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IMPEDANCE MEASUREMENTS AT THE SEMICONDUCTOR-SOLUTION INTERFACE

J. LEDUC AND S.M. AHMED

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IMPEDANCE MEASUREMENTS AT THE SEMICONDUCTOR-SOLUTION INTERFACE

by

J. Leduc* and S.M. Ahmed*

ABSTRACT

The physics and chemistry of the semiconductor-solution interface have been presented in detail with particular reference to impedance measurements and determination of the flat band potential of the semiconductor surface. The basic theory of A.C. circuits applied to impedance measurements at the semiconductor-solution interface has been developed. Techniques for impedance measurements and data analysis have been described for a method using an LCR meter and a computer for experimental control and data acquisition. The necessary software has been developed.

Impedance measurements on n-GaAs electrodes on the (1 1 1) face have revealed an irreversible chemical change in the anodic region absent for n-GaAs on the opposite face ($\bar{1}$ $\bar{1}$ $\bar{1}$).

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MESURE DE L'IMPÉDANCE À L'INTERFACE ENTRE LE SEMI-CONDUCTEUR ET LA SOLUTION

par

J. Leduc* et S.M. Ahmed*

RÉSUMÉ

Ce rapport présente une description détaillée de la physique et de la chimie de l'interface entre le semi-conducteur et la solution, surtout en rapport avec les mesures de l'impédance et l'évaluation du potentiel de bandes plates de la surface semi-conductrice. La théorie de base des circuits C.A. appliquée à la méthode de mesure de l'impédance à l'interface entre le semi-conducteur et la solution a été développée. On y décrit de plus les techniques servant à mesurer l'impédance et à analyser les données à l'aide d'une méthode dans laquelle on emploie un appareil de mesure avec affichage à cristaux liquides et un micro-ordinateur pour la vérification des essais et l'acquisition de données; le logiciel nécessaire pour effectuer ces essais a été mis au point.

Les mesures d'impédance des électrodes de GaAs de types n sur la surface (1 1 1) ont révélé l'existence d'une transformation chimique irréversible seulement pour la région anodique et non pour le GaAs de type n sur la face opposée ($\bar{1}$ $\bar{1}$ $\bar{1}$).

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I INTRODUCTION

Measurement of impedance at the semiconductor-solution interface is one of the important techniques used in studies of the electrochemical physics of semiconductors. Such studies have been undertaken at the Mineral Sciences Laboratories as part of a broad program with the objective of developing semiconductor catalysts for the conversion of solar to electrical energy in storable, chemical forms (e.g., hydrogen and hydrocarbons) through electrocatalytic or photoelectrocatalytic processes (1).

Although impedance measurements have been used for studies of kinetics and reaction mechanisms at metal electrodes (2), the main application of this technique to the semiconductor electrodes is in the evaluation of the space charge capacitance (C_{sc}), flat band potential (U_{fpb}), donor concentration, information on the adsorption-induced surface states and built-in surface states, e.g., by measuring photocapacitance through sub-bandgap illumination. The flat-band potential, at which the band bending is zero, is a fundamental property of semiconductors. A knowledge of U_{fpb} is also essential in constructing the energy level diagram and in the understanding of the photoexcitation and charge transfer processes.

The earlier methods of measuring C_{sc} consisted of bridge techniques in which C_{sc} was compared to known capacitances (3-6) under steady state conditions. Alternatively, D.C. pulse techniques (7,8) were used where the charging curves were measured on an oscilloscope to evaluate $C_{sc} = i(t)/(dU/dt)$. The current (i(t)) is allowed to flow for a known length of time (dt) while the voltage response (dU) is measured. These techniques are time consuming.

The more recently developed methods (9-12) are based on superimposing an A.C. field over a D.C. bias and measuring the impedance with a phase lock amplifier. Using a potentiostat for the D.C. bias with potential scanning, with a three electrode system, has the advantage of achieving precise control of the electrical D.C. potential regardless of the interfacial reactions. The present method is based on the same principles, but the instrumentation is much more simplified, using a multifrequency LCR meter with a built-in source of D.C. bias under non-potentiostatic, floating conditions (two electrode system). The third electrode, a saturated calomel electrode (SCE), was used only as a reference electrode for measuring the working electrode potential. Experimental control, data acquisition and processing were achieved with the use of a microcomputer linked to the LCR meter and the digital voltmeter with IEEE-488 data bases.

Basic information on the structure of the semiconductor-liquid interface and the space charge region will be presented first in this report. This is followed by presentation of the basic theory of the A.C. circuits and the measurement techniques. A description of the algorithms used in the data acquisition and control software developed is given. The experimental results of impedance measurements on GaAs and determination of the flat band potential are presented subsequently. The listings of the software used are available on request. Only the data acquisition and control software are listed in the Appendices.

II THE SEMICONDUCTOR-SOLUTION INTERFACE

(a) General Structure

The semiconductor-solution (Sc-Sol) interface normally consists of an electrical 'double layer' on the electrolyte (solution) side and a 'space charge' layer on the semiconductor side of the interface, as shown schematically in Fig. 1. These layers are capacitative in nature and are characterized by a non-uniform distribution of charge and potential in the interface region with respect to that in the neutral bulk. The subject of interfacial potentials in general, and the conventions used, have been discussed elsewhere (13-18) in a number of reviews.

