NBSIR 79-1950

Measurements on Insulating Materials at Cryogenic Temperatures

William E. Anderson and Richard S. Davis

Electrosystems Division
Center for Electronics
and Electrical Engineering
National Bureau of Standards

August 1979
Issued January 1980

Final Report

Under Department of Energy Contract No. EA-77-A-01-6010
Task No. A023-EES

Prepared for
Brookhaven National Laboratory
Department of Energy

NBSIR 79-1950

MEASUREMENTS ON INSULATING MATERIALS AT CRYOGENIC TEMPERATURES

William E. Anderson and Richard S. Davis

Electrosystems Division
Center for Electronics
and Electrical Engineering
National Bureau of Standards

August 1979
Issued January 1980

Final Report

Under Department of Energy Contract No. EA-77-A-01-6010
Task No. A023-EES

Prepared for
Brookhaven National Laboratory
Department of Energy

U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, ***Secretary***

Luther H. Hodges, Jr., ***Deputy Secretary***
Jordan J. Baruch, ***Assistant Secretary for Science and Technology***

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

TABLE OF CONTENTS

Abstract

This final report describes the results of a four-year effort to study the high voltage dielectric behavior of various materials at cryogenic temperatures. Dissipation factors at 60 Hz were measured for polymer tapes and epoxy samples at 4.2 K, atmospheric pressure. Multi-layer polymer samples in coaxial geometries at temperatures from 7 to 10 K and helium pressures up to 1.5 megapascals were also studied. The measurements were performed at stresses up to 40 MV/m. Since partial discharges were a major source of losses at the higher stresses and their presence was possibly detrimental to the integrity of the insulation, instrumentation was developed and implemented to study these discharges under conditions found in proposed ac superconducting power-transmission lines.

Summary

The contents of the following report are here summarized for the convenience of the reader. The report covers the period from November 1974 through October 1978.

In November of 1974 the National Bureau of Standards began a project sponsored by the then Energy Research and Development Administration to study ac losses in dielectrics at cryogenic temperatures and at high electrical stresses. The ultimate goal of the project was to provide dissipation factor and partial discharge data under the proposed operating conditions for Brookhaven National Laboratory's (BNL's) ac superconducting power-transmission line (ac SPTL). Because of BNL's urgent need for engineering data and the necessary delay involved in designing and constructing a supercritical cryostat, initial efforts were toward providing 60-Hz dissipation factor data of polymer films at 4.2 K and at atmospheric pressure. These measurements provided valuable data at the electrical stresses proposed for the ac SPTL. Dissipation factor measurements on layers of polymer films suggested that losses at interfaces may dominate the intrinsic dielectric losses of the polymer films. These interfacial losses are probably due to partial discharges. Since their effect may diminish under the proposed supercritical conditions of the actual ac SPTL, measurements were extended to more realistic conditions. A partial discharge measurement system was designed to carefully monitor the integrity of the dielectric under partial discharge conditions.

Besides the measurements on the polymer tape insulation for the BNL SPTL, dissipation factor and dielectric constant values of various epoxies were provided to Union Carbide Corporation, Linde Division (UCC-Linde). These epoxies were to be used as spacers in their liquid helium-insulated cable.

In order to accomplish the necessary measurements, two different cryogenic facilities were built. The first consisted of a conventional glass double-dewar system. High voltage was introduced into the cryostat by means of a vacuum-insulated bushing which was discharge free to 8.5 kV. All experiments were performed with the sample material immersed in liquid helium at atmospheric pressure. Size limitations of the dewar necessitated the use of a small (10 cm^2) parallel-plate capacitor as sample-holder. The second cryogenic facility consisted of a conventional stainless steel dewar with a liquid nitrogen jacket. The sample was placed in a pressure vessel which allowed measurements at pressures up to 1.5 megapascals. Polymer films were wrapped around the bare cylindrical high-voltage electrode permitting measurements in the coaxial geometry and under the temperature and pressure conditions of the proposed BNL SPTL.

Electrical measurement of dissipation factor was made by comparing the loss of the sample dielectric with that in a commercial compressed-gas high-voltage capacitor. This comparison was made with sufficient accuracy by using the NBS current-comparator bridge. Samples formed the dielectric of a three-terminal capacitor. Due to the small dissipation factor allowable in any practical superconducting cable insulation, an accuracy of $\pm 1 \times 10^{-6}$ was desirable in the measurements. Success in this was achieved through a meticulous absolute determination of our compressed-gas high voltage capacitor.

As an initial consistency check we measured the dissipation factor of liquid helium at 4.2 K. At a stress of 1.5 kV/mm the 60 Hz dissipation factor was $(0.3 \pm 0.7) \times 10^{-6}$. This is consistent with the fact that liquid helium has no intrinsic loss mechanisms at power frequencies.

As previously mentioned initial measurements were made of single-layer films with the parallel-plate sample holder at 4.2 K and atmospheric pressure. No attempt was made to measure a representative sample of polymer tapes. Only those tapes that proved to be among the most promising from mechanical tests, low-voltage electrical tests, or economic considerations were sent to us by BNL. Each sample was measured at least twice to test repeatability and prevent erroneous values caused by the occasional cracking of some materials. The polyethylenes and polypropylenes both have dissipation factors considerably less than 30×10^{-6} (upper limit for BNL SPTL) at cryogenic temperatures and at design stresses of the order of 20 kV/mm. These films along with the polyamide sample, however, have poor mechanical properties at liquid helium temperatures. The polycarbonate and polysulfone films are much better mechanically but have dissipation factors in the range of 50 to 100×10^{-6}. An attempt by the manufacturer to improve the dissipation factor of one of these materials (green polysulfone) by reducing the concentration of sodium impurities was somewhat successful.

While the dissipation factor of most of the materials increases slightly with increasing voltage, both of the polyether-sulfone samples measured have negative voltage coefficient. We do not know whether the cause of this is related to the well-understood similar behavior of oil-impregnated paper-insulated capacitors.

The dissipation factor of the epoxies submitted by UCC-Linde were an order of magnitude larger than the polymer tapes but below the 500×10^{-6} limit for the UCC-Linde SPTL. There were inconsistencies in dissipation factor results between different thickness samples made of the same material. A model was developed that accounted for this behavior.

We found it impossible to make these single-layer atmospheric-pressure measurements without coating the electrode-sample interfaces with paraffin oil. Presumably this procedure suppresses partial discharges at the interfaces. It was observed that when samples were not coated with paraffin oil prior to insertion into the sample capacitor, the measured dissipation factor exhibited a large voltage coefficient.

To examine further the effects of paraffin oil on various interfaces, several stacking arrangements of polypropylene films were studied. We measured the dissipation factor of three-sheet stacks of this material with and without paraffin oil on the various interfaces. As the number of uncoated surfaces increased, the positive voltage coefficient of the dissipation factor increased. Since this effect may be suppressed under the supercritical conditions of the BNL proposed SPTL, our measurements were extended to these conditions.

Dissipation factor measurements on multi-layer coaxial samples under supercritical conditions were for the most part encouraging. Dissipation factors for many samples were less than 20×10^{-6} for stresses of several megavolts/meter. As the stress increased there appeared a break point or point at which the dissipation factor became strongly dependent on electrical stress. This break-point stress agreed with the measurements of others on the breakdown of supercritical helium when allowance was made for the dielectric mismatch of the polymer and the helium butt gaps. The actual BNL SPTL will contain bedding and screen layers. The screen layer was found to have little effect on the dissipation factor. Preliminary measurements with the bedding layer did indicate serious problems.

Part of the NBS program was to study the effect partial discharges might have on the electrical insulation. NBS designed and constructed a partial discharge measurement system for this purpose. The system which includes a minicomputer, measures partial discharge amplitude spectra. A change in a given spectrum would indicate that the properties of the dielectric were changing. Measurements under conditions of varying electrical stress, frequency of the applied voltage, impurity or defect concentration, temperatures, and pressures could yield important information on aging processes at cryogenic temperatures.

Only a small number of long (3 hour) measurements were made with this instrumentation yielding limited information. The effort near the end of the NBS program was redirected to providing dissipation factor data for BNL on new materials thought to be promising. (The partial discharge measurement system recently has been used extensively on measurements of the partial discharge behavior of SF_6 at room temperatures).

Introduction

In November of 1974 the High Voltage Measurements Section in the Electricity Division of the Institute for Basic Standards (now the Applied Electrical Measurements Group in the Electrosystems Division of the Center for Electronics and Electrical Engineering) began a project sponsored by the then Energy Research and Development Administration to study ac losses in dielectrics at cryogenic temperatures. The ultimate goal of the project was to provide dissipation factor and partial discharge data for the dielectric materials under consideration for use in ac superconducting power-transmission lines (ac SPTLs). At that time there were two ac SPTLs being developed domestically. One was a rigid cable that used liquid helium for both the coolant and the dielectric. The center high voltage conductor was held in place by epoxy spacers. This cable was being developed by the Linde Division of Union Carbide Corporation (UCC-Linde). Brookhaven National Laboratory (BNL) was developing the other ac SPTL. This cable was flexible until cooled. The insulation contemplated was analogous to conventional oil-impregnated paper cables in that helium played the role of oil and a suitable polymer played the role of paper.

The early work then was involved with the measurement of the dielectric constant and dissipation factor for the insulating materials to be used in the BNL and UCC-Linde SPTLs. A group of workers at Oak Ridge National Laboratory were complementing this effort by determining the breakdown characteristics of these insulating materials under high electrical stress.

In order to provide timely data to BNL and UCC-Linde our early work was limited to measurements of thin polymer and epoxy films at atmospheric pressure and at 4.2 K. Dielectric constant and dissipation factor measurements were made up to stresses of 40 MV/m. Of the polymer tapes being considered for the BNL SPTL, several were found to have dissipation factors less than the 30×10^{-6} upper limit that BNL personnel had originally ascribed in order to minimize refrigeration load. However, when stacks of these thin polymer films were measured, their dissipation factor showed an alarmingly strong positive voltage dependence. This necessitated measurements under the operating conditions of the BNL SPTL in order to determine if the resulting higher helium densities would reduce this problem. Several epoxy samples were initially measured for UCC-Linde. Since the epoxy represented only a small fraction of the total dielectric volume in their cable, a higher dissipation factor could be tolerated. Development of this cable was curtailed and, as a result, no additional epoxy measurements were made.

Dissipation factor measurements on polymer tapes for BNL were thus extended to multi-layer coaxial geometries, 7 to 10 K temperatures, and 1.5 MPa pressures. The dissipation factors for the most part under these conditions showed far less voltage dependence than for multi-layer samples at atmospheric pressure. The voltage dependence that did occur seemed to be a result of partial discharges.

A partial discharge measurement system was developed based on the pulse-height-analysis technique to study the behavior of these tapes under the proposed operating conditions. The instrumentation is described in an appendix to this report. The evolution of the partial discharge amplitudes as a function of time for various pressures, temperatures, electrical stresses, materials, frequencies, impurity or defect concentrations would yield important information on aging processes at these low temperatures. These measurements were never completed because of the termination of funding in September 1978.

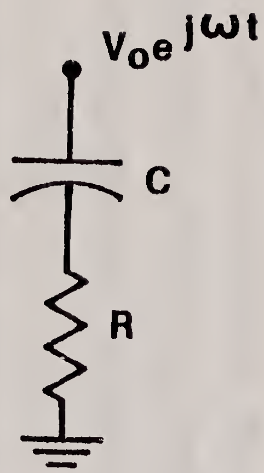
This report covers the period from November 1974 through October 1978. The work through June 1976 will be described in lesser detail as it was contained in an earlier report.[1] Also the previous report contained a bibliography of useful references that will not be repeated here. This report is divided into three major sections: Dielectric Loss Measurement Methodology; Dielectric Loss Results and Discussion; and Partial Discharge Measurements. The appendix provides a complete description of the partial discharge measurement system developed for this project.

I. Dielectric Loss Measurement Methodology

In considering the measurement of dielectric loss, it is convenient to model the dielectric and its electrodes as a combination of an ideal capacitor and an ideal resistor. This model, in the absence of partial discharges is adequate to explain the loss behavior of a capacitor containing a dielectric. Two equally valid configurations of capacitor and resistor are shown in Fig. 1. In general, the resistor value will be a function of the frequency and of the applied voltage. The problem of measuring dielectric loss may be thought of as equivalent to finding the value of the resistor in either Fig. 1A or 1B.

While many techniques to measure dielectric loss have been used, circumstances generally limit the optimum choice. For instance, for very lossy capacitors the test capacitor may be combined with an inductor to produce an LC circuit. The value of L which causes the circuit to resonate at a given frequency determines the value of C in Fig. 1 while the width of the resonance can be used to find R or R'. Clearly, this technique is unsuitable if the capacitor's loss is less than that of the inductor.

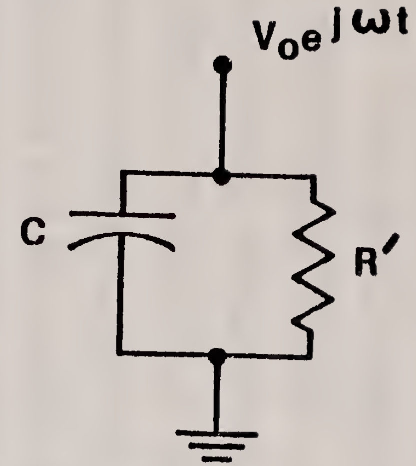
Two techniques have been successfully applied to the measurement of dielectric loss at cryogenic temperatures. One of these techniques depends on the fact that current through the resistor of Fig. 1 is shifted



$$I = \frac{V_o}{1/j\omega C + R}$$

$$\tan\delta = \omega CR$$

A.



$$I = V_o(j\omega C + 1/R')$$

$$\tan\delta = 1/\omega CR'$$

B.

FIGURE 1 Model of capacitor with dielectric loss.

by 90 ° with respect to capacitive current. In the case of Fig. 1A,

$$I = \frac{(\omega^2 C^2 R + j\omega C) V_o}{1 + \omega^2 C^2 R^2}$$ and in the case of Fig. 1B, $I = V_o \left(\frac{1}{R} + j\omega C\right)$.

The angle by which the total current vector differs from the vector for a pure capacitor is known as δ. The tangent of δ (or tan δ) is a figure of merit for dielectric materials. This number is also known as the "dissipation factor", or "D.F.". In Fig. 1A, $\tan \delta = \omega CR$; in Fig. 1B, $\tan \delta = \frac{1}{\omega CR}$. For any good dielectric material tan δ is small. If the dielectric constant of a material is written in terms of its real and imaginary parts, i.e., $\varepsilon = \varepsilon' + j\varepsilon''$ where ε' and ε'' are real numbers, then $\tan \delta = \frac{\varepsilon''}{\varepsilon'}$. One can use ac bridge techniques to balance the two current components against known standards of capacitance and resistance and thereby determine tan δ. This is the technique we have used. It will be discussed in detail within this report.

A second technique, which has been successfully applied to the measurement of single dielectric sheets at cryogenic temperatures, measures tan δ using a calorimetric method. The power dissipated in a capacitor in the form of heat is $P = I \cdot V = \omega C V^2 \tan \delta$. If the heat capacity of the sample and holder can be determined and is small, a measurement of temperature rise can be used to find tan δ. This technique was pioneered in England by Vincett.[2] It has been used successfully in this country by King and Thomas.[3] Calorimetric measurements have proven to be extremely useful for studying intrinsic dielectric behavior at 4 K over a wide range of frequency. The technique is, however, not well suited to measurements of composite dielectric structures such as actual cables because of the large heat capacities involved.

We have thus far assumed that the tan δ losses are independent of the applied voltage. It was further assumed that whatever be the source of the dielectric loss, it causes no deterioration of the material. At a high enough voltage, partial discharges begin to be observed and the above two assumptions are no longer valid. No cable is designed to operate in the partial discharge regime. Nevertheless, it is important that partial discharges be examined because unplanned circumstances may temporarily force the cable into partial discharge. Techniques for the study of partial discharges in the cryogenic cable models will be presented later in this report.

Dissipation Factor Measurements

We have measured tan δ for various samples at cryogenic temperatures by using a current comparator bridge operating at 60 Hz. The details of the electronic instrumentation will be described below. Common to every capacitance bridge technique is the balancing of an unknown capacitance against a known standard. The unknown or sample capacitor contains the dielectric to be measured. Thus, ideally, the sample capacitance is determined by a combination of the capacitor dimensions and the dielectric constant of the material filling the capacitor. The tan δ of the capacitor depends only on the sample dielectric. We used two sample capacitors in the course of our measurements. One, constructed at NBS, was in the form of parallel plates and was designed for measurements of single sheets of dielectric material. The other, given to us by Brookhaven National Laboratory, was a mandrel designed for the simulation of the composite dielectric and coaxial geometry used in cryogenic cables of the BNL design.

A. Parallel Plate Sample Holder

The sample holder consists of the two plates forming the parallel-plate capacitor, the dielectric of which is the material to be measured. The stainless-steel electrodes are shown in Fig. 2. The bottom plate consists of an active (inner) electrode and a guard ring. These two electrodes were epoxied together then lapped and polished. The area of the active electrode is 1.05×10^{-3} m^2 resulting in the following relation between capacitance C and thickness d (in μm) of the dielectric:

$$C \simeq 9.29 \times 10^3 \, (\varepsilon'/d) \text{ picofarads.} \qquad (1)$$

Typical thickness of the sample dielectric ranged from 25 μm to 125 μm so that the capacitances to be measured are in the range of about 100 to 1000 pF ($\varepsilon' \sim 2$ or 3 for proposed polymer insulation).

The capacitor is held together with two polyetrafluorethylene plates using nylon screws and nuts with phosphor-bronze springs as shown in Fig. 3. During the actual measurement the top electrode is energized and the resulting current from the inner, active electrode is sent to the current comparator bridge via a coaxial cable. The outer shield of the cable is connected to the guard ring on the one end and to ground at the bridge.

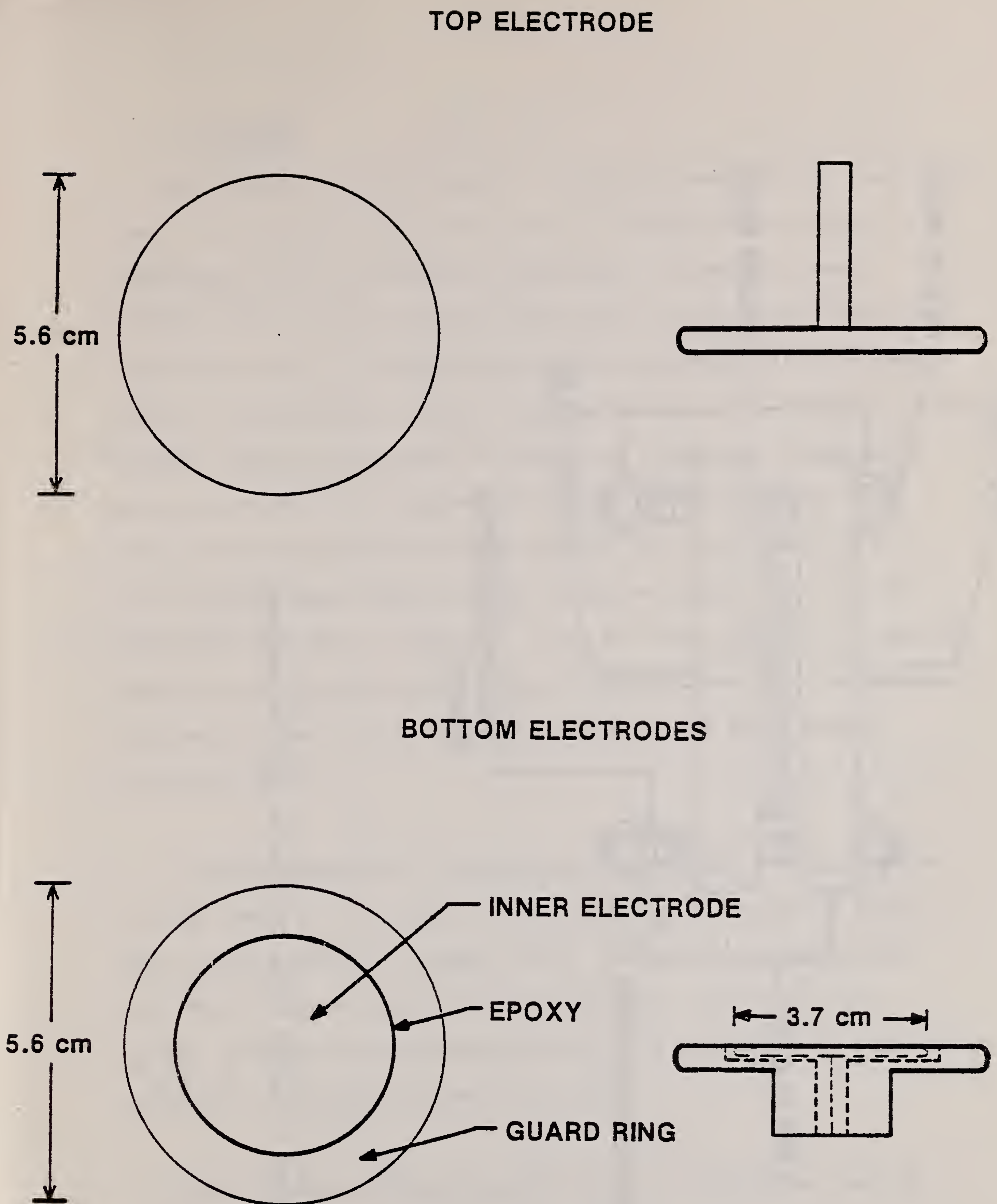


FIGURE 2 Electrodes for parallel plate sample holder.

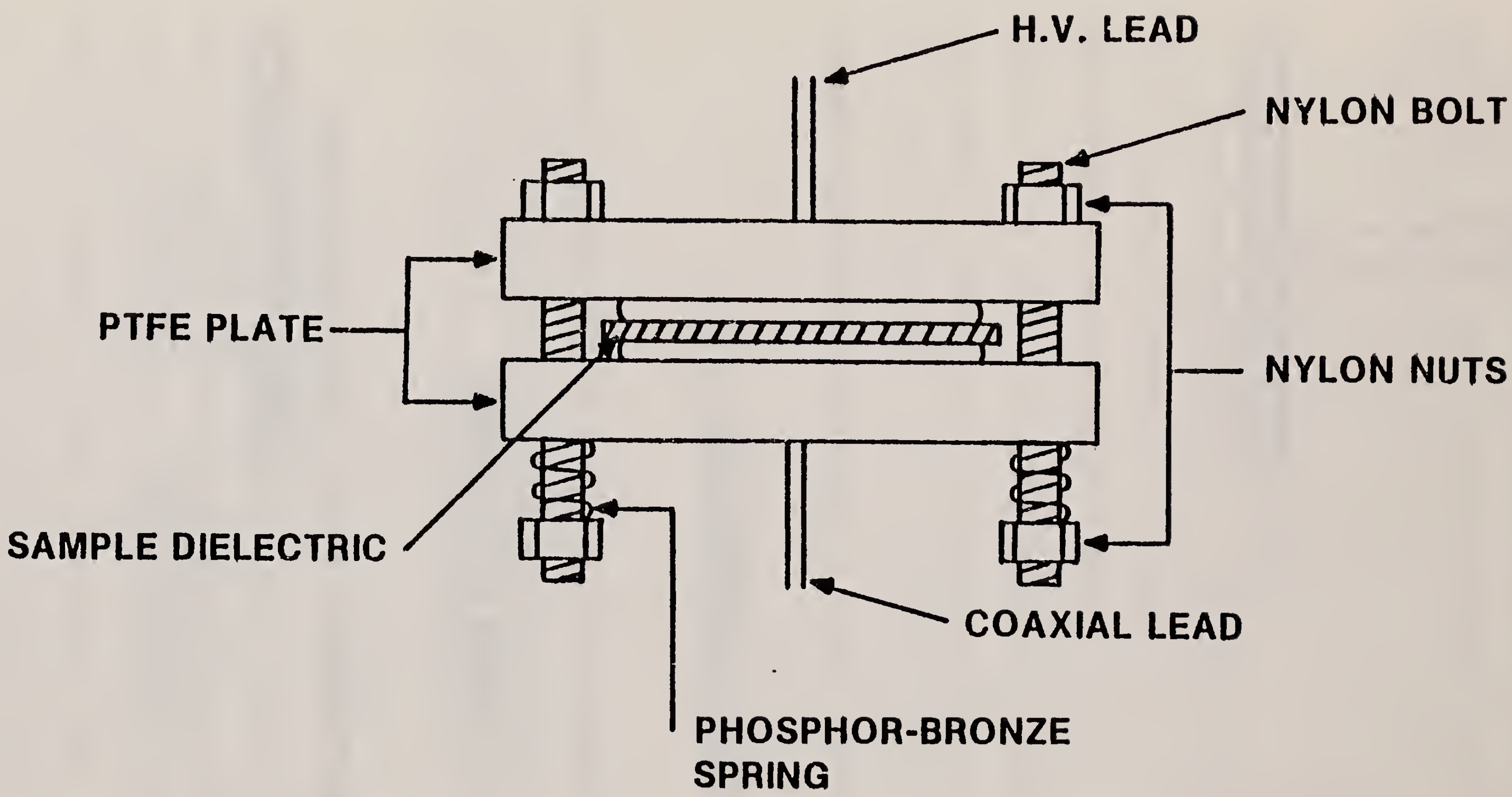


FIGURE 3 Sample holder for parallel plate measurements.

B. Cryostat

The cryostat is shown in Fig. 4. The inner diameter of the inner glass dewar is 11 cm with a usable height of 1 m. A high-vacuum electrical feedthrough ($\sim 10^{-5}$ Pa) terminated at both ends by commercial ceramic bushings (rated at 8.5 kV rms) was used to get the high voltage below the liquid helium level. This was necessary because gaseous helium has poor breakdown characteristics (several times worse than air). A stainless steel, shielded, coaxial cable brings the low-voltage signal out of the liquid helium to the top of the cryostat. The total resistance of the leads running from the capacitor to the bridge was less than 1 Ω. At 60 Hz, this resistance would cause an added dissipation factor 1×10^{-6} in the measurement of a 2600 pF capacitor. Since the capacitances of all samples measured in this apparatus were substantially less than this, the lead resistance is seen to have a negligible effect on the measurement of dissipation factor.

A typical measurement required about 5 to 6 liters of liquid helium allowing from 3 to 4 runs per 25 liter supply dewar. The helium would remain in the cryostat for several hours, if necessary, although most measurements were completed in less than an hour. The time for the cryostat to cycle from room temperature to 4.2 K and back to room temperature was about 20 hours which allowed daily runs.

Since the dewars are constructed of glass, no attempt was made to measure the dissipation factor as a function of increasing helium pressure. Also in these measurements the sample was immersed directly in liquid

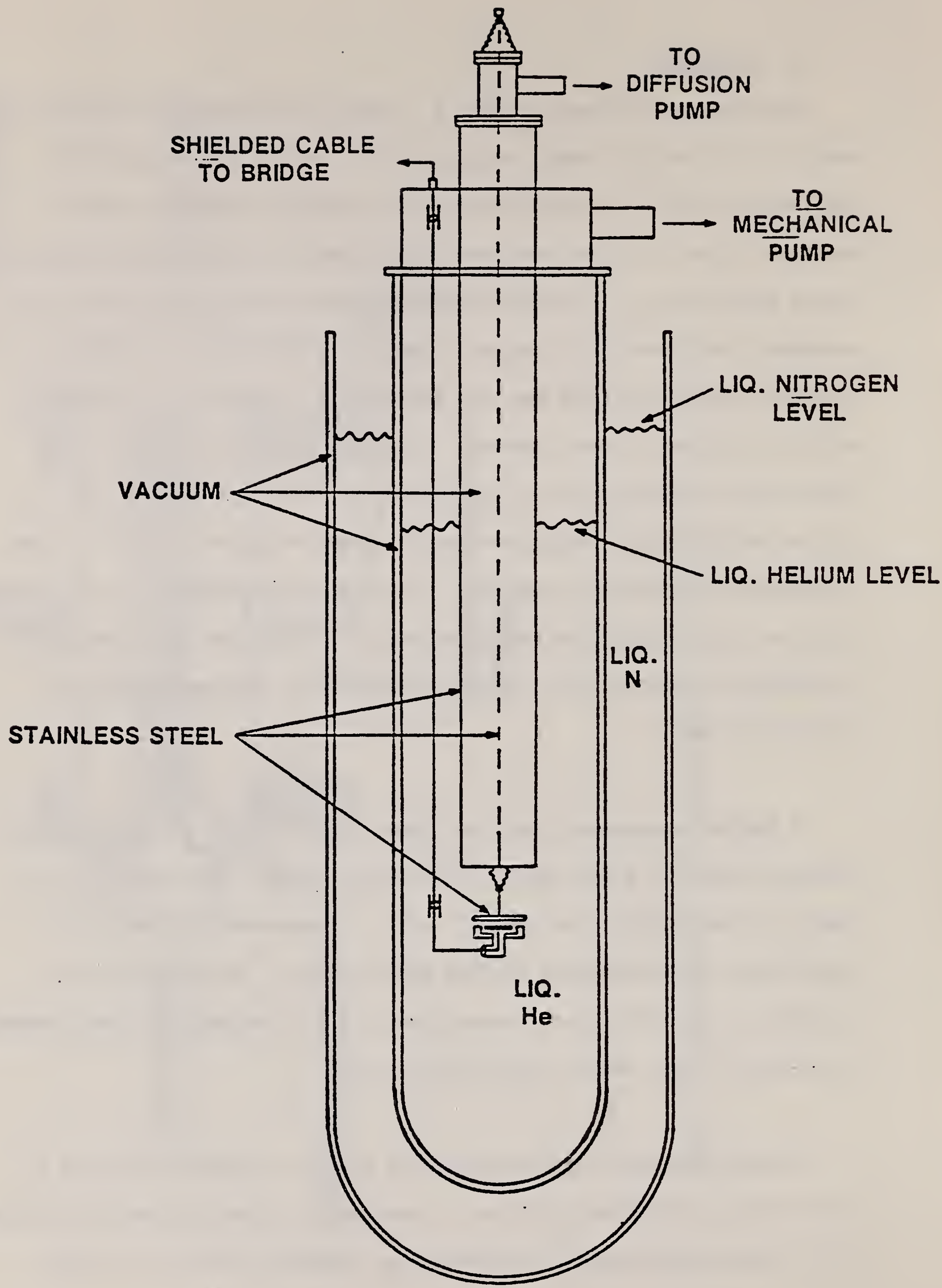


FIGURE 4 Cyrostat for parallel-plate measurements.

helium while in the calorimetric measurements of King and Thomas[3], the sample was in a vacuum.

C. Mandrel and Associated Cryostat for Coaxial Measurements

In order to test selected tapes at conditions more nearly simulating the BNL cable design than those of our parallel-plate sample holder, we acquired, in October 1976, apparatus developed by BNL. The apparatus consisted of a cryostat specially designed to accommodate mandrels around which were wound plastic tapes in simulation of cable insulation. These mandrels were also designed and built by BNL personnel. In addition, BNL provided us with a tapewinding device with which it was possible to wind layers of tape on a mandrel at selectable pitch angles. Although the cryostat and mandrel facility have been described in detail by their designers[4], it will be useful to restate the features of this facility which were most important to our work and to detail our own modifications to the equipment. The mandrels terminated in stress-relief cones at either end. The bare portion of the mandrel was a cylinder of $\sim$ 50 cm in length and 1.3 cm in diameter. The mandrels could be mounted vertically in the cryostat at which time the bare portion of the mandrel was centered along the vertical axis of the cryostat. The inner chamber of the cryostat was 5 cm in diameter. The stress-relief cones of the mandrels allowed one to energize the center electrode to at least 50 kV without the onset of corona. In addition, the cryostat was designed to withstand helium pressures of over 10^6 Pa at temperatures from 4 K to 10 K. The cryostat was housed in a liquid-nitrogen jacketed, stainless-steel helium dewar identical to that used at BNL.

Extensive modifications of the mandrels were necessary before they could be used for D.F. measurements. At BNL, the mandrels were used for breakdown studies. Therefore, the center electrode was simply energized and the cryostat grounded. On the other hand, D.F. measurements of the precision required by this project require that the sample holder be a three-terminal capacitor. What is more, the low voltage and guard electrodes must only be grounded at the current comparator bridge. These problems were solved in the following way.

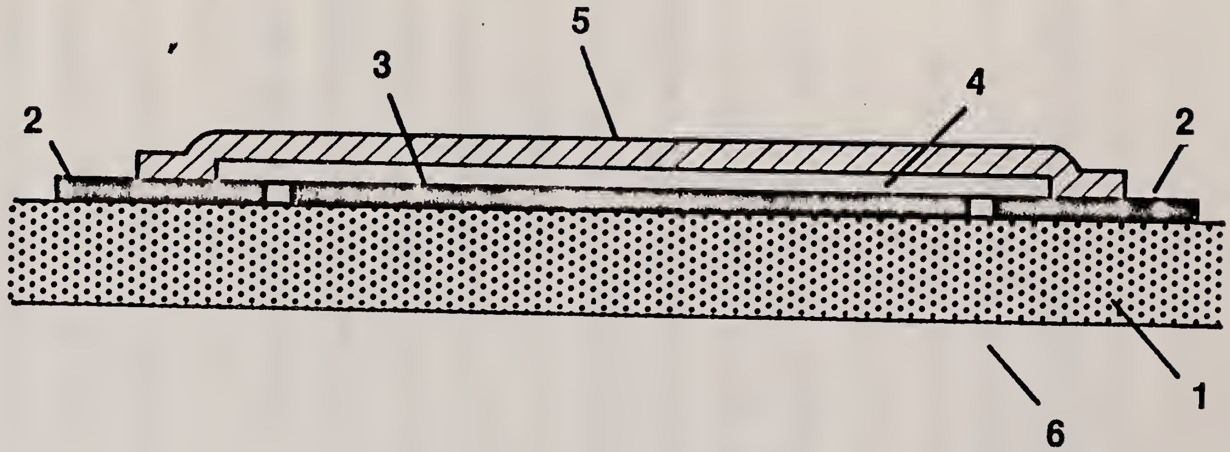
First, a shallow groove was machined along the mandrel insulation from the point at which it enters the cryostat to the point at which it begins to taper toward the bare center electrode. A shielded cable (made of an insulated wire in a stainless-steel tube) was cemented into the groove with epoxy. The top of the cable was terminated with a BNC connector. It was found that upon cooling, shrinkage of the polytetrafluoroethylene insulation in the connector sometimes caused a leak to the pressurized cryostat. Replacement of a small segment of the insulation with epoxy solved this problem.

A second groove machined along the mandrel insulation provided space for thermometer leads. For our three-terminal measurements it was possible to introduce thermometers directly into the inner chamber of the cryostat instead of relying on thermometers placed in the vacuum space surrounding the inner chamber as was done at BNL.

At first, germanium resistance thermometers were used, but it was found that these were not robust enough to withstand repeated cycling to pressures of many atmospheres. Instead, calibrated carbon resistors were used and proved to be nearly ideal.

