODEL
Marx Generator 2-7 Stages 0.3 MFD - 0.1 MFD 35KV - 225kv	USAF	
Voltage Divider	Hipotronics	RVD 1000
Power Supply	Hipotronics	8100-25
Storage Oscilloscope	Hewlett-Packard	1744A (100 MHz)

6.3.7 Partial Discharges. The test articles listed in Paragraph 6.2 shall be tested for partial discharges. When tested for partial discharges to the specified test parameters, there shall be no evidence of breakdown, arcing, or other visible damage to the test article.

6.3.7.1 Procedure. Each test article listed in Paragraph 6.2, in turn, shall be connected to the high voltage circuit of a partial discharge test facility and tested for partial discharges and/or corona. Capacitors shall be tested with dc voltages only. The cable, connector, and cable assembly shall be tested with ac and dc voltages. AC voltages (rms) shall be 35.5% of the dc voltage. Generator and transformer coils shall be tested with ac voltages only. The following details shall apply:

(a) Magnitude of test voltage - 100%;
(b) Nature of potential - dc or ac, as applicable to the test article;
(c) Duration of application of test voltage - partial discharges shall be measured for 60 seconds after operating voltage is attained. Voltage shall be increased from 0 to operating test voltage at a rate of 500 volts per second;
(d) Points of application of test voltage - as specified in Paragraph 6.2;
(e) Examination after test - the test article shall show no visible damage;
(f) Partial discharges shall not exceed more than one discharge per minute above 10 pc. Partial discharges greater than 1000 pc are unacceptable.

Partial discharges within the test article shall be calculated per ASTM D1868 or ASTM D3382-75.

6.3.7.2 Instruments. Partial discharges shall be measured using the corona test facility located at the U.S. Air Force Aero Propulsion Laboratory AFWAL/POOS-2, which includes a 17000-3 Partial Discharge Detector, a 150 kV (17187-2) Power Separation Filter, 400 Hz (17189-1) Power Separation Filter manufactured by J. G. Biddle Co.; an ND60 Nuclear Data, Inc., Multichannel Analyzer; and a 150 kV 400 Hz Power Supply manufactured by Hipotronics.

6.4 Test Data. Seven of the eight test articles were tested for insulation resistance, capacitance, and dielectric withstanding voltage using the test procedures and equipment delineated in Paragraph 6.3.

6.4.1 Insulation Resistance. The insulation resistance test data is shown in Table 6.4-1. Insulation resistance was measured at 500 volts, dc.

TABLE 6.4-1: INSULATION RESISTANCE

Test Article	Part Designation	Insulation Resistance, Megohms
Cable	A-1, Connector Unmated	2.0×10^6
Cable Assemblies	A-1, Connector Mated	2.0×10^6
Connector	A-2, Connector Mated	2.0×10^6
	A-3, Connector Unmated	2.0×10^6
Capacitors	B-1	1.25×10^5
	B-2	1.0×10^6
	B-3	5.6×10^5

Two alternator coil sections were tested in four configurations; 1) in parallel, 2) in parallel with one strip insulation 3) in parallel with two strips insulation; and 4) in parallel with three strips insulation. The insulation strips are

6-mil Fusa-Fab polyester material. The strips are 0.88 inch wide and 20 inches long. The insulation resistances for four configurations are shown in Table 6.4-2.

TABLE 6.4-2: ALTERNATOR COIL INSULATION RESISTANCE

Configuration Insulation Strips	Insulation Resistance Megohms
0	7×10^5
1	1×10^6
2	2×10^6
3	2×10^6

6.4.2 Capacitance. The capacitance of each test article is shown in Table 6.4-3.

TABLE 6.4-3: CAPACITANCE

Test Article Configuration	Part Designation	Capacitance
Capacitors	B-1	0.00499 mfd
	B-2	0.00484 mfd
	B-3	0.00102 mfd
Cable	A-1 Connector Unmated	173 pfd
Cable Assemblies	A-1	177.5 pfd
Connector	A-2	170.5 pfd
Cable	A-3 Connector Unmated	165 pfd
Alternator coil sides (parallel with insulation strips)		
	0 strips	320.8 pfd
	1 strip	268.8 pfd
	2 strips	228.8 pfd
	3 strips	203.8 pfd

6.4.3 Dissipation Factor. The dissipation factor for each capacitor is shown in Table 6.4-4.

TABLE 6.4-4: CAPACITOR DISSIPATION FACTOR

Part Designation	Dissipation Factor
B-1	0.0020
B-2	0.0040
B-3	0.0015

6.4.4 Dielectric Absorption. The dielectric absorption was measured by energizing the capacitors to 100 volts dc. The percent dielectric absorption is calculated by the formula:

$$d = \frac{V_1}{V_2} \times 100$$

Where:

d = Percent dielectric absorption
V_1 = Maximum recovery voltage
V_2 = Charging voltage

Test results are shown in Table 6.4-5.

TABLE 6.4-5: DIELECTRIC ABSORPTION

Part Designation	Dissipation Absorption Percent
B-1	2.1%
B-2	2.2%
B-3	2.7%

6.4.5 Dielectric Withstanding Voltage. Each test article was subjected to the dielectric withstanding voltages shown in Table 6.3-6 using the instrument shown in Table 6.3-7. The test results are shown in Table 6.4-6. The laboratory report data is shown in Appendix A.

TABLE 6.4-6: DIELECTRIC WITHSTANDING VOLTAGE TEST DATA

		Test Voltage	
Test Article	Part Designation	Rated kV dc	Passed kV dc
Cable	A-1 Connector Unmated	90	144
Cable Assembly	A-2 A-3	90	144
Cable	A-3 Connector Unmated	60	100
Connector	A-3	60	100
Capacitor	B-1	100	200
Capacitor	B-2	100	200
Capacitor	B-3	80	160
Alternator Coil	Insulation Layers	KV ac	KV ac
	0	2.8	6
	1	2.8	6
	2	2.8	6.4
	3	2.8	6.8

Dielectric withstanding voltage measurements were taken in a step series with 10 seconds hold at each of the lower voltage levels and one minute hold at the highest voltage. All test articles passed the dielectric withstanding voltage test as it is specified in the High Voltage Specification Criteria documents. The voltage levels are shown on the laboratory data sheet shown in Appendix A.

6.4.6 Surge Test. Each test article was subjected to the surge test voltages shown in Table 6.3-8 using the equipment shown in Table 6.3-9. The test results are shown in Table 6.4-7. The laboratory report data is in Appendix A.

6.4.5 Dielectric Withstanding Voltage. Each test article was subjected to the dielectric withstanding voltages shown in Table 6.3-6 using the instrument shown in Table 6.3-7. The test results are shown in Table 6.4-6. The laboratory report data is shown in Appendix A.

TABLE 6.4-6: DIELECTRIC WITHSTANDING VOLTAGE TEST DATA

		Test Voltage	
Test Article	Part Designation	Rated kV dc	Passed kV dc
Cable	A-1 Connector Unmated	90	144
Cable Assembly	A-2 A-3	90	144
Cable	A-3 Connector Unmated	60	100
Connector	A-3	60	100
Capacitor	B-1	100	200
Capacitor	B-2	100	200
Capacitor	B-3	80	160
Alternator Coil	Insulation Layers	KV ac	KV ac
	0	2.8	6
	1	2.8	6
	2	2.8	6.4
	3	2.8	6.8

Dielectric withstanding voltage measurements were taken in a step series with 10 seconds hold at each of the lower voltage levels and one minute hold at the highest voltage. All test articles passed the dielectric withstanding voltage test as it is specified in the High Voltage Specification Criteria documents. The voltage levels are shown on the laboratory data sheet shown in Appendix A.

6.4.6 Surge Test. Each test article was subjected to the surge test voltages shown in Table 6.3-8 using the equipment shown in Table 6.3-9. The test results are shown in Table 6.4-7. The laboratory report data is in Appendix A.

The alternator coil sections were surge tested with and without insulation strips. A fast pulse was used for this test, having a 500 nanosecond rise to full voltage (negative) and a fall to near 0 voltage in 2.5 microseconds as shown in Figure 6.4-1. The coil sections were short (approximately 20 cm long) low-inductance test articles. These short pulse tests give a higher surge stress to the insulation system. The test data are shown in Table 6.4-8.

TABLE 6.4-7: SURGE TEST DATA

TEST ARTICLE	PART DESIGNATION	TEST VOLTAGE KV	STATUS
Cable (90kv)	A-1	120	Failed
Cable Assembly	A-2	120	Failed
Connector	A-3	75	Failed
		Retest 34, 45	Passed
		60	Failed
Cable Assembly	A-4	34, 50	Pass
		68	Connector Joint Failed
Capacitor	B-1	110	Pass
		165	Failure Borderline
Capacitor	B-2	58, 92, 110	Pass
		155, 210	Damage Indicated
Capacitor	B-3	51	Pass
		48	Fail
Capacitor	C-1	7, 12.6, 14.5	Passed

After connector A-3 was removed from the cable, the cable was retested. The cable failed at 60 kV in subsequent testing.