In Fig. 1, the Sc-Sol interface is shown as part of an electrochemical cell, under short

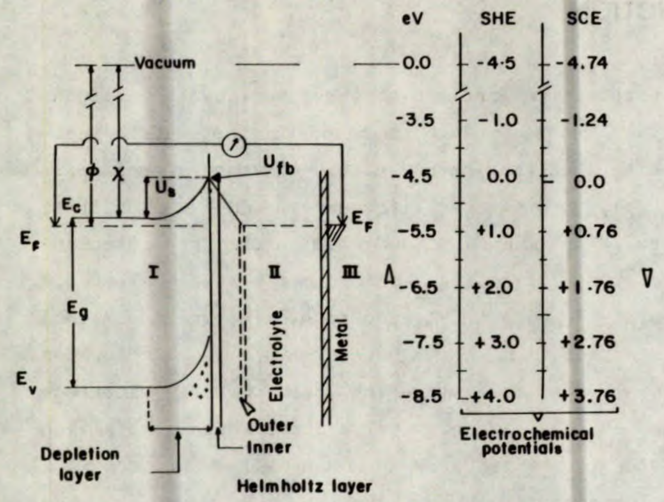


Fig. 1. Electrochemical cell energies

circuited and equilibrium conditions so that the Fermi level (E_F) or the electrochemical potentials of electrons ($\bar{\mu}$) in different phases get adjusted to the same value through electron flow from a higher to a lower level. Here, $E_F = \bar{\mu}/F$, where F is Faraday's constant. The position of E_F on a potential scale can be measured against a reference electrode such as the standard hydrogen electrode (SHE) or a saturated calomel electrode (SCE). Three such reference scales, one for the solid state energy levels (eV) and the other two (SHE and SCE) for the electrochemical potentials, are shown with reference to the vacuum level as zero in Fig. 1. Thus the vacuum level (0.0 eV) coincides with -4.5 V (SHE, pH=0) or -4.74 V (SCE). The electrochemical potentials change by -0.059 V/pH unit increase. Also, the scale for the electron energy levels, in which the semiconductor work function (ϕ) is expressed, is opposite in sense to the two electrochemical scales, as shown in Fig. 1.

The type of space charge shown in Fig. 1 on a n-Sc is a depletion layer where the bands are shown to bend upwards from the bulk to the surface. This band bending or barrier height is denoted as U_s in Fig. 1. It will be shown later mathematically that such a band bending results when the concentration (n_s) of the majority carriers (electrons for n-Sc) in the space charge region is less than that in the bulk region (n_b), so that there is an excess of ionized donors (+ ve, in the n-Sc) left in the depletion region. A depletion layer in a p-Sc is formed similarly, with the majority carriers being holes.

An accumulation layer is formed similarly when the $n_s > n_b$, with the bands bending downwards from the bulk to the surface (not shown in Fig. 1).

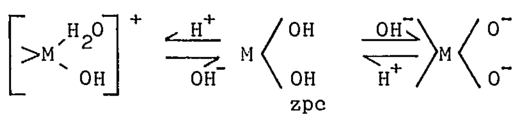
A semiconductor may have a built-in space charge layer with natural band bending, so that the net space charge is neutralized by a counter charge on the surface (surface states, see later). In any case, unless the Sc has a pinned E_F (by surface states), the bands can be bent upwards or downwards at the surface, producing a depletion layer or an accumulation layer, by applying a positive or negative voltage to the Sc with respect to the flat band condition, respectively. An electrochemical bias can also be applied for this purpose using a redox couple as a source or sink of electrons. The potential at which the bands remain flat, is known as the flat band potential (U_{fbp}). At the U_{fbp}, the Sc surface remains electrically neutral, and there is no excess of space charge. Hence, if U_s refers to the degree of band bending (Fig. 1) then the field strength dU/dx is zero at the U_{fbp} and the differential capacity of the space charge layer is a minimum for an intrinsic semiconductor.

A deep depletion region, created by applying an anodic bias, is most interesting in the present work for the determination of the U_{fbp} by impedance measurements of the Sc-Sol interface. Under conditions of a large reverse bias (anodic) the space charge region is almost entirely depleted of the majority carriers, leaving the ionized donor (for n-type) and acceptor (for p-type) impurity atoms in the depletion layers. This subject is discussed in greater detail in the following section.

Figure 1 closely represents the energy level diagram of a n-TiO_2 semiconductor with a band gap energy, Eg = 3eV with the U_{fbp} being located just below the hydrogen evolution potential (~ -0.15 V, SHE) at pH = 0.

(b) The Helmholtz Layer and Distribution of Charge and Potential

The surface charge (±) on the semiconductor on the solution side of the Sc-Sol interface originates from a pH-dependent acid-base dissociation of the surface groups or adsorption-desorption of the potential determining ions (e.g., H^+, OH^- for oxides and the lattice ions such as $S^=$ and metal ions for metal sulphides). This equilibrium at the oxide-solution interface for example, is given as:



(1)

etc.

This excess surface charge (±) is surrounded by a layer of oriented water molecules which constitute the compact Helmholtz layer (or Hm-layer). The excess counter charge (∓) is distributed in a diffuse part of the double layer known as the Gouy layer, and is commonly separated from the surface charge by the Hm-layer, with the exception of the case when certain ions are specifically adsorbed on the surface by displacing the water molecules. The counter charge in the diffuse double layer is provided by the indifferent electrolyte ions, so that this ionic double layer consisting of the excess surface charge (±) and the counter charge (∓), as a whole is electrically neutral.