Pressure in the cryostat was read using a Bourdon-tube type aneroid barometer. A somewhat less accurate transducer was also used as a check. The mandrels were wound on the tape-winding machine that we obtained from BNL. This machine allows the pitch angle to be easily varied. Figure 5 (a cross-sectional view parallel to the axis) shows how the mandrels were wound and illustrates the guarding arrangement that is necessary with the NBS current comparator bridge. The connection to the stainless steel coaxial cable, mentioned above, is not shown. The tape to be measured (Valeron* in Fig. 5) was first wound on the mandrel with the proper registration and tension. The low voltage electrode and the two guard electrodes were then attached. The inner wire of the stainless-steel coaxial cable was soldered to the low voltage electrode (the active electrode), and this electrode and wire were then covered with a layer of insulation. Another guard, electrically attached to the two guard electrodes and the outer conductor of the stainless-steel coaxial cable, was placed over this insulation. A final layer of insulation (not shown) was then wound around the outer guard to isolate it electrically from the pressure vessel wall.

Under these conditions, the capacitance in picofarads of a measured sample is



1. 4 LAYERS OF VALERON, 65-35 REGISTRATION
2. GUARD ELECTRODES (tin)
3. LOW VOLTAGE ELECTRODE (tin)
4. 1 LAYER OF INSULATION, OVERLAPPED
5. SHIELD (tin)
6. HIGH VOLTAGE ELECTRODE (stainless steel)

FIGURE 5 Cross-section of mandrel showing wound layers.

$$C \simeq \frac{8.85\ \varepsilon' L}{\ln r_2/r_1},$$

where L is the length of the active electrode in meters, r_1 is the radius of the inner electrode (mandrel) and r_2 is the distance from the center axis of the mandrel to the active outer electrode. The quantity ε' is an effective value for the composite structure of polymer tapes and helium-filled butt gaps.

D. Standard Capacitor

Since the dielectric properties of the sample are obtained by electrically balancing the current in the sample capacitor with the current in the standard capacitor, a knowledge of the properties of the standard capacitor is essential for this measurement. A 100 pF compressed-gas (nitrogen) capacitor was used for the standard. In the majority of high voltage measurements, this type of capacitor can be assumed to be lossless. (Commercial capacitors generally claim a dissipation factor of "less than 10×10^{-6}"). In our measurements, where a total dissipation factor uncertainty of $\pm 1 \times 10^{-6}$ was necessary, the dissipation factor of the standard capacitor must be accurately measured. The current comparator bridge which will be described in the next section has the capability of measuring relative dissipation factors to better than $\pm 1 \times 10^{-6}$ but the absolute dissipation factor of the standard must be known in order to determine the dissipation factor of the material being measured. The dissipation factor of our standard capacitor was measured by John Q. Shields of the Center for Absolute Physical Quantities, NBS. A brief discussion of how this was done[5,6] follows.

A guard ring capacitor with variable plate separation is placed in one arm of a transformer ratio-arm bridge and the standard capacitor to be measured in the other. Successive relative dissipation factor balances between the variable capacitor at different plate settings and the standard capacitor with auxiliary capacitors in parallel with it are made. Since the relative dissipation factors between the standard capacitor and each of the auxiliary capacitors can readily be measured, then the relative dissipation factor between the standard and the variable plate capacitor at several settings will be known. If the dissipation factor for the variable plate capacitor is caused only by a surface film, a plot of the relative dissipation factor versus capacitance should be on a straight line as will be shown below. The guard-ring capacitor with electrode spacing, d, and film thickness, t, is shown in Fig. 6a. This capacitor can be represented by an ideal capacitor, C_1, in series with a lossy capacitor with capacitance, C_2, and parallel resistance, R_2, Fig. 6b. This series combination can be represented as in Fig. 6c by an ideal capacitor, C_0, in parallel with a resistor, R_0.

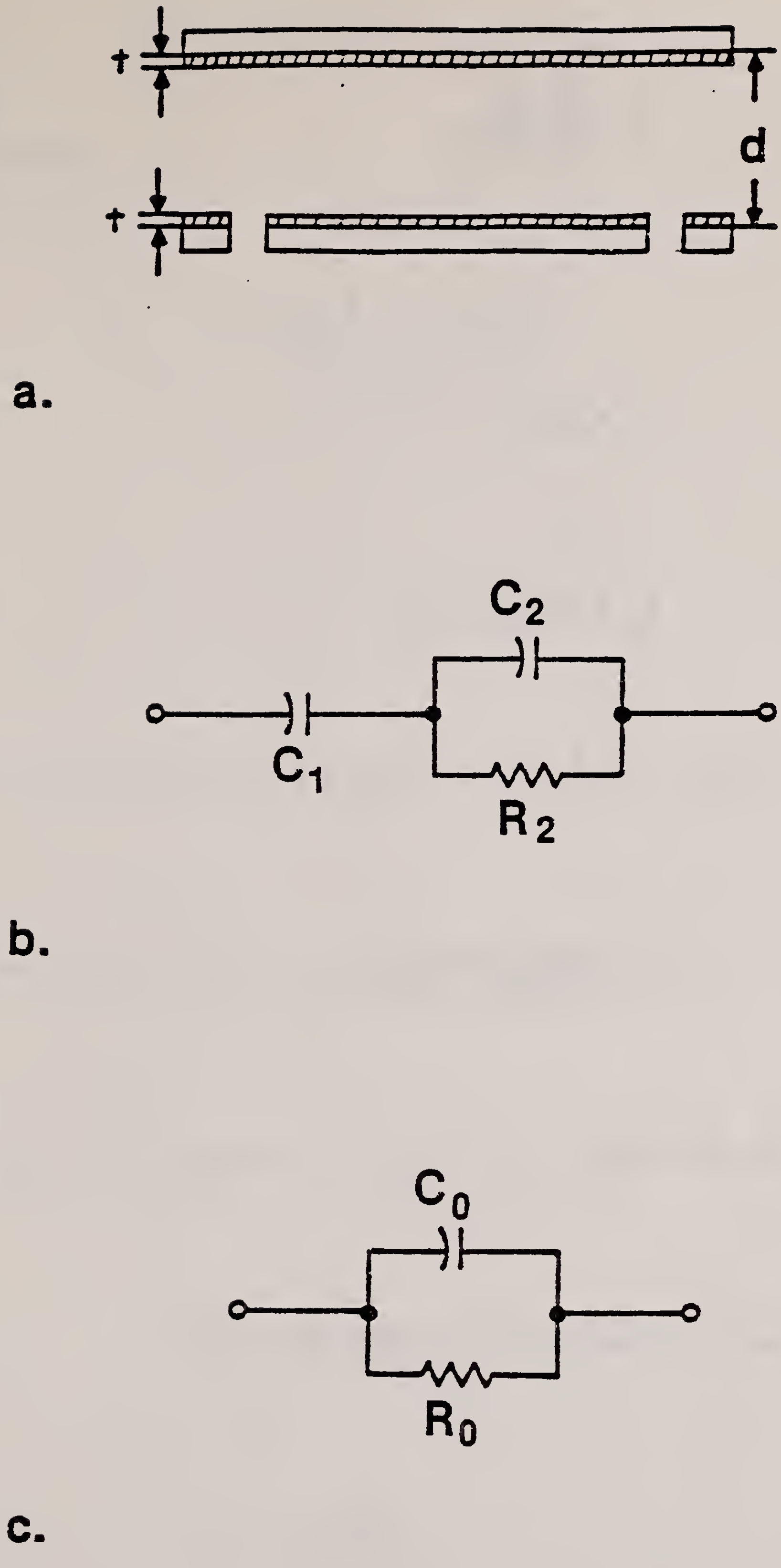


FIGURE 6 Guard-ring capacitor.

$$Y_0 = \frac{Y_1 Y_2}{Y_1 + Y_2} \tag{2}$$

where

$$Y_1 = j\omega C_1 \tag{3}$$

$$Y_2 = 1/R_2 + j\omega C_2 \tag{4}$$

and

$$Y_0 = 1/R_0 + j\omega C_0. \tag{5}$$

From (2), (3), (4), and (5),

$$Y_0 = j\omega C_1 \ (1 + j\omega C_2 \ R_2)/(1 + j\omega R_2 \ (C_1 + C_2))$$

or

$$Y_0 = \frac{\omega^2 C_1{}^2 R_2 + j\omega C_1 \ [1 + \omega^2 \ C_2 \ R_2{}^2 \ (C_1 + C_2)]}{1 + \omega^2 \ R_2{}^2 \ (C_1 + C_2)^2} \quad . \tag{6}$$

Using (5) and (6)

$$R_0 = \frac{1 + \omega^2 R_2^2 (C_1 + C_2)^2}{\omega^2 C_1^2 R_2}$$

and

$$C_0 = C_1 [1 + \omega^2 C_2 R_2^2 (C_1 + C_2)]/[1 + \omega^2 R_2^2 (C_1 + C_2)^2].$$

The dissipation factor, D.F., is equal to $(\omega C_0 R_0)^{-1}$.

$$D.F. = \omega C_1 R_2/[1 + \omega^2 C_2 R_2^2 (C_1 + C_2)]$$

where

$$C_1 = \frac{\varepsilon_0 A}{d - 2t}$$

and

$$C_2 = \frac{\varepsilon_r \varepsilon_0 A}{2t}$$

assuming an area, A, and dielectric constant ε_r for the film.

Since $t << d$ or $C_1 << C_2$

$$\text{D.F.} \approx \omega R_2 \varepsilon_0 A/[(d - 2t)(1 + \omega^2 C_2^2 R_2^2]$$

or

$$\text{D.F.} \approx \frac{K}{d - 2t} \tag{7}$$

where for a particular frequency K is a constant independent of plate spacing.

The film thickness t is much less than the electrode spacing so (7) can be further approximated

$$D.F. \approx K/d.$$

Therefore, if the dissipation factor is caused by surface films, the D.F. should vary inversely with the electrode separation, d, and hence be proportional to the capacitance. A plot of relative dissipation factor for the variable capacitor versus capacitance should be on a straight line. The intercept of this line with the dissipation factor axis represents the relative dissipation factor for infinite electrode separation and, therefore, the dissipation factor of the standard capacitor. The fact that the points do lie on a straight line supports this model.

A portable standard capacitor was calibrated in this fashion and found to have a 60-Hz dissipation factor of -1.1×10^{-6} with an uncertainty of $\pm 0.3 \times 10^{-6}$. Our compressed-gas standard capacitor had a relative dissipation factor of 2.9×10^{-6} with respect to this portable standard or an absolute dissipation factor of $1.8 \times 10^{-6} \pm 0.5 \times 10^{-6}$.

The negative dissipation factor, seemingly worrisome, is easily explained. To see how this is possible, consider Fig. 7. The three-terminal measurement of a guarded lossless capacitor, C_s, is shown in Fig. 7a.

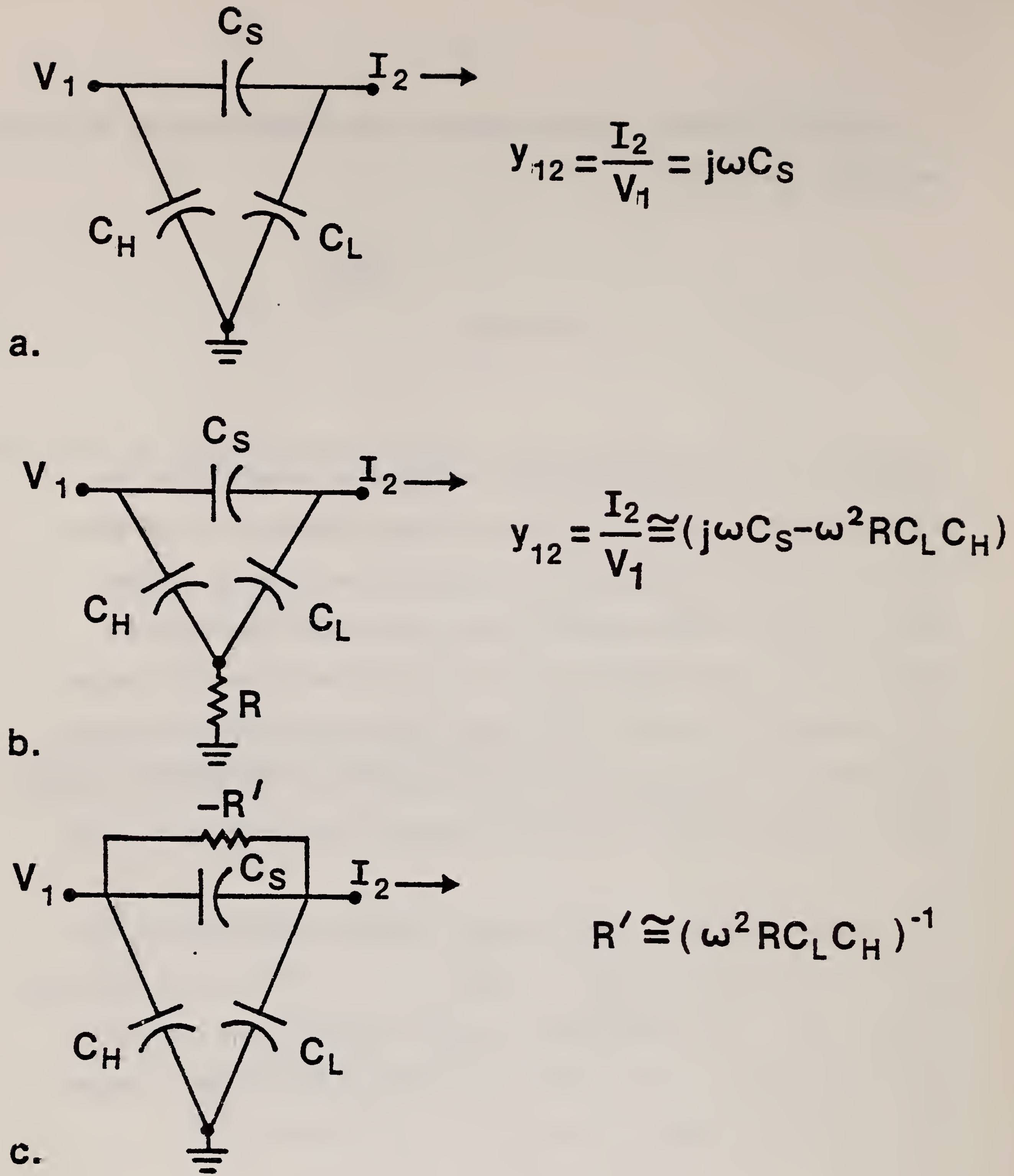


FIGURE 7 Three-terminal capacitor with negative dissipation factor.

Capacitors C_H and C_L are the capacitances formed by the guard and the high and low voltage electrodes. In a bridge measurement, the low voltage side is grounded. In this case, the short-circuit transfer admittance of the circuit shown in Fig. 7a is $y_{12} = j\omega C_s$. Now suppose, as in Fig. 7b, the capacitor's construction is flawed by loss in a common ground return. This frequency-dependent mechanism is represented by a resistance, R. If $1/R\omega$ is large, compared to both C_H and C_L, then $y_{12} \approx j\omega C_s - \omega^2 R C_H C_L$. The right hand side of this relation differs from the ideal case by containing a small term which is $\pi/2$ radians out of phase with $j\omega C_s$. Since the measurement of y_{12} is made on a "black box", the results of the measurement could be caused either by the circuit in Fig. 7b or Fig. 7c. Fig. 7c is the schematic representation of a guarded capacitor with capacitance C_s and dissipation factor equal to $-1/\omega C_s R'$ where $R' = (\omega^2 R C_H C_L)^{-1}$. The dissipation factor is negative. In the case of our portable standard capacitor, the negative dissipation factor was caused by the unsuspected presence of a layer of a high-loss adhesive between the guard and ground.

Measuring the loss of a capacitor containing liquid helium as its dielectric provided an independent means of checking the loss of our standard. At low enough voltages a liquid helium capacitor should be lossless -- the helium itself has no loss mechanisms and its temperature, 4.2 K, reduces to insignificance the loss of any adventitious film on the electrode surface.[7] Our parallel-plate sample holder with 100 μm dielectric spacers between the guard ring and the active electrode was used as a liquid helium capacitor. The results of a bridge measurement against our compressed-gas standard confirmed loss measurements of the standard described above. (At a stress of 1.5 kV/mm the 60 Hz dissipation factor was $(0.3 \pm 0.7) \times 10^{-6}$).

E. Current Comparator Bridge

The real part of the dielectric constant and the dissipation factor of a sample are measured by balancing the current in the sample capacitor against the current in the standard capacitor using a bridge. A simplified version of how this is done is illustrated in Fig. 8. The lossy sample capacitor is represented by a parallel combination of an ideal capacitor, C_X, and a resistor, R_X. At balance (i.e., zero signal at the detector, D) since $I_X N_X = I_S N_S$,

$$C_X = n_{sd}\, n_{dx}\, C_s$$

and

$$D.F. = (\omega\, R_s\, C_s)^{-1}$$

where

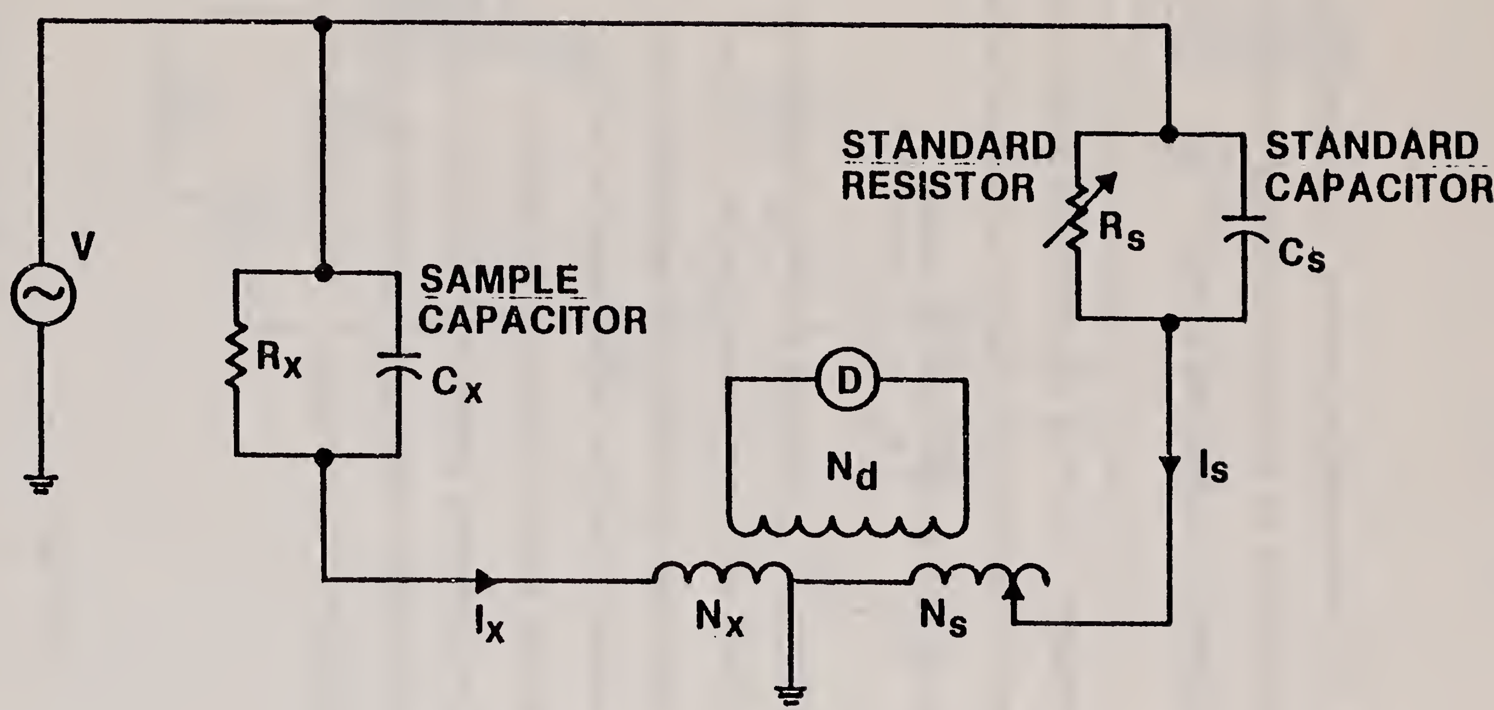


FIGURE 8 Simplified current comparator bridge.

$$n_{sd} \equiv N_s/N_d.$$

The transformer in Fig. 8 is a three-winding current transformer or a current comparator. Extensive work on this type of bridge has been done at the National Research Council in Canada and at NBS.[8,9]

Unfortunately, the bridge in Fig. 8 is not practical because resistance standards for high voltage are impractical to make, and another method for balancing the in-phase or loss current must be sought.

The circuit in Fig. 9 provides a suitable method for balancing the loss component. An operational amplifier, which provides a virtual ground for the current through the N_S winding (the amplifier's open loop gain being greater than 10^4), outputs a voltage signal equal to $-V\ C_s/C_f$, typically one thousandth of the source voltage, V, or smaller. A variable resistance which is connected between the amplifier output and the third current-carrying ratio winding, N_3 (opposite in polarity to N_S) can be used to balance the loss component. The balance equation now becomes:

$$C_X = n_{sd}\ n_{dx}\ C_s \tag{8}$$

$$D.F. = (N_3/N_S)\ (1/\omega\ C_f\ R_S). \tag{9}$$

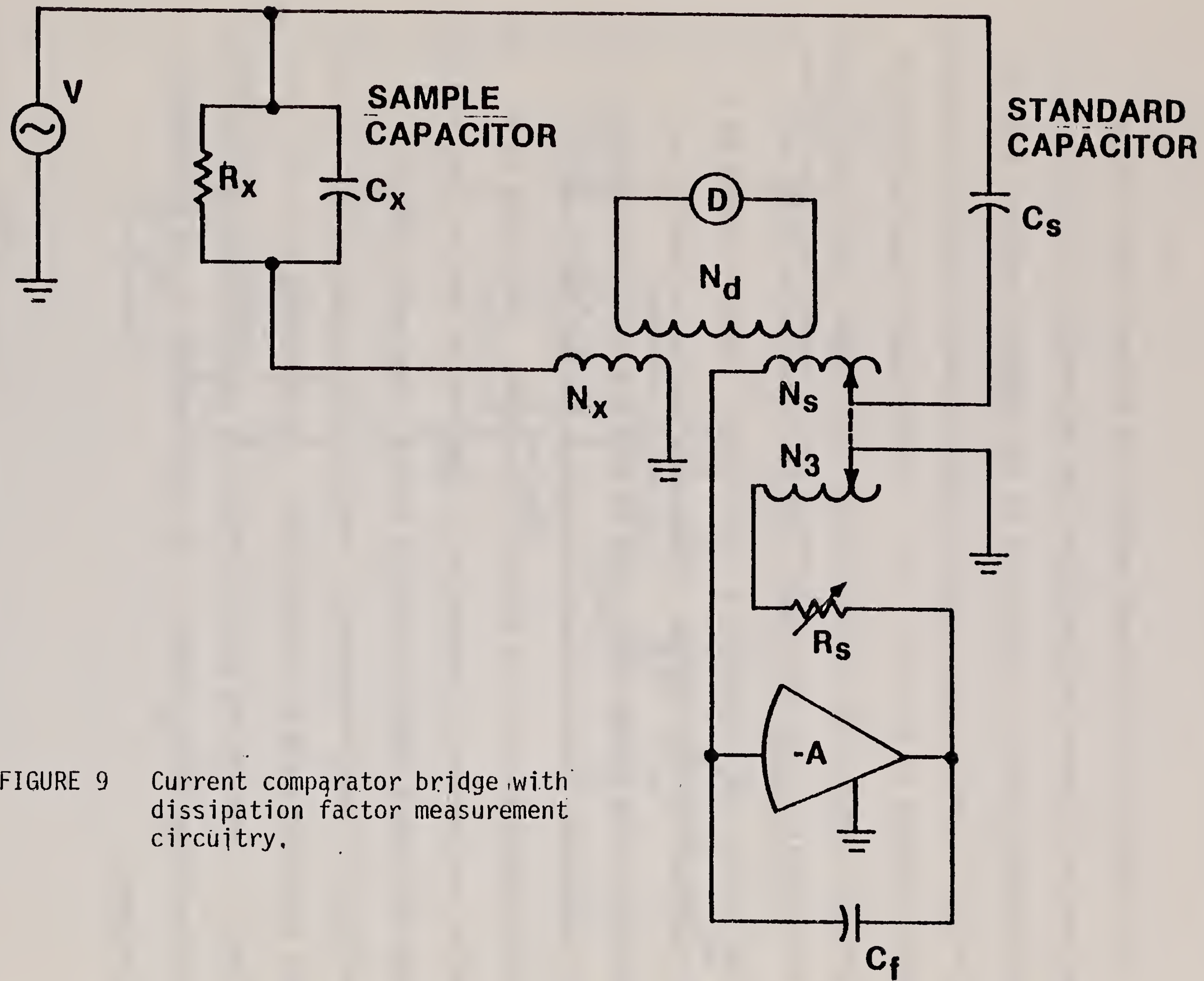


FIGURE 9 Current comparator bridge with dissipation factor measurement circuitry.

In the actual bridge the switches for the N_3 and N_S windings are mechanically coupled so that the bridge can be made direct reading in dissipation factor for a particular frequency (e.g., 60 Hz).

The resistance of the leads between the voltage source and the capacitors and between the capacitors and the bridge will contribute to the dissipation factor. In the case of the standard capacitor side of the bridge, it would take a lead resistance of about 25 ohms to cause an apparent decrease in D.F. of 1×10^{-6}. On the sample capacitor side of the bridge, however, the lead resistance could become significant. From (1) the capacitance for the sample capacitor could be as large as 1000 pF so that an increase in D.F. of 1×10^{-6} would be caused by a lead resistance of 2 to 3 ohms. The actual lead resistance in our measuring circuit is less than 1 ohm so that the lead resistance is still negligible. Larger capacitance sample holders would require careful consideration of the effect of the leads. The bridge in Fig. 10 remedies this problem by automatically compensating for the lead resistance between the sample capacitor and the bridge. The small voltage, v, caused by this lead resistance, r, results in the voltage drop across the sample capacitor being V-v instead of V. To compensate for this, the voltage v is inverted and passed through the capacitor, C_S', the resulting current entering the N_S winding. The total current in the N_S winding then becomes

$$I_S = Vj\omega C_S - vj\omega C_S'$$

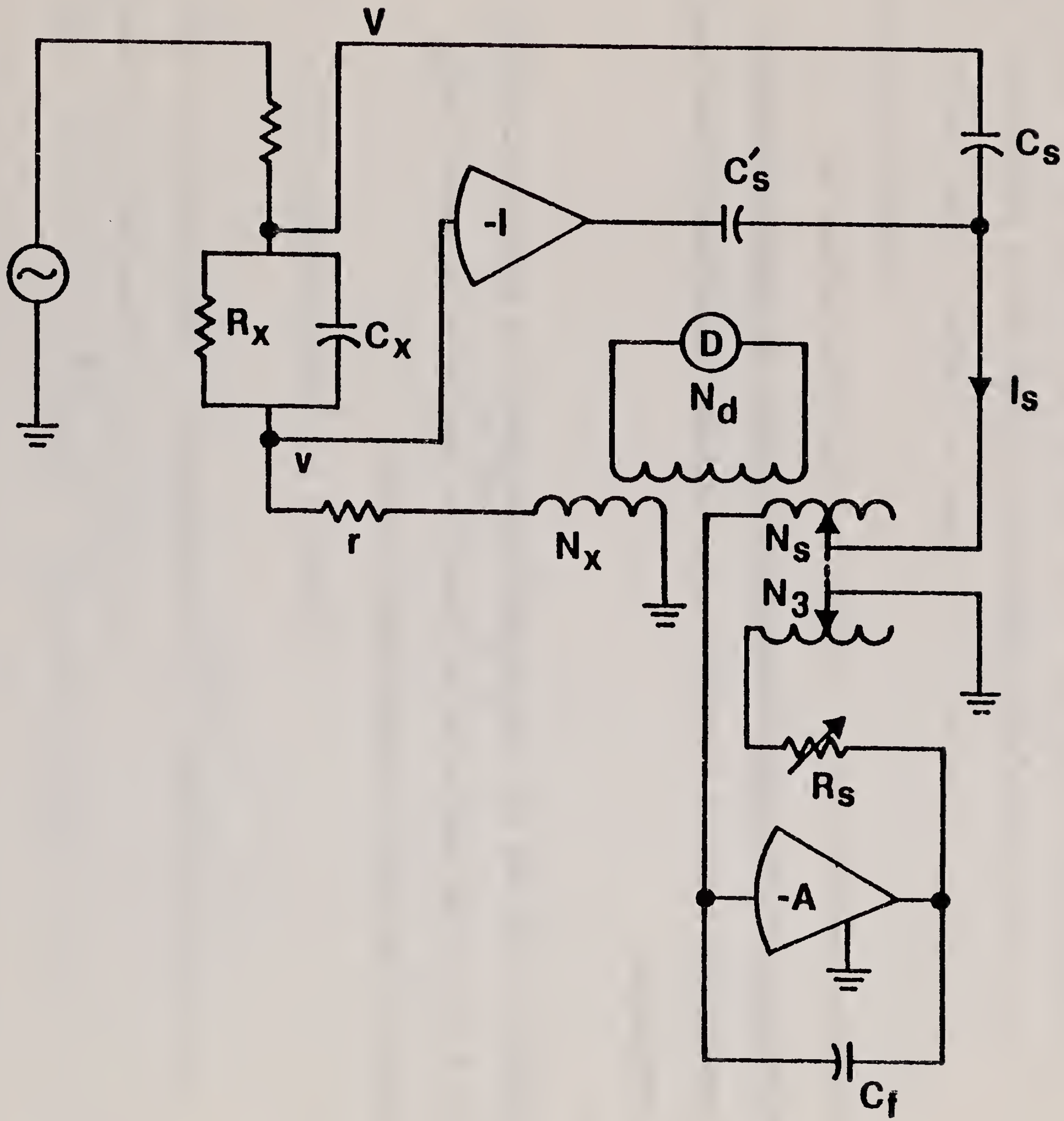


FIGURE 10 Current comparator bridge with lead compensation.

or

$$I_S = j\omega C_S \; (V - vC_S'/C_S).$$

If C_S' is set equal to C_S, then

$$I_S = j\omega C_S \; (V-v).$$

The resulting current is as if a voltage V-v was placed across the standard capacitor, the same voltage that is across the sample capacitor. The compensating circuit, therefore, has eliminated the effect of this lead resistance.

From (1), (8) and (9) the dielectric-constant, ε', and the dissipation factor, D.F., of the sample can be found from the bridge by the following equations for the parallel-plate sample holder:

$$\varepsilon' = (1.08 \times 10^{-4}) \; (d \; n_{sd} \; n_{dx} \; C_S) \tag{10}$$

$$D.F. = (N_3/N_S) \; (1/\omega \; C_f \; R_S) + 1.8 \times 10^{-6} \tag{11}$$

where C_S is in picofarads and d is in micrometers.

The effect of the dissipation factor of the standard capacitor discussed in the previous section is included in (11).

The estimated uncertainty of (11) is $\pm 1 \times 10^{-6}$ at 60 Hz. The uncertainty in (10), the dielectric constant, may be as large as ±10 percent even though the turns, n_{sd} and n_{dx}, are known to 1×10^{-6}. This is because the actual electrode spacing at low temperature is not known. In our measurements the room temperature value of d is used thereby assuming no thermal contraction of the sample. The thickness of these thin samples is not always uniform which also contributes to the error. Errors due to coating the sample with paraffin oil (discussed below) are negligible.

Similar considerations hold for the mandrel measurements. The real component of the dielectric constant is

$$\varepsilon' = 0.113\, n_{sd}\, n_{dx}\, C_S \ln Cr_2/r_1/L \qquad (12)$$

where C_S is in picofarads and L is in meters.

The dissipation factor is the same as (11). Measurement errors are the same as for the parallel plate capacitor.

II. Dielectric Loss Results and Discussion

A. Parallel Plate Geometry

Many samples of different polymer tapes and epoxies were studied using the parallel plate apparatus described above. The polymers were all candidate insulators for the BNL flexible cable. The epoxies were either under consideration as spacers in the pipe-type cable being developed by the Linde Division of the Union Carbide Corporation (UCC-Linde) or were used as bushing material in BNL test apparatus. The sample holder was immersed in liquid helium at atmospheric pressure (4.2 K).

All samples were coated with paraffin oil prior to loading in the sample holder. Without the paraffin oil coating, the dissipation factor of all samples showed a strongly positive voltage dependence. This dependence could be greatly reduced by use of the paraffin oil, indicating the presence of voltage-dependent interfacial losses at the metal - plastic interface. These losses will be discussed more fully below. King and Thomas[10] have shown that the paraffin oil coating introduces no additional contribution to the dissipation factor. They place the uncertainty of this determination at less than 1×10^{-6} at 60 Hz.

1. Polymer Tapes

The results of the polymer measurements are shown in Table I. The voltage dependence on tan δ is in most cases quite small. Measurements were terminated at the first signs of partial discharge inception as

TABLE I. SUMMARY OF RESULTS AT 60 HZ AND 4.2 K

Material*	Thickness	Maximum Voltage (Stress) Applied	Tan δ at Maximum Voltage	Tan δ at 200 V rms
Polyamide (Nylon 11-A, non-oriented)	40 μm	1000 V rms (25 kV/mm)	27×10^{-6}	24×10^{-6}
Polycarbonate-A (uniaxially oriented)	75	2000 (27)	69	61
Polyethylene-D (biaxially oriented, cross laminated)	100	2000 (20)	9	6.5
Polyethylene-B (biaxially oriented)	40	800 (20)	18	7
Polypropylene-C (non-oriented)	125	2000 (16)	7	3
Polypropylene-A (biaxially oriented)	30	1200 (40)	26	24
Polypropylene-B (biaxially oriented)	40	1200 (30)	15.5	17.5
Polysulfone-B (clear)	100	1000 (10)	100	96
Polysulfone-C (blue)	140	3000 (21)	126	113
Polysulfone-D (green)	140	1200 (9)	110	105
Polysulfone-E (green, fewer Na impurities)	110	1000 (9)	82	79
Polyether-sulfone-A (biaxially oriented)	10	400 (40)	28	62
Polyether-sulfone-B (non-oriented)	30	800 (27)	42	70

evidenced by unstable bridge behavior. The repeatability of polymeric samples from the same manufacturer is generally good although polymers with the same generic name may differ markedly. Several of the samples are seen to have tan δ's less than 20×10^{-6} at design stresses of the order of 10 to 20 kV/mm. However, these materials have rather poor mechanical properties. The mechanically-sound materials have tan δ's in the range of 50 to 100×10^{-6}. An attempt by the manufacturer to improve the tan δ of one of these materials (green polysulfone) by reducing the sodium concentration met with some success.

The significant decrease in dissipation factor with increasing stress for the two polyether-sulfone samples is unique in our low-temperature experience. This negative voltage coefficient is a commonly observed property of power-factor capacitors and there the effect is well understood.[11] The explanation for the observed behavior of polyether-sulfone remains unexplained.

As a check of our measurements one can compare our data with the published data of King and Thomas[12] for experimental conditions of 4.2 K and 60 Hz. Agreement is excellent. The measurements are quite independent of each other since theirs rely on a temperature rise and ours on an electrical bridge balance to measure dissipation factor. Our measurements also agree rather well with those of Mopsik made at NBS.[13] Mopsik's apparatus is capable of studying the low voltage behavior of small polymer samples as a function of temperature and frequency of applied voltage. Comparison of our data with his is not quite independent because the dissipation factor of his standard capacitor was supplied by us. Nevertheless, we feel secure that this number is correct.