TABLE 6.4-8: ALTERNATOR COIL SURGE TEST DATA

Alternator Coil Insulation Layer	Impulse Voltage, kv	
	Pass	Failed
0	-	8
1	8	10
2	11	13
3	-	13

Photographs of good insulation integrity and breakdown are shown in Figures 6.4-1 and 6.4-2. Breakdown is indicated by loss of the original wave shape, such as an oscillation.

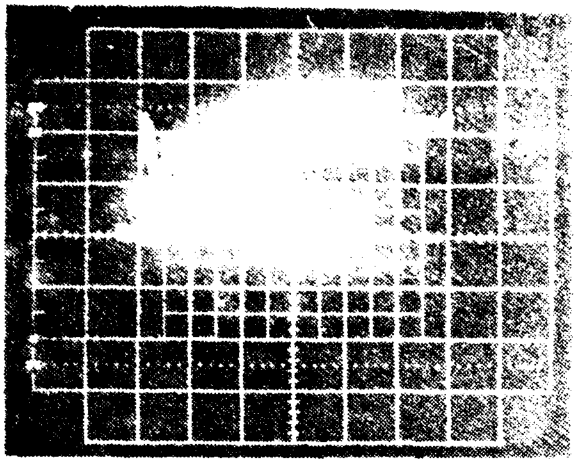

Figure 6.4-1: Generator Coil, D-2 Negative Surge; Vertical: 4kV/div, Horizontal: 500ηs/div.

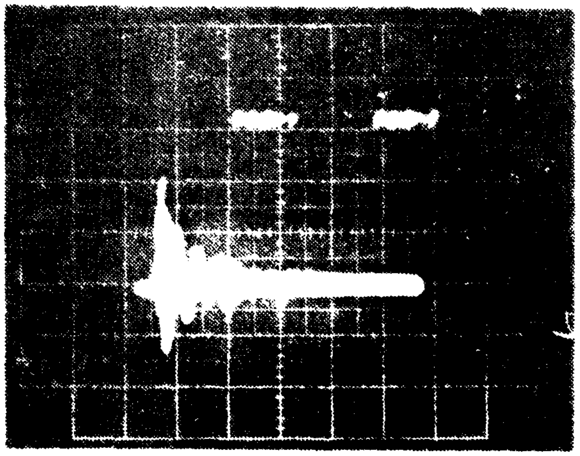

Figure 6.4-2: Generator Coil, D-1 Negative Surge Failure;
Vertical: 2kV/div, Horizontal: 500ηs/div.

6.4.7 Partial Discharge Test. Each test article was subjected to the partial discharge test delineated in Paragraph 6.3.7.1 using the instrumentation specified in Paragraph 6.3.7.2. Test results for the cables, cable assemblies, connectors and capacitors are shown in Table 6.4-9. The laboratory test data for these items are tabulated in Appendix B.

TABLE 6.4-9: PARTIAL DISCHARGE TEST DATA

Number partial discharge/second at rated voltage

Test Article	Part Designation	Test Voltage	Pulse Height - PC						
			1-2	3-4	4-5	9-10	20-30	30-40	
Cable	A-1	75.3	Multitude	1.45	0.65	0.03	0.7	0.012	failed
Cable Assembly	A-2	Connector breakdown							
Connector	A-3	60.3	2.77	0.5	0	0	0	0	
Cable Assembly	A-4	50.3	3.4	1.5	0.02	0	0	0	
Capacitor	B-1	100.1	50	0.8	0.41	0.18	0.33	0.03	failed
Capacitor	B-2	99.7	0.5	0.215	0	0	0	0	
Capacitor	B-3	Breakdown occurred at 2.5 kV							
Capacitor	C-1								
Presurge		15	0.0	0	0	0	0	0	
Postsurge		15	0.016	0	0	0	0	0	

The generator coils were tested with three 6-mil Fusa-Fab^R polyester strips between the coils. The ac initiation and extinction voltages are tabulated in Table 6.4-10. In addition, the counts/minute at the specific partial discharge magnitude and pulse height analyzer channels are recorded in Table 6.4-11.

TABLE 6.4-10: GENERATOR COIL INITIATION/EXTINCTION VOLTAGES

Test	Insulation Thickness, mils	Initiation Voltage, kV	Extinction Voltage, kV
1	42	2.9	2.6
2	42	2.9	2.7
3	42	2.85	2.75

TABLE 6.4-11: GENERATOR COIL PARTIAL DISCHARGE/MINUTE AT 2.9kV

Picocoulombs, PC	Pulse Height Channel	Analyzer Counts/minute
20	19	87
40	56	92
60	94	78
80	129	52
100	166	42
200	333	8
350	498	1

6.5 Discussion of Test Results. Test data are discussd and analyzed in the following paragraphs. The High Voltage Criteria Documents listed as Appendices in AFAPL-TR-2024, "High Voltage Specifications and Tests (Airborne Equipment)", April 1979 will be updated using the information obtained from the test data.

6.5.1 Test Objectives. The primary objective for the testing was to determine the acceptable test limits for airborne high voltage components. The secondary objective was to evaluate each type test and determine whether it is a destructive test or an evaluation test.

Tested components were to be unqualified commercial devices that may be tested to destruction to meet the above goals. The destructive tests were dielectric withstanding voltage and surge tests.

6.5.2 Insulation Resistance. These tests are usually taken at low voltage (500 volts dc or less) and are used to determine the probability of short circuits and the current rating of the power source required for high voltage dc testing. Components and short cable assemblies used in airborne and airborne support high voltage systems should have insulation resistance readings exceeding 500 megohms. All test articles exceeded that value.

Insulation resistance values specified in the criteria documents are compared to the test data as shown in Table 6.5-1. These data show that the values specified in the documents are much lower than the values obtained for the test articles. This implies that the criteria document data should be increased to the values shown for "New Criteria Document Values" in Table 6.5-1.

TABLE 6.5.1: INSULATION RESISTANCE

Components Specified	Tested	Criteria Document, Megohms	Test Data, Megohms	New Criteria Document Value, Megohms
Cable	A-1	Not Specified	$2X10^6$	$1X10^7$/ft
	A-3		$2X10^6$	
Cable Assembly	A-1	500	$2X10^6$	$1X10^7$/ft
Capacitors	B-1	50,000	$1.25X10^5$	$1X10^5$
	B-2		$1.0X10^6$	
	B-3		$5.6X10^5$	
Connectors	A-2	500	$2.0X10^6$	$1X10^6$
Generator Coil	D-1	Not Specified	0.7 to $2X10^6$	$1X10^4$

6.5.3 Capacitance and Dielectric Absorption. These tests are component rating verification tests used to evaluate the component quality. No changes are required for the criteria documents.

6.5.4 Dielectric Withstanding Voltage. The values listed in the High Voltage Criteria documents must be modified. Although all the components passed the specified dielectric withstanding voltage (DWV) tests, the capacitors were damaged by the test as determined by the high partial discharge readings. The cable assembly, cable, and connector test values are acceptable as recorded in the criteria documents. The compared data and new data are shown in Table 6.5-2.

Each test article should be tested for partial discharges before and after the DWV test to further evaluate the probability of damage to the test article.

TABLE 6.5-2: DIELECTRIC WITHSTANDING VOLTAGE

Components Specified	Tested	Rating, kV DC	Test Specified, kV	Voltage Passed, kV	Proposed Value, kV	% Rated Voltage
Cable	A-1	90	144	144	144	160
	A-3	60	100	100	100	160
Cable Assembly	A-2	90	144	144	144	160
Connector	A-3	60	100	100	100	160
Capacitor	B-1	100	200	200	160	160
	B-2	100	200	200	160	160
	B-3	80	160	160	128	160
Alternate Coil	D-1	2.8	3.6	3.6	4.5	160

6.5.5 Surge Test. More information was gained from the surge test than from the DWV test. First, the values specified in the criteria documents are too high, and second, high voltage surge may permanently damage the insulation system in the vicinity of a bonding flaw. Surge test data corrections to the criteria documents are shown in Table 6.5-3.

TABLE 6.5-3: SURGE TEST COMPARISON

Components Specified	Tested	Rating, kV DC	Test Voltage Specified, kV	Passed, kV	Proposed Value, kV	% Rated Voltage
Cable	A-1	90	360	failed 120	180	200
Cable Assembly	A-2	90	360	failed 120	180	200
Cable Assembly	A-4	60	210	50 failed	120	200
Connector	A-3	60	210	75 failed	120	200
Capacitor	B-1	100	400	110	175	175
	B-2	100	400	110	175	175
	B-3	80	400	51	190	175
	C-1	15	60	14.5	26	175
Alternator Coil	D-1	2.8	5.6	11	5.6	5.6

The proposed values for the components are easily justified since each of these items must be capable of withstanding the normal line transients imposed upon these components. Crowbar circuits and vacuum tube (when used) shorts can generate transient peak values of 160% normal line voltage (Reference 2). In addition, insulation systems should be capable of withstanding short duration peaks (less than one second) 20% higher than the one minute DWV peak voltage.

Examples of insulation system damage by surge testing is shown in Figures 6.5-1 through 6.5-5. The first example shows the damage to test article A-2, a 90 kV cable assembly.