The pH of the zero surface charge is known as the zero point of charge (zpc), and is the counterpart of the fbp, so that at the zpc the effective surface charge and hence the field strength outside the Hm-layer are both zero. If U_H refers to the potential drop in the Helmholtz layer, then U_H varies with pH at equilibrium conditions (pH_{eq}) by -0.059 V/pH unit increase, for most oxides and some non-oxide (e.g., GaAs, GaP) semiconductors and by ± 0.0295 V/pH unit for some sulphides. Hence,

$$\Delta U_H = -0.059(pH_{eq} - pH_{zpc}) \quad (2)$$

This subject has been discussed in detail elsewhere by one of the authors (15,19,20). The U_{fbp} and U_H are therefore related, with reference to SHE as:

$$U_{fbp}\ (SHE) = \chi + \Delta E_F + U_H - 4.5 \quad (3)$$

or

$$U_{fbp}\ (SHE) = \phi_{sc} + U_H - 4.5, \quad (4)$$

where χ is the electron affinity and ϕ_{sc} is the work function of the semiconductor, ΔE_F being the difference between χ and ϕ_{sc}. The last term in Eq. 3 and 4 will be 4.74 with reference to SCE (see Fig. 1).

The Helmholtz layer is about 0.3 nm in thickness with a dielectric constant, $\varepsilon \sim 7$. It consists of oriented water dipoles and is capacitative in nature. However, the Gouy or the diffuse double layer is similar to the space charge layer in the semiconductor. The Debye length (see later), which is the diffuse double layer thickness, depends on the electrolyte concentration and varies from 1000 to 1 nm for a univalent electrolyte concentration of 10^{-6} to 10^{-1} ML^{-1}, respectively. This is comparable to the space change depth in a semiconductor ($\varepsilon = 16$) with a carrier concentration varying from 10^{14} to 10^{18} cm^{-3}. Consequently, the diffuse double layer in a unimolar electrolyte solution is negligible in impedance measurements, hence it has not been included in Fig. 1 and in the corresponding equivalent circuits. For metallic electrodes, the large value of the carrier density (10^{22} cm^{-3}) gives a space change depth of only 0.05 nm, which is also insignificant.

(c) Surface States

Surface states are localized energy levels that appear on the semiconductor surface in the forbidden energy zone as a result of (a) the termination of the lattice periodicity, (b) lattice imperfections, chemical inhomogeneity and geometrical irregularities, (c) adsorbed impurities, (d) electrical polarization and (e) contact with another phase with a different work function. Further details on surface states and their occupational statistics are available in a number of papers and reviews (15,21-32), particularly with regard to the Sc-solution interface (15,26-31).

If the Fermi level in the Sc phase passes through the surface states energy levels, E_t, ($E_t \sim E_F$), the maximum change can occur in the occupation of these states. The state can then act as donor or acceptor level. When $E_t - E_F \ll kT$, electrons can be excited from the donor-like surface levels to the conduction band. Similarly, electrons can be excited from the valence band to the acceptor-like states. If the equilibrium is maintained between the surface states and the space charge layer, then the latter layer has a charge equal and opposite to that in the former, for a built-in space charge. A surface may have a series of independent surface levels. The total density of electrons captured or donated by all the surface states is given by the sum of their individual occupancies (25).

By changing the E_F and band bending, e.g. by applying an external voltage, the surface state occupancy can be changed.

The charge in the surface states is described (24,32) as that part of the space charge which, while not forming part of the extended space charge, is yet in good electrical contact, and in electronic and thermal equilibrium with the conduction or valence band. On the other hand, the chemically ionizable surface groups that constitute the surface charge in the Helmholtz layer, are in ionic and electrochemical equilibrium with the electrolyte solution, as described earlier. Thus, in the absence of an applied electric field, the conditions of electrical neutrality are maintained, so that

$$q_{sc} + q_{ss} + q_{sH} + q_{sol} = 0 \qquad (5)$$

where the terms, q_{sc}, q_{ss} refer to the excess charge densities in the space charge and surface states respectively, while q_{sH} and q_{sol} are the excess surface charge density in the Hm-layer and that of the counter charge in the diffuse Gouy layer region.

The surface states also participate in the recombination process and serve as trapping centres (23,24). Depending on their relaxation times, the surface states are also distinguished as fast or slow. The fast surface states have relaxation times of the order of a millisecond or less and their densities are small ($\sim 10^{11}$ cm^{-2}), compared to the slow surface states ($\sim 10^{13}$ cm^{-2}, on clean Ge).

Hence, the space charge can be investigated experimentally by using short duration pulse techniques, or A.C. signals of sufficiently high frequencies, provided the density of fast surface states remains small.

(d) The Space Charge Layer and Capacitance

(i) Semiconductor Surface

The distribution of charge and potential, at the Sc-solution interface, as described previously is shown in Fig. 2a and 2b schematically.

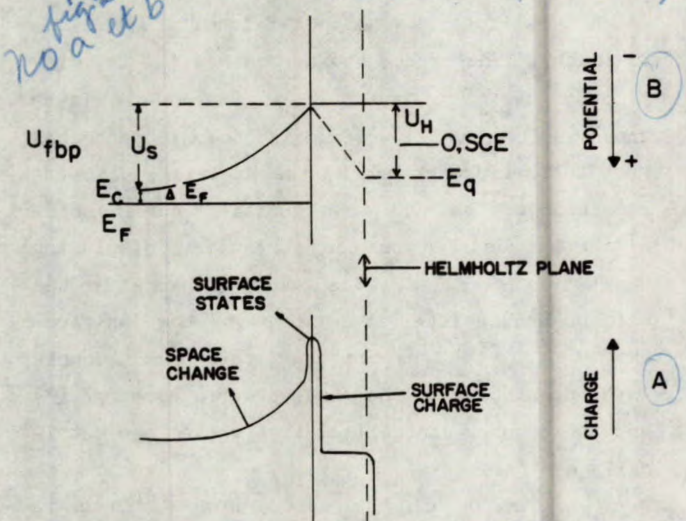


Fig. 2. Interfacial potentials and charges

The dependence of the space charge density $\rho(x)$ at a distance x, in a direction normal to the surface, on the surface potential U, may be obtained from the one dimensional Poisson equation, (37)

$$\nabla^2 U = \partial^2 U/\partial x^2 = -(1/\varepsilon\varepsilon_o)\,\rho(x) \qquad (6)$$

where, ∇^2 is the Laplace operator, and ε and ε_o are the relative dielectric constant at the material and the permittivity of vacuum, respectively. The net charge density $\rho(x)$ (C cm^{-3}) includes both mobile charges, (n_x and p_x) as well as the ionized donors and acceptors (N_D and N_A), so that,

$$\rho(x) = e(N_D - N_A - n_x + p_x) \qquad (7)$$

Since the bulk is electrically neutral, for $n_x = n_o$, and $p_x = p_o$; $\rho = o$.