To examine the effects of paraffin oil on various interfaces, we studied several stacking arrangements of 30 μm-thick polypropylene films. This film was chosen because it exhibited a small voltage coefficient over a wide range of voltage stress. The dissipation factor of three-sheet stacks of this material was measured under the following conditions. In one case, both sides of each sheet were coated with paraffin oil. In another instance only the metal-insulator interfaces were coated. A two-sheet stack with oil only between the metal-insulator interfaces was also measured.

The results of these measurements are plotted in Fig. 11. The slopes are consistent with similar measurements made using the calorimetric method at another laboratory.[13] Nevertheless, it is clear that the nature of the interfaces plays an important role in the dissipation factor of a composite structure at high stress. For this reason we decided that simulated cable insulation must be studied under conditions as close to those of the actual cable as possible. Hence, future studies of dissipation factor in composite structures were undertaken using the coaxial mandrel apparatus already described. The results of these measurements will be described below.

2. Epoxy Samples

Epoxy measurements offered an additional experimental difficulty as compared to polymer measurements: epoxy sheets must have surfaces which are parallel and free from imperfections. This is because epoxy, unlike

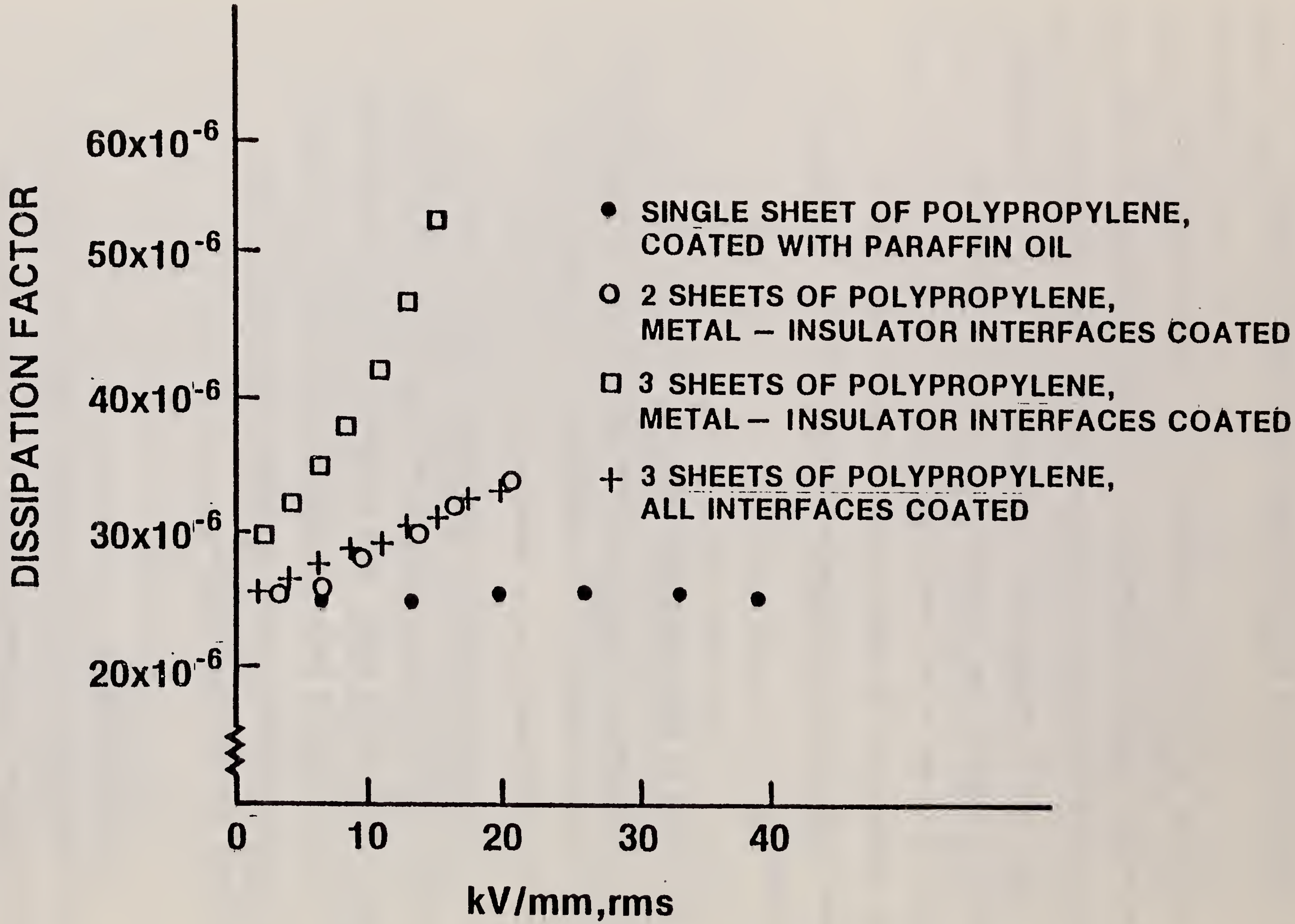


FIGURE 11   Multilayer stacks of polypropylene at 4.2 k, 1 atmosphere pressure.

plastic tapes, is not compliant at room temperature and thus will not seat well between the electrodes of the sample holder. Due to this problem, tan δ measurements of epoxy samples which were not carefully fabricated exhibited a pronounced voltage dependence. In samples which were well-made, we observed a dependence of tan δ with sample thickness. We were able to develop a theoretical model which explains the thickness dependence and allows us to ascertain the intrinsic D.F. of the material.

Our hypothesis to explain the observed thickness dependence of tan δ is based on the following considerations. As a result of imperfect parallelism of the epoxy surfaces as well as the rigidity of epoxy at room temperature, the sample capacitance behaves as the model shown in Fig. 12. In addition to the epoxy, the capacitor dielectric includes a thin film of thickness τ and dielectric constant ε_1. In our measurements this film is either mineral oil or liquid helium both of which have negligible loss. We assume τ is roughly the same for all well-made samples.

Assume the epoxy has a complex dielectric constant $\varepsilon' + j\varepsilon''$. Then the capacitance and dissipation factor of the epoxy-film composite may be found from the schematic representation of Fig. 12.

$$C_{EF} = A\varepsilon'\varepsilon_0/\{d(1 + \varepsilon'\tau/\varepsilon_1 d)\}$$

$$(\tan\delta)_{EF} = (\varepsilon''/\varepsilon')/(1 + \varepsilon'\tau/\varepsilon_1 d) \tag{13}$$

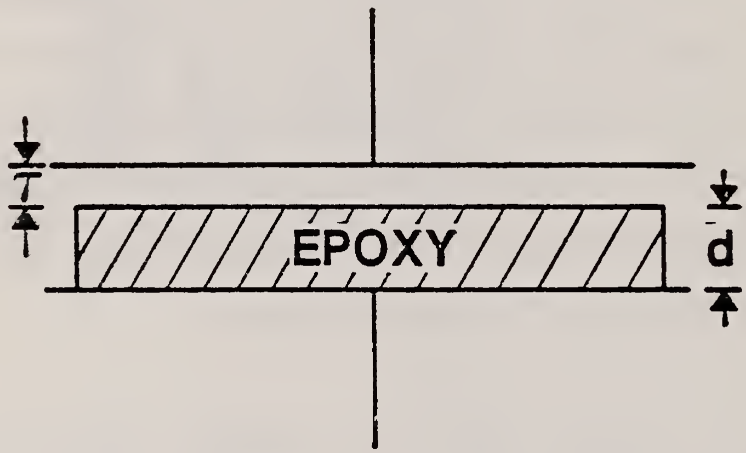


FIGURE 12   Model of epoxy behavior.

where A is the active electrode area, d is the sample thickness and ε_0 is the permittivity of free space. The model, therefore, predicts that the quantity $(\tan\delta)_{EF}/C_{EF}d$ is a constant which we shall call γ, and which depends only on properties of the epoxy.

$$\gamma \equiv \frac{(\tan\delta)_{EF}}{C_{EF}d} = \frac{\varepsilon''}{A\varepsilon_0\varepsilon'^2} \qquad (14)$$

Our hypothesis was tested with the aid of four samples of Perma-Rez CRS-48* differing in thickness but identical in composition. The samples were provided by UCC-Linde which took great care in their fabrication. Each sample was measured twice. The raw data are shown in Table II. The calculation of γ is carried out in Table III. The average value, γ, is equal to $11.94 \times 10^9\ (\mathrm{F \cdot m})^{-1}$ with a standard deviation of 1.6%. Thus, a prediction of the model has been verified.

Equation 13 may be rewritten in the form

$$(\tan\delta)_{EF}^{-1} = \varepsilon'/\varepsilon'' + \tau\varepsilon'^2/\,\varepsilon''\varepsilon_1 d. \qquad (15)$$

A plot of $(\tan\delta)_{EF}^{-1}$ as a function of 1/d should give a straight line if our hypothesis is correct. Figure 13 shows this to be the case. The solid line was obtained using a least squares fit to the data. This fit gives a y-intercept of 2.55×10^3 and a slope of 0.3039 m. Then

TABLE II

Dissipation Factor Data of Epoxy Samples
Tan δ was read directly from bridge,
ε' was calculated from the thickness of the epoxy and
the capacitance reading of bridge.

Perma-Rez CRS-48*, 60 Hz, 4.2 K

1020 μm thick sample

Voltage (volts-rms)	tan δ Run #1 (ε' = 3.14)	tan δ Run #2 (ε' = 3.22)
100	348×10^{-6}	354×10^{-6}
200	347	353
400	344	
600	340	
800	337	
1000	335	
2000	335	

510 μm thick sample

Voltage	tan δ Run #1 (ε' = 2.86)	tan δ Run #2 (ε' = 3.08)
100	314×10^{-6}	335×10^{-6}
200	312	333
400	303	
600	297	
800	289	
1000	283	
1500	270	

249 μm thick sample

Voltage	tan δ Run #1 (ε' = 2.24)	tan δ Run #2 (ε' = 2.38)
100	252×10^{-6}	265×10^{-6}
200	249	260
400	247	
600	244	
800	245	
1000	251	

140 μm thick sample

Voltage	tan δ Run #1 (ε' = 1.96)	tan δ Run #2 (ε' = 1.88)
100	223×10^{-6}	204×10^{-6}
200	219	200
400	217	
600	225	

TABLE III

Calculation of Model Constant, γ

d(m)	D.F.	C(F)	γ $\frac{1}{F \cdot m}$
1.016×10^{-3}	348×10^{-6}	28.6×10^{-12}	11.98×10^{9}
1.016×10^{-3}	354	29.3	11.89
0.508×10^{-3}	314	52.1	11.86
0.508×10^{-3}	335	56.2	11.73
0.249×10^{-3}	252	83.5	12.12
0.249×10^{-3}	265	88.7	12.00
0.140×10^{-3}	223	129.8	12.27
0.140×10^{-3}	204	124.5	11.70
			AVE = 11.94×10^{9}

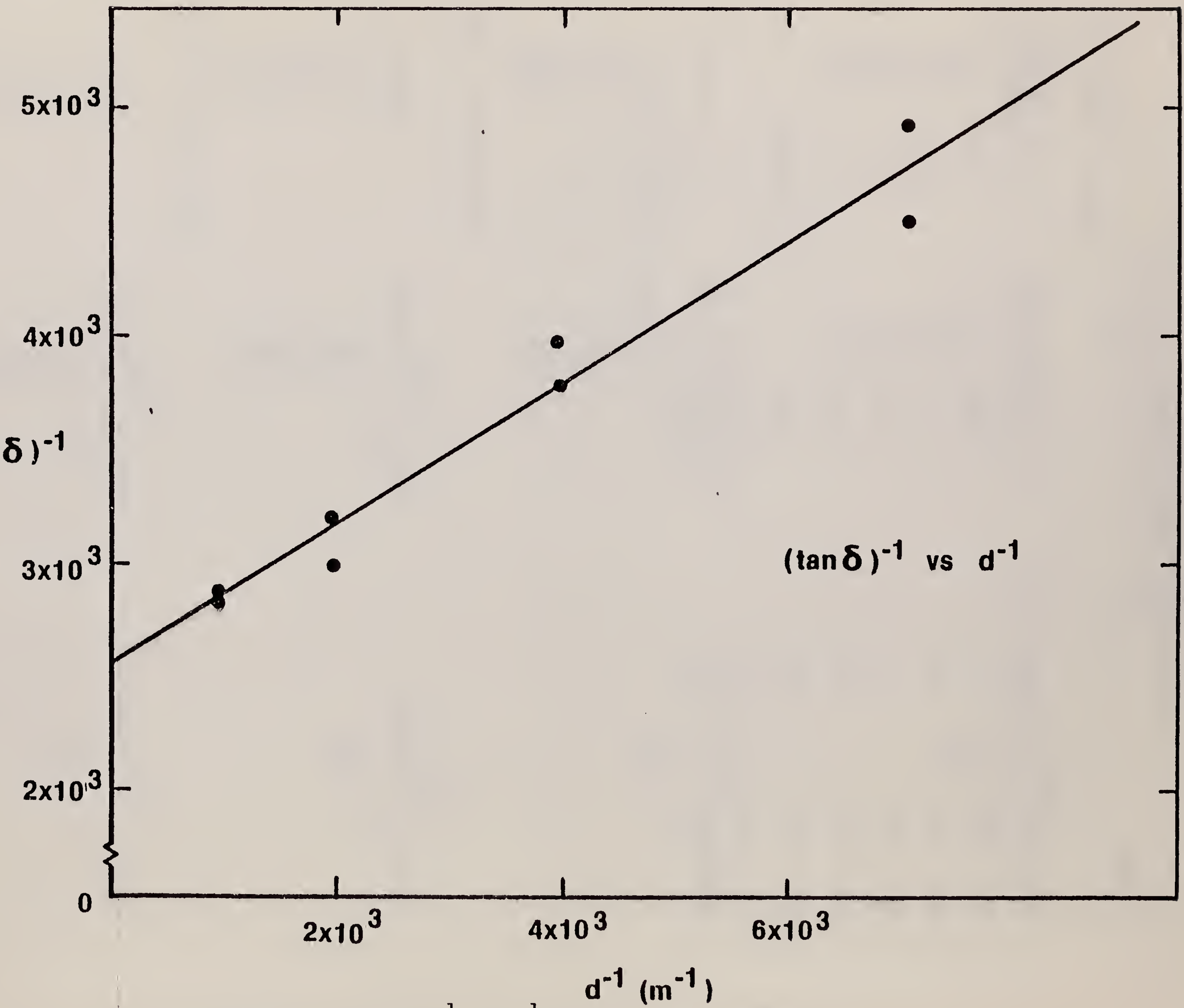


FIGURE 13 $(\tan\delta)^{-1}$ vs d^{-1} for epoxy measurements.

$$\tan \delta = \varepsilon''/\varepsilon' = 392 \times 10^{-6} \text{ and}$$

$$\varepsilon' = 3.53.$$

The one adjustable parameter in our model, γ/ε_1, is found to have a value of 3.37×10^{-5} m. Since the dielectric constant of the helium or mineral oil film is about 1 or 2, τ, the thickness of the film is predicted to be about 20 µm. This number cannot be verified but it seems reasonable to us since it is the same order as machining tolerances.

Evidently, epoxy sample results must be interpreted with considerable care in order to avoid error. Measurements on a single, thin sample must be viewed with dubiety. Further, different lots of epoxy may have dissipation factors which depend on the details of preparation. We have measured various epoxies used in the casting of high voltage bushings and find their dissipation factors to vary over a range of $(200 - 350) \times 10^{-6}$ depending on the lot. We have also measured a 1.6 mm-thick sample of G-10, a material commonly used as circuit board and found its $\tan \delta$ to be 560×10^{-6} and its dielectric constant to be 4.2.

B. Coaxial Geometry

The tests using the parallel-plate electrodes were designed to obtain data on the intrinsic behavior of various materials under consideration as insulation in superconducting cables. The mandrel measurements were designed to study the behavior of the composite insulation being considered for the BNL cable. This insulation composite consists of layers of plastic tape wound at a particular registration (we used a 65-35 registration for all our measurements) and the helium which fills the butt gaps formed by the plastic tape layers. This is analogous to conventional, flexible oil-filled cable but, instead of kraft paper and oil, one uses plastic tapes and helium. Of particular concern at high electrical stress is the butt gap region. It is here that field enhancement will occur, caused by the dielectric mismatch between helium ($\varepsilon' \sim 1.0$) and plastic ($\varepsilon' \sim 2$). In an effort to improve the breakdown properties of the helium-filled butt gaps, the cable is operated at high pressure. At design conditions, the helium is in a region past its triple-point. In this "supercritical" region the formation of bubbles is suppressed because a gas-liquid interface cannot exist under equilibrium conditions. The suppression of bubble formation improves the breakdown properties of the helium. In addition, the heat capacity of the helium is a maximum along the transposed critical line[14] which is useful to the engineering of the cable refrigeration.

The first measurements made were with a simple composite structure: four layers of 75 μm - thick Valeron* wound directly on the bare mandrel. Copper was wrapped around the Valeron* in order to form a three-electrode, guarded coaxial capacitor as described above.

The sample was immersed in helium and the dissipation factor was measured at a range of helium pressures (170 kPa to 1,150 kPa). The temperature was varied from 8 K to 9.5 K. Typical data are shown in Fig. 14. As with all the data obtained from this sample, the dissipation factor begins at a value less than 10^{-5}, increases very gradually with applied stress and then at a well-defined, reproducible point begins to increase rapidly with electrical stress. The "break point", or point at which the D.F. becomes strongly dependent on electrical stress, is a function of the density of helium in the butt gaps. Pertinent numbers are gathered in Table IV.

The variability in D.F. measurements before the break point as a function of different helium densities has a range of less than 2×10^{-6}. The tendency for D.F. to be somewhat lower at higher He density may be due to experimental scatter but might also be caused by the disappearance of interfacial losses at higher helium densities. The observed effect is too small to permit one to be certain of its origin.

The observed function of break point stress with helium density, when normalized to the maximum stress, is identical to Meats' results for the breakdown of supercritical helium.[15] The correlation of our break point data with Meats' helium breakdown data suggests strongly that the break point signals the start of discharges in the butt gaps. We were not able to correlate the numerical values of break point stress with Meats' data because of the geometrical complexity of a practical cable sample.

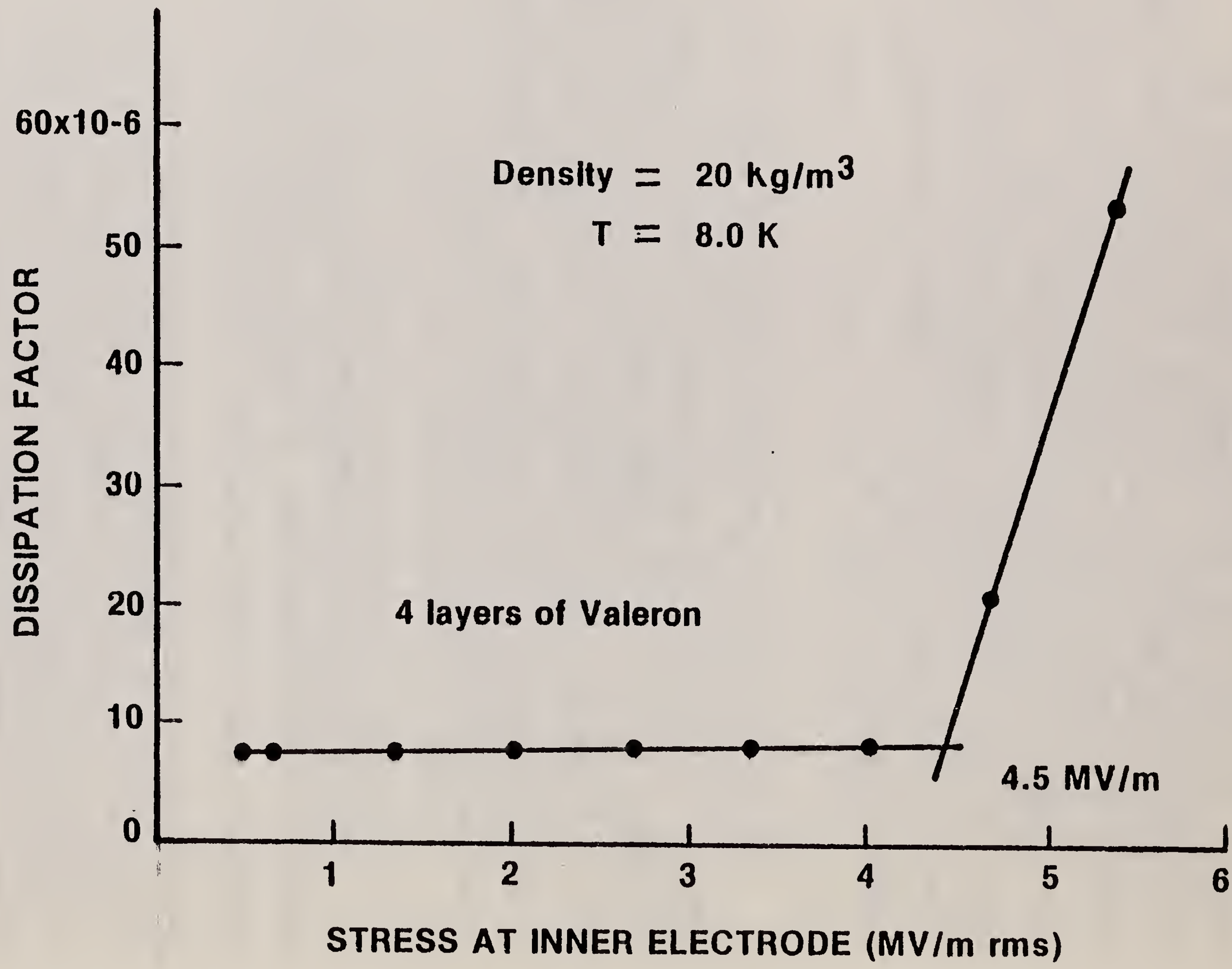


FIGURE 14 D.F. of Valeron* in coaxial geometry.

TABLE IV

Dissipation Factor Results of Valeron* Samples in Coaxial Geometry

He Density	Temperature	D.F. at 1MV/m (inner electrode)	Stress at Inner Electrode at "Break Point"
9 kg/m^3	9.3 K	8.2×10^{-6}	3.2 MV/m
20	8.4	8.4	4.5
45	8.5	7.4	7.2
70	8.7	6.4	12.5
90	8.9	7.3	11.1

It was also observed by using a commercial partial discharge detector that the break point corresponds to the partial discharge inception voltage. The sensitivity of the partial discharge detector was $\sim$ 0.2 pC. If the increase in D.F. is due to discharges of magnitude q at a single site, then elementary considerations[16] predict that the dissipation factor caused by these discharges is

$$\text{D.F.} = \sqrt{2}\, q/\pi CV$$

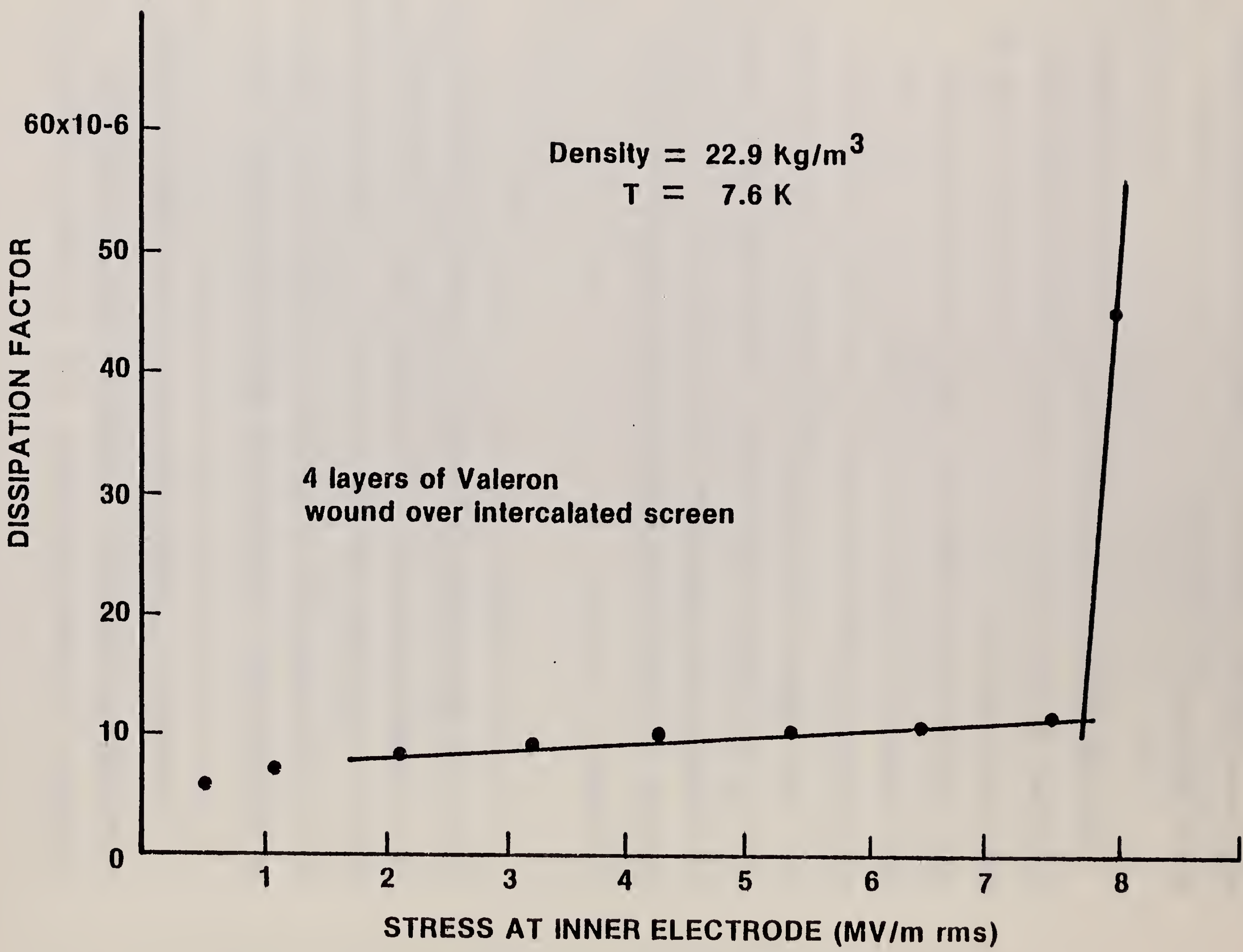
where C is the sample capacitance and V is the applied rms voltage. In the case of the sample under study, C $\cong$ 950 pF. Since the resolution of our capacitance bridge is $\pm 0.2 \times 10^{-6}$ in D.F., repetitive discharges of order $\sim$ 1 pC can be detected at an applied voltage of 1 kV. (This voltage corresponds for the sample under study, to a stress of 3.4 MV/m at the inner electrode).

Partial discharges were detected using a commercially available, balanced detector. Balanced detection was used to suppress the effect of voltage pulses which may occur at the output of the power supply. These unwanted discharges were further suppressed by the presence of a 100 kΩ resistor between the power supply and the sample. This resistor and the stray capacitance to ground on the load side of the resistor form an effective low-pass filter. The resistor also limits current in the event of a flashover or breakdown at the sample. The high voltage wiring was identical for the measurement of D.F. and for corona detection. Only low-voltage leads needed to be changed in order to proceed from one type of measurement to the other.

Once the behavior of this simple system was studied and reliably reproduced, the next step was to see how the addition of bedding and screen layers would alter the behavior. It was anticipated that the BNL cable insulation would be wound over a spongy semiconducting bedding layer covered by an intercalated layer of plastic tape. The plastic tape would have one metallized surface (at the bedding interface) and would thus serve as a screen. Polytetrafluoroethylene impregnated with carbon was the choice of bedding layer. The bedding was deemed necessary for mechanical reasons and, of course, the screen would then be necessary to prevent ac losses which the semiconducting bedding would otherwise introduce.

We first ran a sample of four layers of Valeron* wound over an intercalated layer of metallized Valeron*. The results were similar to the system without the screen. The screen did cause a slight slope to appear in the pre-break point section of the D.F. vs. stress curve (Fig. 15) but the break point itself now occurred at a somewhat higher stress. No additional partial discharges were observed below the break point.

Introduction of a bedding layer could not be studied carefully due to more immediate needs of BNL for measurements on a new candidate insulation. Preliminary measurements (Fig. 16), however, indicated that introduction



60x10-6
50
40
30
20
10
0
DISSIPATION FACTOR
Density = 22.9 Kg/m3
T = 7.6 K
4 layers of Valeron
wound over intercalated screen
1
2
3
4
5
6
7
8
STRESS AT INNER ELECTRODE (MV/m rms)

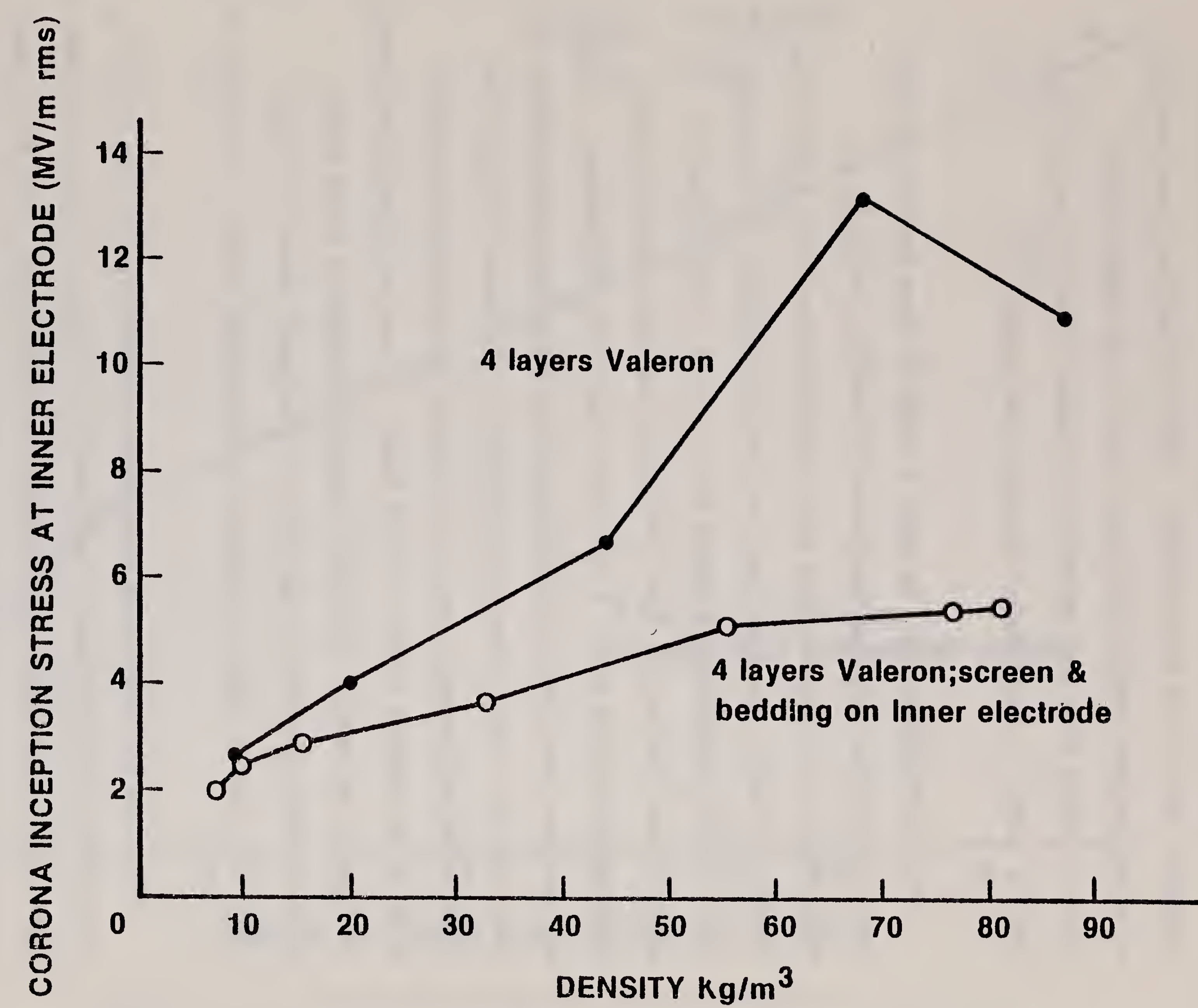


FIGURE 16 Corona inception stress of Valeron* sample in coaxial geometry with and without screen and bedding layers.

of a bedding layer between the bare electrode and the screen greatly increased the D.F. of the composite. Partial discharges were detected at voltage minima indicating contact noise in the sample holder. Similar results have been observed by a General Electric group studying bedding layers in experimental cryoresistive cables.[17]

At the request of BNL, we began a study of three composite polymer tapes. The tapes have been designated PP-U-PP(B), 3PP-2U(A) and PP-PE-PP(B). All three were 19 mm in width and were color-coded (blue, violet, and red). The blue tape (PP-U-PP(B)) consisted of two layers of 32 μm - thick polypropylene bonded with a 2.5 μm - thick layer of polyurethane. The violet tape (3PP-2U(A)) had three layers of the polypropylene bonded with 2.5 μm - thick layers of polyurethane. Finally, the red tape (PP-PE-PP(B)) had two layers of the polypropylene bonded with a 2.5 μm - thick layer of polyethylene. Microscopic study of the tapes by the NBS polymers group had revealed the presence of numerous voids in the bonding layers of these tapes. It was anticipated that measurement of the D.F. and partial discharge inception voltages of these tapes would elucidate the role of the voids in the tapes' behavior at high electrical stress. Some of the results are plotted in Figs. 17 through 19.