The cable assembly A-2 was tested to 120 kV peak. Following the test, the test data waveform indicated an insulation breakdown. The cable was examined and a puncture was visible at the cable shield termination, Figure 6.5-1. The termination was dissected and the insulation flaw was found to be between the primary insulation and the shield extending into the primary insulation toward the inner conductor, Figure 6.5-2. In Figure 6.5-3, the delaminated insulation system is exposed. Shown is a crack and a very dark spot where the arcing occurred. The bright area indicates an unbonded section near the shield termination - an air filled void.

The second cable assembly A-4 also failed the surge test. Following the test, the cable was examined for visual failure. Found was a smokey haze on the connector termination. The termination was unassembled and the parts examined. In Figures 6.5-4 and 6.5-5 are shown the inner surface of the connector shell and the braid. Both show indications of the internal insulation failure. The insulation was badly charred between the braid and inner conductor.

6.5.6 Partial Discharge Test. The partial discharge test data indicate that test articles damaged by DWV or surge testing have very high partial discharge test signatures. This is an indication that more voids exist either

Reference 2. "Transmitter Transient Study"
Boeing memo, J. Fitch to W. G. Dunbar

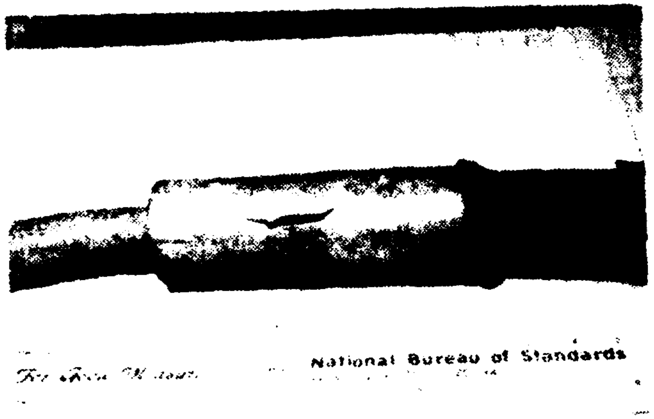

Figure 6.5-1. Cable Assembly A2 Surge Test Failure

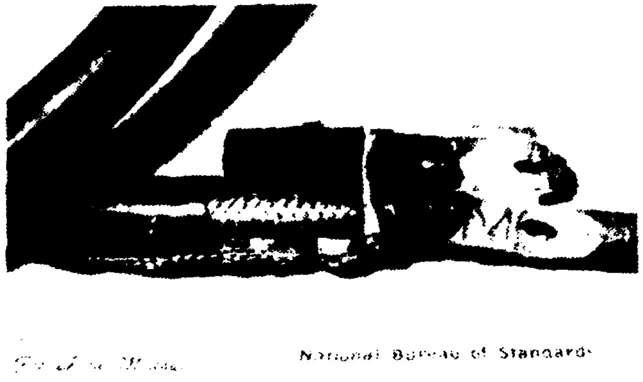

Figure 6.5-2. Shield Bond Failed

Figure 6.5-3. Detail of Bond Failure

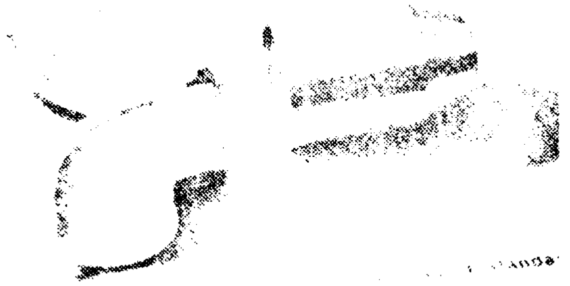

Figure 6.5-4. Cable Assembly A-4 Surge Test Failure Showing Residue on the Connector Shell

Figure 6.5-5. Failure Occurred Between Braid and Center Conductor

by delamination as in the case of cable assemblies, or by the liquid being forced from weak areas within the capacitor foils. All capacitor cables and cable assemblies that indicated surge test damage had higher than normal picocoulomb readings.

A capacitor with no indication of surge test or DWV test damage (C-1) had very low picocoulomb readings. Likewise connector A-3 had very low readings.

The actual test data shown in Appendix B has a multitude of pulses at picocoulomb readings less than 0.6 picocoulomb. Most of these pulses were caused by laboratory background noises generated by transformers, wiring, and other electromagnetic interference from electronic systems within the unshielded portion of the laboratory. The large power supply used for high voltage testing was unshielded.

The generator coils are insulated with a glass impregnated matrix with the edges of each coil exposed to atmospheric conditions. Therefore, partial discharges will be generated within the glass matrix and in the air space across the coil edges. These values may approach or exceed 400 picocoulombs. These large readings, although undesirable, will not damage the glass matrix insulation within the allowable lifetime of the insulation system of 100 to 1000 hours.

7.0 CONCLUSIONS

Based on the test articles evaluated in this program, the following summary statement, overall conclusions, and results are presented.

- Seven high-voltage test articles were subjected to the insulation resistance, capacitance, dielectric withstanding voltage, surge, and partial discharge tests as specified in the High Voltage Criteria Documents published in the USAF document AFAPL-TR-79-2024. It was found that the insulation resistance and capacitance test methods and parameters are acceptable. The partial discharge and dielectric withstanding voltage test methods are acceptable but the parameters must be revised, and the surge test parameters must be revised.

- The dielectric withstanding voltage parameter must be reduced to 160% component rated voltage.

- The surge peak voltage must be limited to 200% component rated voltage. In addition, the surge test time-voltage wave shape must be revised to the acceptable limits of test equipment and instrumentation. However, if more realistic wave shapes cannot be determined due to lack of system definition, the standard 1.2 X 50 micro second pulse shall be used.

- A new test sequence should be followed. The sequence should be:
  - insulation resistance
  - capacitance
  - partial discharge
  - dielectric withstanding voltage
  - surge
  - partial discharge

- Components passing the DWV and surge tests must pass the second partial discharge test with less than 20% increase in maximum picocoulomb partial discharge magnitude in a one-minute test period.

- Partial discharge magnitudes for the generator coils must be much higher than for shielded or contained components, such as cable assemblies and capacitors. Picocoulomb values to 400 pc are acceptable for the glass matrix materials.

- Generator cable assemblies and connectors must be tested separately and remain within the acceptable limits for the components.

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APPENDIX A

SURGE TEST DATA

Two sets of surge data were taken. High voltage test data to 225 kv peak were taken at Technology/Scientific Services, Inc. at Dayton, Ohio for the cables, cable assemblies, capacitor and connector. The generator coils were tested at the Boeing Lightning Laboratory. Both sets of data are in this Appendix.

TECHNOLOGY/SCIENTIFIC SERVICES, INC.
A SUBSIDIARY OF TECHNOLOGY INCORPORATED
P. O. Box 3065, Overlook Branch, Dayton, Ohio 45431
Tel. (513) 426-2405

November 20, 1980

TEST RESULTS OF TEST ARTICLES - CONTRACT No. F33615-79-C-2067.

LIST OF TEST EQUIPMENT USED:

A Marx Generator: 2-7 stages used, .35μfd - .1μfd, 35 KV-225 KV.

A Hipotronics Voltage Divider: Model RVD 1000

A Hipotronics Power Supply: Model #8100-25

A Hewlett-Packard Storage Oscilloscope: Model #1744A (100 MHz).

A schematic of the test setup is shown in Figure 14.

TEST ARTICLES AND RESULTS

#1. Cable Assembly (A-3) and connector (60 KV)

Initial charge on the Marx generator was set for 120 KV as per test plan. ("Test Articles", Boeing memo 2-3743-OSWS-426. 27 October 1980).

The oscillograms show that the cable broke down at 75 KV. (See figures 1 and 2).

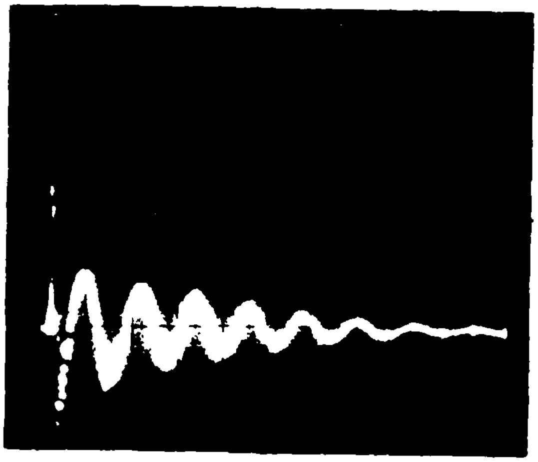

Figure 1. Vertical: 25 KV/div Horizontal: 5μsec/div Oscillogram of First Shot onto Cable Assembly (≈75 KV).

2

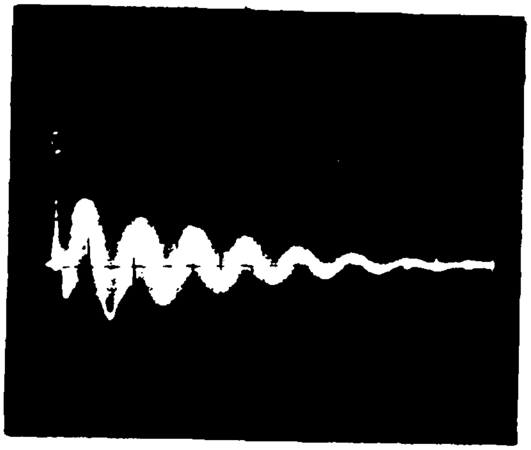

Figure 2. Vertical: 25 KV/div Horizontal: 5μsec/div
Oscillogram of #2 shot to Cable Assembly with
#1 Breakdown Point Put in Liquid Freon. (~75 KV)

The connector was removed from the end of the cable assembly and the HV end was tested with the open end of the cable in the freon. Figures 3-6 show the resulting impulse test results.