The carrier concentration itself in the bulk phase of a non-degenerate semiconductor is given by the standard Maxwell-Boltzmann relationship. The electron concentration (n) in the conduction band and the hole concentration (p) in the valence band are given as

$$n_b = N_c \exp[-(E_c - E_F)/kT] \tag{8}$$

and
$$p_b = N_v \exp[-(E_F - E_v)/kT], \tag{9}$$

where, N_c and N_v refer to the available density of states in the conduction and valence bands with energy levels E_c, (bottom edge) and E_v (top edge), respectively. By combining the above equations, it may be shown after certain approximations that the electron (n_s) or hole (p_s) density at the surface, is related to their bulk concentration and band bending U_s, as follows:

$$n_s = n_b \exp(-e\, U_s/kT) \tag{10}$$

and
$$p_s = p_b \exp(e\, U_s/kT) \tag{11}$$

where e is the electronic charge. When $n_s < n_b$, in an n-Sc, the bands bend upwards giving rise to an exhaustion layer or an inversion layer ($p_s > n_s$). If $n_s > n_b$ the energy bands bend downwards, forming an accumulation layer. When $n_s = n_b$ or $p_s = p_b$, $U_s = 0$, which represents the flat band condition.

Information can be obtained on the space charge, surface states and flat band potential by measuring several interfacial properties such as photocurrents and photopotentials, surface conductivity and differential capacitance. Measurement of the space charge capacitance is described in this work.

(ii) Space Charge and Capacitance

The space charge from Gauss' theorem, using a rationalized MKS system, is given as:

$$Q_{sc} = -\varepsilon\varepsilon_o E_s \tag{12}$$

where
$$E_s = -\frac{dU(x)}{dx} \quad x = 0 \tag{13}$$

in the space charge layer, and can be obtained from the first and second integration of the special Poisson's equation (Eq. 6) together with Eq 10 and 11, assuming non-degeneracy of the semiconductor and complete ionization of the donors and acceptors. The boundary conditions are the band bending, $dU/dx = 0$ in the bulk and $U_x \rightarrow U_s$ as $x \rightarrow 0$, x being any point in the space charge layer. Details may be found elsewhere (13-15,32). The final expression is given as:

$$E_s = \pm \left(\frac{2\, kT\, n_i}{\varepsilon\varepsilon_o}\right)^{1/2} F(Y,\lambda) \tag{14}$$

where, $Y = -eU_s/kT$; $U_s = U - U_{fbp}$ (15)

and λ is related to the carrier, donor/acceptor, concentrations (14,15) as:

$$\lambda = \left(\frac{p_b}{n_b}\right)^{1/2} = \frac{p_b}{n_i} = \frac{n_i}{n_b} \tag{16}$$

since $n_b \cdot p_b = n_i^2$, where n_i = carrier concentration (bulk) for an intrinsic semiconductor, and n_b and p_b are electron and hole concentrations in the bulk semiconductor. In Eq. 14,

$$F(Y,\lambda) = [\lambda.(e^{-Y} - 1) + \lambda^{-1}(e^{Y} - 1) + (\lambda - \lambda^{-1})Y]^{1/2} \tag{17}$$

The space charge is then given from Eq. (12) and (13) as

$$Q_{sc} = \mp \frac{\varepsilon\varepsilon_o\, kT}{e\, L} F(Y,\lambda), \tag{18}$$

where L is the Debye length given as:

$$L = \left(\frac{\varepsilon\varepsilon_o\, kT}{2\, e^2\, n_i}\right)^{1/2} \tag{19}$$

The differential space charge capacitance defined as:

$$C_{sc} = (dQ_{sc}/dU_s) \tag{20}$$

obtained after differentiation of Eq. 18, is given as

$$C_{sc} = \left(\frac{\varepsilon\varepsilon_o n_i e^2}{2kT}\right)^{1/2} \frac{\lambda e^{-Y} + \lambda^{-1} e^{Y} - (\lambda - \lambda^{-1})}{[\lambda (e^{-Y} - 1) + \lambda^{-1} (e^{+Y} - 1) + (\lambda - \lambda^{-1})Y]^{1/2}} \qquad (21)$$

For the case of a semiconductor with E_g = 1.84 eV, ε = 12.9 and the doped, donor concentration (n) = 10^{17} cm^{-3} and assuming $n_b = N_D$, the capacitance as a function of Y (-Y = 1 means 0.025 V anodic) is shown in Fig. 3. The variation of C vs Y is discussed below.