While the different tapes show different behavior, the results are such as not to be explained by consideration of voids in the polyurethane binding layer. Such consideration would predict the violet tape, with the highest percentage of binding layer, would have the greatest loss. A comparison of the data for the three laminated samples shows that the violet sample (3PP-2U(A)) has somewhat superior dissipation factor properties at the high electrical stresses of interest. The violet

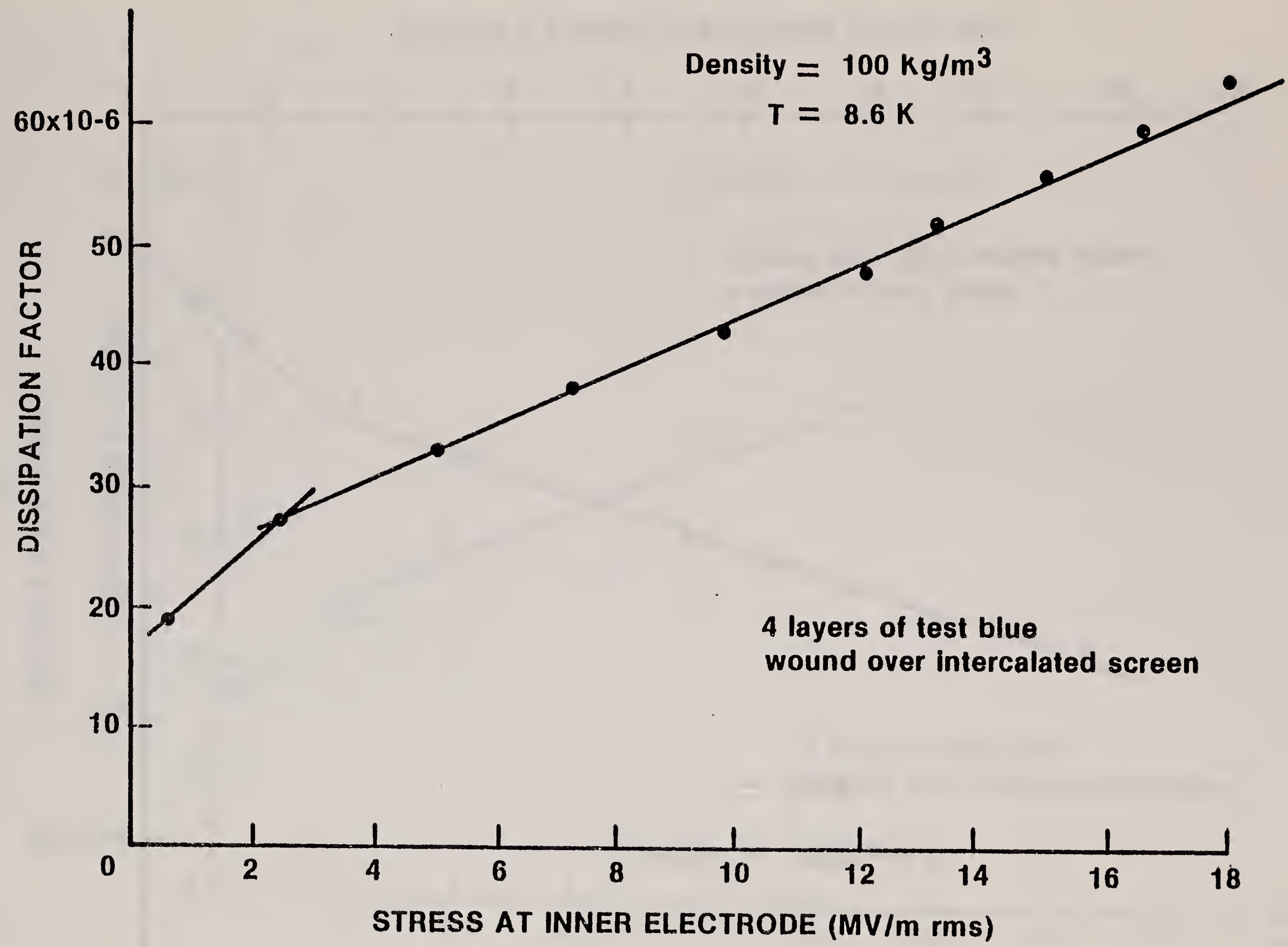


FIGURE 17 D.F. of PP-U-PP(B) sample in coaxial geometry.

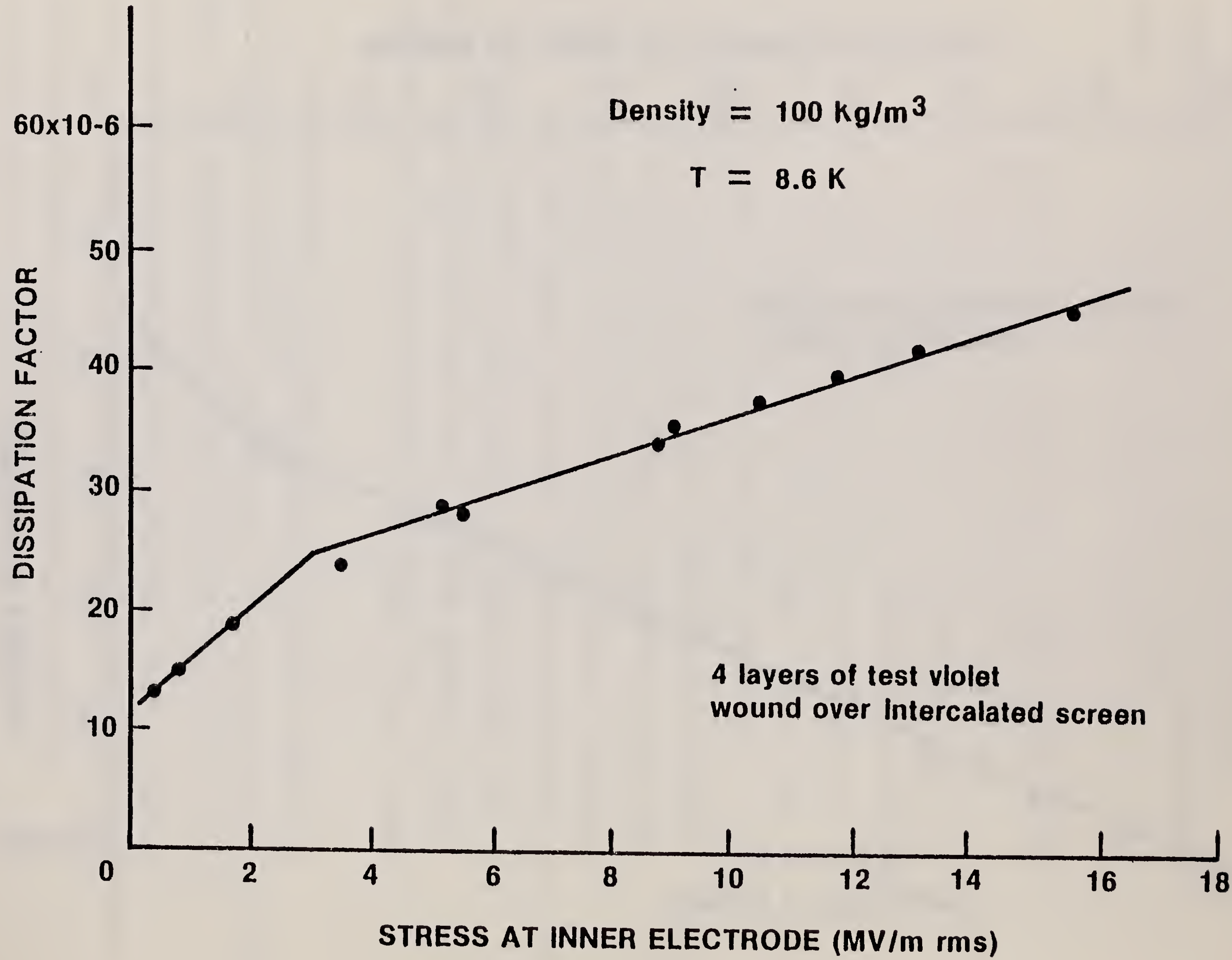


FIGURE 18 D.F. of 3PP-2U(A) sample in coaxial geometry.

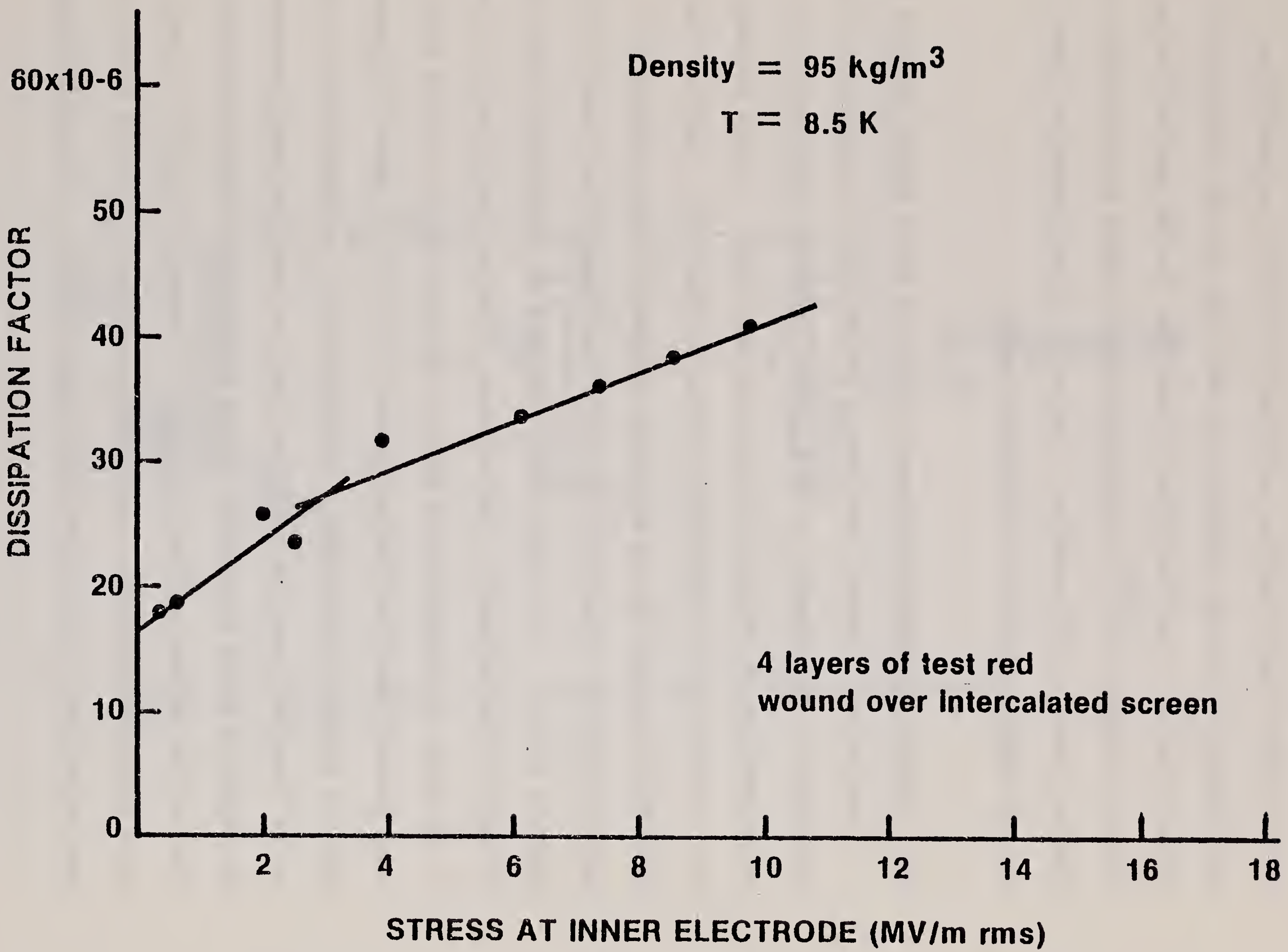


FIGURE 19 D.F. of PP-PE-PP(B) sample in coaxial geometry.

sample and the blue sample both have relatively thin polyurethane layers but the violet sample has two such layers with four polypropylene-polyurethane interfaces compared with one layer and two interfaces for the blue sample. The discussion by Khoury in the BNL quarterly report dated 2 November 1977[18] on the morphology of these two tapes does not give any clues to this behavior. The voids in the laminating layers of the two tapes are similar in shape and number.

III. Partial Discharge Measurements Using the Pulse Height Analysis System

The partial discharge measurement system (PDMS) as developed at NBS (described in the appendix to this report) performs high-speed pulse-height-analysis of the partial discharge amplitudes. It can be used much the same way as conventional discharge detectors. That is, the PDMS may be attached to the detection impedance of any conventional partial discharge circuitry.[19] The circuit used in our laboratory is shown in Fig. 20. It is very nearly the same as the bridge circuit used for our D.F. measurements. The resistor, R, which limits supply current in the event of breakdown also forms a low-pass filter with the stray capacitance between the load and ground. This filter tends to suppress spurious spikes in the supply. The capacitor C_k is conventionally known as the "coupling capacitor". In our case, we used the same compressed-gas capacitor which also served as our standard for bridge measurements. The low side of the coupling capacitor is connected directly to ground as is its guard electrode. The sample capacitor, C_x, is, of course, the same as was used in our mandrel measurements of D.F. The guard electrodes

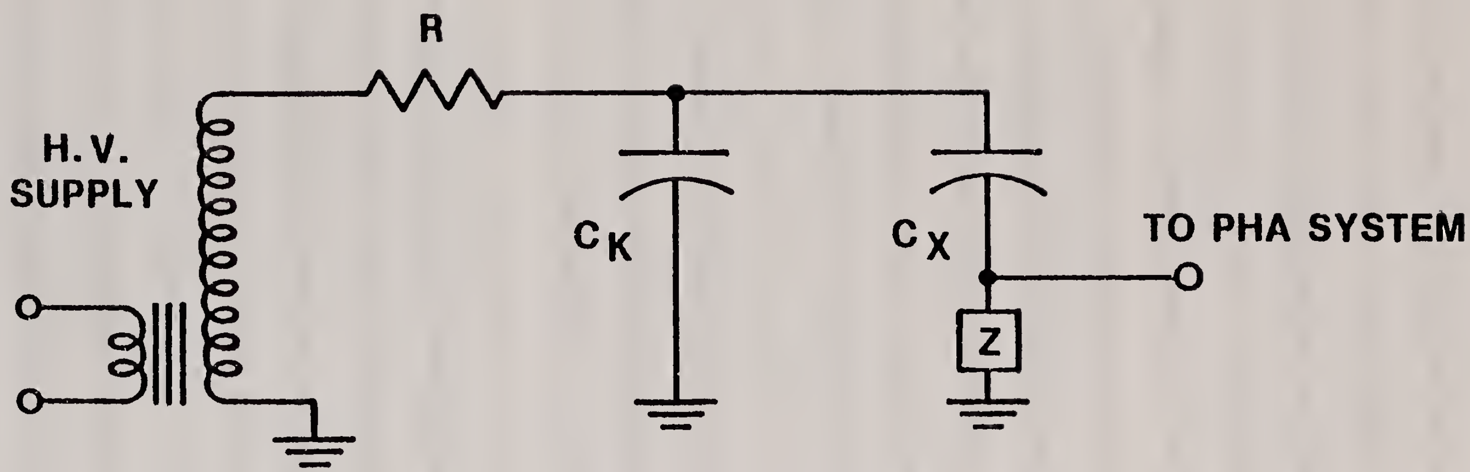


FIGURE 20 High-voltage circuit for partial discharge measurements.

of C_x are connected to ground while the low voltage electrode is connected to the detection impedance, Z. In our case, Z consisted of a resistor, capacitor and inductor in parallel. The RLC circuit parameters were chosen so that a very narrow pulse ($\leq$ 30 ns) produces an output of a critically damped pulse of width $\sim$ 2 μs. Of course, the choice of capacitance in the RLC circuit is not entirely discretionary because of unavoidable strays in parallel with R and L. It should also be noted that the guard capacitances of the three-terminal capacitors C_k and C_x act in parallel to effectively increase the value of C_k. This is an important consideration if the signals on the detection impedance are to be related theoretically to partial discharges in the sample. The actual calibration of the entire system was carried out experimentally at low voltage by using a pulse generator in conventional fashion.[18]

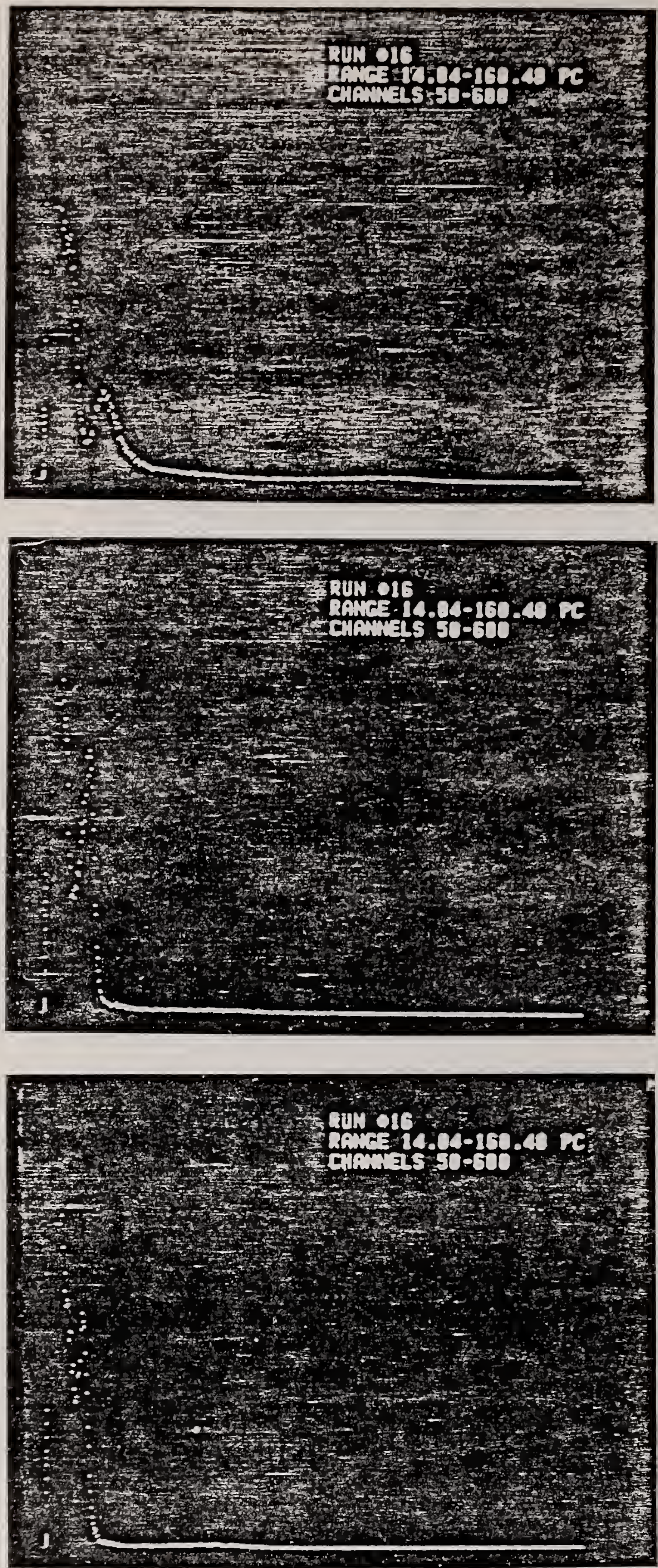
Time and other constraints only permitted the use of the PHA system in one actual test. This was an attempt to monitor a sample of cable insulation under consideration of accelerated aging.

The partial discharge measurement system is a powerful tool for studying the aging of cryogenic dielectrics under discharge conditions. In order to design a meaningful experiment, some mechanism must be provided to accelerate this aging process so that some changes might be observed during the course of the experiment. Accelerated aging might be accomplished by increasing the frequency of the alternating voltage, raising the sample temperature or some other means. An attempt was made to accelerate the dielectric aging by running at high stresses so that large discharge activity was observed (discharges of the order of 200-300 pC).

The sample measured consisted of four layers of Valeron* wound over two intercalated tapes of metalized Valeron*. There was no bedding layer. The sample was run at a pressure of about 1.35 megapascals and a temperature of about 8 K. The applied voltage was 6.95 kV which is equivalent to an electrical stress of about 18 MV/m. The partial discharge inception level for this sample was at about half this stress.

The original plan was to run this sample at this elevated stress for as long as liquid remained in our cryostat ($\sim$ 15 hours). The pulse height distributions at the beginning of the run, two hours later, and 3-1/2 hours into the run are shown in Fig. 21. These are not cumulative distributions but are fresh distributions taken for a 10 minute interval at the measurement time. While there appear to be some differences (the valley disappears with time), the distribution of large discharges does not vary significantly. About a half hour after the last picture in Fig. 21 was taken, our partial discharge measurement system suddenly stopped working. An analysis of the hardware indicated that a protection diode in a preamplifier failed. After removing this preamplifier and the partial discharge measurement system, the sample was reenergized and discharges monitored with a conventional discharge detector. The sample appeared to be normal suggesting that the failure was unrelated to the sample.

It was decided to repeat the same test using the same sample with improved preamplifier protection. Figures 22a and b show the results at the beginning of the test and 2-1/2 hours later. The results are similar to the first test on this sample except that the valley has disappeared.

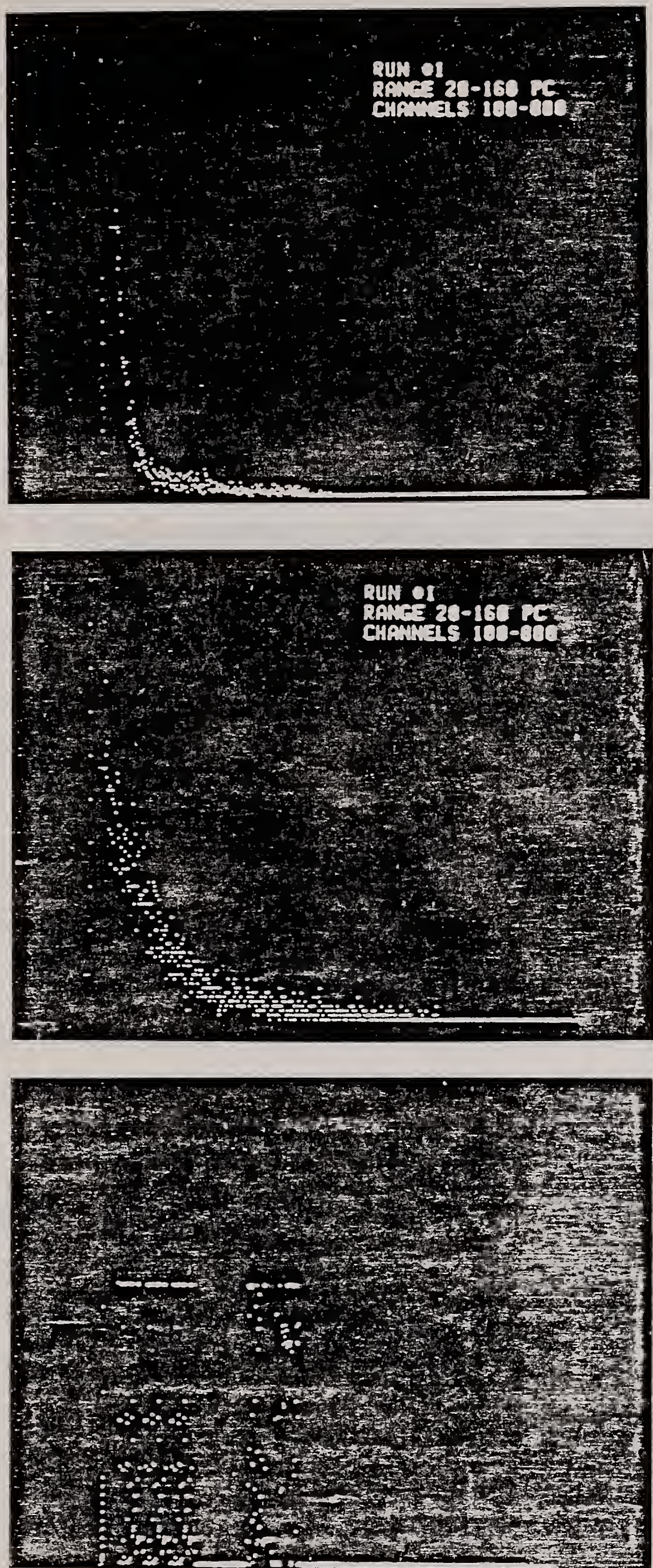


(a) Beginning

(b) 2 hours later

(c) 3 1/2 hours later

FIGURE 21 Discharge spectra-first run.



(a) Beginning

(b) 2 1/2 hours later

(c) After failure

FIGURE 22 Discharge spectra-second run.

Between the two runs the problem of the dynamic range of the system, mentioned in the Appendix, was readdressed. It now appears likely that the valley in the distribution observed in the first run was a result of improper setting of the threshold detector caused by an erroneous value for the dynamic range. It appears that the sample in the second run has changed little after almost 3 hours at 18 MV/m. At the three hour point the sample failed. This time, with improved protection for the preamplifier, the system survived and the discharges indicating failure were observed on both the conventional corona detector and the pulse-height analysis system. Figure 22c shows the output of the latter system. The discharge rate was so large that the minicomputer was "locked up" and had to be shut off and "rebooted" to retrieve the data. Figure 22c shows that several of the channels are filled (32,767 counts). The fact that certain channels are filled and others appear empty probably is not significant. At high discharge rates the a-d converter and related logic could not perform accurate conversions.

The voltage was reduced to zero and the inception voltage for this failure was measured. As opposed to the first run on the sample, this time the inception voltage was practically at the turn-on voltage indicating permanent damage to the sample. After the sample had reached room temperature, it was measured again with SF_6. The inception voltage was still very low.

There was a striking similarity between the failures for the two runs (or possible failure for the first run). They both occurred about the same time after the run began. It was first thought that this meant the dielectric tapes were aging in the presence of this high stress. But now the significant similarity appears to be that the liquid helium in the dewar had reached the identical level at the time of the two failures, 63 cm from the bottom of the helium dewar. Since this is near the bottom of the pressure vessel, it is likely that the temperature differential along the mandrel length is increasing at this point. While a 2 K temperature differential is often observed, an increase to 4 K would decrease the helium density at the top of the mandrel to about half the value at the bottom.

When the mandrel was removed from the pressure vessel, a puncture was observed through the four layers of Valeron* and the intercalated screen. The site of the puncture was under a relatively sharp corner edge of the guard electrode at the very top of the sample.

Termination of this project prevented us from continuing these measurements in order to systematically study aging processes at cryogenic temperatures. The partial discharge measurement system has proven most valuable in other measurements such as the study of partial discharge behavior in sulfur hexafluoride.

APPENDIX

Partial Discharge Measurement System

A partial discharge measurement system (PDMS) was developed in order to study aging processes in electrical insulation. While the original system was designed for the studies of partial discharge behavior at cryogenic temperatures, the PDMS has been used for more conventional insulation systems as well. The PDMS uses the technique of pulse-height-analysis in order to obtain amplitude spectra of the partial discharges as a function of time. Changes in these spectra as a function of applied electrical stress, frequency, temperature, pressure, impurity or defect concentration could yield important information on aging processes.

Pulse-height-analysis has been used to study partial discharges previously.[A-1] The system developed at NBS has the advantage of being significantly faster (i.e., the dead time is only 8 μs compared to about 50 μs for conventional systems). The key to this speed is a fast analog-to-digital converter and the use of the direct-memory-access input to a minicomputer used for data acquisition. Having a minicomputer as part of the system results in increased power and versatility compared to other systems based on conventional multichannel analyzers.

A description of the PDMS will be presented in two sections: hardware and software. The intent is to provide enough information so that the system could be duplicated by others if they wished.

I. Hardware

A. Detection Impedance and Amplifier

A typical detection impedance, Z, is shown in Fig. A-1. Typically the impedance is some RLC circuit tuned for optimum system behavior. The selection of this impedance can affect the dynamic range of the PDMS. If a discharge results in an under-damped oscillation, the PDMS can be adjusted so as not to trigger on the subsequent peaks. This, however, increases the dead time. This detection impedance also severely limits protection devices that can be used. Normally some protection should be placed between the detection impedance and the amplifiers to follow. Unfortunately high-speed protection devices have too large a capacitance resulting in very small signal levels and far from critically damped performance. Care must therefore be taken in circuit design so that if a breakdown does occur the most likely component to fail will be readily replaceable.

A small but significant level of 60-Hz voltage (and harmonics) is present at the detection impedance. This voltage, becoming more serious at higher voltage levels, can cause the peak-and-hold circuitry to trigger on the peaks of the applied sinusoidal voltage giving erroneous discharge spectra and ultimately saturating the lower channels.

A standard method of reducing this voltage is to use balanced detection of the partial discharge pulses. The balance is made to null the common-mode partial discharges which may be occurring in the power supply, for example, but this balance is generally close enough to a 60 Hz balance to eliminate this source of voltage. Balanced

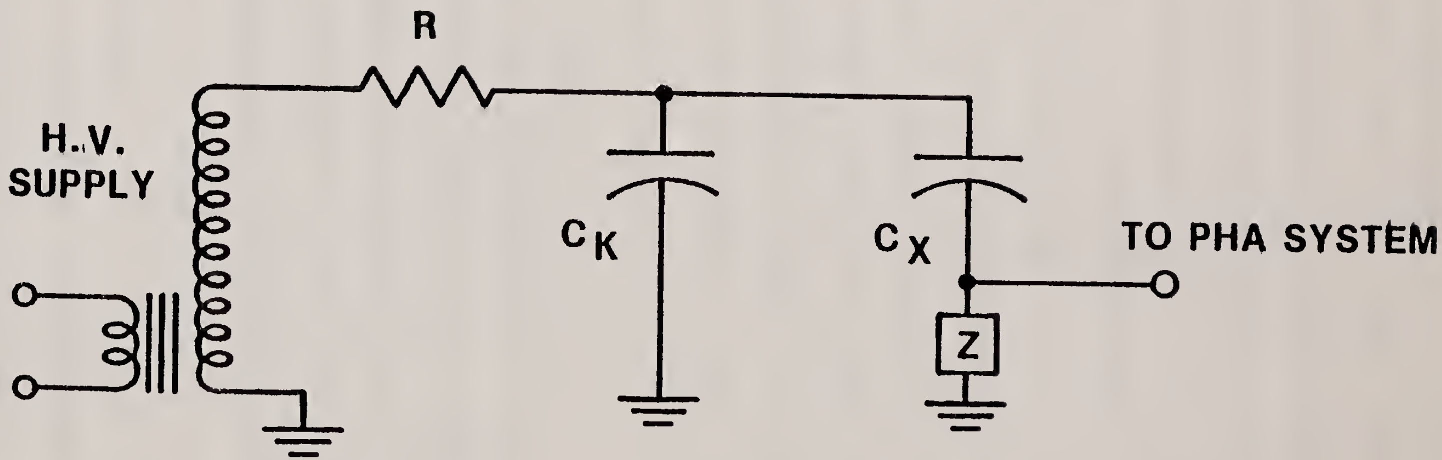


FIGURE A-1 High-voltage circuit for partial discharge measurements.

detection seemed impractical in this development system, however, and was not pursued. Instead of a balancing impedance, active circuitry was used, Fig. A-2, to inject a 60 Hz signal of adjustable amplitude and phase into one input of a differential amplifier Fig. A-3. The other amplifier input is derived from the corona detection impedance after being amplified by the wide-band FET preamplifier Fig. A-4. This preamplifier incorporates a high pass filter (cut-off frequency of 5 kHz) to also help reduce the effects of the applied voltage and the harmonics. The input of the 60 Hz buck-circuit can be connected to the primary of the supply transformer. Since the transformer itself generates harmonics, the buck-circuit is only useful for canceling out the 60 Hz component. An oscilloscope is used for this balancing, adjusting the phase and amplitude controls until the signal is zero (below the partial discharge inception voltage). Once the zero has been obtained no further adjustments are normally necessary over the transformer's working range. The presence of harmonics in the supply voltage ultimately limits the dynamic range of the PDMS. That is, partial discharges must appear larger than the sinusoidal harmonics in order to be observed.

B. Absolute Value Circuit

The partial discharge measurement system as it is now designed, measures the discharge magnitude and ignores the polarity of the discharge. The system could be easily modified to keep track of the discharge polarity. It would, however, necessitate a redesign of the peak and hold circuitry.

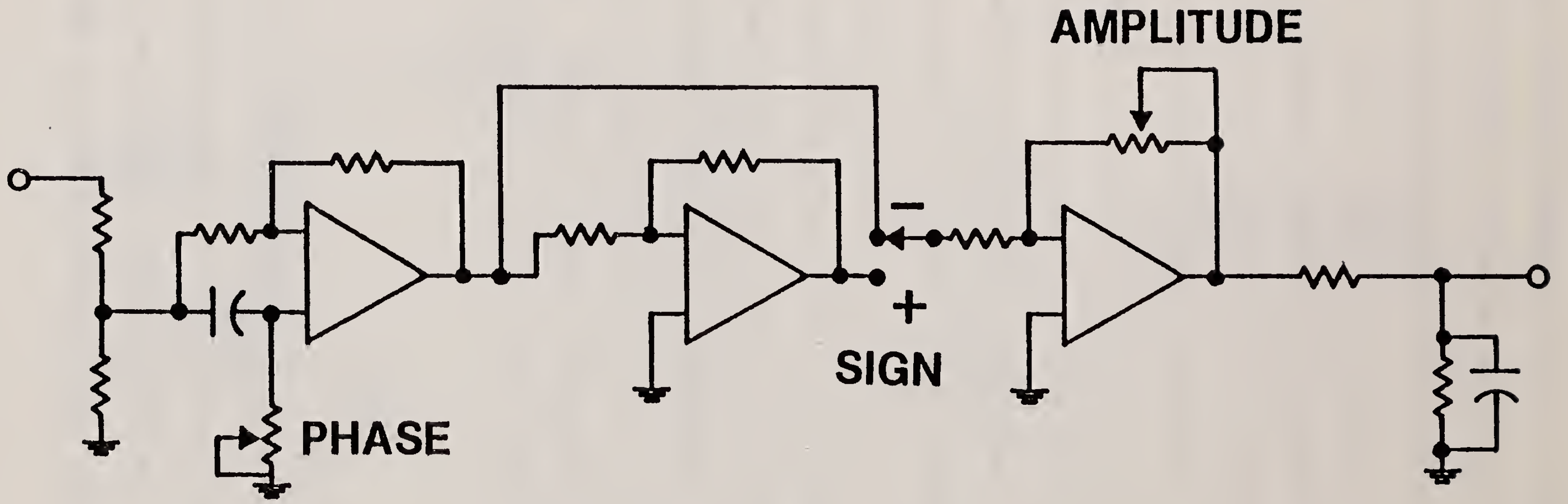


FIGURE A-2 Circuit for reducing 60-Hz common-mode voltage.

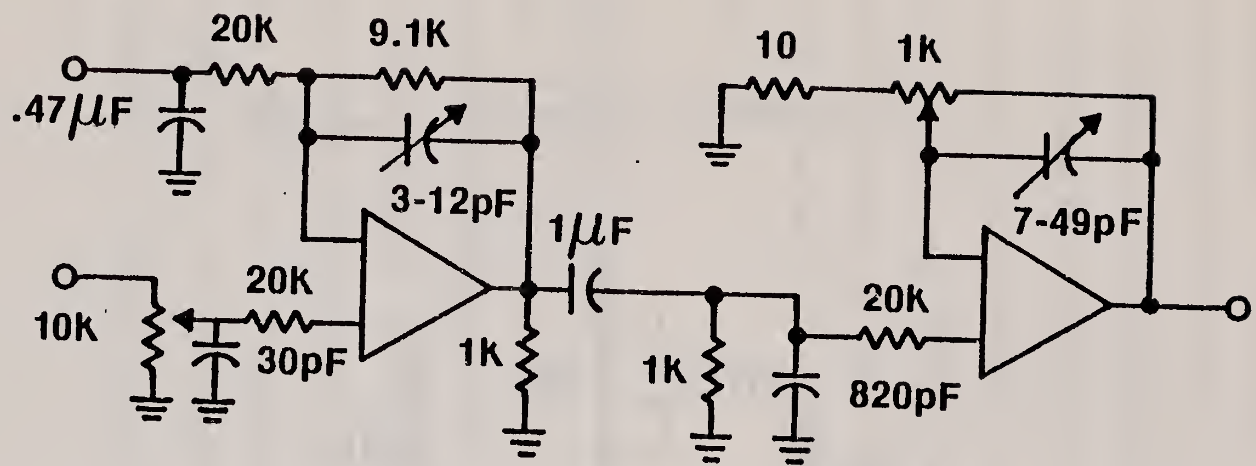


FIGURE A-3 Differential pulse amplifier.