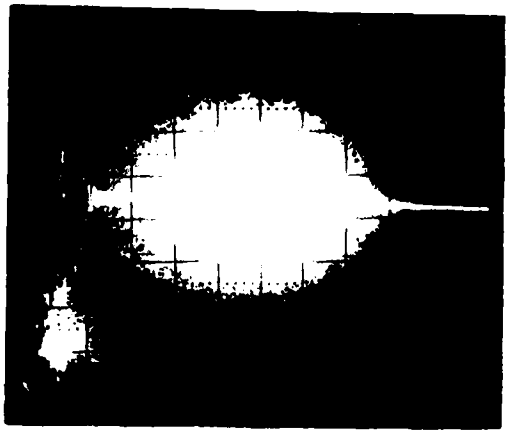

Figure 3. Vertical: 10 KV/div Horizontal: 2μsec/div
An Oscillogram of the Impulse Applied to Connector
With Cable Open End in Freon. (≈34 KV).

3

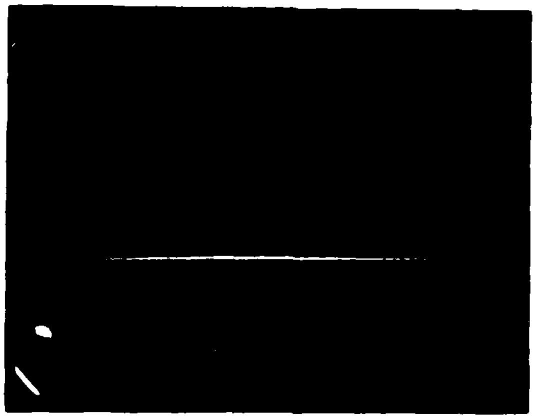

Figure 4. Vertical: 20KV/div Horizontal: 2μsec/div
A Repeat of Shot #3 to Verify Voltage Level(≈34KV).

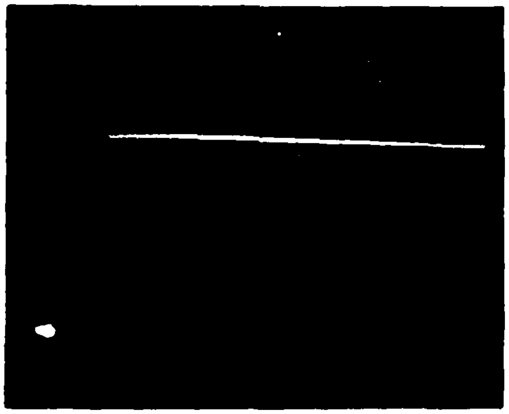

Figure 5. Vertical: 10 KV/div Horizontal: 2μsec/div
Increased Voltage Applied to Connector Assembly and Cable Open End in Freon (≈ 45 KV).

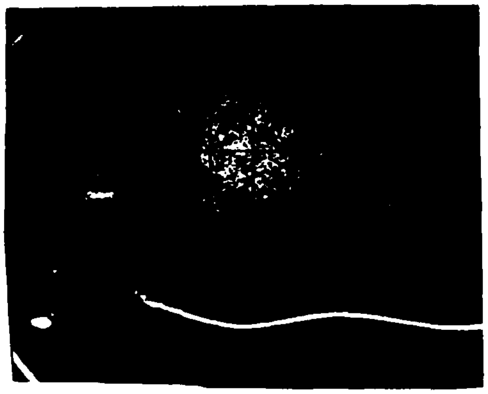

Figure 6. Vertical: 20 KV/div Horizontal: 2μsec/div
Breakdown Voltage Waveform on the Connector and Cable Assembly with Open End of Cable in Freon. (≈ 60 KV).

#2. The 40 KV Cable (A-4) and End Recepticles

A single pulse of 51 KV potential was applied to the assembly and it broke down at an estimated level of 48 KV. A poor quality trace was recorded on the oscilloscope which prevented an oscillogram from being obtained.

#3. Capacitor B-3

The Marx Generator was set up to discharge with a 51 KV peak voltage impulse waveform across the capacitor. The capacitor broke down prior to that level. Oscilloscope camera problems prevented an oscillogram of the results.

#4. Capacitor B-2

The initial test level on this capacitor was just under 60 KV. Due to previous corona testing it was felt that some dielectric polarization had taken place; since the B-2 capacitor had gone at such a low voltage. Thus the negative end of the capacitor was attached to the Marx. The Marx was being fired with a negative pulse. Figures 7-11 show the applied voltage

5

impulse waveforms on the capacitor.

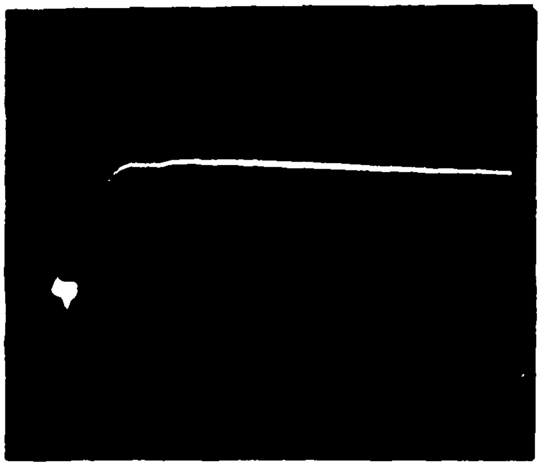

Figure 7. Vertical: 20 KV/div Horizontal: 2μsec/div
Initial Pulse Applied to Capacitor B-2
Peaking at Approximately 58 KV.

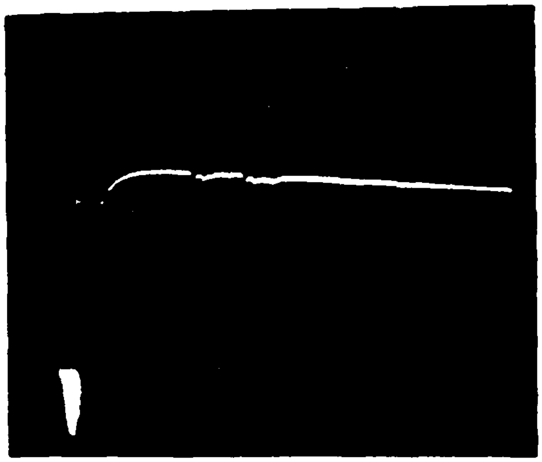

Figure 8. Vertical: 20 KV/div Horizontal: 2μsec/div
Second Level of Applied Voltage to Capacitor
B-2 Peaking at ~92 KV. Note: Slight
Breakup in Decay Side of Waveform.

6

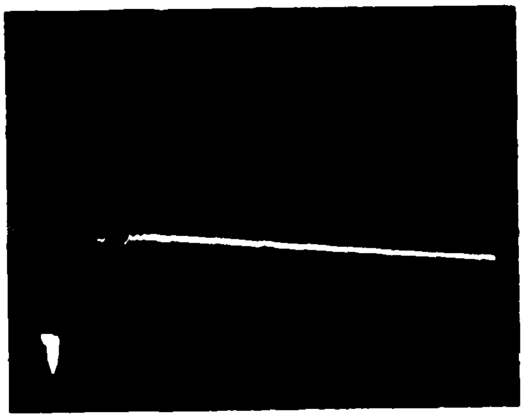

Figure 9. Vertical: 50 KV/div Horizontal: 2μsec/div
Third Voltage Level Applied to B-2
Peak Voltage ≈110 KV. No Break up of Waveform Noted.

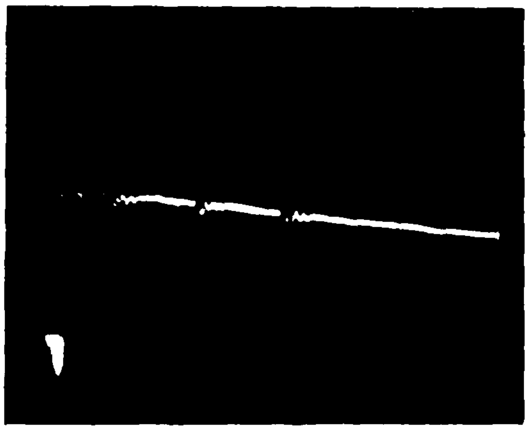

Figure 10. Vertical: 50 KV/div Horizontal: 2μsec/div
Fourth Level of Applied Voltage to B-2
Peak Voltage ≈155 KV. The Spiking Seen on the Decay Side is Due to Observed Arcing in the Discharge Circuit of the Marx Generator.

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Figure 11. Vertical: 50 KV/div Horizontal: 2μsec/div
The Last Shot of Applied Impulse Voltage to
Capacitor B-2 of Approximately 210 KV.
Note Just at the Peak the Waveform Breaks Up.
It was Felt That This Would be About The Upper
Limit For the Dielectric Hold Off.