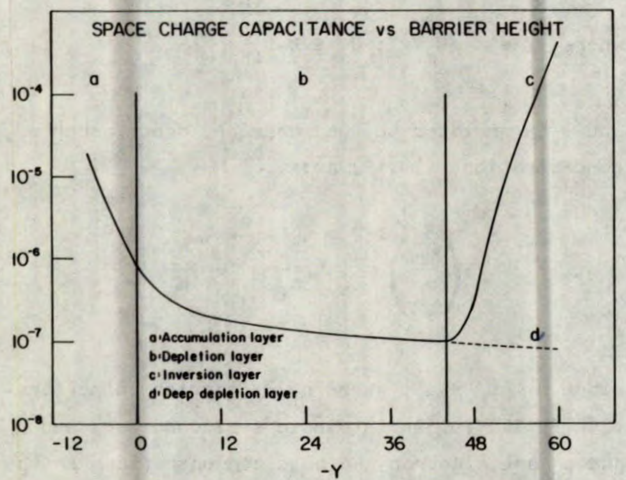


Fig. 3. Space charge capacitance vs barrier height

(iii) The Capacitance of Accumulation, Inversion and Depletion Layers

From the neutrality condition in the bulk $N_A - N_D = p_b - n_b$ and Eq. 16 we have:

$$\lambda - \lambda^{-1} = \frac{N_A - N_D}{n_i} \qquad (22)$$

This means that the term linear in Y in the denominator of the r.h.s. factor of the capacitance in Eq. 21 represents the contribution of the fixed charges (i.e., depletion layer) and the exponential terms, that of the mobile carriers. When the semiconductor is intrinsic this term in Eq. 21 and 22 is zero, hence the intrinsic semiconductor can never have a depletion layer. For the case of Fig. 3 it can be seen that the depletion layer covers a significant range of voltage (1.2 V).

For a semiconductor with a band gap of 0.76 eV such as Ge, the depletion layer will exist in a range of about 0.1 V for a dopant density of 10^{16} cm^{-3}.

When the band bending becomes negative (-Y<0) the major contribution to the capacitance is that of the majority carriers (for n type in Fig. 3 these are the electrons). The capacitance is then given by:

$$C_{sc} = \left(\frac{\varepsilon\varepsilon_o n_b e^2}{2kT}\right)^{1/2} e^{(Y/2)} \qquad (23)$$

The capacitance is thus related to the concentration of majority carriers in the bulk; this is an accumulation layer, shown in Fig. 3, region 'a'.

When the band bending (-Y>0) becomes sufficiently positive, the exponential factors in the capacitance formula associated with the holes dominate and the capacitance is given by:

$$C_{sc} = \left(\frac{\varepsilon\varepsilon_o p_b e^2}{2kT}\right)^{1/2} e^{(-Y/2)} \qquad (24)$$

The capacitance is thus related to the concentration of minority carriers in the bulk. This is the inversion layer (region, in Fig. 3).

For small band gap semiconductors, the range for which the depletion layer exists is small. This means that the minimum in capacitance where the depletion layer is changed into the inversion layer will be close to the value Y=0 (flat band potential). For a band gap of 0.76 eV and dopant concentration of 5 X 10^{15} cm^{-3} this minimum will be about 0.071 V away from the flat band potential, whereas for a band gap of 2 eV with the same dopant concentration the minimum will be 1.4 V away from the flat band potential. This region is the depletion region, shown as b in Fig. 3. For small band gap semiconductors it is possible to measure the flat band potential with capacitance measurements by a location of the minimum of the capacitance. However this method is not applicable for the moderate to high band gap semiconductors which are the type normally used in our work. For pure intrinsic semiconductors Eq. 21 reduces to:

$$\lambda = 1;$$

$$C_{sc} = \left(\frac{\varepsilon\varepsilon_o n_i e^2}{2kT}\right)^{1/2} \cdot 2\cosh\left(\frac{Y}{2}\right) \qquad (25)$$

The behaviour of the capacitance is symmetric on both sides of the flat band potential and the location of the minimum is exactly at the flat band potential.

(iv) The Mott-Schottky Approximation

The Mott-Schottky approximation consists in taking only the contribution of the fixed charges (depletion layer) in the factor in the r.h.s. of Eq. 21 and that of the residual majority carriers (neglect of all the exponentials). If U represents electrode potential measured against a reference electrode then $U_s = U - U_{fbp}$ and, with Eq. 15, Eq. 21 becomes: (for n-type $N_A = 0$ and $N_D = n$.)

$$C_{sc} = \left(\frac{\varepsilon\varepsilon_o N_D e}{2}\right)^{1/2} (U - U_{fbp} - kT/e)^{-1/2} \qquad (26)$$

Equation 27 can also be written as:

$$(1/C_{sc})^2 = (2/(\varepsilon\varepsilon_o N_D e))(U - U_{fbp} - kT/e) \qquad (27)$$

A plot of the inverse square of the capacitance measured as a function of the voltage of the electrode with respect to SCE will give U_{fbp}(SCE) (from the intercept at the abscissa) and the dopant density (from the slope).

The deep depletion region shown in Fig. 3 is a non-equilibrium configuration where the inversion layer fails to form and Eq. 27 still applies. This is discussed in the next section. The restrictions on the validity of the Mott-Schottky approximation for real crystals have been presented elsewhere by Cardon, Gomes and coworkers (33,34) and will be discussed further in the section on GaAs.

III MEASUREMENT TECHNIQUES

(a) Basic A.C. Circuit Theory

Under conditions of linearity, the sinusoidal voltage across an element in an A.C. circuit is associated with a sinusoidal current of the same frequency. The amplitude of the current is proportional to the amplitude of the voltage. There will be a phase difference, in general, between the current and that voltage.