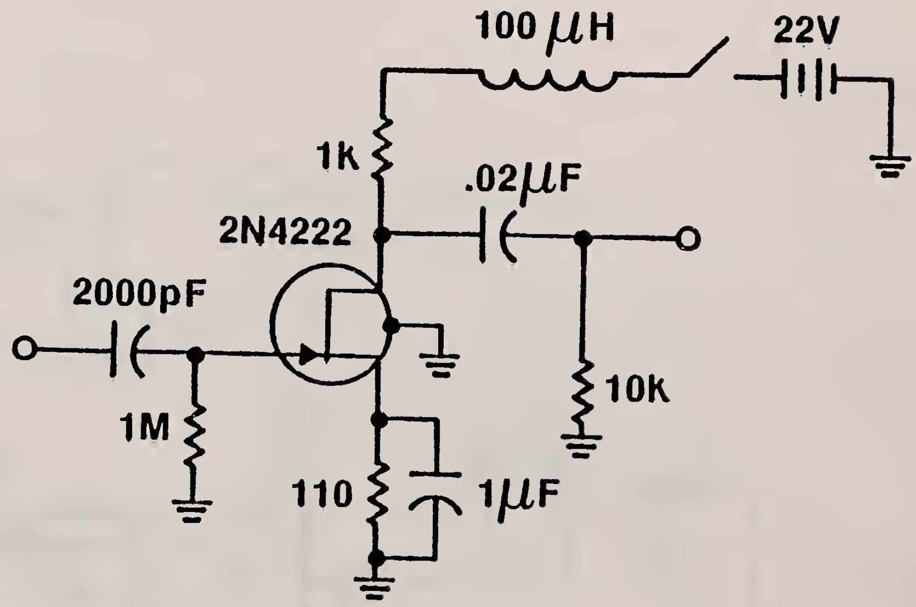


FIGURE A-4 Wide-band FET preamplifier.

The present system requires an absolute value circuit, Fig. A-5, to convert the bipolar pulses to negative pulses suitable for the peak-and-hold circuit. This circuit is basically an ideal diode circuit and an adder-subtractor. For positive input pulses diode D_1 conducts and D_2 does not so that the voltage, V_2, is zero. The feedback variable resistor is adjusted so the output of the second operational amplifier is equal in magnitude but opposite in polarity to the positive input. For negative pulses, D_2 conducts and D_1 does not. The signal at V_2 is a positive pulse of equal magnitude to the input. The output of the adder-subtractor is minus two times the positive pulse plus minus one times the negative pulse or a negative pulse of equal magnitude to the input pulse.

C. <u>Peak and Hold Circuit</u>

The peak and hold circuit shown in Fig. A-6 is designed for a negative input pulse whose magnitude is less than 5 volts and whose duration is from 1 to 3 μs. The purpose of the circuit is to hold the peaks of the voltage pulses and provide a signal to the peak and hold control logic when the peak is above some selectable threshold values. After the voltage pulse has been processed by the analog to digital converter and the minicomputer, the peak and hold circuit is reset for the next measurement.

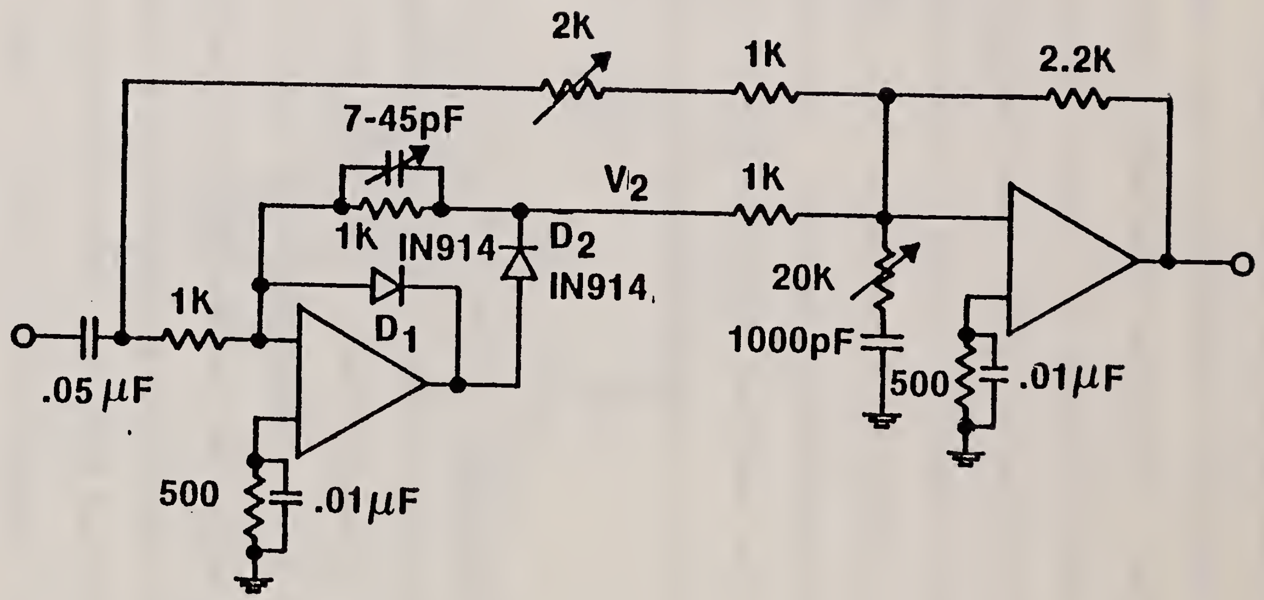


FIGURE A-5 Absolute-value circuit.

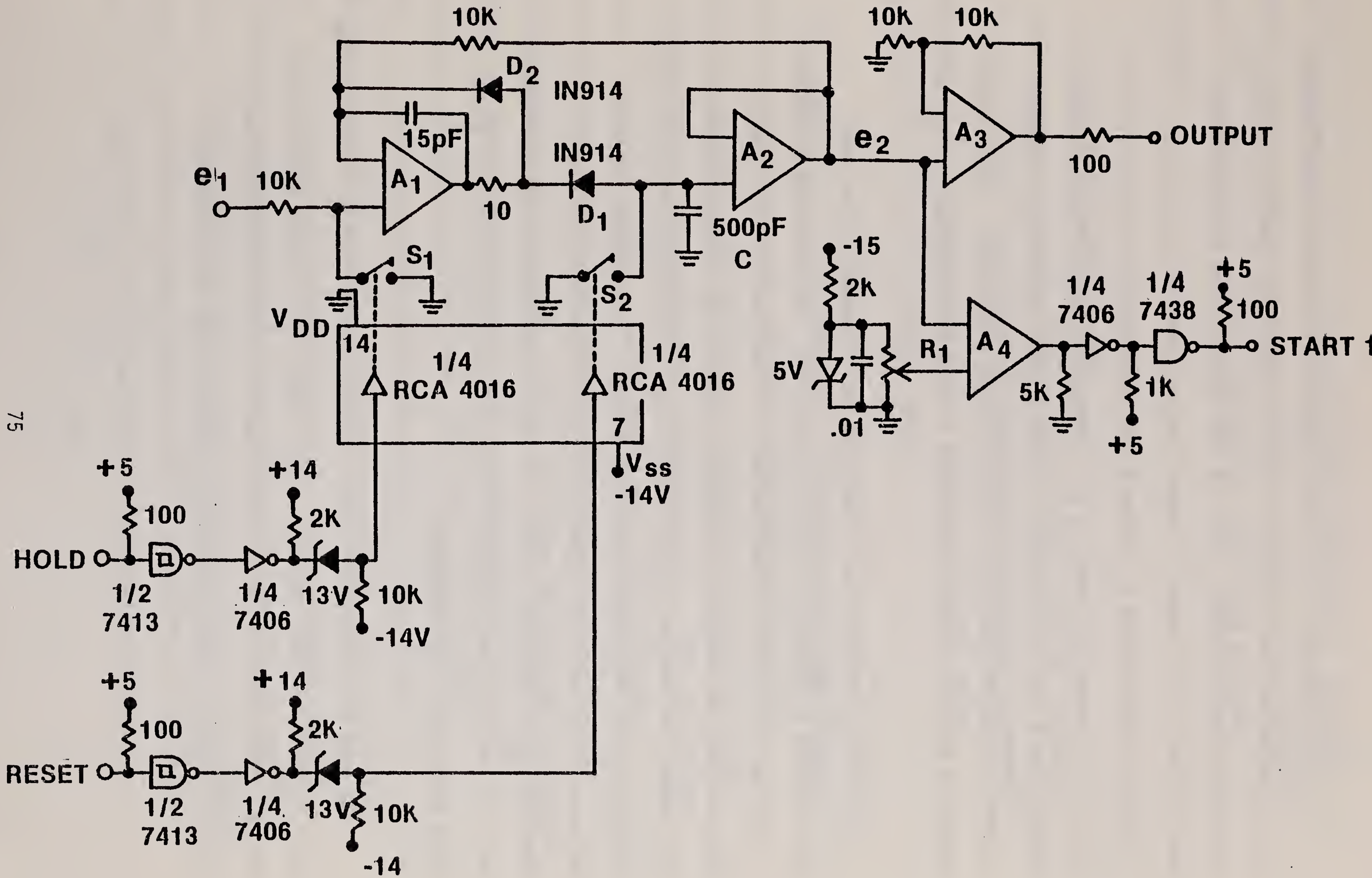


FIGURE A-6 Peak and hold circuit.

The basic peak and hold circuit consists of operational amplifiers A_1, A_2, and associated circuitry. With S_1 and S_2 open the circuit will follow the negative peaks. If e_1 is less than e_2 (and both less than zero), diode D_1 will conduct thereby charging the 500 pF capacitor. If e_1 is less negative than e_2, diode D_1 will not conduct (and capacitor C will not discharge) but diode D_2 will conduct so that a feedback path is provided and A_1 will not lockup. A_2 must have a large input impedance in order to prevent the 500 pF capacitor from discharging. Amplifier A_3 provides a gain of 2 before the signal is sent to the analog to digital converter.

In order to prevent the system from being swamped by low-level noise signals a threshold circuit, A_4, is used. The reference potential is adjusted by a 20-turn potentiometer. If the peak circuit is more negative than the threshold voltage the output of A_4 swings positive. This causes the inverter output (7406) to go low which causes the output of the positive NAND buffer (7438) to go high. This signal, START $\bar{1}$, indicates the presence of a partial discharge event of sufficient magnitude to be measured. START 1 is used by the peak and hold control logic (to be discussed below) to initiate the necessary chain of events for a discharge to be processed.

The peak and hold control logic, after allowing time for the discharge pulse to reach its peak value ($\sim$ 3 μs), sends a hold signal back to the peak and hold circuit. This signal closes S_1 so that additional pulses cannot interfere. After the partial discharge has been processed a RESET signal momentarily discharges the 500 pF capacitor, C, through switch S_2, which grounds e_2 and causes START 1 to go low. The subsequent removal of the HOLD signal opens S_1 and thereby enables the peak and hold circuit.

D. Peak and Hold Control Logic

The peak and hold control logic is shown in Fig. A-7 along with the various signal levels. Input X104 is connected to the computer's general reset signal and on computer turn-on this signal (a low-level pulse) initializes the peak and hold control logic.

When START 1 goes high (indicating a discharge of magnitude greater than the threshold) the output of the positive-NAND Schmitt-trigger (7413) goes low. This does two things. First of all a low-level pulse is outputted from $\overline{Q}$ of the monostable multivibrator, M_4. This goes to the preset of the J-K flip-flop, J_1 which sets $\overline{Q}$ low. This effectively causes the output of the positive-NAND Schmitt-trigger (7413) to return to the high state and stay there until the discharge pulse has been processed. Secondly it causes a high-level pulse to be outputted by Q of M_1 with a 3 μs delay time to its trailing edge. This pulse does two things. First it causes the monostable multivibrator M_5 to output a low-level pulse which goes to the preset of the J-K flip-flop, J_2. This causes $\overline{Q}$ of J_2 to go low which raises the HOLD signal. Also the output pulse of M_1 goes to M_2 which causes a high-level pulse to be outputted by Q of M_2 with a 1 μs width and subsequently a high-level pulse out of Q of M_3 which results in a similar low level pulse at START 2 which goes to the analog-to-digital control logic circuit and starts the conversion process.

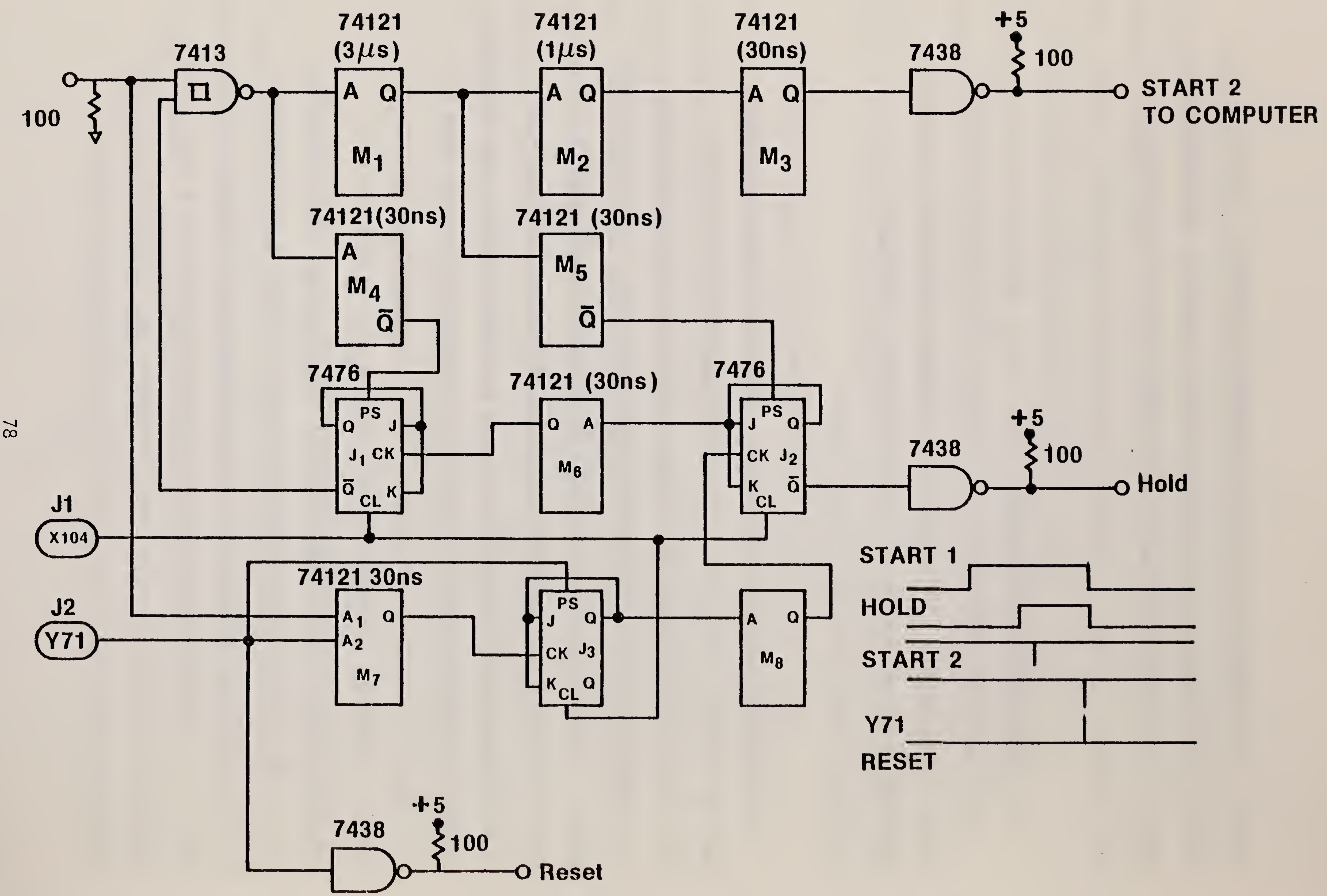


FIGURE A-7 Peak and hold control logic.

The hold signal stays high until a low-level pulse is returned on Y71 indicating that the data point has been read by the selector channel. This low-level pulse does several things. It causes a high-level pulse on RESET which partially enables the peak and hold circuit by zeroing the hold capacitor, C. The Y71 pulse also causes a high-level pulse at Q of M_7. Since the clear, preset, J, and K inputs of J-K flip-flop J_3 are high (by the Y71 preset) the high level input clock pulse causes J_3 to toggle or Q to go low. This causes a high level output pulse at Q of M_8. This pulse causes J-K flip-flop J_2 to toggle which results in the input of M_6 going low and the HOLD pulse going low. The removal of the HOLD signal opens switch S_1 of Fig. A-6 and enables the peak and hold circuit. A high level pulse is outputted from Q of M_6 which causes J_1 to toggle thereby causing $\overline{Q}$ to go high. This enables the next sizable pulse to trigger the 7413 positive-NAND.

E. Analog-to-Digital Control Logic Circuit

The control logic for the analog-to-digital converter is shown in Fig. A-8 along with the various signal levels. This circuitry is designed to give the analog-to-digital converter a suitable start signal, to notify the computer when the conversion is completed and data can be read, and to produce a signal level to indicate when the digital data has been read by the computer.

The low-level pulse, START 2, from the peak and hold control logic circuit causes a high level pulse to be outputted at Q of the retriggerable monostable multivibrator, M_1. This output pulse is suitable to start the analog-to-digital converter. After the conversion process is completed

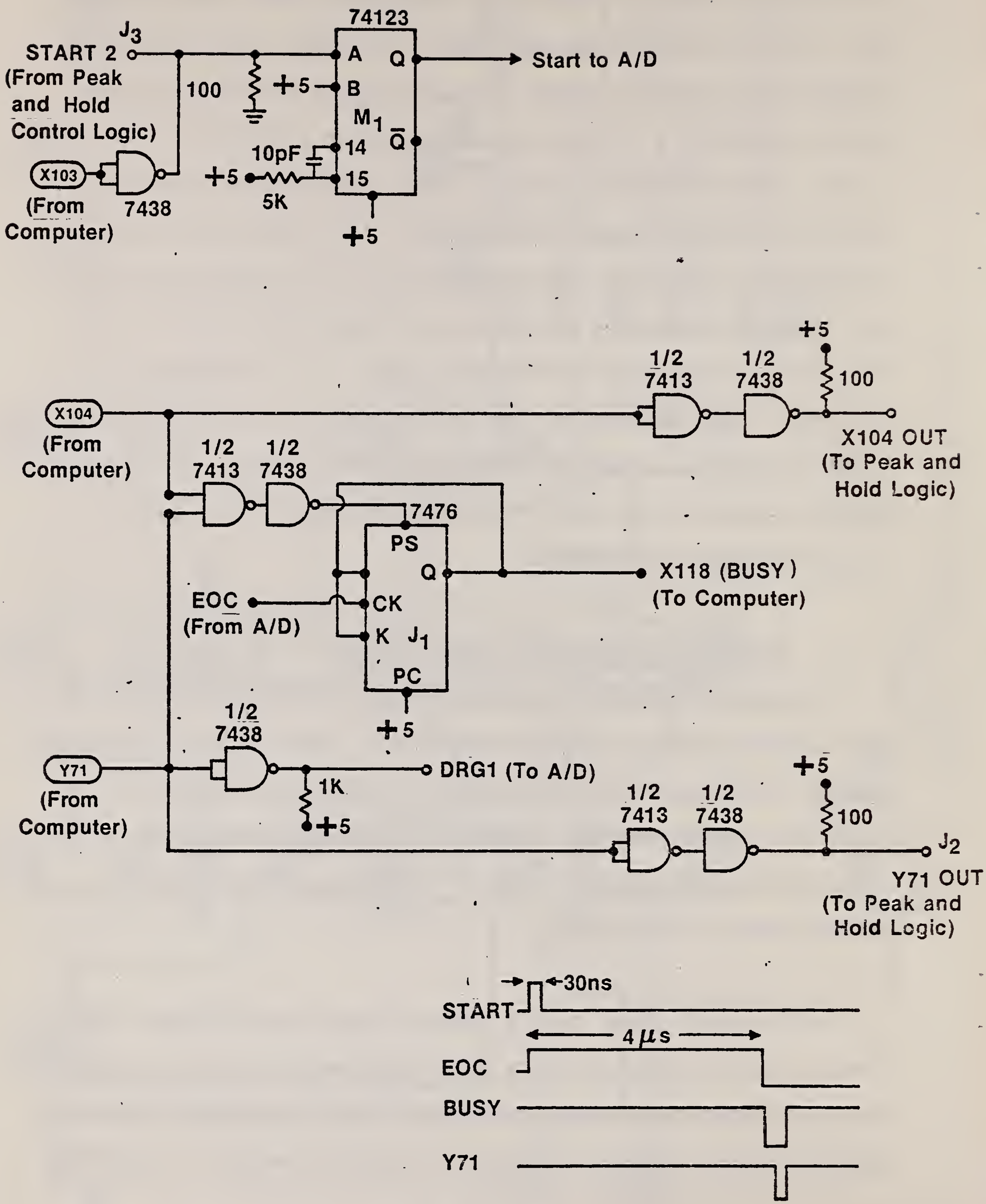


FIGURE A-8 A/D converter control logic.

the analog to digital converter sends the trailing edge of the positive pulse, EOC to the 7476 J-K flip-flop, J_1. The output of this flip flop, Q, is initially high because of the preset going low caused by the X104 clear pulse. The EOC pulse causes the flip flop to toggle resulting in Q of J_1 and hence BUSY, (X118) going low. This tells the selector channel that data is ready to be read. If the computer is not busy the computer sends back the Y71 low-level pulse. This causes the flip-flop preset to again go low which causes J,K, and Q to go high. The Y71 also causes a high-level DRG1 pulse which strobes in the data. BUSY is again high and stays there until the next data point has been converted. If the computer is busy (exchanging buffers, for example), the Y71 low-level pulse will not be returned until the computer is not busy and the data point can be read. This means that the data point will not be lost. However, the peak and hold control logic will also not be reset until it sees the Y71 pulse so any additional discharges will not be measured. The Y71 pulse functions to keep other data from entering the peak and hold circuitry (and hence the analog-to-digital converter) until the previous data point has been completely processed. A convert command can be simulated by the computer by sending to the interface board any output command. This causes a high-level pulse at X103 which results in a low-level pulse at the A input of M_1.

F. <u>Analog-to-Digital Converter</u>

The analog-to-digital wiring diagram is shown in Fig. A-9. The converter used is a DATEL* ADC-N12B2A with a conversion time of 4 μs for a 12 bit binary output. In order to achieve the fast conversion time, the converter uses the technique of successive approximations. After receiving the START pulse from the analog-to-digital control logic,

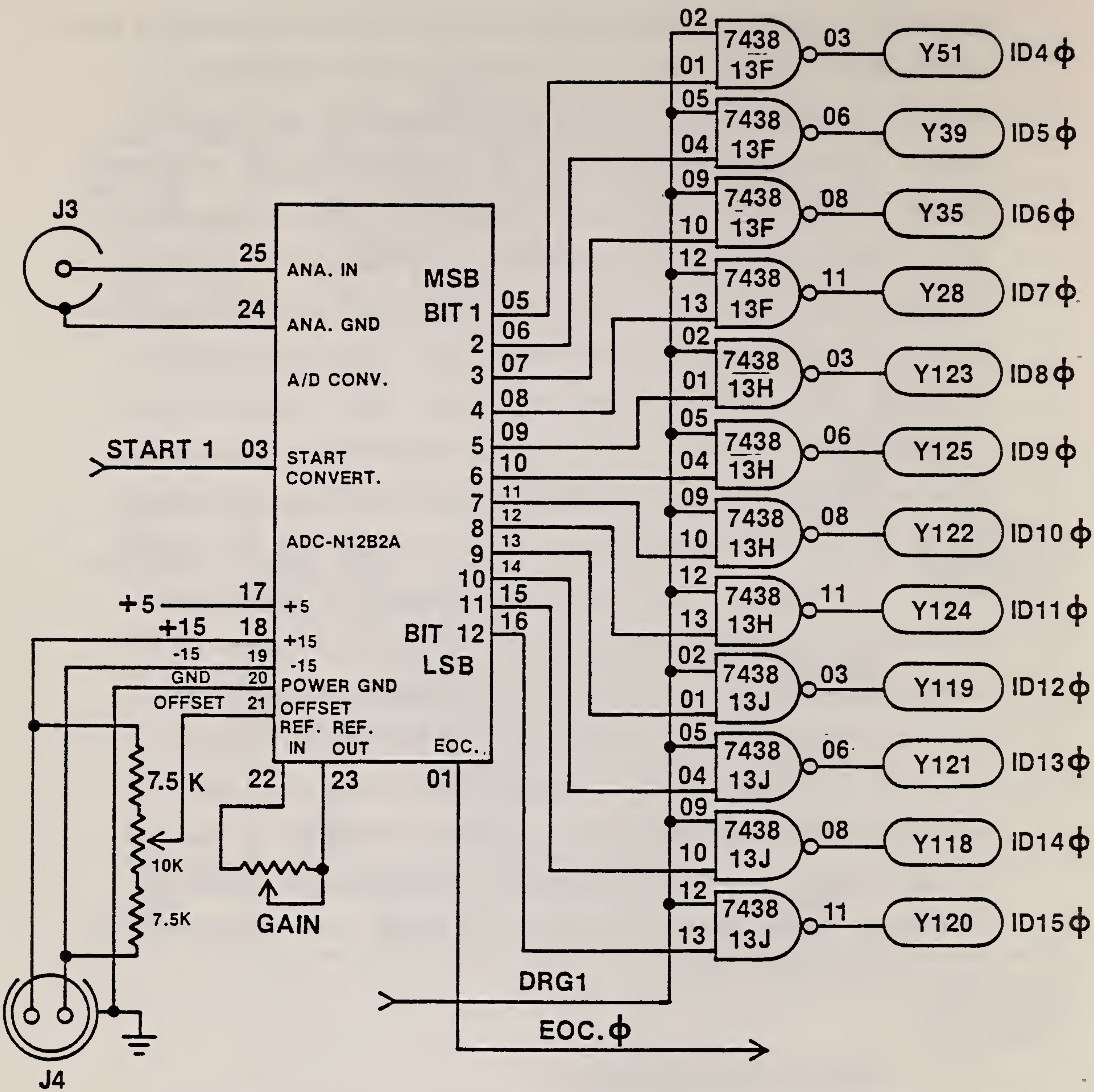


FIGURE A-9 Analog-to-digital converter interface circuit.

all the internal D/A switches are set to the off state except the most significant bit. The voltage level to be converted is compared to the analog equivalent of the most significant bit. If the voltage level is higher, the most significant bit is kept and if not, the bit is dropped. Next the voltage level is compared to the sum of the first choice and the second bit on. The process is completed at the rate of 220 ns per bit until all 12 bits have been determined. The EOC stays high until the conversion is completed. After the conversion is completed its trailing edge toggles the J_1 flip-flop on the analog-to-digital control logic circuit.

The input range of this analog-to-digital converter is 0 to -10 volts. The output format is straight binary. The 12 parallel data lines are strobed to the computer by the Y71 low-level pulse which results in the DRG1 high-level pulse. The converter has both a zero-offset adjustment and a gain adjustment. The manufacturer claims a long term stability for the converter of ±0.1% for six months and a linearity of ±1/2 least-significant-bit. The temperature coefficient is about ±20 ppm/°C.

II. Software

The software will be first described in very general terms and later in this report the details will be presented. The main challenge is to gather data as fast as possible, sort it, and display it. The program must allow user intervention but without sacrificing the data acquisition rate. There are three distinct parts of the software: the main routine, the utility routines, and the data collection routines.

The data collection routines run independently of the others (except for the starting and stopping of the data collection routines) and have priority over anything else in the system. They are interrupt driven, which means they get control when a collection of data has been completed (i.e., data buffer is full). They use a double buffering scheme to insure that data collection always continues. The data collection routines process the input data quickly (i.e., sort it by amplitude and add it to data already collected) and return to whatever else was going on at the time of the interrupt (Fig. A-10).

The main routine consists of a simple main loop which displays the processed data, pauses for a time, displays again and so on. If the operator presses the escape key on the terminal, this loop is broken and the routine will now accept operator commands. After the operator command is acted on, the display loop is begun again. Meanwhile, during all this, the data collection goes on.

The utility routines do the work for the main routine such as: starting and stopping the data collection, drawing the display, varying the oscilloscope screen brightness, displaying characters, controlling the channels to be displayed,etc.

The utility and data collection routines are written in Assembler and the main routine is in BASIC.

A. Timing Constraints Imposed by Software and Processor

The maximum average rate of the data collection is determined by the time it takes to sort the contents of a filled data buffer while

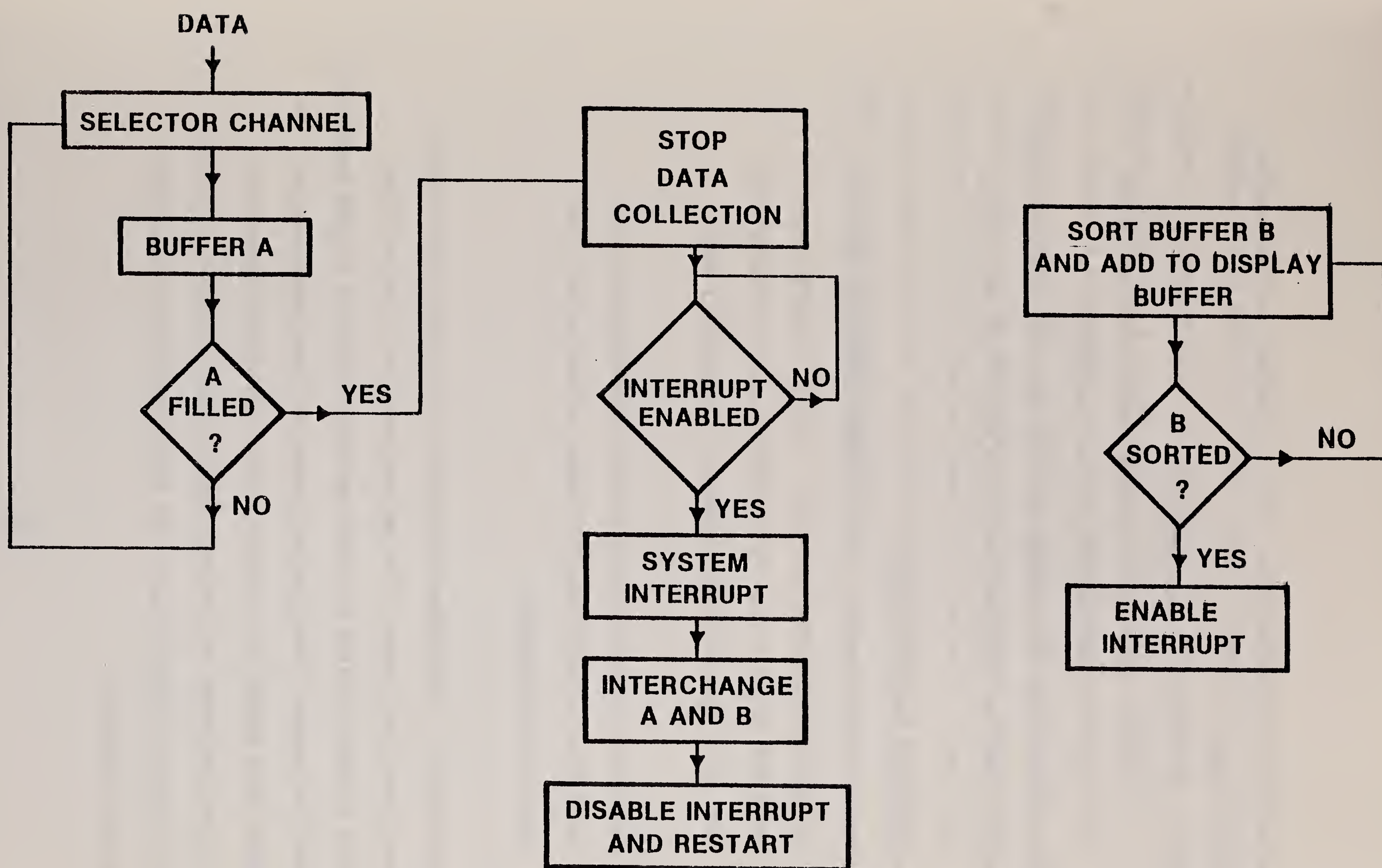


FIGURE A-10 Data collection logic diagram.

the other buffer is collecting data. In the interrupt service routine is found this loop:

```
LOOP    LH R15, 0(11) Load Data Point
        AHM R14, CHANL (R15) Increment Memory Location by One
        BXLE 11, LOOP Loops for Entire Data Buffer.
```

These three instructions are executed once for each data point collected. The execution times for the three are 3.00 + 4.50 + 4.75 or 12.25 μs.

There are two other smaller effects:

1) For each buffer emptied, there is some overhead in setting up for the next buffer (∿ 50 μs). Typically there are at least 200 points in the filled buffer (user selectable) and each one's share in this overhead is consequently small.

2) While the interrupt service routine is running, the data collection is busily stealing memory access cycles, which can slow the processor.

Experimentally, the maximum average data acquisition rate is about 80,000 data points per second. The maximum burst rate (the rate that data can be properly handled for short periods of time) is 125,000 twelve-bit data points per second. The selector channel or direct-memory-access can transfer data points at a rate of 1 MHz. The limiting factor in bursts is the time taken for the peak and hold and the analog to digital circuits to cycle. Bursts of up to the number of points in the buffer can be properly handled.

Another timing constraint is the amount of dead time. After receipt of a partial-discharge pulse, the circuitry will not recognize a new pulse until after its 8 μs cycle time (the burst rate limitation). Also, whenever a data buffer is filled, the selector channel will be inactive for a time while the new data buffer is being initiated. If one pulse enters during that time, it will be correctly handled (the peak and hold circuitry does not reset until the point is read) but successive pulses would be lost. The selector channel is inactive during the following command sequence:

Immediate Interrupt	8.00 μs	Sent to interrupt service routines
STM 12, REGS+2	10.00	
LHI SELCH, SDA	1.50	
OC SELCH, SSTOP	4.50	Clear selector channel
RHR SELCH, R13	4.75	Get ending address
OC SELCH, SSTOP	4.50	Clear selector channel
WH SELCH, ASOB	5.75	Send new address
WH SELCH, AEOB	5.75	
LHI AD, ADDA	1.50	
SSR AD, R12	4.00	Access device
OC SELCH, SREAD	4.50	Start selector channel
	54.75 μs	

In practice it is extremely rare that the partial discharge rate is so fast that data points are lost. There is usually a considerable amount of time during a 60-hertz cycle when partial discharge pulses are not being generated. For example, there are usually no discharges near the voltage zeroes except in the cases of discharge caused by poor contact.

The selector channel (or direct-memory-access) used for data input can transfer data to memory at up to 2 megabytes/s. (One byte is equal to 8 bits). The selector channel has two registers: current address and final address. The selector channel attempts to raise an interrupt when it has filled the final address.

While the selector channel is filling up one buffer, A, with new data, the other buffer, B, is being processed. For each data point in buffer B, the appropriate channel in the display buffer is incremented by one. The interrupt from the selector channel will not be raised until buffer B is done being processed. If buffer B is still being processed when the selector channel has finished filling buffer A, new data may be lost and the message "Possible Lost Data" will be printed on the system console when there is time. If buffer B is done being processed when the selector channel interrupt is raised, the two buffers are quickly interchanged ($\sim$ 55 μs) and data collection continues. As mentioned above it is extremely rare in practice that the data sorting cannot keep up with the data collecting.