#5. Capacitor B-1

The capacitor was set up similiarly to the B-2 and it was checked to ensure that the negatively static tested lead was attached to the Marx Generator output. The initial level was about 100 KV. (See Figures 12 and 13)

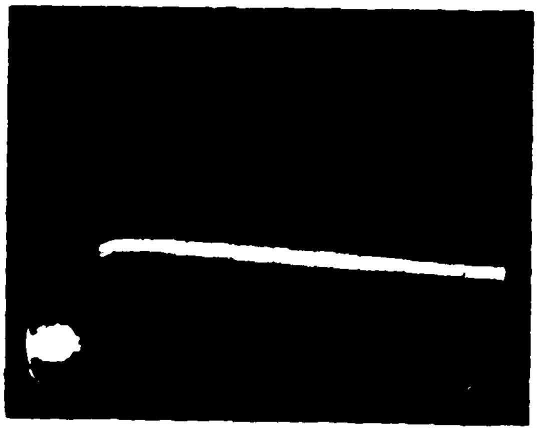

Figure 12. Vertical: 50 KV/div Horizontal: 2μsec/div
Initial Pulsed Voltage Waveform Applied to
B-2 ~110 KV Peak.

8

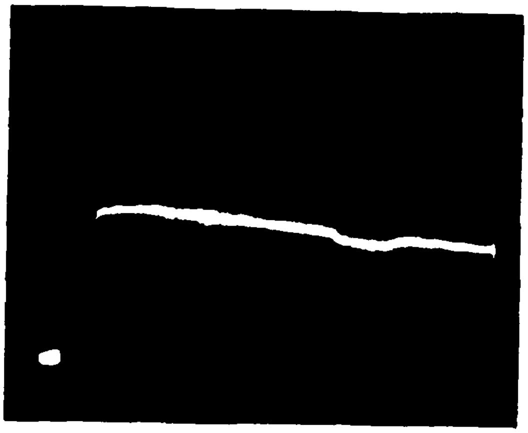

Figure 13. Vertical: 50 KV/div Horizontal: 2μsec/div The Second and Last Voltage Waveform Applied to B-1 with ≈165 KV Peak. The Reason for the Last Shot is the Break Up of the Waveform Indicating That the Level is Close to Breakdown of the Capacitor's Dielectric.

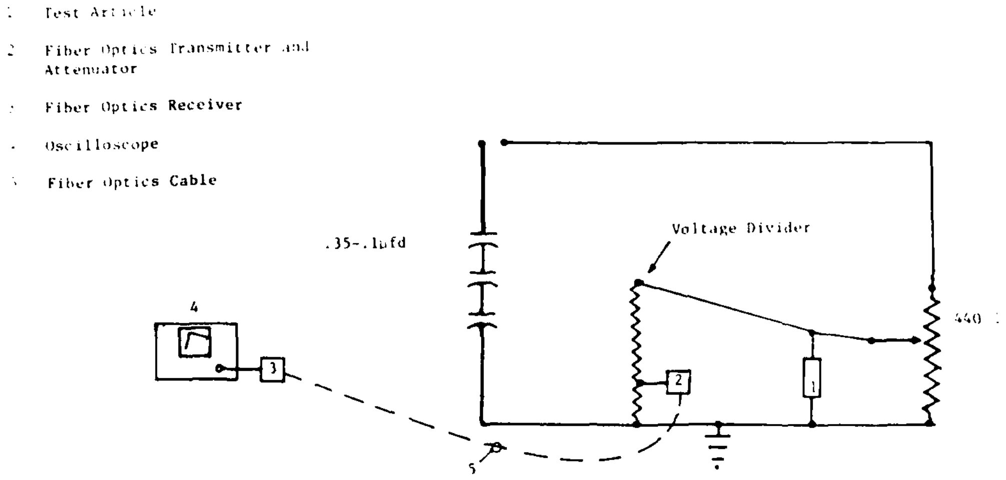

Figure 14. A Schematic Showing the Setup of the Marx Generator, Test Article Location, and Measurement System.

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#6. Capacitor - C-1, Serial #13 (2.2μfd - 15 KV)

The capacitance of the Marx generator proved too low to test the Hughes capacitor, therefore, another generator needed to be set up. This consisted mainly of a 4μfd, 50 KV capacitor and discharge circuit. Figure 14a is a line drawing which shows the resultant circuit used.

1 - HV Probe

2 - Oscilloscope

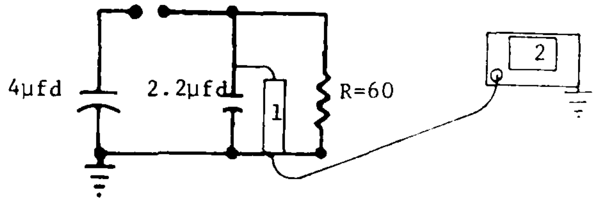

Figure 14a. A Schematic Drawing of the Circuit and Measurement System Used During the 2.2μfd Capacitor Test.

No specification on applied waveform was given, so a one microsecond front time with a 40-50 microsecond tail time was set up without the test capacitor added. Figure 15 shows the voltage waveform measured across the Hughes capacitor on the initial pulse of 7 KV.

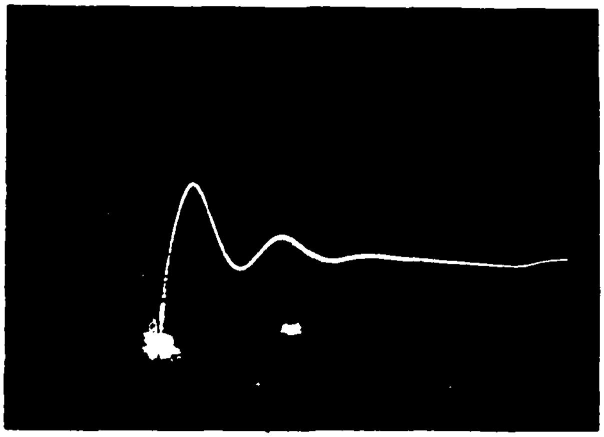

Figure 15. Vertical: 2 KV/div Horizontal: 5μsec/div
The Oscillogram of the Pulsed Voltage Waveform
Across the **C-1, Serial #13 Capacitor,**
7 KV Peak.

Figure 1b shows a frequency riding the impulse of [illegible]. The exact cause is not clear but the internal inductance of the capacitors along with lead and connection inductance could be sufficient to cause the ringing noted. The equivalent capacitance [illegible] be 6.2 fd, with the 100 KHz signal, the inductance would be

$$L = \frac{1}{(2\pi f)^2 C} = 0.409 \text{ h}$$

The [illegible] resistor in parallel with the two capacitors effectively dampens out the oscillation in about 40 microseconds.

Another observation was that the charging voltage on the generator 4 fd capacitor was approximately 5 KV. There appears to be a voltage addition involved.

Figure 1c brings out an interesting waveform which may help determine the addition mechanism. The charge voltage on the generator capacitor was set for 10 KV.

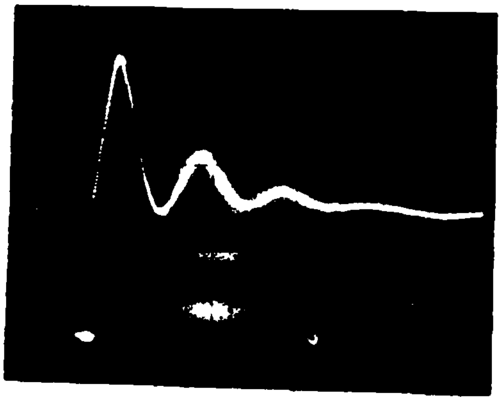

Figure 1c Vertical: 2 KV/div Horizontal: 5 µsec/div
The Oscillogram of the Impulse Voltage as Applied to Capacitor C-1, Serial #13. The Voltage Peak at 12.6 KV. The Oscillation is Present and Also a Change in Rate-of-Rise of the Wave Front Can Be Seen.

The change in rate-of-rise is of great interest but an exact explanation is beyond the scope of this report, unfortunately.