Linear relations between sinusoidal quantities can be expressed in terms of complex numbers. If a complex voltage is denoted as $\hat{V}$, it has both an amplitude (a positive number) denoted V (without the hat) and a phase ψ. The corresponding relationship is:

$$\hat{V} = V(\exp j\psi)(\exp j\omega t) \qquad (28)$$

The real part of $\hat{V}$, i.e. $V\cos(\omega t + \psi)$ represents the actual physical quantity or the effective voltage. Here ω is the angular frequency, t, the time and j, the imaginary. The current $\hat{I}$ under conditions of linearity is related to the voltage as:

$$\hat{V} = \hat{Z}\,\hat{I} \qquad (29)$$

The complex current is understood in the same way as the complex voltage. The complex number $\hat{Z}$ is the impedance. Its amplitude is Z and its phase is θ. It is independent of time and of the parameters of phase and amplitude of current so that,

$$\hat{Z} = Z\exp j\,\theta \qquad (30)$$

In electrochemical cells voltage amplitudes less than 10 mV peak-to-peak (p-p) are enough to ensure linearity. Under those conditions Eq. 20 can be applied to the derived value of the capacitance.

In an electrochemical cell (or any other device) the A.C. part of the current and voltage can be measured. This is discussed below in section (c). Briefly, by means of phase lock amplifiers the in-phase and out-of-phase parts of both current and voltage can be determined. The phase of both current and voltage is defined by a reference signal. If the in-phase part is denoted V_{in} and the out-of-phase part, V_{out} then, by definition:

$$V_{in} = V\cos\psi;\ V_{out} = V\sin\psi \qquad (31)$$

Equation 28 can be written as:

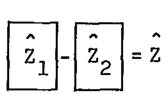
$$\hat{V} = (V\cos\psi + jV\sin\psi)\ \exp j\omega t$$
$$= (V_{in} + jV_{out})\ \exp j\omega t \qquad (32)$$

The current can be expressed in a similar manner. The time dependent exponential for both can be omitted and still Eq. 29 applies. Therefore the impedance can also be expressed in a similar manner. The phase of the impedance represents the phase difference between the current and the voltage by Eq. 29. This is the basic measured quantity. Its inverse denoted $\hat{Y} = 1/\hat{Z}$ is the admittance. Equation 29 can be written as:

$$\hat{Z} = (V_{in} + j\ V_{out})/(I_{in} + j\ I_{out}) \qquad (33)$$

The differential capacitance has been defined in the preceding section. It can be seen from Eq. 33 that the capacitance can never be measured directly but only derived from the impedance (35). The value of the capacitance thus obtained will depend on the assumed composition of the equivalent circuit. This is a hypothetical circuit replacing the resistive/capacitive elements in an electrochemical cell by combinations of resistors and capacitors. Only the simplest of combinations will be considered. The inductance is not included in this presentation, although it is normally involved in intrumental corrections.

If two impedances are connected in series the circuit is drawn as:



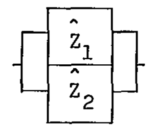
(34)

The two individual impedances are $\hat{Z}_1$ and $\hat{Z}_2$ and the impedance of the combination is $\hat{Z}$. The total voltage drop is equal to the sum of the voltage drops across each impedance while the current is the same throughout. Therefore we have:

$$\hat{Z}\ \hat{I} = \hat{Z}_1\hat{I} + \hat{Z}_2\hat{I} \quad \text{or}$$

$$\hat{Z} = \hat{Z}_1 + \hat{Z}_2 \qquad (35)$$

The parallel combination is drawn as:



$= \quad \hat{Z}$ (36)

Equation 29 can also be written in terms of the admittance $Y = 1/Z$ as:

$$\hat{I} = \hat{Y}\ \hat{V} \qquad (37)$$

The voltage across each component and the parallel combination is the same. The current through the impedance of the combination is the sum of the currents through each impedance. Then with $\hat{Y}=1/\hat{Z}$, $Y_1 = 1/\hat{Z}_1$ and $\hat{Y}_2 = 1/\hat{Z}_2$ we have:

$$\hat{Y}\ \hat{V} = \hat{Y}_1\ \hat{V} + \hat{Y}_2\ \hat{V} \quad \text{or}$$

$$1/\hat{Z} = 1/\hat{Z}_1 + 1/\hat{Z}_2 \qquad (38)$$

The value of the capacitance has been given by Eq. 20. If V replaces U and with the current $I(t)=dQ/dt$ (subscript omitted on Q), Eq. 20 is written as:

$$I(t) = C\ dV/dt \qquad (39)$$

The subscript has been omitted on C since Eq. 20 is quite general and applies to any capacitance. For sinusoidal signals the current and voltages take on their complex form and for that case Eq. 39 is written as:

$$\hat{I} = j\omega C\ \hat{V} \qquad (40)$$

From Eq. 29 the impedance associated with a capacitor is given by:

$$\hat{Z}_C = -j/(\omega C) = -jX \qquad (41)$$

The value $X=1/(\omega C)$ is called the reactance. With a single capacitor as the circuit element the current is 90° in advance with respect to the voltage for all frequencies and its amplitude varies linearly with the frequency. This is depicted in Fig. 4a. On the r.h.s. of Fig. 4a an (x,y) plane is shown with the positive x axis representing current in phase with the voltage and the positive y axis representing currents in advance of phase of 90° with respect to the voltage. The same convention applies to all the (x,y) planes of Fig. 4. The effect of increasing ω, by factors of 2, on currents is shown by open circles (Fig. 4a). The arrow shows the direction of increasing frequencies. This convention also applies for the rest of the figure.

Ohm's law for a resistor also applies in A.C. Therefore the impedance of a pure resistor is a real number independent of frequency and is denoted as R (the resistance). For fixed voltage, the current remains the same for all frequencies and is always in phase with the voltage. This is shown in Fig. 4b.