Once the selector channel interrupt has been handled, the control will revert to the main program which will keep displaying the updated data on the oscilloscope. If there is channel overflow (> 32,767 counts in a channel), data collection will be halted. No information is lost; the data can be outputted to a floppy diskette and the experiment started over again.

B. Operator Commands

The operator commands allow user interaction with the partial discharge measurement system. They are entered by hitting the "escape key" and then at least the first two letters of the appropriate command. The escape key causes an error which temporarily breaks the loop in the BASIC main routine. The command is then read and if necessary the appropriate utility routine is called to execute the command. If the data collection rate is high, the system will temporarily ignore the new operator command since the data collection has top interrupt priority. All commands will be executed, however, when there is sufficient free time. Listed below are the current operator commands and what they explicitly do. New commands can easily be added.

OPERATOR COMMAND LIST

GO - Begins the collection of data

COUNT - Prints the total number of data points collected

HALT - Stops the collection of data

RESUME - Continues a run after HALT

END - Ends a run, writes data to floppy diskette

ABORT - Stops a run

SELECT [N,M] - Display channel N to M, if no operand writes on system console the N and M in use

PRINT N,M - Prints on the system console all the nonzero channels and their contents from N to M

TOGGLE - Toggles data collection buffers (i.e., forces buffers A and B to interchange thereby allowing the display of a non-filled buffer)

BASIC - Stops main routine and returns to BASIC compiler

BUFFERSIZE [N] - Sets buffersize to N, if no operand prints buffersize currently in use (500 is the default size)

BRIGHT - Intensifies display

LOW - Dims display

DISPLAY - Displays a standard test pattern for adjusting the oscilloscope

DVM - For testing the analog to digital converter, +5 volts in series with 1 kΩ required on "start", 0 - -10 Vdc required on "data", reading displayed on minicomputer front panel meter in hexadecimal

INFO [N] - Writes information (run number, calibration, channels being displayed) on screen in quadrant N. If no operand, writes in first quadrant

NOINFO - Removes information from screen

C. Detailed Software Description

The software was specifically written for an Interdata* 7/16 minicomputer. The detailed software presentation that follows should enable the software to be modified for other machines.

1. BASIC Main Routine

This routine has three main functions:

a) Waste time by executing the loop:

```
FOR I=1 TO D1
NEXT I
```

where D1 is currently set for 700 (statements 90, 800, 810).

b) Update the display, if data collection is going on (statements 620-850).

c) Handle commands from the operator.

If the operator hits the "escape" key on the system console, an "ES" BASIC error results (statements 20, 1140, 1150) which causes a transfer due to the ON ERROR TO statement. Then an operator command is read, and a transfer is made to the appropriate section (1250-1590). If

```
10 R=40
20 ON ERROR GOTO 1140
30 GOTO R
40 DIM C$(2)
50 B=500
60 T=B
70 DIM B1(B/2),B2(B/2)
80 N=1023
90 D1=700
100 DIM C(N),D(N+5)
110 DIM S$(11),T$(10)
120 S$="@.@@@@↑↑↑↑ "
130 T$=S$
140 DIM L$(65)
150 L$=S$+S$+S$+S$+S$+S$
160 DIM Q$(1),E$(2)
170 FOR I=0 TO N+5
180 D(I)=0
190 NEXT I
200 I1=1
210 S1=0
220 S2=N
230 U=3
240 W=0
250 S=0
260 X1=9
270 Y1=11
280 P5=0
290 S5=0
300 O1=0
310 O2=0
320 O3=0
330 DIM L(4,2)
340 MAT READ L
350 DATA 0,1433,-1842,1433,-1842,0,0,0
360 DIM A$(80),O$(10)
370 READ P1
380 DIM P(P1)
390 FOR I=1 TO P1
400 READ P(I)
410 NEXT I
420 DATA 31,0
430 DATA 10,20,30,40,50,60,70,80,90
440 DATA 100,200,300,400,500,600,700,800,900
450 DATA 1000,2000,3000,4000,5000,6000,7000,8000,9000
460 DATA 10000,20000,30000
470 CALL 1007,P(1),P1
480 ;"RUN NUMBER?"
490 INPUT N5
500 ;"CALIBRATION? (PC)"
510 INPUT S5
520 ;"AT CHANNEL?"
530 INPUT S4
540 IF S4=0 GOTO 570
550 S5=S5/S4
```

```
560 GOTO 590
570 S5=0
580 REM                                  MAIN LOOP
590 CALL 1026,E
600 IF E<>0 GOTO 870
610 IF S=0 GOTO 590
620 IF P5<=0 GOTO 780
630 X=L(P5,1)
640 Y=L(P5,2)
650 A$="RUN <35>"+STR$(N5)
660 CALL 1001,A$,X,Y,X1,Y1,I1
670 Y=Y-13*Y1
680 IF S5=0 GOTO 760
690 S7=100*S1*S5
700 S7=INT(S7)/100
710 S8=100*S2*S5
720 S8=INT(S8)/100
730 A$="RANGE "+STR$(S7)+"-"+STR$(S8)+" PC"
740 CALL 1001,A$,X,Y,X1,Y1,I1
750 Y=Y-13*Y1
760 A$="CHANNELS "+STR$(S1)+"-"+STR$(S2)
770 CALL 1001,A$,X,Y,X1,Y1,I1
780 CALL 1008,S1,S2,I1
790 CALL 1005
800 FOR I=1 TO D1
810 NEXT I
820 GOTO 590
830 IF E<>0 GOTO 870
840 CALL 1005
850 GOTO 620
860 REM                                  ERRORS FROM ASSEMBLER ROUTINES
870 IF E=1 GOTO 910
880 IF E=2 GOTO 930
890 IF E=3 AND S GOTO 950
900 GOTO 590
910 ;"ERROR ON SELECTOR CHANNEL"
920 GOTO 840
930 ;"POSSIBLE LOST DATA"
940 GOTO 590
950 ;"CHANNEL OVERFLOW, DATA COLLECTION HALTED"
960 CALL 1005
970 CALL 1008,S1,S2,I1
980 CALL 1005
990 CALL 1026,E
1000 IF E<>0 GOTO 990
1010 ;"KEEP CURRENT DATA? (Y OR N)"
1020 INPUT Q$
1030 IF Q$<>"Y" GOTO 1080
1040 CALL 1024,C(0)
1050 FOR I=0 TO N
1060 D(I)=D(I)+C(I)
1070 NEXT I
1080 ;"COLLECT MORE DATA? (Y OR N)?"
1090 INPUT Q$
1100 IF Q$="Y" GOTO 1710
```

```
1110 S=0
1120 GOTO 600
1130 REM                                     ERRORS FROM BASIC
1140 E$=ERR$(0)
1150 IF E$="ES" GOTO 1250
1160 IF E$="IN" GOTO 1600
1170 IF E$="SB" GOTO 1600
1180 IF E$="UF" GOTO 2410
1190 IF E$<>"IO" GOTO 1220
1200 IF W GOTO 2540
1210 GOTO 2070
1220 ;ERR$(0);"ERROR, LINE";ERL(0)
1230 STOP
1240 REM                                     OPERATOR COMMANDS
1250 LINPUT A$
1260 C$=A$
1270 M=LEN(A$)
1280 B1=M
1290 C1=M+1
1300 O3=0
1310 FOR I=M TO 1 STEP -1
1320 IF A$(I,I)=" " THEN B1=I
1330 IF A$(I,I)="," THEN C1=I
1340 NEXT I
1350 IF B1=M GOTO 1430
1360 O3=1
1370 O$=A$(B1+1,C1-1)
1380 O1=VAL(O$)
1390 IF C1>=M GOTO 1430
1400 O3=2
1410 O$=A$(C1+1,M)
1420 O2=VAL(O$)
1430 IF C$="HA" GOTO 1630
1440 IF C$="TO" GOTO 1680
1450 IF C$="AB" GOTO 1630
1460 IF C$="EN" GOTO 2590
1470 IF C$="GO" GOTO 1710
1480 IF C$="PR" GOTO 1760
1490 IF C$="RE" GOTO 1850
1500 IF C$="CO" GOTO 1900
1510 IF C$="SE" GOTO 1980
1520 IF C$="BA" GOTO 2070
1530 IF C$="BU" GOTO 2100
1540 IF C$="BR" GOTO 2180
1550 IF C$="LO" GOTO 2210
1560 IF C$="DI" GOTO 2290
1570 IF C$="DV" GOTO 2240
1580 IF C$="IN" GOTO 2460
1590 IF C$="NO" GOTO 2510
1600 ;"INVALID COMMAND"
1610 GOTO 600
1620 REM                                                          HA
1630 CALL 1021
1640 ;"DATA COLLECTION HALTED"
1650 S=0
```

```
1660 GOTO 840
1670 REM                                                         TO
1680 CALL 1023
1690 GOTO 830
1700 REM                                                         GO
1710 ;"DATA COLLECTION BEGUN"
1720 S=1
1730 CALL 1020,T,B1(0),B2(0)
1740 GOTO 830
1750 REM                                                         PR
1760 IF O3<>2 GOTO 1600
1770 CALL 1024,C(0)
1780 FOR I=O1 TO O2
1790 IF C(I)=0 GOTO 1810
1800 ;I;"-";C(I)
1810 NEXT I
1820 ;"CHANNELS";O1;"-";O2;"WERE SCANNED FOR PRINTING"
1830 GOTO 600
1840 REM                             RESUME
1850 ;"DATA COLLECTION RESUMED"
1860 S=1
1870 CALL 1022
1880 GOTO 830
1890 REM                                                         COU
1900 CALL 1024,C(0)
1910 C1=0
1920 FOR I=0 TO N
1930 C1=C1+C(I)
1940 NEXT I
1950 ;C1;"POINTS COLLECTED"
1960 GOTO 600
1970 REM                                                         SEL
1980 IF O3=2 GOTO 2010
1990 ;"CURRENTLY SET TO DISPLAY CHANNELS";S1;"-";S2
2000 GOTO 600
2010 S1=O1
2020 S2=O2
2030 IF S1<0 OR S1>N THEN S1=0
2040 IF S2>N OR S2<S1 THEN S2=N
2050 GOTO 830
2060 REM                                                         PAU
2070 ;FNA(0)
2080 GOTO 600
2090 REM                               BUFFERSIZE
2100 IF O3=1 GOTO 2130
2110 ;"BUFFERSIZE IS";T
2120 GOTO 600
2130 T=O1
2140 IF T>B THEN T=B
2150 ;"USE COMMAND GO TO PUT NEW BUFFERSIZE INTO EFFECT"
2160 GOTO 600
2170 REM                                                         BRI
2180 I1=3
2190 GOTO 830
2200 REM                                                         DIM
```

```
2210 I!=1
2220 GOTO 600
2230 REM                                    DVM
2240 CALL 1021
2250 CALL 1002
2260 GOTO 2250
2270 GOTO 600
2280 REM                                                  DISPLAY
2290 CALL 1005
2300 FOR I=5 TO -5 STEP -1
2310 X=INT(I*409.4)
2320 FOR J=-4 TO 4
2330 Y=INT(J*409.4)
2340 CALL 1003,X,Y,I1
2350 NEXT J
2360 NEXT I
2370 ;"ADJUST DISPLAY PLEASE"
2380 S=0
2390 CALL 1005
2400 GOTO 600
2410 R=ERL(0)+10
2420 ;"TYPE <34>RUN 20<34> TO CONTINUE"
2430 STOP
2440 GOTO 20
2450 REM                             INFO
2460 P5=ABS(O1)
2470 IF O3=0 THEN P5=1
2480 IF P5>4 THEN P5=4
2490 GUTO 830
2500 REM                          NO INFO
2510 P5=0
2520 GOTO 830
2540 ;"ERROR IN WRITING TO UNIT";U
2550 W=0
2560 ;FNA(0)
2570 GOTO 2690
2580 REM                                                  END
2590 CALL 1021
2600 ;"DATA COLLECTION ENDED"
2610 ;"KEEP CURRENT DATA? (Y OR N)"
2620 INPUT Q$
2630 IF Q$<>"Y" GOTO 2680
2640 CALL 1024,C(0)
2650 FOR I=0 TO N
2660 D(I)=D(I)+C(I)
2670 NEXT I
2680 ;"ALL SAVED DATA WILL BE WRITTEN TO LOGICAL UNIT";U
2690 ;"IS LOGICAL UNIT";U;"READY? (Y OR N)"
2700 INPUT Q$
2710 IF Q$="Y" GOTO 2740
2720 ;FNA(0)
2730 GOTO 2690
2740 W=1
2750 PRINT ON (U) USING T$,N5
2760 PRINT ON (U) USING T$,S5
```

```
2770 FOR I=0 TO N STEP 6
2780 PRINT ON (U) USING L$,D(I),D(I+1),D(I+2),D(I+3),D(I+4),D(I+5)
2790 NEXT I
2800 WFM U
2810 W=0
2820 END
```

the command is invalid, a message is printed and the routine returns to the main loop (1600-1610). This escape strategy rules out using GOSUB and RETURN because an escape could interrupt execution in the middle of a subroutine and there would be no way to know where to return.

The commands are broken up into a two-character variable, C$ (being the first two letters of the command), a variable telling the number of operands (O3), and the operands (O1 and O2) if present. The commands are straightforward, execution typically being accomplished by calls to a utility routine. A flag variable, S, tells whether data collection is going on. If no data are being collected, the display is not continually updated.

The END command causes the collected data to be written to a floppy diskette. The run number, sensitivity, and the contents of the 1023 channels are outputted. The run number and sensitivity are written on the first two records in an E10.4 format. The channels are written, 6 per record, in a (5(E10.4, 1X), E10.4) format. Each diskette track contains 16 sectors or 288 channels (3 records per sector) so that an entire run can be stored on 4 tracks. This implies that seventeen runs could be stored on each side of a diskette. The current format is chosen because each number has exactly one space between it and its neighbor and no spaces occur at the end of a line, so BASIC can read the file. It is also a fixed field format (the numbers always fall in the same columns) so FORTRAN can read the file.

If a data-related error is detected, a message is printed (statements 590, 870-950). Data collection is not halted on a selector channel error or a lost data error. For a channel overflow error data collection is halted. The main routine then asks whether the data collected should be saved. If so, the data are added into the data previously collected (if any). Therefore, on channel overflow no information is lost -- not even from the channel which overflowed (statements 950-1070).

The return to the BASIC host environment, either due to the operator command "BASIC" or because the operator responded "no" when asked if the output device is ready, is accomplished by causing an undefined function error (statements 20, 30, 1180, 1520, 2070, 2410, 2420, 2720). The next statement to be executed is found by adding 10 to the line number of the statement which caused the error. This number is stored, variable R, and a stop issued. The operator continues operation with a "RUN 20", which reinstates the "ON ERROR GO TO" statement (which is killed by the "STOP") and branches to statement number R.

2. Data Collection Routines (statements 94-161 of Assembler Language Listing

Upon selector channel interrupt, control is transferred to this routine by way of the immediate interrupt sequence. Three steps occur in this transfer: (1) the old Program Status Word (PSW) is saved at location ISR, (2) the new PSW status part is loaded from ISR+4 (X '2000' is loaded), and (3) the location counter is set to ISR÷6 (at the start of the program). The new PSW has locked out all interrupts except machine malfunction. This does not mean interrupts occurring during this time will be lost; they are just not acknowledged. When a normal PSW status is restored any pending interrupts will occur. When this routine is running nothing (except a machine malfunction) will interrupt it.

The ISR or data collection routine has two specific duties. The first is to restart the selector channel on a new buffer as quickly as possible. A double buffer technique is used where one buffer is given to the selector channel to fill while the other one is being processed. When the one is filled, their roles are exchanged. The error checking and actual buffer exchange are postponed until the selector channel is restarted. The ending address of the selector channel is read and compared to the expected ending address. If they do not agree, some selector channel error has occurred.

The second duty is to process the data buffer just filled by the selector channel. The selector has read numbers off the analog-to-digital converter in the range 0-4095 (12-bit converter). This number is used directly as an index into the channel array. The channels array is 2048 halfwords (4096 bytes) long. (On the Interdata machine an address which is not on a halfword boundary is truncated to be on a halfword boundary thereby effectively compacting the data. Each halfword location thus indexed is incremented by one).

The routine senses two error conditions. The selector channel error occurs when the address of the selector channel stopping point is different from that expected indicating a premature halt. Variable SFLAG is set on this error. The possible lost data error occurs when the selector channel has finished collecting a new buffer of data before the old buffer has been processed. This condition is detected in the following way. Suppose the selector channel has finished during processing (it will not interrupt the processing because interrupts are disabled). As soon as the interrupts are enabled it will interrupt. During this time span it is inactive and data would be lost. So if the processing routine is ever re-entered with a return address of the last statement of the processing routine then this situation has occurred and variable LOST is set on this error. "POSSIBLE LOST DATA" usually means too high a rate of input data. Increasing the buffer size thereby decreasing the dead time could help if the rate is only slightly too high. Having the buffer size too large, however, results in long waits before collected data is displayed. Note that it is not desirable to print an error message at the time this error occurs because then is precisely when all activity should be directed towards collecting and processing data.

3. Utility Routines

There are a number of utility routines. Some are executed using calls from BASIC. Others are used in the execution of different routines.

a. Name: DVM

Calling Sequence: CALL 1002

Operands: None

Purpose: To check the A-to-D (analog-to-digital) converter.

Each call to this routine causes an output command to be sent to the A-to-D board triggering a conversion then reading the converted value and displaying it on the hexadecimal display panel.

The start input (see hardware section) must have +5 volts in series with 1 kΩ placed on it. The data input should have a dc level from 0 to -10 volts. The 10 most significant bits of the A-to-D are displayed giving numbers from 0 to 1023 but in hexadecimal (0 - 3FF).

b. Name: STRT

Calling Sequence: CALL 1020, N, B1(0), B2(0)

Operands: N is the number of halfwords in each buffer (each array element in BASIC consists of 2 halfwords)

B1 and B2 are arrays to be used as buffers, each N halfwords long. These are the input buffers used in the double buffering scheme. (Zero indexing is suggested for B1 and B2 so that the case N=1 will be handled without a problem).

Purpose: To begin data collection.

This routine sets up the interrupt service table to handle interrupts from the selector channel. The operating system has set bits 1 and 4 of the PSW, so when an interrupt occurs, it is handled as an immediate interrupt. That is, an interrupt causes the processor to send out an acknowledge interrupt signal. The first device (often the only device) on the interrupt chain which is in an interrupt state responds by giving its device number. The processor takes this number and uses it as an index into the interrupt service table, retrieving from the table the address of the interrupt service routine for that device. The routine sets up an entry in the table so that a selector channel interrupt will be sent to routine "ISR".

This routine also zeros out the channels (CHANL) where the collected data is accumulated, stores the addresses of the starting and ending points of the two buffers (ASFB, AEFB, ASOB, AEOB), and calls routine "RESUME" which starts the selector channel.

c. Name: RESUME

   Calling Sequence: CALL 1022

   Operands: None

   Purpose: To start the selector channel, used in commands GO and RESUME.

This routine sets the A-to-D board to halfword mode, initializes the A-to-D logic with a READ, and starts the selector channel. It locks out interrupts for a time using an exchange program status command. This is necessary because the selector channel accesses the device last addressed on the private bus before the selector channel was started. If another device interrupted at the wrong time, the selector channel would be reading from that device instead of the A-to-D board.

d. Name: CLOSER

   Calling Sequence: Set RESTART to 0 or 1

   BAL 14, CLOSER

Operands: None

Purpose: To stop the selector in the middle of a buffer, and possibly to restart it, used in HALT, TOGGLE, END, ABORT. Command affected variables: CHANL, ASFB, ASOB, AEFB, AEOB.

If RESTART = 0, the selector channel is not restarted. The code is similar to the interrupt service routine (ISR). Interrupts are shut out with an exchange program status command. Only the part of the buffer filled is processed into the channels. Note that this routine clears the interrupt caused by halting the selector channel.

If the selector channel is already stopped, this routine does nothing.

e. Name: HALT

Calling Sequence: CALL 1021

Operands: None

Purpose: To halt data collection

Affected Variables: RESTART.

This routine makes a call to routine CLOSER with RESTART set to 0. The selector channel is not restarted.

f. Name: TOGGLE

Calling Sequence: CALL 1023

Operands: None

Purpose: To halt data collection and resume it immediately, this is to cause processing of data collected in a buffer that has not yet filled.

This routine makes a call to routine CLOSER with RESTART set equal to 1.

g. Name: DATA

Calling Sequence: CALL 1024 C(0)

Operands: C is an array dimensioned C(1023) into which the channel counts will be placed. The channels are stored internally in array CHANL in I*2 form (halfword integer). They are converted to R*4 (fullword real numbers).

Purpose: To make the channels available to the BASIC main routine for calculations or printing.

This routine takes each adjacent pair of the 2048 channels, sums them and converts the sums to real numbers giving 1024 actual channels. Negative numbers are treated as large positive numbers permitting channel overflow to occur without any information being lost.

h. Name: ERROR

Calling Sequence: CALL 1026,E

Operands: E-Error code, will be set to:

0 - no error,

1 - error on selector channel,

2 - possibility of lost data,

3 - channel overflow.

Purpose: To communicate errors raised to the main program.

Affected Variables: LOST, OVER, SFLAG

This routine checks the error flags LOST, OVER, and SFLAG (in that order) to see if those flags have been raised. After setting E to reflect an error, the error flag involved is cleared.

i. Name: PLOTR and PLOTI

Calling Sequence: CALL 1003, X, Y, I

or BAL 14, PLOTI

Operands: X and Y - the X and Y values in the range -2047 to 2047,

I - the intensity (1-dim, 2-off, 3-bright).

Purpose: To plot an X and Y pair.

Affected Variables: MANY, BLOCK

PLOTR is for a call from BASIC with real number arguments. PLOTI is for calls from other Assembler routines. Return register for both is register 14 and register 15 points at the parameter address list.

This routine converts the numbers into numbers suitable for the dual D-to-A (which outputs to an oscilloscope display) and sets them into a buffer. If the buffer is filled, it is automatically dumped by a CALL 1005 or CALL 1006 to be displayed. If an X value is repeated from point to point, the X being unnecessary, is left out the second time.

j. Name: DUMP and LOOK

Calling Sequence: CALL 1005 for DUMP

CALL 1006 for LOOK

Operands: None.

Purpose: To dump the plot buffer to the display, DUMP resets the buffer to be empty and LOOK does not.

This routine does the actual plotting. The sequence is as follows:

turn on the bus,

set the mode of the dual D to A,

set the memory to sequential mode,

write the plot buffer to memory,

set the memory to external mode (to continosly sweep through memory to the D to A).

Most of these operations are done with supervisor calls available in the Interdata* operating system.

k. Name: SIDES

Calling Sequence: CALL 1007,P(1),N

Operands: P - an array of Y values to be plotted on the left side of the display as a reference,

N - the dimension of P, N less than 50.

Purpose: To set up the margin display.

Affected Variables: SIDE, NSIDE

This routine is necessary only because the main histogram drawing routine is written in Assembler. This routine takes a list of Y values, converts them from R*4 as they are in BASIC to I*2 and stores them.

l. Name: SLAP

Calling Sequence: CALL 1008, S1, S2, I

Operands: S1 - the starting channel to be plotted,

S2 - the ending channel to be plotted,

I - the intensity (1-dim, 2-off, 3-bright).

Purpose: To plot the histogram of the channels.

Affected Variables: OVER

This routine makes a quick copy of the channels which is necessary since they are constantly changing. It then scales the histogram to fit on the display using variable LEFT (the direction of the shift) and CONS (the magnitude of the shift). The channel with the largest count in the range of channels S1 and S2 will be scaled to be in the upper half of the display (unless all channels are empty).

The margin display undergoes the same scaling as the main display. If a margin point winds up off screen, it is simply not plotted.

This routine can raise the error "CHANNEL OVERFLOW". Suppose during the data accumulation, more points (> 32767) than an I*2 variable can hold are collected in one channel. This is no real problem for the addition hardware treats an I*2 variable as if it were unsigned (e.g., $7FFF_{16}[32767_{10}] + 1 = 8000_{16}[32768_{10}]$ and so on). The other instructions will recognize 8000_{16} as a negative number (the sign bit is on). This is the way an overflow condition is detected. No information is lost if we treat this number as unsigned. However, once overflow has occurred, data collection should be halted. Channel overflow indicates either to much data or, a dc input to the A-to-D, or positive pulses. Channel overflow is not checked during data collection because too much time would be wasted. This routine would be better written in a higher language if floating point hardware were available. It is in Assembler to take advantage of the shift instructions which provide a very fast way of multiplying and dividing by powers of two.

m. Name: MFIX

Calling Sequence: BAL 15,MFIX

Operands: Floating point register 0 contains the input and register 0 contains the output.

Purpose: This routine converts a R*4 number to I*2, numbers in the range -32767 to 32767 are converted correctly.

This routine uses the method of adding an unnormalized zero to the number which yields an unnormalized result. The I*2 equivalent is the least significant 4 bytes.

Consider floating point 2:

41200000.

Add 46000000 (unnormalized zero), result is:

46000002.

This is still floating point but unnormalized. The second half can be picked off as fixed point 2. Negative numbers will have their two's complement taken.

n. Name: MFLOAT

Calling Sequence: BAL 15,MFLOAT

Operands: Register 0 contains the input, floating point register 0 contains the output.

Purpose: To convert an I*2 number to R*4.

This routine uses the method of creating an unnormalized number.

Consider fixed point 2:

0002.

If the halfword 4600 is placed in front of it, the number becomes:

46000002

which is floating point two unnormalized. The LE command (load floating point) automatically normalizes the number. Negative numbers are complemented and the sign bit set. Both MFIX and MFLOAT are faster than the corresponding FORTRAN routines.

o. Name: WRITE

Calling Sequence: CALL 1001,N$,X,Y,X1,X2,I

Operands: N$-- character string to be written, X and Y-- the X and Y location of where to begin the string in the range -2047 to 2047, X1 and Y1-- the spacing between dots in the letters in the X and Y directions, this determines the size and proportion of the letters, and I-- the intensity (1-dim, 2-off, 3-bright).

Purpose: To write characters on the screen.

```
PROG= *NONE*      03-066R03M96

                        1  *SUBROUTINE TABLE FOR BASIC
0000R                   2          EXTRN  DVM
0000R  03EA             3          DC     1002,A(DVM),0
0002R  0000F
0004R  0000
0006R                   4          EXTRN  PLOTR
0006R  03EB             5          DC     1003,A(PLOTR),3
0008R  0000F
000AR  0003
000CR                   6          EXTRN  DUMP
000CR  03ED             7          DC     1005,A(DUMP),0
000ER  0000F
0010R  0000
0012R                   8          EXTRN  LOOK
0012R  03EE             9          DC     1006,A(LOOK),0
0014R  0000F
0016R  0000
0018R                  10          EXTRN  SIDES
0018R  03EF            11          DC     1007,A(SIDES),2
001AR  0000F
001CR  0002
001ER                  12          EXTRN  SLAP
001ER  03F0            13          DC     1008,A(SLAP),3
0020R  0000F
0022R  0003
0024R                  14          EXTRN  STRT
0024R  03FC            15          DC     1020,A(STRT),3
0026R  0000F
0028R  0003
002AR                  16          EXTRN  HALT
002AR  03FD            17          DC     1021,A(HALT),0
002CR  0000F
002ER  0000
0030R                  18          EXTRN  RESUME
0030R  03FE            19          DC     1022,A(RESUME),0
0032R  0000F
0034R  0000
0036R                  20          EXTRN  TOGGLE
0036R  03FF            21          DC     1023,A(TOGGLE),0
0038R  0000F
003AR  0000
003CR                  22          EXTRN  DATA
003CR  0400            23          DC     1024,A(DATA),1
003ER  0000F
0040R  0001
0042R                  24          EXTRN  ERROR
0042R  0402            25          DC     1026,A(ERROR),1
0044R  0000F
```

```
0046R  0001
0048R                EXTRN  WRITE
0048R  03E9          DC     1001,A(WRITE),6
004AR  0000F
004CR  0006
004ER                END
```

```
NO ERRORS     0 SQUEZ PASSES
CALR03
  ABSTOP          0000
  ADC             0002
> DATA            003ER
> DUMP            000ER
> DVM             0002R
> ERROR           0044R
> HALT            002CR
  IMPTOP          004ER
  LADC            0001
> LOOK            0014R
> PLOTR           0008R
  PURETOP         0000R
> RESUME          0032R
> SIDES           001AR
> SLAP            0020R
> STRT            0026R
> TOGGLE          0030R
> WRITE           004AR
```