[illegible] was determined to be [illegible] the charge [illegible] the maximum [illegible] of the [illegible] series [illegible] oscillogram [illegible] maximum [illegible]

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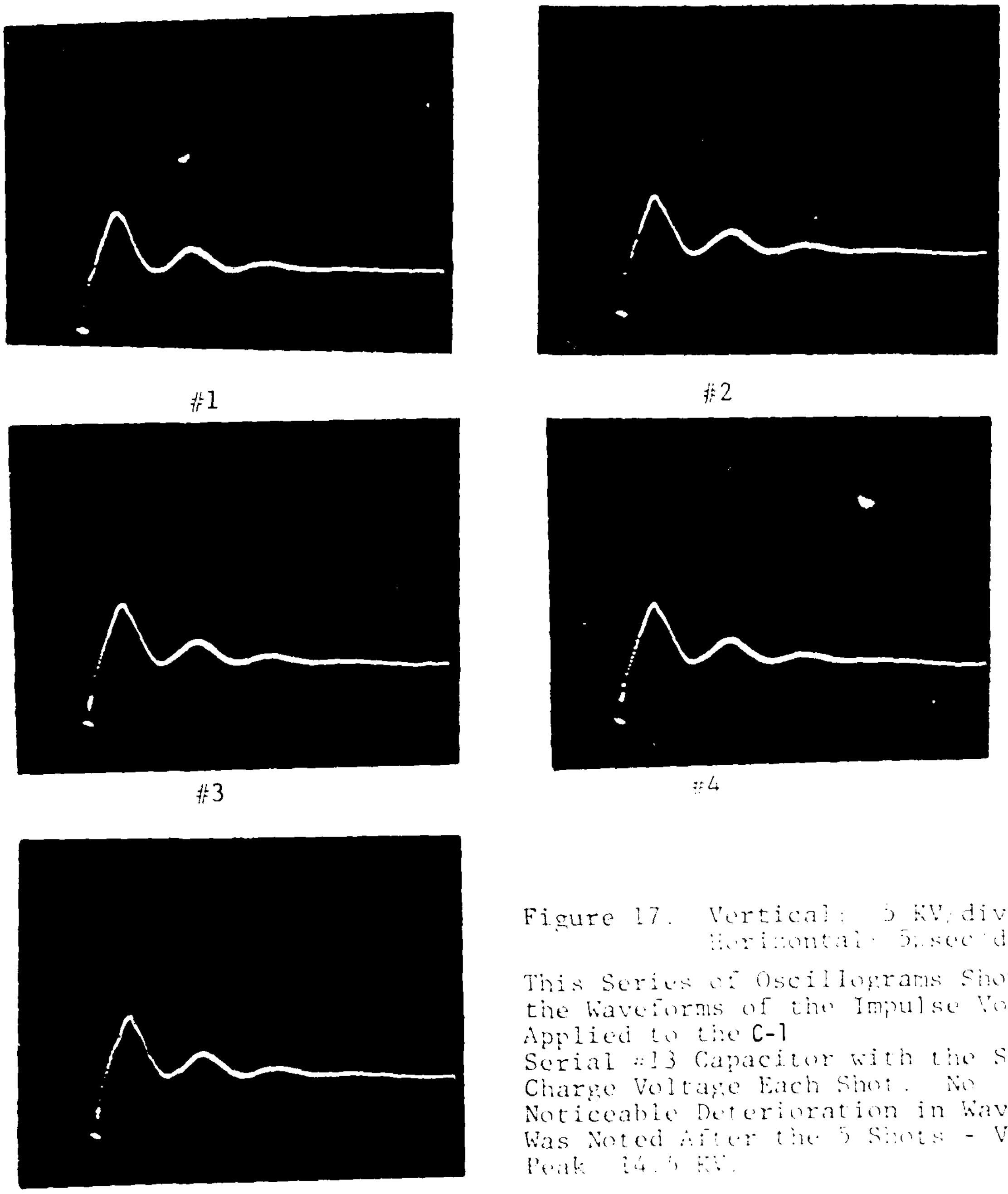


#1

#2

#3

#4

#5

Figure 17. Vertical: 5 KV/div
Horizontal: 5μsec/div

This Series of Oscillograms Shows the Waveforms of the Impulse Voltage Applied to the C-1 Serial #13 Capacitor with the Same Charge Voltage Each Shot. No Noticeable Deterioration in Waveform Was Noted After the 5 Shots - Voltage Peak 14.5 KV.

John G. Schneider

John G. Schneider
High Voltage Test Engineer

Rel. Humidity = 58%

Parts		Serial Number of Parts	Test Frequency	Voltage Applied for 10 sec. #1 Test	Voltage Applied for 1 sec. #2 Test	Voltage Applied for 1 minute #3 Test	Result	in air	D-C Result in oil	D-C Impulse Voltage	
Cable Assy	W/O Conn.	A-1	D-C	108 (KV)	125 (KV)	144 (KV)	area 50 KV	ok			
	W/ Conn.	A-2	D-C	108 (KV)	125 (KV)	144 (KV)	area 60 KV.	ok			
Cable Assy.	W/O Conn.	A-3	D-C	72 (KV)	86 (KV)	100 (KV)	area 65 (KV)	ok			
	W/ Conn.	A-3	D-C	72 (KV)	86 (KV)	100 (KV)	65 (KV)	ok			
Capacitor 100 KV		B-1	D-C	160 (KV)	180 (KV)	200 (KV)	ok				
Capacitor 100 KV		B-2	D-C	160 (KV)	180 (KV)	200 (KV)	ok				
Capacitor 80 KV.		B-3	D-C	130 (KV)	145 (KV)	160 (KV)	ok				
Coils		No Insulation							< 8 KV		I II III
		1 Layer	60 Hz		6.0 (KV)				> 8 (KV)		V
Coils		2 Layers	60 Hz		6.4 (KV)				> 11 (KV)		VI
		3 Layers	60 Hz		6.8 (KV)				> 11 (KV)		VII
		D-C Power Supply	200 KV	BC 365467							
		A-C Power Supply									
		Impulse, High "V" Divider		BC 369649							
		"O" Scope 7633	BEHC	30-021366							

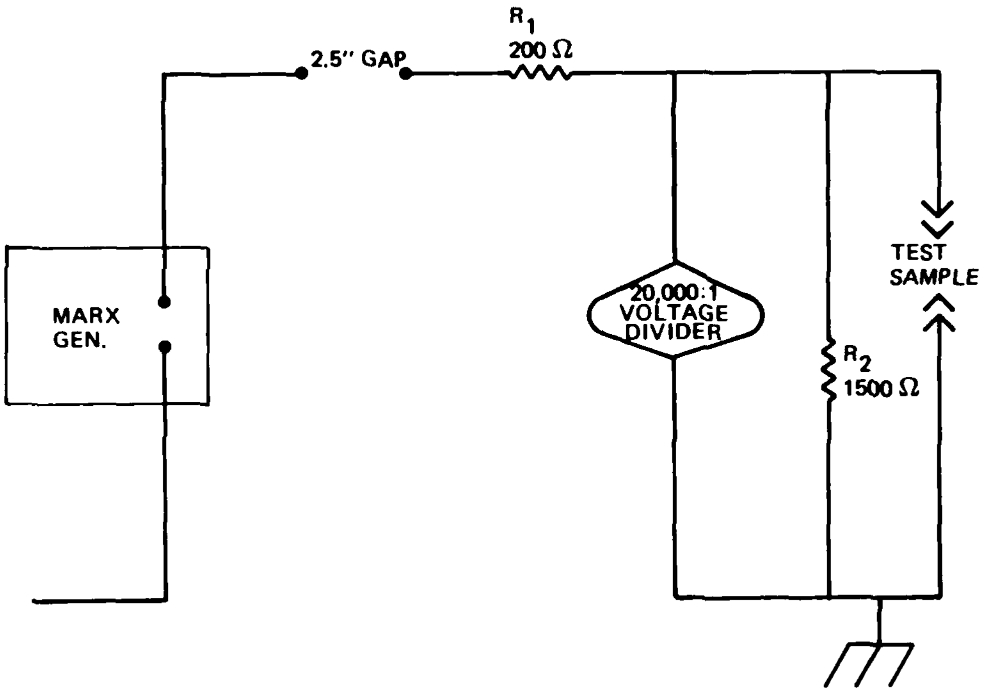
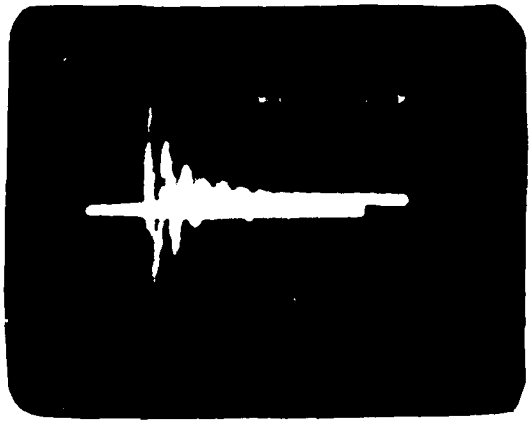
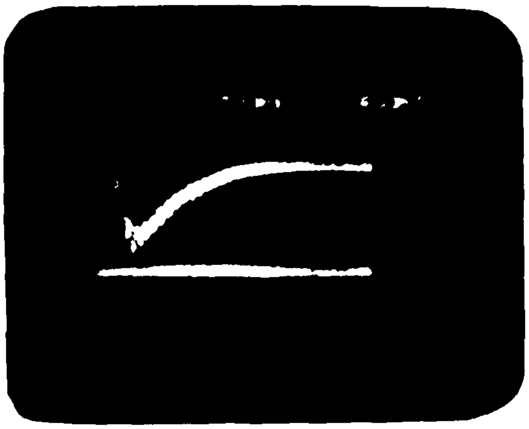