Figure 4c represents the series combination of resistor (R) and a capacitor (C). From the value of the impedance of a pure resistor (R) and that of a capacitor (Eq. 41) and Eq. 35 we have:

$$\hat{Z}_S = R - j/(\omega C) \qquad (42)$$

The subscript S signifies the series combination. The variation of current as a function of frequency only, with fixed voltage, capacitance and resistance is shown on the r.h.s. of Fig. 4c. The angle θ_S defined by Eq. 30 is the phase of the impedance.

In actual practice, it is the impedance, in terms of its amplitude Z and phase θ which is measured. If the capacitance and resistance are to be derived in terms of the series combination, then from Eq. 30 and 42 we have:

$$R = Z_S \cos\theta_S;\ C = -1/(\omega Z_S \sin\theta_S) \qquad (43)$$

Figure 4d shows the parallel combination with a capacitor (C) and a resistor (R). From Eq. 38 and 41 we have:

$$\hat{Z}_P = \frac{R}{1 + (RC\omega)^2} - \frac{jR(RC\omega)}{1 + (RC\omega)^2} \qquad (44)$$

Since from Eq. 38, the admittance of the combination is the sum of the individual admittances, in this case we also have:

$$\hat{Y}_P = 1/R + j\omega C \qquad (45)$$

The admittance associated with the capacitor is $j\omega C$, from Eq. 37 and 41, and that associated with the resistor is 1/R. The latter is also called conductance. The value ωC is called susceptance. The subscript P indicates the parallel combination. The amplitude of the admittance is $1/Z_P$ and its phase angle, $-\theta_P$. From the measured value of the impedance, Z_P and θ_P, the equivalent parallel combination resistance and capacitance can be calculated as:

$$R = Z_P/\cos\theta_P\ ;\ C = -\sin\theta_P/(Z_P\omega) \qquad (46)$$

A comparison of Fig. 4c and 4d reveals some important differences between the frequency dependence of the current (at fixed voltage, resistance and capacitance) for the two cases. For low frequencies ($RC\omega \ll 1$), the series case behaves almost as a pure capacitor circuit and the parallel case, as a pure resistor circuit. For very large frequencies ($RC\omega \gg 1$), the situation is the opposite. As the frequency increases, the phase of the impedance in the series case goes from near -90° to 0° and vice versa for the parallel case. If the measuring instrument has a dozen or so frequencies going by octaves, it is possible to decide which of those two simple combinations is the better approximation to the two equivalent circuits of the cell. For more complicated equivalent circuits a quasi continuum of frequencies would be needed.

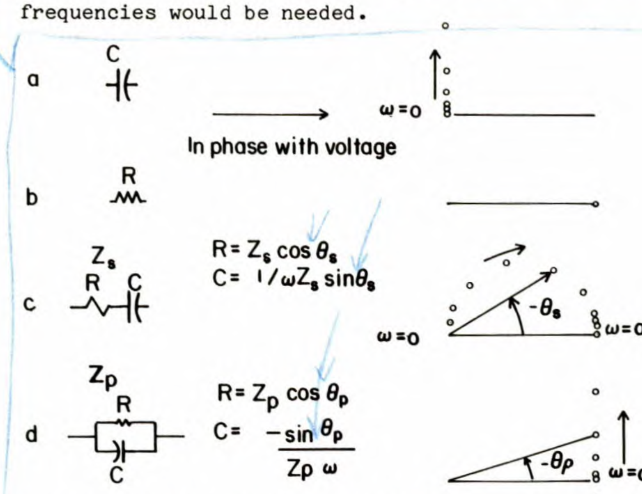


Fig. 4. Argand diagrams of simple A.C. circuits

(b) A Typical Equivalent Circuit for a Semiconductor Electrochemical Cell

The equivalent circuit for a cell in the dark with an inert electrolyte and with a n-type GaAs working electrode is shown in Fig. 5. This represents an experimental condition with a 1 M electrolytic solution and a counter electrode with a surface area (49 cm^2) which is much larger than that of the working electrode (0.5 cm^2 or less). It is assumed that the working electrode can be biased into a deep depletion region. Some issues not covered in the first section about deep depletion will be briefly discussed here.

ELEMENT	DEFINITION	IMPEDANCE, OHMS
Z_{DMM}	Voltmeter impedance	$4x10^6$
R_{ct}	Electrode back contact resistance	0.1 to 10
R_f	Faradaic resistance	$2x10^5$
C_{sc}	Space charge layer	$5x10^3$
C_{ss}	Surface states	10^5 @
C_H	Helmholtz layer	10
C_{sg}	Surface group	?
R_{SLN}	Resistance of bulk liquid	20
C_H	Helmholtz layer (counterelectrode)	0.05
r_f	Faradaic resistance (counterelectrode)	*

@: In the deep depletion region.

*: This is practically infinite without the redox couple and of the order of 10^3 Ohms with it.

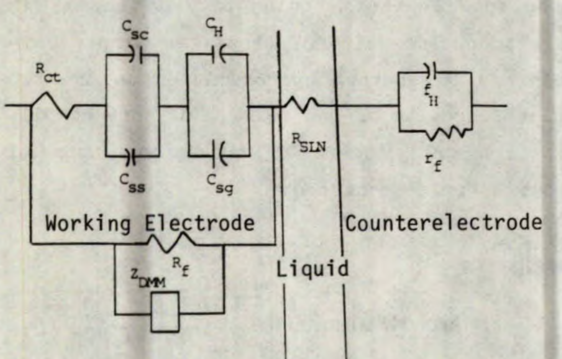


Fig. 5. Equivalent circuit of electrochemical cell with a n-GaAs working electrode in the dark at 1 KHz