PROG= *NONE* 03-066R03M96

```
                              CROSS
0000R                         EXTRN  PLOTT,MANY,MFIX,MFLOAT
0000R                         ENTRY  STRT,HALT,TOGGLE,DVM,DATA,ERROR,SIDES,SLAP,RESUME
      0000 0000       R0      EQU    0
      0000 0001       R1      EQU    1
      0000 0002       R2      EQU    2
      0000 0003       R3      EQU    3
      0000 0004       R4      EQU    4
      0000 0005       R5      EQU    5
      0000 0006       R6      EQU    6
      0000 0007       R7      EQU    7
      0000 0008       R8      EQU    8
      0000 0009       R9      EQU    9
      0000 000A       R10     EQU    10
      0000 000B       R11     EQU    11
      0000 000C       R12     EQU    12
      0000 000D       R13     EQU    13
      0000 000E       R14     EQU    14
      0000 000F       R15     EQU    15
      0000 00F0       SDA     EQU    X'F0'          SELCH DEVICE ADDRESS
      0000 008C       ADDA    EQU    X'8C'          A TO D DEVICE ADDRESS
      0000 0800       NCHAN   EQU    2048           NUMBER OF CHANNELS
      0000 000E       RETURN  EQU    14
```

```
                           *THIS ROUTINE BEGINS DATA COLLECTION FROM THE A TO D
                           *CALL IS OF THE FORM CALL 1020,N,B1(0),B2(0)
                           *WHERE
                           * N IS THE NUMBER OF HALFWORDS IN EACH BUFFER
                           * B1 & B2 ARE ARRAYS, TO BE USED AS BUFFERS,
                           *  EACH N HALFWORDS LONG
                           *  (A REAL NUMBER IS USUALLY 2 HALFWORDS)
                           *THE ROUTINE ZEROS THE CHANNELS
                           *GET PARAMETERS
       0000 0009           BUF1     EQU    9
       0000 000A           BUF2     EQU    10
       0000 0008           N        EQU    8
0000R  D000 005AR          STRT     STM    0,R1020            STORE REGISTERS
0004R  6000 10A4R                   STE    0,FR
0008R  D18F 0000                    LM     0,0(15)            LOAD PARAMETER ADDRESSES
                           *SET UP INTERRUPT HANDLER FOR SELCH
000CR  C820 10D8R                   LHI    R2,ISR             PLACE ADDRESS OF INTERRUPT SERVICER
0010R  4020 02B0                    STH    R2,2*SDA+X'D0'     IN INTERRUPT SERVICE TABLE
                           *ZERO OUT THE CHANNELS
0014R  C820 0000                    LHI    R2,0
0018R  C830 0000                    LHI    R3,0               START FOR BXLE
001CR  C850 0FFE                    LHI    R5,NCHAN-1*2
0020R  C840 0002                    LHI    R4,2               INCREMENT FOR BXLE
0024R  4023 0082R          ZLOOP    STH    R2,CHANL(R3)       ZERO OUT CHANNEL
0028R  C130 0024R                   BXLE   R3,ZLOOP
                           *SET UP ADDRESSES
002CR  6808 0000                    LE     0,0(N)             CONVERT N
0030R  41F0 0000F                   BAL    R15,MFIX           RESULT RETURNED IN REG 0
0034R  0A00                         AHR    R0,R0              DOUBLE IT TO GET NO. BYTES
0036R  2701                         SIS    R0,1
0038R  4090 007AR                   STH    BUF1,ASFB          SET UP FIRST BUFFER
003CR  0A90                         AHR    BUF1,R0
003ER  4090 007CR                   STH    BUF1,AEFB
0042R  40A0 007ER                   STH    BUF2,ASOB          SET UP OTHER BUFFER
0046R  0AA0                         AHR    BUF2,R0
0048R  40A0 0080R                   STH    BUF2,AEOB
                           *START UP SELCH, RETURN
004CR  41E0 10A8R                   BAL    14,RESUME
0050R  6800 10A4R                   LE     0,FR
0054R  D100 005AR                   LM     R0,R1020
0058R  030E                         BR     RETURN
005AR                      R1020    DSH    16
007AR                      ASFB     DS     2                  START OF BUFFER BEING FILLED
007CR                      AEFB     DS     2                  END OF BUFFER BEING FILLED
007ER                      ASOB     DS     2                  START OF OTHER BUFFER
0080R                      AEOB     DS     2                  START OF OTHER BUFFER
                           *CHANNELS
0082R                      CHANL    DSH    NCHAN              THE CHANNELS
1082R                      R1022    DSH    16
10A4R                      FR       DSF    1
```

```
                        *THIS ROUTINE RESUMES DATA COLLECTION
                        *CALL IS OF THE FORM CALL I022
10A8R  D000 1082R       RESUME   STM    0,RI022
10ACR  C0F0 00F0                 LHI    SELCH,SDA
10B0R  C8E0 008C                 LHI    AD,ADDA           LOAD A TO D DEVICE ADDRESS
                        *START SELCH
10B4R  C820 2000                 LHI    R2,X'2000'        SHUT OFF
10B8R  9532                      EPSR   R3,R2             INTERRUPTS
10BAR  DEF0 110FR                OC     SELCH,SSTOP       STOP SELCH
10BER  DEE0 110ER                OC     AD,HALF           TELL INTERFACE THIS IS HALWORD TYPE
10C2R  D0F0 007AR                WH     SELCH,ASFB
10C6R  D8F0 007CR                WH     SELCH,AEFB        GIVE STARTING AND ENDING ADDRESSES
10CAR  99E5                      RHR    AD,R5             READ TO INITIALIZE DEVICE
10CCR  DEF0 1190R                OC     SELCH,SREAD       START SELCH
10D0R  9523                      EPSR   R2,R3
10D2R  D100 1082R                LM     0,RI022
10D6R  030E                      BR     RETURN            RETURN TO CALLER
```

```
                        *INTERRUPT SERVICE ROUTINE FOR SELCH
                        *PROCESSING DONE WITH INTERRUPTS DISABLED
                        *WISH TO FINISH DATA PROCESSING BEFORE USING NEW DATA
        0000 000B       BEGIN    EQU    11
        0000 000D       END      EQU    13
        0000 000F       SELCH    EQU    15
        0000 000E       AD       EQU    14
10D8R                   ISR      DSF    1                 OLD PSW STATUS PART
        0000 10DAR      OPSWA    EQU    ISR+2             OLD PSW ADDRESS PART
10DCR   2000                     DC     X'2000'           NEW PSW STATUS PART, INTERRUPTS DISABLE
10DER   D0C0 1186R               STM    12,REGS+2         STORE REGS 12-15
10E2R   C8F0 00F0                LHI    SELCH,SDA
10E6R   DEF0 118FR               OC     SELCH,SSTOP       CLEAR SELCH FOR COMMANDS
                        *READ SELCH FINISHING ADDRESS
10EAR   99FD                     RHR    SELCH,R13
                        *START SELCH READ
10ECR   DEF0 118FR               OC     SELCH,SSTOP       CLEAR SELCH FOR COMMANDS
10F0R   D8F0 007ER               WH     SELCH,ASOB        SEND STARTING AND
10F4R   D8F0 0080R               WH     SELCH,AEOB        ENDING ADDRESSES
10F8R   C8E0 008C                LHI    AD,ADDA           LOAD A TO D DEVICE ADDRESS
10FCR   9DEC                     SSR    AD,R12            TO ADDRESS DEVICE
10FER   DEF0 1190R               OC     SELCH,SREAD       START SELCH
                        *STORE MORE REGISTERS
1102R   4080 1184R               STH    R11,REGS
                        *ERROR ON SELCH?
1106R   49D0 007CR               CH     R13,AEFB          DID IT STOP AT END?
110AR   4330 1118R               BE     LCK
110ER   2421                     LIS    R2,1
1110R   4020 117ER               STH    R2,SFLAG          SET ERROR FLAG
1114R   C200 10D8R               LPSW   ISR               RETURN TO INTERRUPTEE
                        *POSSIBILITY OF LOST DATA?
1118R   48C0 10DAR      LCK      LH     R12,OPSWA
111CR   49C0 1176R               CH     R12,ACONT         CHECK IF WE CAME FROM CONTINUE
1120R   4230 1130R               BNE    NORMAL
1124R   C0C0 0001                LHI    R12,X'0001'       SET LOST DATA FLAG
1128R   40C0 117CR               STH    R12,LOST
112CR   4300 113CR               B      TRUCK
1130R   40C0 1182R      NORMAL   STH    R12,PSWHOLD+2     STORE AWAY CALLERS PSW
1134R   48C0 10D8R               LH     R12,ISR
1138R   40C0 1180R               STH    R12,PSWHOLD
                        *SWITCH BUFFERS
113CR   48B0 007AR      TRUCK    LH     BEGIN,ASFB
1140R   48C0 007ER               LH     R12,ASOB
1144R   40B0 007ER               STH    BEGIN,ASOB
1148R   40C0 007AR               STH    R12,ASFB
114CR   48D0 007CR               LH     END,AEFB
1150R   48C0 0080R               LH     R12,AEOB
1154R   40D0 0080R               STH    END,AEOB
1158R   40C0 007CR               STH    R12,AEFB
                        *ACCUMULATE THE DATA
```

```
115CR  24C2                HEART    LIS    12,2              LOAD INCREMENT FOR BXLE
115ER  24E1                         LIS    R14,1
1160R  40FD 0000           LOOP     LH     R15,0(11)         LOAD DATA POINT
1164R  61EF 0002R                   AHM    R14,CHANL(R15)    INCREMENT MEM LOCATION
1168R  C100 1160R                   BXLE   11,LOOP
                           *RESTORE REGISTERS
116CR  D180 1184R                   LM     11,REGS
1170R  C200 1174R                   LPSW   ENABLE            BRANCH TO CONTINUE, ENABLE INTERRUPTS
1174R  6800                ENABLE   DC     X'6800'
1176R  1178R               ACONT    DC     A(CONTINUE)
1178R  C200 1180R          CONTINUE LPSW   PSWHOLD           RETURN TO CALLER
117CR  0000                LOST     DC     H'0'
117ER  0000                SFLAG    DC     H'0'
1180R                      PSWHOLD  DSF    1
1184R                      REGS     DS     10
118ER  A0                  HALF     DB     X'A0'
118FR  08                  SSTOP    DB     X'08'
1190R  30                  SREAD    DB     X'30'
```

```
                         *CLOSE BUFFERS EARLY ROUTINE
                         *CODE SIMILAR TO INTERRUPT SERVICE ROUTINE
                         *SUBROUTINES NOT MADE, HOWEVER, IN ORDER TO
                         * RESTART SELCH AS QUICKLY AS POSSIBLE
1192R  D000 1226R        CLOSER   STM    0,CREGS           STORE REGISTERS
1196R  C8F0 00F0                  LHI    SELCH,SDA         LOAD SELCH DEVICE ADDRESS
119AR  C8E0 000C                  LHI    AD,ADDA           LOAD A TO D DEVICE ADDRESS
119ER  C820 2000                  LHI    R2,X'2000'
11A2R  9532                       EPSR   R3,R2             SHUT OUT INTERRUPTS
11A4R  9DF5                       SSR    SELCH,R5          SEE IF SELCH IS BUSY
11A6R  4300 121ER                 BFC    8,RCLOSE          IF NOT BUSY, DO NOTHING
11AAR  4850 1246R                 LH     R5,RESTART        FIND OUT WHETHER TO RESTART
11AER  4230 11C0R                 BNZ    REST
                         *STOP SELCH
11B2R  DEF0 118FR                 OC     SELCH,SSTOP       STOP SELCH
11B6R  99F0                       RHR    SELCH,R0          READ FINISHING ADDRESS
11B8R  DEF0 118FR                 OC     SELCH,SSTOP       RESET SELCH
11BCR  4300 11D8R                 B      MERGE
                         *STOP SELCH, RESTART
11C0R  DEF0 118FR        REST     OC     SELCH,SSTOP       STOP SELCH
11C4R  99F0                       RHR    SELCH,R0          READ FINISHING ADDRESS
11C6R  DEF0 118FR                 OC     SELCH,SSTOP       CLEAR SELCH FOR COMMANDS
11CAR  D0F0 007ER                 WH     SELCH,ASOB
11CER  D0F0 0080R                 WH     SELCH,AEOB
11D2R  99EC                       RHR    AD,R12            ADDRESS DEVICE, RESTART
11D4R  DEF0 1190R                 OC     SELCH,SREAD       START SELCH
                         *CLEAR THE INTERRUPT WE CAUSED
11D8R  9F45              MERGE    AIR    R4,R5             ACKNOWLEDGE INTERRUPT
11DAR  0844                       LHR    R4,R4             NO DEVICE?
11DCR  4230 11D8R                 BNZ    MERGE             NOTE WE CLEAR ALL INTERRUPTS
                         *SWITCH BUFFERS
11E0R  48D0 007CR                 LH     END,AEFB
11E4R  48C0 0080R                 LH     R12,AEOB
11E8R  40D0 0080R                 STH    END,AEOB
11ECR  40C0 007CR                 STH    R12,AEFB
11F0R  48B0 007AR                 LH     BEGIN,ASFB
11F4R  48C0 007ER                 LH     R12,ASOB
11F8R  40B0 007ER                 STH    BEGIN,ASOB
11FCR  40C0 007AR                 STH    R12,ASFB
                         *FIND ENDING ADDRESS
1200R  2701                       SIS    R0,1              ROUND DOWN TO
1202R  C600 0001                  OHI    R0,X'0001'        NEAREST ODD NUMBER
1206R  08D0                       LHR    END,R0            THIS IS ENDING ADDRESS
                         *ACCUMULATE DATA
1208R  09BD                       CHR    BEGIN,END
120AR  4380 121ER                 BNL    RCLOSE
120ER  24C2                       LIS    12,2              LOAD INCREMENT FOR BXLE
1210R  24E1                       LIS    R14,1
1212R  48FB 0000         LOOP1    LH     R15,0(11)         LOAD DATA POINT
1216R  61[illegible] 0082R        AHM    R14,CHANL(R15)    INCREMENT TALLY
```

```
121AR  C1B0 1212R      213            BXLE   11,LOOP1
                       214  *RETURN TO CALLER
121ER  9523            215  RCLOSE    EPSR   R2,R3
1220R  D100 1226R      216            LM     0,CREGS
1224R  030E            217            BR     14
1226R                  210  CREGS     DS     32
1246R  0000            219  RESTART   DC     X'0000'
```

```
                          *THIS ROUTINE HALTS A DATA COLLECTION, TEMPORARILY
                          *CALL IS OF THE FORM CALL 1021
1248R  D000 125CR         HALT     STM    0,R1021            STORE REGISTERS
124CR  2420                        LIS    R2,0
124ER  4020 1246R                  STH    R2,RESTART         SET RESTART FLAG
1252R  41E0 1192R                  BAL    14,CLOSER          CALL CLOSER
1256R  D100 125CR                  LM     0,R1021
125AR  030E                        BR     RETURN
125CR                     R1021    DSH    16
```

```
                          *THIS ROUTINE SWITCHES DATA COLLECTION BUFFERS AND CONTINUES
                          *CALL IS OF THE FORM CALL 1023
                          *ITS MAIN USE IS TO DUMP OUT DATA WHICH HAS BEEN COLLECTED BY
                          * THE SELCH TO THE REAL WORLD FOR IMPATIENT PEOPLE LIKE ME
127CR   D000 125CR        TOGGLE   STM    0,R1021          STORE REGISTERS
1280R   2421                       LIS    R2,1
1282R   4020 1246R                 STH    R2,RESTART       SET RESTART FLAG
1286R   41E0 1192R                 BAL    14,CLOSER        CALL CLOSER
128AR   D1C0 125CR                 LM     0,R1021
128ER   030E                       BR     RETURN
```

```
                       *THIS ROUTINE READS A VALUE FROM THE A TO D AND DISPLAYS IT
                       *CALL IS OF THE FORM CALL 1002
                       *A HALT(CALL 1021) SHOULD BE ISSUED BEFORE THIS CALL
1290R  D000 12B2R      DVM      STM    0,R1002
1294R  CBE0 008C                LHI    AD,ADDA
1298R  2401                     LIS    R0,1
129AR  DE00 12B0R               OC     R0,HEXON         SET THE DISPLAY PANEL
129ER  DEE0 11BER               OC     AD,HALF          TRIGGER A TO D, SET HALFWORD MODE
12A2R  99E3                     RHR    AD,R3            READ VALUE
12A4R  9032                     SRLS   R3,2             CHUCK 2 LSB
12A6R  9433                     EXBR   R3,R3            SWAP BYTE ORDER
12A8R  9003                     WHR    R0,R3            DISPLAY IT
12AAR  D100 12B2R               LM     0,R1002          RETURN
12AER  030E                     BR     RETURN
12B0R  80              HEXON    DB     X'80'
12B2R                  R1002    DSH    16
```

```
                    *THIS ROUTINE TAKES THE CHANNELS AND PLUNKS THEM OUT TO AN ARRAY
                    *CALL IS OF THE FORM CALL 1024,C(0)
                    *WHERE C IS DIMENSIONED C(1023)
                    *(THE ROUTINE CONVERTS TO R*4 ON THE WAY)
       0000 0000    C          EQU    8
12D2R  D000 1302R   DATA       STM    0,R1024           STORE REGISTERS
12D6R  D18F 0000               LM     8,0(15)           LOAD PARAMETER ADDRESSES
12DAR  C070 4600               LHI    R7,X'4600'        LOAD TOP HALF
12DER  2410                    LIS    R1,0              LOAD START FOR BXLE
12E0R  2424                    LIS    R2,4              LOAD INCREMENT
12E2R  C030 0FFC               LHI    R3,NCHAN-2*2
12E6R  4861 0082R   DLOOP      LH     R6,CHANL(R1)
12EAR  4A61 0084R              AH     R6,CHANL+2(R1)
12EER  4078 0000               STH    R7,0(C)           STORE NUMBER
12F2R  4068 0002               STH    R6,2(C)
12F6R  2684                    AIS    C,4
12F8R  C110 12E6R              BXLE   1,DLOOP
12FCR  D100 1302R              LM     0,R1024
1300R  030E                    BR     RETURN
1302R               R1024      DSH    16
```

```
                      *THIS ROUTINE CHECKS FOR VARIOUS ERROR CONDITIONS
                      *CALL IS OF THE FORM CALL 1026,E
                      *E WILL BE SET TO
                      * 0-NO ERRORS
                      * 1-ERROR ON SELECTOR CHANNEL
                      * 2-POSSIBILITY OF DATA LOSS
                      * 3-CHANNEL OVERFLOW
                      *ERROR CONDITIONS ARE CLEARED
       0000 0000      E        EQU    0
1322R  D000 136CR     ERROR    STM    0,R1026            STORE REGISTERS
1326R  D18F 0000               LM     8,0(15)            LOAD PARAMETER ADDRESSES
132AR  C070 4600               LHI    R7,X'4600'
132ER  4070 0000               STH    R7,0(E)
1332R  2470                    LIS    R7,0               INITIALLY SET TO 0
                      *LOST DATA?
1334R  4060 117CR     LD       LH     R6,LOST
1338R  2336                    BZS    COV
133AR  4070 117CR              STH    R7,LOST            RESET
133ER  2472                    LIS    R7,2
1340R  4300 1362R              B      RERROR
                      *CHANNEL OVERFLOW?
1344R  4060 1630R     COV      LH     R6,OVER
1348R  2336                    BZS    SE
134AR  4070 1630R              STH    R7,OVER            RESET
134ER  2473                    LIS    R7,3
1350R  4300 1362R              B      RERROR
                      *SELECTOR CHANNEL ERROR?
1354R  4060 117ER     SE       LH     R6,SFLAG
1358R  4330 1362R              BZ     RERROR
135CR  4070 117ER              STH    R7,SFLAG           RESET
1360R  2471                    LIS    R7,1
1362R  4070 0002      RERROR   STH    R7,2(E)            RETURN
1366R  D100 136CR              LM     0,R1026
136AR  030E                    BR     RETURN
136CR                 R1026    DSH    16
```

```
                        *THIS ROUTINE SETS UP THE MARGIN DISPLAY
                        *CALL IS OF THE FORM CALL 1007,P(1),N
                        *WHERE P IS AN ARRAY OF Y-VALUES TO BE PLOTTED ON THE
                        * LEFT SIDE OF THE DISPLAY
                        *N IS THE DIMENSION OF P (DIM P(N)), N LESS THAN 50
       0000 0008        P         EQU    0
       0000 0009        PN        EQU    9
13BCR  D000 143AR       SIDES     STM    0,R1007            STORE REGISTERS
1390R  6000 145CR                 STE    0,F1007
1394R  D10F 0000                  LM     0,0(15)            LOAD PARAMETER ADDRESSES
1398R  6009 0000                  LE     0,0(PN)            CONVERT DIMENSION
139CR  41F0 0032R                 BAL    R15,MFIX           RESULT IN REG 0
13A0R  C500 0032                  CLHI   0,50               CHECK IF ABOVE 50 (OR NEGATIVE)
13A4R  4280 13ACR                 BL     POK
13A8R  C800 0032                  LHI    0,50               IF ABOVE SET TO 50
13ACR  4000 1438R       POK       STH    0,NSIDE            SAVE IT AWAY
                        *CONVERT THE P ARRAY
13B0R  2452                       LIS    5,2                START FOR BXLE
13B2R  2462                       LIS    6,2                INCREMENT FOR BXLE
13B4R  0870                       LHR    7,0
13B6R  0A77                       AHR    R7,R7              ENDING FOR BXLE
13B8R  6800 0000        MLOOP     LE     8,0(P)             LOAD NUMBER
13BCR  41F0 139ER                 BAL    R15,MFIX           CONVERT IT
13C0R  4005 13D2R                 STH    0,SIDE-2(5)        STORE IT AWAY
13C4R  2684                       AIS    P,4
13C6R  C150 13B8R                 BXLE   5,MLOOP
                        *RETURN
13CAR  D100 143AR                 LM     0,R1007
13CER  6000 145CR                 LE     0,F1007
13D2R  030E                       BR     RETURN
13D4R                   SIDE      DSH    50
1438R                   NSIDE     DSH    1
143AR                   R1007     DSH    16
145CR                   F1007     DSF    1
```

```
                                *THIS ROUTINE PLOTS THE CHANNELS
                                *CALL IS OF THE FORM CALL 1000,S1,S2,I
                                *WHERE A CALL TO 1007 HAS PREVIOUSLY BEEN MADE
                                * S1 IS THE STARTING CHANNEL TO BE PLOTTED
                                * S2 IS THE ENDING CHANNEL TO BE PLOTTED
                                * I IS THE INTENSITY
                                *IT IS WRITTEN IN ASSEMBLER SOLELY TO AVOID
                                * LARGE SCALE USE OF OPERATIONS WHICH ARE SOFTWARE
                                * SIMULATED (LE MH TO NAME TWO)
       0000 0008                S1       EQU    8
       0000 0009                S2       EQU    9
       0000 000A                INT      EQU    10
1460R  D000 143AR               SLAP     STM    0,R1007              STORE REGISTERS
1464R  6000 145CR                        STE    0,F1007
1468R  D10F 0000                         LM     0,0(15)              LOAD PARAMETER ADDRESSES
146CR  680A 0000                         LE     0,0(INT)             CONVERT INTENSITY
1470R  41F0 138ER                        BAL    R15,MFIX
1474R  4000 1626R                        STH    0,BRIGHT
1478R  6808 0000                         LE     0,0(S1)              CONVERT START
147CR  41F0 1472R                        BAL    R15,MFIX
1480R  0080                              LHR    S1,0
1482R  6809 0000                         LE     0,0(S2)              CONVERT END
1486R  41F0 147ER                        BAL    R15,MFIX
148AR  0090                              LHR    S2,R0
                                *EQUATES FOR THE SPECIFIC DISPLAY
       FFFF F801                LEASTX   EQU    -2047
       0000 07FF                MOSTX    EQU    2047
       0000 0064                MARGINX  EQU    100
       FFFF F99A                LEASTY   EQU    -1638
       0000 0666                MOSTY    EQU    1638
       0000 0000                MARGINY  EQU    0
                                *CALCULATE X START AND X INCREMENT
       0000 000B                XSTART   EQU    11
       0000 000C                XINC     EQU    12
148CR  C0B0 F865                         LHI    XSTART,LEASTX+MARGINX
1490R  2440                              LIS    R4,0
1492R  C050 0F36                         LHI    R5,-2*MARGINX+MOSTX-LEASTX
1496R  0869                              LHR    R6,S2
1498R  0B68                              SHR    R6,S1
149AR  2661                              AIS    R6,1
149CR  0D46                              DHR    R4,R6
149ER  08C5                              LHR    XINC,R5
                                *DOUBLE THE STARTING AND ENDING FOR INDEXING
14A0R  0A88                              AHR    S1,S1
14A2R  0A99                              AHR    S2,S2
                                *MAKE A QUICK COPY OF THE CHANNELS, FOR THEY CONSTANTLY CHANGE
14A4R  0858                              LHR    R5,S1                LOAD START FOR BXLE
14A6R  2462                              LIS    R6,2                 LOAD INCREMENT FOR BXLE
14A8R  0879                              LHR    R7,S2                ENDING FOR BXLE
14AAR  [illegible]                       LHR    R2,S1
```

```
14ACR  0A22                           AHR    R2,R2              INDEX FOR CHANNELS
14AER  4042 0002R       SLOOP         LH     R4,CHANL(R2)       COPY
14B2R  4A42 0004R                     AH     R4,CHANL+2(R2)     SUM ADJACENT CHANNELS
14B6R  2624                           AIS    R2,4
14B8R  4045 1632R                     STH    R4,COPY(R5)
14BCR  C150 14AER                     BXLE   5,SLOOP
                        *SET UP FOR PLOT
       0000 0002        XV            EQU    2
       0000 0003        YV            EQU    3
14C0R  2400             PL            LIS    R0,0               RESET FLAG
14C2R  4000 162CR                     STH    R0,PHALF
14C6R  4000 162ER                     STH    R0,BUMPS
14CAR  C8F0 161CR                     LHI    R15,P1             LOAD ADDRESS FOR CALL
14CER  0858                           LHR    R5,S1              STARTING FOR BXLE
14D0R  0879                           LHR    R7,S2              ENDING
14D2R  0828                           LHR    XV,XSTART
14D4R  4020 1622R       SPLOOP        STH    XV,XVAL            TAKE CARE OF X
14D8R  0A2C                           AHR    XV,XINC
14DAR  4835 1632R                     LH     YV,COPY(R5)        LOAD THE Y VALUE
14DER  4210 15B2R                     BM     CRASH              CHECK FOR OVERFLOW OF A CHANNEL
14E2R  4330 14ECR       MORE          BZ     SCALE
14E6R  2401                           LIS    R0,1               WILL SET FLAG IF WE GET A NON ZERO VALU
14E8R  4000 162ER                     STH    R0,BUMPS           TO TELL IF WE HAVE THE ZERO FUNCTION
                        *SCALE THE YVALUES
14ECR  4810 162AR       SCALE         LH     R1,CONS
14F0R  4800 1628R                     LH     R0,LEFT            CHECK IF WE'RE SHIFTING LEFT
14F4R  4230 1500R                     BNZ    SL
14F8R  CE31 0000        SR            SRHA   YV,0(R1)
14FCR  4300 1504R                     B      BUZZ
1500R  CF31 0000        SL            SLHA   YV,0(R1)
1504R  CA30 F99A        BUZZ          AHI    YV,LEASTY+MARGINY
                        *CHECK FOR TOO BIG
1508R  C930 0566                      CHI    YV,MOSTY-MARGINY
150CR  4280 151CR                     BL     LITTLE
1510R  4800 1628R                     LH     R0,LEFT            CHECK IF WE'RE SHIFTING LEFT
1514R  4230 15E2R                     BNZ    DEC                YES,MAKE IT SHIFT LESS
1518R  4300 15CCR                     B      INC                NO, SHIFTING RIGHT, MAKE IT SHIFT MORE
                        *CHECK IF ANY MAKE IT OVER HALFWAY (SOME SHOULD)
151CR  C930 0000        LITTLE        CHI    YV,MOSTY+LEASTY/2
1520R  4280 152AR                     BL     NOPE
1524R  2401                           LIS    R0,1               SET FLAG, WE'RE FINE
1526R  4000 162CR                     STH    R0,PHALF
                        *ACTUAL PLOT
152AR  4030 1624R       NOPE          STH    YV,YVAL
152ER  41E0 0000F                     BAL    R14,PLOT1
1532R  C150 14D4R                     BXLE   R5,SPLOOP
                        *POST MORTEM, CHECK IF ANY BIG ENOUGH
1536R  4000 162CR                     LH     R0,PHALF
153AR  4230 1552R                     BNZ    DOMARG
153ER  4800 162ER                     LH     R0,BUMPS           NONE WERE BIG ENOUGH, BUT
```

```
1542R  4330 1552R              BZ     DOMARG              IF ZERO FUNCTION, OK
1546R  4800 1620R              LH     R0,LEFT             CHECK IF WE'RE SHIFTING LEFT
154AR  4230 15CCR              BNZ    INC                 YES, MAKE IT SHIFT MORE
154ER  4300 15E2R              B      DEC                 NO ,SHIFT LESS
                        *PLOT MARGINS
1552R  2452             DOMARG LIS    R5,2                START FOR BXLE
1554R  4070 1438R              LH     R7,NSIDE            GET NO. POINTS
1558R  4320 15A8R              BNP    RSLAP               IF NONE, RETURN
155CR  0A77                    AHR    R7,R7               DOUBLE IT
155ER  C800 F801               LHI    R0,LEASTX
1562R  4000 1622R              STH    R0,XVAL             SET X COORDINATE
1566R  C8F0 161CR              LHI    R15,P1              SET UP FOR CALL
156AR  4835 13D2R       MLOOP1 LH     R3,SIDE-2(R5)       PICK UP POINT
156ER  4810 162AR              LH     R1,CONS             LOAD AMOUNT TO SHIFT
1572R  4800 1620R              LH     R0,LEFT             SHIFT LEFT?
1576R  2135                    BNZS   MSL
1578R  CE31 0000        MSR    SRHA   R3,0(R1)            SHIFT RIGHT
157CR  4300 1592R              B      HOP
1580R  2420             MSL    LIS    R2,0                SHIFT LEFT
1582R  EF21 0000               SLA    R2,0(R1)
1586R  0822                    LHR    R2,R2               IF OVERFLOW, DO NOT PLOT
1588R  4230 15A4R              BNZ    SKIP
158CR  0833                    LHR    R3,R3
158ER  4320 15A4R              BNP    SKIP
1592R  CA30 F99A        HOP    AHI    R3,LEASTY+MARGINY
1596R  4030 1624R              STH    R3,YVAL
159AR  C930 0666               CHI    R3,MOSTY-MARGINY    CHECK IF OFF SCREEN
159ER  2303                    BNLS   SKIP                FORGET IT IF SO
15A0R  41E0 1530R              BAL    R14,PLOT1           PLOT IT
15A4R  C150 156AR       SKIP   BXLE   5,MLOOP1
                        *RETURN
15A8R  D100 143AR       RSLAP  LM     0,R1007
15ACR  6800 145CR              LE     0,F1007
15B0R  030E                    BR     RETURN
                        *OVERFLOW OF A CHANNEL
15B2R  C830 7FFF        CRASH  LHI    YV,X'7FFF'          SET TO LARGEST NUMBER
15B6R  4800 1630R              LH     R0,OVER             CHECK IF FLAG UP
15BAR  4230 14E2R              BNZ    MORE                IF ALREADY UP, CONTINUE
15BER  41E0 1248R              BAL    14,HALT             IF NOT, SET FLAG, AND ABORT
15C2R  2401                    LIS    R0,1
15C4R  4000 1630R              STH    R0,OVER
15C8R  4300 14E2R              B      MORE
                        *INCREMENT SHIFTER
15CCR  4800 162AR       INC    LH     R0,CONS
15D0R  2601                    AIS    R0,1
15D2R  4000 162AR              STH    R0,CONS
15D6R  C900 0010               CHI    R0,X'0010'          IF MORE THEN 4 BITS BIG, TAKE ACTION
15DAR  4300 15F4R              BNL    FLIP
15DER  4300 1600R              B      CANCEL              PLOT OUT THESE POINTS, AND START OVER
                        *DECREMENT SHIFTER
```

```
15E2R  4000 162AR        501  DEC       LH     R0,CONS
15E6R  2701              502            SIS    R0,1
15E8R  4320 15F4R        503            BNP    FLIP
15ECR  4000 162AR        504            STH    R0,CONS
15F0R  4300 1608R        505            B      CANCEL              START OVER
                         506  *DRASTIC ACTION
15F4R  2400              507  FLIP      LIS    R0,0
15F6R  4000 162AR        508            STH    R0,CONS
15FAR  4000 1628R        509            LH     R0,LEFT
15FER  4330 1612R        510            BZ     LON
1602R  2400              511            LIS    R0,0                TURN OFF LEFT SHIFT
1604R  4000 1628R        512            STH    R0,LEFT
1608R  2400              513  CANCEL    LIS    R0,0                KILL PLOT BUFFER
160AR  4000 000AF        514            STH    R0,MANY
160ER  4300 14C0R        515            B      PL
1612R  2401              516  LON       LIS    R0,1                TURN ON LEFT SHIFT
1614R  4000 1628R        517            STH    R0,LEFT
1618R  4300 14C0R        518            B      PL
161CR  1622R             519  PI        DC     A(XVAL),A(YVAL),A(BRIGHT)
161ER  1624R
1620R  1626R
1622R                    520  XVAL      DSH    1
1624R                    521  YVAL      DSH    1
1626R                    522  BRIGHT    DSH    1
1628R  0001              523  LEFT      DC     H'1'
162AR  000A              524  CONS      DC     H'10'
162CR                    525  PHALF     DSH    1
162ER                    526  BUMPS     DSH    1
1630R  0000              527  OVER      DC     H'0'
1632R                    528  COPY      DSH    NCHAN
2632R                    529            END
```

NO ERRORS 0 SQUEZ PASSES

CALR03

ABSTOP	0000										
ACONT	1176R	126									
AD	000E	80	85	88	113	114	169	187	246	249	250
ADC	0002										
ADDA	000C	80	113	169	246						
AEFB	007CR	57	87	119	139	142	194	197			
AEOB	0080R	60	112	140	141	186	195	196			
ASFB	007AR	55	86	135	138	198	201				
ASOB	007ER	58	111	136	137	185	199	200			
BEGIN	000B	135	137	198	200	207					
BRIGHT	1626R	368	519								
BUF1	0009	55	56	57							
BUF2	000A	58	59	60							
BUMPS	162ER	412	423	450							
BUZZ	1504R	429									
C	0008	272	273	274							
CANCEL	1600R	499	505								
CHANL	0082R	48	147	212	270	271	402	403			
CLOSER	1192R	226	238								
CONS	162AR	425	464	494	496	501	504	508			
CONTINUE	1170R	153									
COPY	1632R	405	419								
COV	1344R	296									
CRASH	1582R	420									
CREGS	1226R	167	216								
< DATA	12D2R										
DEC	15E2R	436	454								
DLOOP	12E6R	275									
DOMARG	1552R	449	451								
< DVM	1290R										
E	0008	292	311								
ENABLE	1174R	151									
END	000D	139	141	194	196	205	207				
< ERROR	1322R										
F1007	145CR	324	344	364	403						
FLIP	15F4R	498	503								
FR	10A4R	38	63								
HALF	118ER	85	249								
< HALT	1248R	489									
HEART	115CR										
HEXON	1280R	248									
HOP	1592R	468									
HPTOP	2632R										
INC	15CCR	437	453								
INT	000A	366									
ISR	10D8R	41	102	123	132						

LADC	0001													
LCK	1110R	120												
LD	1334R													
LEASTX	F001	385	387	460										
LEASTY	F99A	431	439	475										
LEFT	1620R	426	435	452	465	509	512	517						
LITTLE	151CR	434												
LUN	1612R	510												
LOOP	1160R	140												
LOOP1	1212R	213												
LOST	117CR	129	295	297										
> MANY	160CR	514												
MARGINX	0064	385	387											
MARGINY	0900	431	433	475	477									
MERGE	11D0R	180	192											
> MFIX	1400R	52	327	338	367	370	373							
**MFLOAT	0000													
MLOOP	1380R	341												
MLOOP1	156AR	400												
MORE	14E2R	488	492											
MOSTX	07FF	387												
MOSTY	0666	433	439	477										
MSL	1580R	466												
MSR	1570R													
N	0008	51												
NCHAN	0000	46	72	269	528									
NOPE	152AR	440												
NORMAL	1130R	127												
NSIDE	1438R	331	457											
OPSWA	10DAR	125												
OVER	1630R	301	303	487	491									
P	0008	337	340											
P1	161CR	413	462											
PHALF	162CR	411	442	448										
PL	14C0R	515	518											
> PLOT1	15A2R	445	479											
PN	0009	326												
POK	13ACR	329												
PSWHOLD	1100R	131	133	154										
PURETOP	0000R													
R0	0000	53	53	54	56	59	64	178	183	203	204	205	247	248
		253	374	410	411	412	422	423	426	435	441	442	448	450
		452	460	461	465	487	490	491	494	495	496	497	501	502
		504	507	508	509	511	512	513	514	516	517			
R1	0001	267	270	271	425	428	430	464	467	470				
R10	000A													
R1002	1202R	245	254											
R1007	143AR	323	343	363	482									
R1020	005AR	37	64											
R1021	125CR	223	227	235	239									

```
R1022      1002R     78   91
R1024      1302R    264  276
R1026      136CR    209  312
R11        000B     117
R12        000C     114  125  126  128  129  131  132  133  136  138  140  142  187
                    195  197  199  201
R13        000D     108  119
R14        000E     145  147  210  212  445  479
R15        000F      52  146  147  211  212  327  330  367  370  373  413  462
R2         0002      41   42   44   48   82   83   90  121  122  170  171  215  224
                    225  236  237  268  400  401  401  402  403  404  469  470  471
                    471
R3         0003      45   48   49   83   90  171  215  250  251  252  252  253  269
                    463  467  473  473  475  476  477
R4         0004      47  190  191  191  386  391  402  403  405
R5         0005      46   88  172  174  190  387  392  397  405  414  419  446  456
                    463
R6         0006     270  271  273  295  301  307  388  389  390  391  398
R7         0007     266  272  291  292  293  297  298  303  304  309  310  311  336
                    336  399  415  457  459  459
R8         0008
R9         0009
RCLOSE     121ER    173  208
REGS       1104R    104  117  150
RERROR     1362R    299  305  308
REST       11C0R    175
RESTART    1246R    174  225  237
RESUME     10A8R     62
RETURN     000E      65   92  220  240  255  277  313  345  484
RSLAP      15A8R    458
S1         0008     369  371  389  394  394  397  400  414
S2         0009     372  374  388  395  395  399  415
SCALE      14ECR    421
SDA        00F0      42   79  105  168
SE         1354R    302
SELCH      000F      79   84   86   87   89  105  106  108  110  111  112  115  168
                    172  177  178  179  182  183  184  185  186  188
SFLAG      117ER    122  307  309
SIDE       13D4R    339  463
SIDES      130CR
SKIP       15A4R    472  474  478
SL         1500R    427
SLAP       1460R
SLOOP      14AER    406
SPLOOP     14D4R    446
SR         14F0R
SREAD      1190R     89  115  188
SSTOP      118FR     84  106  110  177  179  182  184
STRT       0000R
TOGGLE     127CR
```