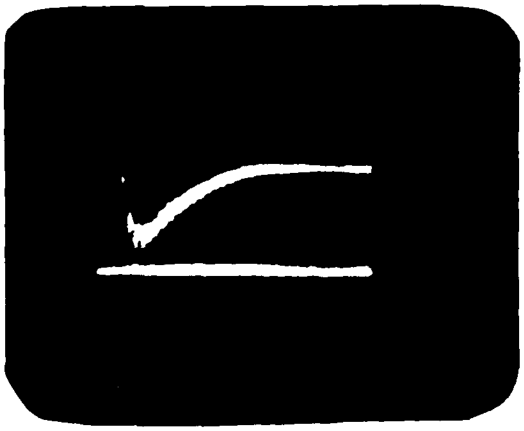
Figure : Impulse Test Setup



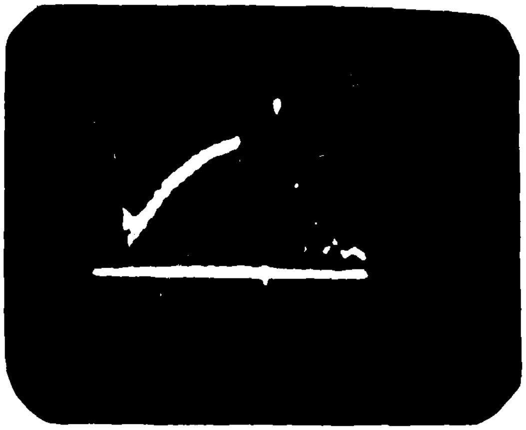
Generator Coil
Breakdown at 8.0
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



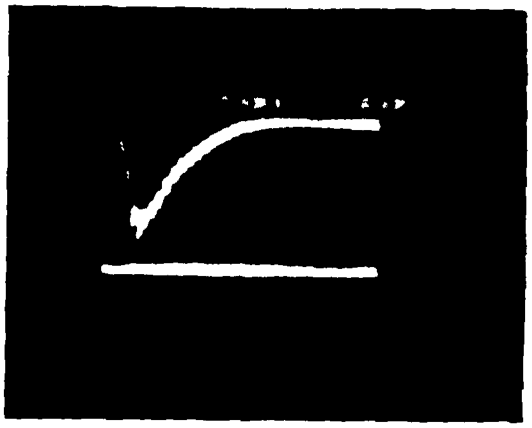
Generator Coil
1 Layer Insulation
Pass 8 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



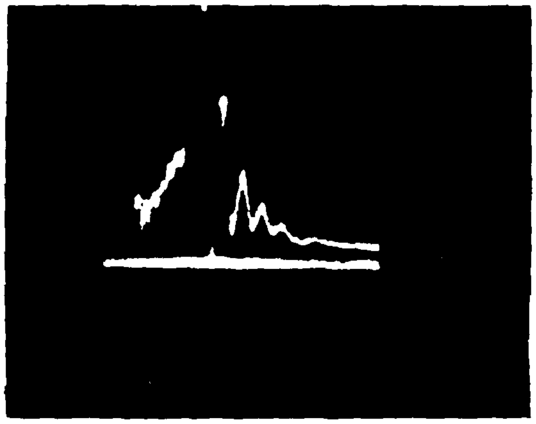
Generator Coil
1 Layer Insulation
Pass 8 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



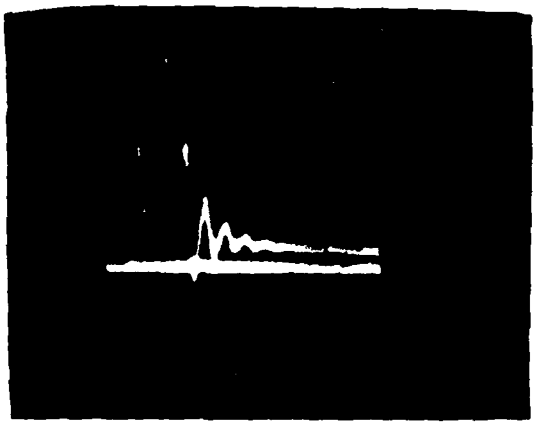
Generator Coil
1 Layer Insulation
Breakdown at 10 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



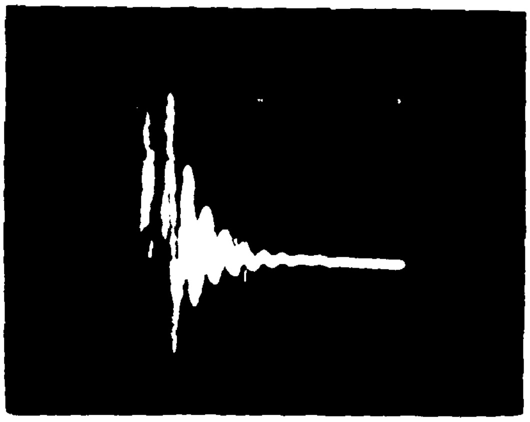
Generator Coil
2 Layers Insulation
Pass 11 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



Generator Coil
2 Layers Insulation
Breakdown at 13 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



Generator Coil
3 Layers Insulation
Breakdown at 16 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.



Generator Coil
3 Layers Insulation
Breakdown at 13 KV
Vertical: 2000 V/div.
Horizontal: 500 ns/div.

APPENDIX B

PARTIAL DISCHARGE TEST DATA

The partial discharge test data were taken in the High Voltage Laboratory using the equipment described in Paragraph 6.3.7.2.

Pulse Height Analyzer Channel	PC (+2)	A3 60 kV Cable Applied Voltage 60.2kV Gain (+2)	50.5kV (+2)	40.3kV (+2)	30.2kV (+1)	B2 Capacitor 99.7kV (+1)	80.1kV (+2)	60.2kV (+2)	C1 Capacitor Before Surge Test 10kV (+2)	19kV (+2)
1										
2										
3		28	7	2	1					
4		393	199	213	222	1	220	244		
5		373	192	153	151	2	199	133		
6		378	98	68	74		95	97		
7		933	272	26	21	1	25	40		
8		12,138	1866	281	109	14	413	417		
9		48,265	4688	619	604	141	808	789		
10		53,768	5763	680	494	109	836	796		
11		47,109	5714	572	382	21	788	780		
12		40,247	5616	521	260	16	752	719		
13		33,314	5558	426	157	27	559	580		
14		27,271	5436	314	80	19	431	485		
15		22,364	5288	241	79	23	296	292		
16	02	17,919	5846	217	21	13	192	195		
17		14,278	4837	152	8	17	115	100		
18		11,446	4577	136	8	17	65	72		
19		9,200	4256	100	9	11	33	29		
20		7,054	3778	87	4	19	41	19		
21		5,488	3362	60		10	55	12		
22		4,099	3128	59	4	10	57	19		
23		2,873	2863	40	3	19	109	26		
24		2,188	2473	44	9	12	166	45		
25		1,497	2242	31	10	4	212	58		
26		1,089	2029	29	5	9	371	111		
27		708	1888	28	6	6	427	191		
28		466	1715	14	4	4	477	332		
29		307	1689	23	4	10	548	403		
30		218	1553	16	3	6	443	405	244	220
31		165	1507	5	4	6	371	499	255	242
32		107	1364	10	1	6	225	499	216	281
33		104	1340	4	3	3	133	400	225	247
34		68	1235	7	2	7	109	281	210	235
35		65	1095	11	5	4	51	157	157	190
36		48	987	11	6	7	29	89	97	124
37		41	807	9	4	2	17	51	78	96
38		33	701	5	3	3	10	21	42	49
39	04	38	679	4	3	3	14	11	22	30
40		28	457	7	6	2	9	5	22	35
41		30	414	5	3	3	11	6	18	22
42		26	287	6	4	2	7	1	8	16
43		17	208	5	2	3	7	6	4	15
44		13	131	5		5	11	11	5	7
45		18	81	4	1	2	9	6		7
46		17	59	4	3	1	18	4	1	10
47		11	32	7	2	4	6	4	1	6
48		9	19	4	1	4	6	3	1	5
49		12	17	2	5	5	8	3	1	6
50		11	15	3	3		10	4		2
51		12	14	5	1	1	6	7	1	1
52		7	10	3	2	3	4	8		
53		10	8	1	2	4	8	3	2	1
54		12	7	1	2	1	9	3		
55		12	6	2		1	7	7		
56		14	3	1	1	3	4	4		1
57		9	3	1	2	1	5	1		
58		8	7	2	4	2	2	4		
59		4	1	1	1	2	4	6		
60		16	1	1	2		4	2		
61		9	5	5	1		6	7		
62		8	2	3	5	1	4	4		
63		2	3	3	2	1	3	1		
64		3	5	2	3		6	2		
65		12	1	2	2		4	4		
66		10	1		4	1	8	2		
67		3	1	2			5	1		
68	06	2	1		1	2	3	2		
69		1				3	3	2		
70		1		3	2	2	1	1		
71		2	1		2	1	8	2		
72		3	1	4	1	1	5	4		
73		3	1	1	1	1	5	2		
74		7	1	1	2		1	3		
75		5	2	1	1	1	2	3		