PROG= *NONE* 03-066R03M96

```
                                     CROSS
0000R                                ENTRY   PLOTI,PLOTR,DUMP,LOOK,MFIX,MFLOAT,WRITE
0000R                                ENTRY   MANY
        0000 0000           R0       EQU     0
        0000 0001           R1       EQU     1
        0000 0002           R2       EQU     2
        0000 0003           R3       EQU     3
        0000 0004           R4       EQU     4
        0000 0005           R5       EQU     5
        0000 0006           R6       EQU     6
        0000 0007           R7       EQU     7
        0000 0008           R8       EQU     8
        0000 0009           R9       EQU     9
        0000 000A           R10      EQU     10
        0000 000B           R11      EQU     11
        0000 000C           R12      EQU     12
        0000 000D           R13      EQU     13
        0000 000E           R14      EQU     14
        0000 000F           R15      EQU     15
        0000 000E           RETURN   EQU     14
```

```
                            *THIS ROUTINE PLOTS AN X&Y PAIR AT A CERTAIN INTENSITY
                            *CALL IS OF THE FORM CALL 1003,X,Y,I
                            *WHERE
                            * X & Y ARE THE X AND Y VALUES. IN THE RANGE -2047 TO 2047
                            *  VALUES OUTSIDE THIS RANGE GIVE BIZARRE RESULTS
                            * I IS THE INTENSITY
                            *  1=DIM
                            *  2=OFF (VERY BORING)
                            *  3=BRIGHT
                            *THE ROUTINE HAS ENTRIES FOR R*4 ARGUMENTS (AS FROM A NORMAL
                            * BASIC CALL) AND I*2 ARGUMENTS
                            *THE ROUTINE DUMPS POINTS TO THE DISPLAY  WHENEVER ITS BUFFER
                            * ITS BUFFER IS FILLED. THE BUFFER CAN BE DUMPED BY THE USER
                            * WITH A CALL 1005
                            *IN THE CASE THAT THE NEW X VALUE IS THE SAME AS THE OLD. THE
                            * ROUTINE ONLY SOCKS AWAY A Y COORDINATE
       0000 0008            X        EQU   8
       0000 0009            Y        EQU   9
       0000 000A            I        EQU   10
       0000 1000            BSIZE    EQU   4096
                            *R*4 DATA ENTRY
0000R  D000 00A2R           PLOTR    STM   0,RI003             STORE REGISTERS
0004R  D18F 0000                     LM    8,0(15)             LOAD PARAMETER ADDRESSES
0008R  6808 0000                     LE    0,0(X)              CONVERT X
000CR  41F0 21C8R                    BAL   15,MFIX
0010R  0880                          LHR   X,0
0012R  6809 0000                     LE    0,0(Y)              CONVERT Y
0016R  41F0 21C8R                    BAL   15,MFIX
001AR  0890                          LHR   Y,0
001CR  680A 0000                     LE    0,0(I)              CONVERT INTENSITY
0020R  41F0 21C8R                    BAL   15,MFIX
0024R  08A0                          LHR   I,0
0026R  4300 003ER                    B     PLOT
                            *I*2 DATA ENTRY
002AR  D000 00A2R           PLOTI    STM   0,RI003             STORE REGISTERS
002ER  D18F 0000                     LM    8,0(15)             LOAD PARAMETER ADDRESSES
0032R  4888 0000                     LH    X,0(X)              LOAD VALUES
0036R  4899 0000                     LH    Y,0(Y)
003AR  48AA 0000                     LH    I,0(I)
                            *ALTER DATA INTO 12 BIT TWO'S COMPLEMENT
003ER  0888                 PLOT     LHR   X,X
0040R  4220 0048R                    BP    CHECKY
0044R  CA80 1000                     AHI   X,4096              IF NEGATIVE, ADD 4096
0048R  0899                 CHECKY   LHR   Y,Y
004AR  4220 0052R                    BP    INTEN
004ER  CA90 1000                     AHI   Y,4096
0052R  C480 0FFF            INTEN    NHI   X,X'0FFF'           MAKE SURE
0056R  C490 0FFF                     NHI   Y,X'0FFF'
                            *PUT IN INTENSITY
005AR  91AC                          SLLS  I,12
```

```
005CR  069A             72          OHR   Y,I              INTENSITY INTO FIRST NIBBLE
005ER  C690 4000        73          OHI   Y,X'4000'        MARK AS A Y POINT
                        74  *PLACE IN X POINT,IF NOT A REPEAT
0062R  4980 00C2R       75          CH    X,LASTX
0066R  4330 007ER       76          BE    PLACEY
006AR  4080 00C2R       77          STH   X,LASTX
006ER  4850 00C4R       78          LH    5,MANY
0072R  2651             79          AIS   5,1              INCREMENT COUNT
0074R  4050 00C4R       80          STH   5,MANY
0078R  9151             81          SLLS  5,1              DOUBLE
007AR  4085 00C6R       82          STH   X,BUFFER-2(5)
                        83  *PLACE IN Y POINT
007ER  4850 00C4R       84  PLACEY  LH    5,MANY
0082R  2651             85          AIS   5,1              INCREMENT COUNT
0084R  4050 00C4R       86          STH   5,MANY
0088R  9151             87          SLLS  5,1
008AR  4095 00C6R       88          STH   Y,BUFFER-2(5)
                        89  *TIME TO DUMP?
008ER  C850 0FFF        90          LHI   5,BSIZE-1
0092R  4950 00C4R       91          CH    5,MANY
0096R  2123             92          BPS   RPLOT
0098R  41E0 20C8R       93          BAL   14,DUMP
                        94  *RETURN
009CR  D100 00A2R       95  RPLOT   LM    0,R1003
00A0R  030E             96          BR    RETURN
00A2R                   97  R1003   DSH   16
00C2R  FFFF             98  LASTX   DC    X'FFFF'
00C4R  0000             99  MANY    DC    X'0000'
00C6R  0000            100  BLOCK   DC    X'0000'
00C8R                  101  BUFFER  DSH   BSIZE
```

```
                          *THIS ROUTINE DUMPS THE PLOT BUFFER TO THE DISPLAY
                          *CALL IS OF THE FORM CALL 1005
                          *CURRENTLY;
                          * NBS BUS SHOULD BE LOGICAL UNIT 8
                          * D TO A SHOULD BE SUBADDRESSES 4&5
                          * MEMORY SHOULD BE SUBADDRESS 6&7
       0000 0004          DTA      EQU    4
       0000 0008          BUSLU    EQU    8
       0000 0006          MEM      EQU    6
                          *DUMP RESETS THE BUFFER
20C8R  D000 21A8R         DUMP     STM    0,R1005          STORE REGISTERS
20CCR  48F0 00C4R                  LH     R15,MANY         GET COUNT
20D0R  033E                        BZR    14               IF NOTHING TO DO, DO NOTHING
20D2R  24E0                        LIS    R14,0            ZERO OUT COUNT
20D4R  40E0 00C4R                  STH    R14,MANY
20D8R  4300 20E6R                  B      LUMP
                          *LOOK DOES NOT RESET THE BUFFER
20DCR  D000 21A8R         LOOK     STM    0,R1005          STORE REGISTERS
20E0R  48F0 00C4R                  LH     R15,MANY         GET COUNT
20E4R  033E                        BZR    RETURN
                          *REPLICATE DATA, AS MANY TIMES AS POSSIBLE
20E6R  0AFF               LUMP     AHR    R15,R15          DOUBLE COUNT
20E8R  C8E0 2000                   LHI    R14,2*BSIZE      LOAD TWICE BUFFERSIZE
20ECR  24C0                        LIS    R12,0            SET UP FOR DIVIDE
20EER  08DE                        LHR    R13,R14
20F0R  0DCF                        DHR    R12,R15
20F2R  0CCF                        MHR    R12,R15
20F4R  C8C0 00C8R                  LHI    R12,BUFFER       STARTING POINT OF BUFFER
20F8R  CAE0 00C8R                  AHI    R14,BUFFER       ENDIND POINT OF BUFFER
20FCR  CAF0 00C8R                  AHI    R15,BUFFER       STARTING POINT OF REPLICATION
2100R  CAD0 00C8R                  AHI    R13,BUFFER       ENDING POINT OF REPLICATION
2104R  09FD               FILL     CHR    R15,R13          AT END OF REPLICATION?
2106R  4300 211AR                  BNL    BLANK
210AR  48BC 0000                   LH     R11,0(R12)       LOAD A POINT
210ER  40BF 0000                   STH    R11,0(R15)       COPY IT
2112R  26C2                        AIS    R12,2            INCREMENT COUNTER
2114R  26F2                        AIS    R15,2
2116R  4300 2104R                  B      FILL
                          *BLANK OUT REST OF BUFFER
211AR  2400               BLANK    LIS    R11,0
211CR  09DE               FILLB    CHR    R13,R14          AT  END OF BUFFER?
211ER  4380 212CR                  BNL    BUSC
2122R  40BD 0000                   STH    R11,0(R13)
2126R  26D2                        AIS    R13,2            INCREMENT COUNT
2128R  4300 211CR                  B      FILLB
                          *NOTE EVERY TIME THE BUS IS RESTARTED
212CR  E110 2176R         BUSC     SVC    1,UP             TURN ON BUS
2130R  E110 217AR                  SVC    1,COM            SELECT COMMAND ADDRESS SUBADDRESS
2134R  E110 217ER                  SVC    1,ACT            SEND COMMAND
2138R  E110 2188R                  SVC    1,MCOM           SELECT MEMORY COMMAND SUBADDRESS
```

```
213CR  E110 218CR                 SVC    1,MACT              SEND COMMAND
                        *THIS BLOCK WRITE SHOULD BE UNDER SVC
                        *YOU'RE RIGHT, THERE IS A BLOCK WRITE UNDER SVC
                        *BUT AT THIS TIME IT IS DEAD
       0000 008B        NBSBUS    EQU    X'8B'
2140R  C8F0 008B                  LHI    15,NBSBUS
2144R  DEF0 2196R                 OC     15,SCOUNT           SELECT THE SUBADDRESS COUNTER
2148R  DAF0 2197R                 WD     15,ME               SELECT THE MEMORY SUBADDRESS
214CR  DEF0 21A2R                 OC     15,SUB              SELECT SUBADDRESS MODE
2150R  48E0 21A4R                 LH     R14,START
2154R  9DFD             WAIT      SSR    R15,R13
2156R  4280 2154R                 BTC    8,WAIT              IF BUSY, WAIT
215AR  D8FE 0000                  WH     R15,0(R14)          WRITE AN ELEMENT
215ER  26E2                       AIS    R14,2
2160R  49E0 21A6R                 CH     R14,STOP
2164R  4280 2154R                 BL     WAIT
                        *TURN ON AND GO
2168R  E110 2188R                 SVC    1,MCOM              SELECT MEMORY COMMAND SUBADDRESS
216CR  E110 2198R                 SVC    1,MGO
                        *RETURN
2170R  D100 21A8R                 LM     0,R1005
2174R  030E                       BR     RETURN
                        *PARAMETER BLOCKS
2176R  9408             UP        DC     X'9400'+BUSLU       1001 0100
2178R                             DS     2
217AR  C508             COM       DC     DTA+1*256+X'C000'+BUSLU
217CR                             DS     2
217ER  2808             ACT       DC     X'2800'+BUSLU       0010 1000
2180R                             DS     2
2182R  2186R                      DC     A(ON),A(ON+1)
2184R  2187R
2186R  0077             ON        DC     X'0077'             77 ARBITRARY
2188R  C708             MCOM      DC     MEM+1*256+X'C000'+BUSLU
218AR                             DS     2
218CR  2808             MACT      DC     X'2800'+BUSLU       0010 1000
218ER                             DS     2
2190R  2194R                      DC     A(MON),A(MON+1)
2192R  2195R
2194R  0001             MON       DC     X'0001'
2196R  03               SCOUNT    DB     X'03'
2197R  06               ME        DB     MEM
2198R  2808             MGO       DC     X'2800'+BUSLU       0010 1000
219AR                             DS     2
219CR  21A0R                      DC     A(MUNGO),A(MUNGO+1)
219ER  21A1R
21A0R  0002             MUNGO     DC     X'0002'
21A2R  20               SUB       DB     X'20'
21A4R  00C6R            START     DC     A(BLOCK)
21A6R  20C7R            STOP      DC     BSIZE*2+1+BLOCK
21A8R                   R1005     DSH    16
```

```
                        *THIS ROUTINE CONVERTS A R*4 NUMBER TO I*2
                        *CALL: BAL 15,MFIX
                        *INPUT: IN FLOATING POINT REGISTER 0
                        *OUTPUT: IN REGISTER 0
                        *NUMBERS IN THE RANGE -32767 TO 32767 ARE CONVERTED CORRECTLY
21C8R  D000 21F2R       MFIX      STM   0,RF              STORE REGISTERS
21CCR  6A00 2210R                 AE    0,UNCON           ADD UNNORMALIZED ZERO
21D0R  6000 2214R                 STE   0,WORK            STORE AWAY, STILL UNNORMALIZED
21D4R  48E0 2214R                 LH    14,WORK           LOAD FIRST PART
21D8R  2115                       BMS   NEG               IS NUMBER NEGATIVE?
21DAR  4800 2216R                 LH    0,WORK+2          NO,WE'RE OK
21DER  4300 21ECR                 B     RMFIX
21E2R  4800 2216R       NEG       LH    0,WORK+2
21E6R  C700 FFFF                  XHI   0,X'FFFF'         COMPLEMENT IT
21EAR  2601                       AIS   0,1
21ECR  D110 21F4R       RMFIX     LM    1,RF+2            LOAD REGISTERS
21F0R  030F                       BR    15
21F2R                   RF        DSH   16
2214R                   WORK      DSF   1
2218R  4600             UNCON     DC    X'4600',X'0000'
221AR  0000

                        *THIS ROUTINE CONVERTS A I*2 NUMBER TO R*4
                        *CALL: BAL 15,MFLOAT
                        *INPUT: REG 0
                        *OUTPUT: FLOATING POINT REGISTER 0
221CR  D000 21F2R       MFLOAT    STM   0,RF              STORE REGISTERS
2220R  0800                       LHR   0,0
2222R  2117                       BMS   NEG1              IS NUMBER NEGATIVE?
2224R  4000 2246R                 STH   0,PLUS+2          NO, FINE
2228R  6800 2244R                 LE    0,PLUS
222CR  4300 223ER                 B     RMFLOAT
2230R  C700 FFFF        NEG1      XHI   0,X'FFFF'         COMPLEMENT IT
2234R  2601                       AIS   0,1
2236R  4000 224AR                 STH   0,MINUS+2
223AR  6800 2248R                 LE    0,MINUS
223ER  D100 21F2R       RMFLOAT   LM    0,RF
2242R  030F                       BR    15
2244R  4600             PLUS      DC    X'4600',0
2246R  0000
2248R  C600             MINUS     DC    X'C600',0
224AR  0000

224CR  0200             LAST      NOPR  0
```

```
                   *THIS ROUTINE PLOTS A CHARACTER STRING
                   * CALL IS OF THE FORM CALL I001,S$,X,Y,XI,YI,I
                   *WHERE
                   * S$ IS THE STRING TO BE WRITTEN AT
                   * COORDINATES X&Y (X & Y BETWEEN -2047 AND 2047)
                   * XI&YI ARE THE SPACINGS BETWEEN THE POINTS
                   *  THES GOVERN THE SIZE AND SHAPE OF THE CHARACTERS
                   * I IS THE INTENSITY, I=DIM,3=BRIGHT
      0000 0009    HIGH     EQU   9
      0000 0007    WIDE     EQU   7
      0000 0009    SEP      EQU   9
      0000 0004    CHAR     EQU   4
      0000 0002    BIT      EQU   2
      0000 0008    STRING   EQU   8
      0000 0009    X        EQU   9
      0000 000A    Y        EQU   10
      0000 000B    XI       EQU   11
      0000 000C    YI       EQU   12
      0000 000D    I        EQU   13
224ER D000 2338R   WRITE    STM   0,R1001
2252R 6000 2358R            STE   0,F1001
2256R D10F 0000             LM    8,0(15)          LOAD PARAMETER ADDRESSES
225AR 6809 0000             LE    0,0(X)           LOAD PARAMETER X
225ER 41F0 21C8R            BAL   R15,MFIX
2262R 0890                  LHR   X,R0
2264R 680A 0000             LE    0,0(Y)           LOAD PARAMETER Y
2268R 41F0 21C8R            BAL   R15,MFIX
226CR 4000 232AR            STH   R0,YBASE
2270R 680B 0000             LE    0,0(XI)          LOAD PARAMETER XI
2274R 41F0 21C8R            BAL   R15,MFIX
2278R 08B0                  LHR   XI,R0
227AR 680C 0000             LE    0,0(YI)          LOAD PARAMETER YI
227ER 41F0 21C8R            BAL   R15,MFIX
2282R 08C0                  LHR   YI,R0
2284R 680D 0000             LE    0,0(I)           LOAD PARAMETER I
2288R 41F0 21C8R            BAL   R15,MFIX
228CR 4009 2330R            STH   R0,IP
                   *STEP THROUGH THE STRING
2290R 2451                  LIS   R5,1             LOAD START FOR BXLE
2292R 2461                  LIS   6,1              LOAD INCREMENT FOR BXLE
2294R D378 FFFF             LB    R7,-1(STRING)    LOAD LENGTH OF STRING
2298R 0877                  LHR   R7,R7
229AR 4330 22C4R            BZ    RWRITE
229ER D348 0000    LOOP     LB    CHAR,0(STRING)   LOAD CHARACTER
22A2R C830 235CR            LHI   R3,TABLE         LOOK IN TABLE FOR CHARACTER
22A6R D443 0000    SEARCH   CLB   CHAR,0(R3)       FOUND IT?
22AAR 4330 22CER            BE    PLOTIT
22AER CA30 0009             AHI   R3,SEP
22B2R C530 2526R            CLHI  R3,EOTABLE       END OF TABLE
22B6R 4280 22A6R            BL    SEARCH
```

```
220AR  2681                NEXT     AIS   STRING,1          GO ON TO NEXT CHARACTER
22BCR  0A9A                         AHR   X,XI              SPACE TO NEXT CHAR
22BER  0A9A                         AHR   X,XI
22C0R  C150 229ER                   BXLE  5,LOOP
                           *RETURN
22C4R  D100 2330R          RWRITE   LM    0,R1001
22C8R  6800 2350R                   LE    0,F1001
22CCR  030E                         BR    14
                           *PLOT A CHARACTER
22CER  2631                PLOTIT   AIS   R3,1              POINT TODATA TABLE
22D0R  2420                         LIS   BIT,0             BIT POINTER
22D2R  4800 232AR          NXTCOL   LI    Y,YBASE
22D6R  0A9A                         AHR   X,XI              INCREMENT X
22D8R  24D1                         LIS   R13,1             COUNTER FOR Y
22DAR  41F0 230CR          MORE     BAL   R15,RETRIEVE      CHECK THE BIT
22DER  4330 22F2R                   BZ    SKIP              IF OFF, NO PLOT
22E2R  4090 232CR                   STH   X,XP
22E6R  40A0 232ER                   STH   Y,YP
22EAR  C8F0 2332R                   LHI   R15,PARBLK
22EER  41E0 002AR                   BAL   R14,PLOTI
22F2R  2621                SKIP     AIS   BIT,1             NEXT BIT
22F4R  C920 003F                    CHI   BIT,HIGH*WIDE     AT END OF CHAR?
22F8R  4220 22BAR                   BP    NEXT
22FCR  26D1                         AIS   R13,1
22FER  C9D0 0009                    CHI   R13,HIGH          AT TOP OF CHARACTER?
2302R  4220 22D2R                   BP    NXTCOL
2306R  0AAC                         AHR   Y,YI              INCREMENT Y
2308R  4300 22DAR                   B     MORE
                           *THIS ROUTINE RETRIEVES THE NTH BIT IN A TABLE,
                           * WHERE REG 2 IS N, AND REG 3 POINTS TO THE TABLE
                           * CONDITION CODE IS SET
230CR  0812                RETRIEVE LHR   R1,R2             LOAD THE NUMBER
230ER  0842                         LHR   R4,R2
2310R  9013                         SRLS  R1,3              DIVIDE BY 8, GIVING WHICH BYTE
2312R  08E1                         LHR   R14,R1            FIND ADDRESS OF BYTE
2314R  0AE3                         AHR   R14,R3
2316R  D3EE 0000                    LB    R14,0(R14)        LOAD THE BYTE IN QUESTION
231AR  9113                         SLLS  R1,3              MULTIPLY BY 8
231CR  0B41                         SHR   R4,R1             FIND WHICH BIT
231ER  C800 0080                    LHI   R0,X'0080'
2322R  EED4 0000                    SRA   R0,0(R4)          GET A ONE IN RIGHT PLACE
2326R  040E                         NHR   R0,R14            AND IT
2328R  030F                         BR    R15               RETURN TO CALLER
232AR                      YBASE    DSH   1
232CR                      XP       DSH   1
232ER                      YP       DSH   1
2330R                      IP       DSH   1
2332R  232CR               PARBLK   DC    A(XP),A(YP),A(IP)
2334R  232ER
2336R  2330R
```

```
2338R                     339  R1001    DSW    16
2358R                     340  F1001    DSF    1
235CR  41FE0084           341  TABLE    DB     C'A',X'FE',X'00',X'84',X'22',X'11',X'08',X'08',X'F8'
       22110808
       F8
2365R  42FFC462           342           DB     C'B',X'FF',X'C4',X'62',X'31',X'18',X'8C',X'45',X'DC'
       31188C45
       DC
236ER  437F4060           343           DB     C'C',X'7F',X'40',X'60',X'30',X'18',X'0C',X'05',X'04'
       30180C05
       04
2377R  4480FFE0           344           DB     C'D',X'80',X'FF',X'E0',X'30',X'18',X'0A',X'08',X'F8'
       30180A08
       F8
2380R  45FFC462           345           DB     C'E',X'FF',X'C4',X'62',X'31',X'18',X'8C',X'46',X'02'
       31188C46
       02
2389R  46FF8442           346           DB     C'F',X'FF',X'84',X'42',X'21',X'10',X'08',X'44',X'02'
       21100844
       02
2392R  477F4060           347           DB     C'G',X'7F',X'40',X'60',X'30',X'19',X'0C',X'87',X'C4'
       30190C87
       C4
239BR  48FF8402           348           DB     C'H',X'FF',X'84',X'02',X'01',X'00',X'07',X'FC',X'00'
       010007FC
       00
23A4R  49000020           349           DB     C'I',X'00',X'00',X'20',X'3F',X'F8',X'08',X'00',X'00'
       3FF80800
       00
23ADR  4A404020           350           DB     C'J',X'40',X'40',X'20',X'10',X'17',X'F8',X'04',X'00'
       1017F804
       00
23B6R  4BFF8405           351           DB     C'K',X'FF',X'84',X'05',X'04',X'44',X'14',X'04',X'00'
       04441404
       00
23BFR  4CFFC020           352           DB     C'L',X'FF',X'C0',X'20',X'10',X'08',X'04',X'00',X'00'
       10080400
       00
23C8R  4DFF8000           353           DB     C'M',X'FF',X'80',X'00',X'00',X'80',X'20',X'08',X'FE'
       00802008
       FE
23D1R  4EFF8101           354           DB     C'N',X'FF',X'81',X'01',X'01',X'01',X'01',X'03',X'FE'
       01010103
       FE
23DAR  4F7F4060           355           DB     C'O',X'7F',X'40',X'60',X'30',X'18',X'08',X'F8',X'00'
       301808F8
       00
23E3R  5000FFC2           356           DB     C'P',X'00',X'FF',X'C2',X'21',X'10',X'88',X'44',X'1C'
       21108844
       1C
```

```
23ECR  517F4060     357      DB   C'Q',X'7F',X'40',X'60',X'34',X'14',X'0D',X'F8',X'00'
       34140DF8
       00
23F5R  52FF8446     358      DB   C'R',X'FF',X'84',X'46',X'25',X'14',X'8C',X'38',X'00'
       25148C38
       00
23FER  53474462     359      DB   C'S',X'47',X'44',X'62',X'31',X'18',X'08',X'88',X'00'
       31180888
       00
2407R  54008040     360      DB   C'T',X'00',X'80',X'40',X'3F',X'F0',X'08',X'04',X'02'
       3FF00804
       02
2410R  557FC020     361      DB   C'U',X'7F',X'C0',X'20',X'10',X'08',X'03',X'FC',X'00'
       100803FC
       00
2419R  5603060C     362      DB   C'V',X'03',X'06',X'0C',X'18',X'03',X'00',X'60',X'0E'
       18030060
       0E
2422R  577FC020     363      DB   C'W',X'7F',X'C0',X'20',X'0E',X'08',X'04',X'01',X'FE'
       0E080401
       FE
242BR  58C19105     364      DB   C'X',X'C1',X'91',X'05',X'01',X'01',X'41',X'13',X'06'
       01014113
       06
2434R  59018101     365      DB   C'Y',X'01',X'81',X'01',X'1F',X'00',X'40',X'10',X'06'
       1F004010
       06
243DR  5AC0D064     366      DB   C'Z',X'C0',X'D0',X'64',X'31',X'18',X'4C',X'16',X'06'
       31184C16
       06
2446R  307F4862     367      DB   C'0',X'7F',X'48',X'62',X'30',X'98',X'28',X'F8',X'00'
       309828F8
       00
244FR  31000020     368      DB   C'1',X'00',X'00',X'20',X'5F',X'F8',X'00',X'00',X'00'
       5FF80000
       00
2458R  32C15064     369      DB   C'2',X'C1',X'50',X'64',X'31',X'18',X'8C',X'38',X'00'
       31188C38
       00
2461R  33414062     370      DB   C'3',X'41',X'40',X'62',X'31',X'18',X'88',X'88',X'00'
       31188888
       00
246AR  34301409     371      DB   C'4',X'30',X'14',X'09',X'04',X'42',X'17',X'FC',X'00'
       044217FC
       00
2473R  3547C261     372      DB   C'5',X'47',X'C2',X'61',X'30',X'98',X'48',X'C4',X'00'
       309848C4
       00
247CR  367F4462     373      DB   C'6',X'7F',X'44',X'62',X'31',X'18',X'88',X'88',X'00'
       31188888
```

```
        00
2485R   37E00842        374      DB     C'7',X'E0',X'08',X'42',X'20',X'90',X'20',X'0C',X'00'
        2090200C
        00
248ER   38774462        375      DB     C'8',X'77',X'44',X'62',X'31',X'10',X'08',X'08',X'00'
        31100808
        00
2497R   39074462        376      DB     C'9',X'07',X'44',X'62',X'31',X'14',X'89',X'F8',X'00'
        311489F8
        00
24A0R   2E000000        377      DB     C'.',X'00',X'00',X'00',X'18',X'0C',X'00',X'00',X'00'
        180C0000
        00
24A9R   2C000020        378      DB     C',',X'00',X'00',X'20',X'0C',X'06',X'00',X'00',X'00'
        0C060000
        00
24B2R   2D000402        379      DB     C'-',X'00',X'04',X'02',X'01',X'00',X'80',X'40',X'00'
        01008040
        00
24BBR   3F010074        380      DB     C'?',X'01',X'00',X'74',X'21',X'10',X'48',X'18',X'00'
        21104818
        00
24C4R   20000000        381      DB     C' ',X'00',X'00',X'00',X'00',X'00',X'00',X'00',X'00'
        00000000
        00
24CDR   3D000A05        382      DB     C'=',X'00',X'0A',X'05',X'02',X'81',X'40',X'A0',X'00'
        028140A0
        00
24D6R   23140A1F        383      DB     X'23',X'14',X'0A',X'1F',X'C2',X'87',X'F0',X'A0',X'50'
        C287F0A0
        50
24DFR   2800000F        384      DB     C'(',X'00',X'00',X'0F',X'08',X'28',X'00',X'00',X'00'
        08280000
        00
24E8R   29000020        385      DB     C')',X'00',X'00',X'20',X'28',X'23',X'E0',X'00',X'00'
        2823E000
        00
24F1R   267644A6        386      DB     C'&',X'76',X'44',X'A6',X'54',X'C4',X'05',X'00',X'00'
        54C40500
        00
24FAR   2F401004        387      DB     C'/',X'40',X'10',X'04',X'01',X'00',X'40',X'10',X'04'
        01004010
        04
2503R   3A000000        388      DB     C':',X'00',X'00',X'00',X'06',X'C3',X'60',X'00',X'00'
        06C36000
        00
250CR   2B000402        389      DB     C'+',X'00',X'04',X'02',X'07',X'C0',X'80',X'40',X'00'
        07C08040
        00
2515R   2A001105        390      DB     C'*',X'00',X'11',X'05',X'01',X'01',X'41',X'10',X'00'
```

```
        01014110
        00
251ER   27000000        391            DB     X'27',X'00',X'00',X'00',X'00',X'70',X'00',X'00',X'00'
        E0700000
        00
        0000 2526R      392   EOTABLE  EQU    *-1
2520R                   393            END
```

```
NO ERRORS     0 SQUEZ PASSES
CALR03
  ABSTOP      0000
  ACT         217ER       151
  ADC         0002
  BIT         0002        301   311   312
  BLANK       211AR       135
  BLOCK       00C6R       197   198
  BSIZE       1000         90   101   125   198
  BUFFER      00C0R        82    00   130   131   132   133
  BUSC        212CR       144
  BUSLU       0008        176   170   180   184   186   192
  CHAR        0004        284   286
  CHECKY      0040R        63
  COM         217AR       150
  DTA         0004        170
< DUMP        20C8R        93
  EOTABLE     2526R       289
  F1001       2350R       261   297
  FILL        2104R       140
  FILLB       211CR       147
  HIGH        0009        312   315
  I           000D         51    53    60    60    71    72   275
  IMPTOP      2520R
  INTEN       0052R        66
  IP          2330R       277   330
  LADC        0001
  LAST        224CR
  LASTX       00C2R        75    77
< LOOK        20DCR
  LOOP        229ER       294
  LUMP        20E6R       118
  MACT        218CR       153
< MANY        00C4R        78    80    84    86    91   114   117   121
  MCOM        2108R       152   170
  ME          2197R       160
  MEM         0006        184   191
< MFIX        21C0R        46    49    52   264   267   270   273   276
< MFLOAT      221CR
  MGO         2198R       171
  MINUS       2248R       233   234
  MON         2194R       188   188
  MORE        22DAR       318
  MUNGO       21A0R       194   194
  NBSBUS      000B        158
  NEG         21E2R       210
  NEG1        2230R       227
  NEXT        228AR       313
```

NXTCOL	22D2R	316												
ON	2106R	102	102											
PARBLK	2332R	309												
PLACEY	007ER	76												
PLOT	003ER	54												
PLOTI	002AR	310												
PLOTIT	22CER	207												
PLOTR	0000R													
PLUS	2244R	228	229											
PURETOP	0000R													
R0	0000	265	268	271	274	277	330	331	332					
R1	0001	322	324	325	328	329								
R10	000A													
R1001	2338R	260	296											
R1003	00A2R	43	56	95										
R1005	21A8R	113	120	173										
R11	000B	136	137	142	145									
R12	000C	126	128	129	130	136	138							
R13	000D	127	133	134	143	145	146	163	304	314	315			
R14	000E	116	117	125	127	131	143	162	165	166	167	310	325	326
		327	327	332										
R15	000F	114	121	124	124	128	129	132	134	137	139	163	165	264
		267	270	273	276	305	309	333						
R2	0002	322	323											
R3	0003	285	286	288	289	300	326							
R4	0004	323	329	331										
R5	0005	279												
R6	0006													
R7	0007	281	282	282										
R8	0008													
R9	0009													
RETRIEVE	230CR	305												
RETURN	000E	96	122	174										
RF	21F2R	206	216	225	235									
RMFIX	21ECR	212												
RMFLOAT	223ER	230												
RPLOT	009CR	92												
RWRITE	22C4R	283												
SCOUNT	2196R	159												
SEARCH	22A6R	290												
SEP	0009	288												
SKIP	22F2R	306												
START	21A4R	162												
STOP	21A6R	167												
STRING	0008	281	284	291										
SUB	21A2R	161												
TABLE	235CR	285												
UNCON	2218R	207												
UP	2176R	149												
WAIT	2154R	164	168											

```
  WIDE      0007      312
  WORK      2214R     208   209   211   213
< WRITE     224ER
  X         0009       45    47    58    58    62    62    64    68    75    77    82   263   265
                      292   293   303   307
  X1        0008      269   271   292   293   303
  XP        232CR     307   330
  Y         000A       48    50    59    59    65    65    67    69    72    73    88   266   302
                      308   317
  Y1        000C      272   274   317
  YBASE     232AR     268   302
  YP        232ER     308   330
```

Character strings in BASIC look like:

03 42 41 44 - - - - - - -.

The first byte (03) is the length of the string. The address passed in a call statement is the second byte which begins the string.

The characters are stored in a table. The first byte for each telling the character and the next 63 bits showing which parts of the 9 x 7 matrix are to be lit. The routine searches through the first bytes for all entries to find a match for the character at hand and then sends the coordinates of the points to be plotted to the plotting routine PLOTI. If a character is not found in the character table, no error is generated and that character is simply skipped.

The example below will illustrate how the values in the table were derived. Consider the letter A in a 7 x 9 matrix

```
bbxxxbb
bxbbbxb
xbbbbbx
xbbbbbx
xbbbbbx
xxxxxxx
xbbbbbx
xbbbbbx
xbbbbbx   .
```

The bits are arranged in order column by column starting at the bottom

xxxxxxx0 0000x000 x0000x00 00x000x0 000x000x 0000x000 x000x0xx xxxxx000

or in hexadecimal

FE 08 84 22 11 08 8B F8.

III. Appendix References

[A] R. Bartnikas, "Corona Pulse Probability Density Function Measurements on Primary Distribution Power Cables," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-94, May/June 1975.

* Certain commercial instruments are identified in order to adequately specify the results. In no case does such identification imply recommendation by the National Bureau of Standards, nor does it imply the instruments are the best available.

IV. References

[1] W.E. Anderson and R.S. Davis, "Measurements on Insulating Materials at Cryogenic Temperatures Annual Report, Part I," CONS/2062-1 (1976).

[2] P.S. Vincett, "Calorimetric Measurement of Very Low Dielectric Loss at Low Temperatures," Brit. J. Appl. Phys. (J. Phys. D), Ser. 2, Vol. 2, p. 699 (1969).

[3] C.N. King and R.A. Thomas, "The Calorimetric Measurement of Low Temperature Dielectric Loss," 1975 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, National Academy of Sciences, Washington, D.C. p. 61 (1978).

[4] E.B. Forsyth, R.B. Britton, J. Dean, J.E. Jensen and K.F. Minati, "A Supercritical Helium Facility for Measuring High-Voltage Breakdown," Advances in Cryogenic Engineering, 19, Plenum Press, (1974).

[5] Allen V. Astin, "The Nature of Energy Losses in Air Capacitors at Low Frequencies," Jour. of Res. NBS 22, p. 673 (1939).

[6] E. So, "Losses in Electrode Surface Films in Gas Dielectric Capacitors," Masters' Thesis, George Washington University, unpublished (1973).

[7] R.L. Nelson, "Bridge Measurement of Very Low Dielectric Loss at Low Temperatures," Proc. IEEE, 127, p. 764 (1974).

[8] N. L. Kusters and O. Petersons, "A Transformer-Ratio-Arm Bridge for High-Voltage Capacitance Measurements," IEEE CE-82, p. 606 (1963).

[9] O. Petersons and W.E. Anderson, "A Wide-Range High-Voltage Capacitance Bridge with One PPM Accuracy," IEEE IM-24, p. 336 p. 4-7 (1975).

[10] C.N. King and R.A. Thomas, private communication.

[11] C.G. Garton, "Dielectric Loss in Thin Films of Insulating Liquids," Proc. IEE 88II, p. 103 (1941).

[12] R.A. Thomas and C.N. King, Dielectric Loss of Polymers and Composite Materials at Liquid Helium Temperature," J. of Appl. Phys.

[13] "Measurements on Insulating Materials at Cryogenic Temperatures, Annual Report, Part II," F.I. Mopsik et al., CONS/20621 (1976).

[14] For example, see E.B. Forsyth, ed., "Underground Power Transmission by Superconducting Cable," Brookhaven National Laboratory, BNL 50325, pp. 57-59 (1972).

[15] R.J. Meats, "Pressurized-Helium Breakdown at Very Low Temperatures," Proc. IEE 119, p. 760 (1972).

[16] F.H. Kreuger, Discharge Detection in High Voltage Equipment, American Elsevier, New York (1965).

[17] "Resistive Cryogenic Cable Phase III, Final Report," prepared for EPRI and ERDA by General Electric, Schenectady, NY, CONS-2104-1.

[18] Brookhaven National Laboratory Power Transmission Project, Quarterly Report for July 1, 1977 - September 30, 1977, PTP #76, DoE Contract No. EY-76-C-02-0016.

[19] ASTM D-1868-68, 1969 Book of ASTM Standards, part 29, p. 884.

* Certain commercial materials and electronic devices are identified in order to adequately specify the experimental results. In no case does such identification imply recommendation by the National Bureau of Standards, nor does it imply the material is the best available.

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 89-1950	2. Gov't. Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

Measurements on Insulating Materials at Cryogenic Temperatures

5. Publication Date

6. Performing Organization Code

7. AUTHOR(S)

William E. Anderson and Richard S. Davis

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Brookhaven National Laboratory
Upton, New York 11973

13. Type of Report & Period Covered

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This final report describes the results of a four-year effort to study the high voltage dielectric behavior of various materials at cryogenic temperatures. Dissipation factors at 60 Hz were measured for polymer tapes and epoxy samples at 4.2 K, atmospheric pressure. Multi-layer polymer samples in coaxial geometries at temperatures from 7 to 10 K and helium pressures up to 1.5 megapascals were also studies. The measurements were performed at stresses up to 40 MV/m. Since partial discharges were a major source of losses at the higher stresses and their presence was possibly detrimental to the integrity of the insulation, instrumentation was developed and implemented to study these discharges under conditons found in proposed ac superconducting power-transmission lines.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Capacitance; cryogenic; dielectric constant; dielectric properties; dissipation factor; electrical transmission; partial discharges; polymers; precision electric measurements; pulse-height-analysis; superconducting transmission

18. AVAILABILITY ☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PRINTED PAGES
UNCLASSIFIED	163
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	$8.00