Pulse Height Analyzer Channel	PC	A3 60 kV Cable Applied Voltage				B2 Capacitor		
		60.2kV	50.5kV	40.3kV	30.2kV	99.7kV	80.2kV	60.2kV
76		5	4		1	2	4	1
77		4	2		1	1	9	2
78		8	2	2	3	1	2	2
79		6	1	3		1	7	2
80		7	1	1	1		8	3
81		7	3	2	1	1	4	2
82		7	3	1	1	2	6	2
83		3	1		1	3	6	
84		4	3	1	1	1	5	5
85		6	2	4			6	2
86		7	2	2	2		5	2
87		3	2	2	1	1	2	4
88		4	2	1	1	2	4	2
89		5	2	1		1	3	1
90		4	1	3	2	2	4	1
91		2	1	1	1		5	4
92		5	4			1	7	1
93	0.8	4	4	2	3	1	5	4
94		2	1	3	1		3	
95		5	1	1	2	4	3	3
96		4	4		1	1	1	3
97		5	2		3	1	5	
98		7	2	3			3	1
99					2	2	9	
100		3	1	1	2		1	2
101		3		1	2	3	1	2
102		2	4	1	1	1	3	2
103		2		1			2	2
103		2	2	1				
104		1	2		1	1	8	1
105		2		1	1	1	3	
106		4	8	1			2	1
107		2	4	1	1		3	
108		5	4	1			4	2
109		3	1				6	4
110		1		2			7	1
111		3		1		1	2	
112		6	4		1	1	4	2
113		3	2	1			4	2
114		3		1	4	3	1	
115		1	1		2	3	3	1
116		2	3				4	2
117		3	3	1	1	3	7	3
118		4	1	1		1	3	
119		8	1	3	1		5	
120		1		1	3		3	1
121	1.0	2	1	7		4	8	1
122		1					6	
123		3		1	1		5	2
124		-			1	1	2	1
125		2		2	1	1	3	2
126		-	1		1		1	1
127		4	2	1		1	1	
128		2	2	1		3	6	1
129		2	2				4	
130		2	1			1	4	
131		2	2	1			2	1
132		3	2			1	3	2
133		2	1	1			3	
134		3	1			1	3	1
135		4	1	1				1
136		3	1	2		1	2	
137		2		1	2		1	2
138		3	1				2	
139		2	1	1			3	
140		2		2		2	3	
141		1	1				1	
142		1	1		1	1		
143		1	1	1			3	1
144		4		1	1	1	2	
145		3	2	1		1	2	1
146		1		1	1	1	1	1
147		2	2		1	2	2	2
148		7		2				
149		1	1			1	2	2
150		1	1	1	1	2	3	1

PULSE HEIGHT ANALYZER CHANNEL	PC	A3 60 KV CABLE APPLIED VOLTAGE				B2 CAPACITOR		
		60.2kV	50.3kV	40.3kV	30.2kV	99.7kV	90.2kV	60.2kV
151		3		1			1	
152		3	2			1	3	1
153		3				4	4	2
154		2	2	2		1	1	
155			1	1	1		2	
156		3		1	1	1	6	1
157		4	1			3	1	
158			2	1	1		1	
159					1		4	1
160		2	1			1	5	2
161		1		1	1	1		
162		2	2	1	2	2	1	1
163			1	1	3	2	2	1
164		1	2		1	2		1
165		1	1				1	1
166				1			1	1
167		1				1	1	
168		2			1	2	3	
169		1				2	3	
170						2	4	
171					2	1	4	1
172					1	1	1	1
173		2	2			1	2	1
174				1		2	3	2
175		3		2			6	
176		1	1	2	1	2	1	1
177		2		1		1	3	
178		5		2			4	1
179		1	2				1	1
180		2	1				2	
181		2	1				2	
182					2	2	1	
183		1	3	1	1	3	1	
184		2	2	3	1			
185			1		2	1	2	
186		3	1			1	1	1
187			2		2		2	
188			1				3	
189							3	
190		1					3	
191								1
192		3	1					
193		1				2	2	
194						1	1	1
195								1
196		3	2			2	2	1
197		2				1	1	1
198		1	2					
199		1	1	1			1	
200		3		1	2	2	1	1
201				1	1			
202			2				1	1
203			1			1		1
204		1	1	1			2	
205			1			2	2	
206		2					1	
207		2	1	1				2
208		1	1	2			1	1
209							1	1
210		2		2	1	1	1	1
211		1		2				
212		1	1			1	1	
213		1	1	1	1		1	
214		2					1	
215							3	
216					1			
217		1					2	
218		4	2		1	2		
219			1		1			2
220							1	
221		2	1					
222				1			1	1
223							1	1
224		1					1	
225				1			1	

PULSE HEIGHT ANALYZER CHANNEL	PC	A3 60 KV CABLE APPLIED VOLTAGE				B2 CAPACITOR		
		60.2KV	50.5KV	40.3KV	30.2KV	49.7KV	50.1KV	60.2KV
226								
227		1	1		1		1	
228							3	2
229				2	2	1	1	1
230		2		1		3		
231					1	1		
232		1	1				1	
233							4	
234			2	1				
235			1					
236		1		1			3	1
237								
238		2			1		2	
239						1		
240			1	1		1		
241		2	2			1		1
242		2	1	1			2	
243							2	1
244								
245		1			1			
246				1		1	5	
247		1		1		1		
248			1	1			1	
249		2		1				1
250				1				
251	2	1	1				1	1
252					1		2	
253				2				
254		2		1		1	3	
255				1		2	2	1
256		2		1			3	
257			1					
258			1		1	1	3	
259			1			1		
260		1	1			1		
261						1	1	
262							1	2
263		1		2	1	3	1	1
264				2			1	
265						2		
266		1	1		1		2	
267					1		1	
268		1					1	1
269								
270			1			1		
271						2	3	
272		1				2	1	
273			1				1	
274		2						
275		3		1				1
276				1				
277							1	1
278								
279						1		
280				1	1			1
281							1	
282			1		1			
283		1						2
284		1						1
285							4	
286				1				1
287		1						1
288						2	1	
289		1		1	1			
290				1				1
291		1		2				
292		1		1	1			
293				1	1			
294		1		1				
295				1			1	
296					1		1	
297			1		1			
298			1				1	
299					1			
300			1	1		1	1	
			1				2	1

PULSE HEIGHT ANALYZER CHANNEL	PC	A3 60 KV CABLE APPLIED VOLTAGE				B2 CAPACITOR		
		60.2KV	50.5KV	40.3KV	30.2KV	99.7KV	80.2KV	60.2KV
301						1		1
302								
303		1					1	
304			1				1	
305		4				1		
306						1		
307		1	1					
308		1						
309			1	1				
310		1	1				1	
311							2	
312					1			
313		1				1		
314								
315		2			1	1		
316		1					1	
317								
318						1		1
319		1				1		1
		2						
321		1					1	
322		1	1		1	1		
323		1			1			1
324		1				1	2	1
325		1					1	
326			1				1	
327						1		
328		1			1	1	1	
329		1						1
330							1	
331			1					
332		1						
333						1		
334						1		
335		1					2	
336						1	1	
337			1					
338								
339		2	1		1			
340		1			1	1		
341		1		1		1		
342		2						1
343				1	1			
344						1	1	1
345				1			1	
346			1		1			
347								
348							1	
349		1	1		1			
350		1						1
351			1					
352			1					
353				2				
354	3.0							1
355			1				1	
356					1			
357		1						
358								
359		1		1		1		
360		1				1		
361		1	1					
362								
363								
364								
365							1	
366			1					
367							1	
368							1	1
369		1					1	
370			1				1	
371			1				1	
372								
373							1	
374						1		
375								1

PULSE HEIGHT ANALYZER CHANNEL	PR	A3 60 kV CABLE APPLIED VOLTAGE				B2 CAPACITOR		
		60.2 kV	50.5 kV	40.3 kV	30.2 kV	99.7 kV	80.2 kV	60.2 kV
376								
377							1	
378		1			1		1	
379						1		
380		1		1	1	1	1	1
381								
382			1	1				
383								
384								
385		1	1					
386		1						
387				1				
388								
389								
390		2						
391			1					
392						1	1	
393								
394		1						
395				1			1	
396					1			
397			1			1		1
398		1						
399		1	1		1			
400				1		1		
401		1						
402			1	1	1			
403								
404			1					
405								
406				1				
407			1					
408					1		1	
409								
410		1						
411								
412								1
413		1					1	
414								
415							1	
416							1	
417		2				1		1
418							1	
419			1				1	
420		1	1	1		1	1	1
421								
422							1	
423					1			
424				1				
425								
426				1	1		1	
427			1					
428								
429								
430					1			1
431								
432				1		1		
433		2						1
434					1			
435		1						
436								
437								
438					1			
439								1
4 0							1	
441								
442							1	
443		1					1	
444								
445								
446					1			
447							1	
448							1	
449								
450								

		A3				B2			C1
		60KV CABLE				CAPACITOR			CAPACITOR
PULSE HEIGHT ANALYZER CHANNEL	PC	APPLIED VOLTAGE 60.2KV	50.5KV	40.5KV	30.2KV	99.7KV	80.2KV	60.1KV	
451							1		
452									
453									
454									
455									
456			1						
457		1	1						
458			1						
459									
460			1						
461									
462			1				1		
463						1	1		
464			1						
465		1							
466								1	
467									
468							1	1	
469							1	1	
470									
471							1		
472									
473		2							
474							1	1	
475				1					
476		1							
477									
478									
479			1						
480									
481							1		
482		1							
483									
484				1					
485									
486									
487							1		
488									
489									
490									
491		1		1					
492		1					1	1	
493					1			1	
494									
495									
496									
497			1				1		
498									
499									
500									
501									
502			1						
503								1	
504							1		
505				1		1	1		
506									
507									
508			1				1		
09							1		
510								1	
511	4								
512					1				

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