With a band gap of 1.5 eV for GaAs at 2 K (36) the number of intrinsic carriers is given by (37):

$$n_i = (N_C N_V)^{1/2} \exp-(E_g/2kT) \quad (47)$$

The factor in front of the exponential represents the number of states per unit volume $\approx 10^{22}/cm^3$. Hence n_i at room temperature is about 6×10^8. From Eq. 8, 9 and 47 we have:

$$n_b p_b = n_i^2 \quad (48)$$

Therefore if the number of electrons due to donor impurities is $\tilde{}\ 10^{17}/cm^3$, then $p_b \tilde{}\ 4/cm^3$. For a band bending of 1 eV and from Eq. 10 and 11 we have $n_s \tilde{}\ 0.4/cm^3$ and $p_s \tilde{}\ 10^{18}/cm^3$. From the discussion of the preceding section, it is quite clear that the Mott-Schottky relation (Eq. 27) is valid only for $n_s, p_s << N_D \approx n_b$. In the case considered here, $N_A = 0$. Therefore under conditions of strict thermal equilibrium, the n-GaAs/electrolytic solution interface should form an inversion layer in the semiconductor. As will be discussed in the chapter on GaAs, it was found from measurements of the impedance that the Mott-Schottky relation still applied in this region. This is due to the fact that the holes go into solution (faradic currents, still low). Deep depletion is a non-equilibrium condition (38).

Since the frequencies available allow only a distinction between a simple series and parallel circuit analysis, an effort has to be made in the design of the cell to simplify its equivalent circuit. The values presented in Fig. 5 are those of a realistic case but should not be considered general. They are fairly typical for a semiconductor with about 10^{17} 10^{18} dopant atoms per cm^3. This is a photoelectrochemical grade semiconductor.

A further approximation to the general equivalent circuit of Fig. 5 is obtained as follows. The measured capacitance (C_m) for this circuit is the sum of the Helmholtz layer capacitance (C_H) in series with the parallel capacitances of the space charge (C_{sc}) and of the surface states (C_{ss}), so that:

$$\frac{1}{C_m} = \frac{1}{C_{sc} + C_{ss}} + \frac{1}{C_H} \quad (49)$$

Since the $C_H >> C_{sc}$ (2 orders of magnitude) and assuming that the number of fast surface states is small, that the slow surface states have relaxation times >> the experimental periods, and that these can be minimized by careful surface preparation, we have:

$$\frac{1}{C_m} \approx \frac{1}{C_{sc}} \tag{50}$$

Hence, the equivalent circuit in Fig. 5, reduces to a parallel RC circuit, with $C_m = C_{sc}$. The parallel resistance is related to the minute faradaic charge transfer. The faradaic resistance should be as high as possible since it is in parallel with the space charge layer capacitance. This involves the avoidance of redox couples in the electrolyte solution, which are normally responsible for the charge transfer. If the bias is too anodic (positive) certain effects could increase the current either by having too many holes being captured or dielectric breakdown (38). From the figure $R_f C_{sc} \omega = 40$ and from Eq. 38 (with $R = R_f$ and $C = C_{sc}$) it can be seen that the faradaic resistance will make only a small contribution to the impedance. The faradaic resistance is also kept low if the cell is kept in the dark.

The resistance of the bulk liquid solution can be estimated by using a platinum electrode in lieu of the semiconducting electrode with the same surface area as the latter. The measurement is performed with an A.C. signal at about 1 kHz and the series analysis is performed.

The resistance of the back contact is measured by a three-point probe, Fig. 6. The D.C. current I is measured as a function of the D.C. voltage V, as shown in Fig. 6. Examination of the equivalent circuit of measurement shows that the effect of the work contact is eliminated. The measured resistance is that of the bulk in series with that of the contact being tested. When the relationship of current as a function of voltage is linear then the contact is said to be ohmic and effects due to the presence of its own space charge layer (if any) can be neglected. The smallest value quoted here refers to a Ge-Au alloy contact on n-GaAs with 10^{17}-10^{18} dopant atoms per cm^3. The resistance refers to a sample of semiconductor 1 mm thick and with an area of about 0.5 cm^2. For dopant densities that are less, the contact can have resistances as high as 10 Ωcm^2. Non-ohmic contacts can have resistances as high as several k Ω.

The surface states' capacitance can be minimized by proper preparation of the surface, for example by degreasing, polishing and etching. From general considerations it can be shown that the surface states' densities are negligible for those states with energy levels in the valence band (39). If the Fermi level is driven below the top of the valence band (very positive bias) then the effect of those states remains small. This is illustrated in the section on certain n-type GaAs electrodes.

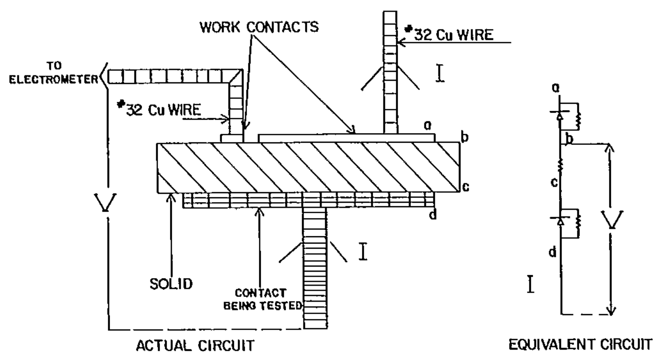


Fig. 6. Three point probe circuit

(c) Theory of the LCR Meter; Five Terminal Technique

The variation of impedance as a function of voltage is measured and the variation of capacitance as a function of applied voltage is derived by a simple circuit analysis. If the Mott-Schottky model applies, then the flat band potential and the number of dopant atoms can be derived (Eq. 27). To make these measurements a small A.C. signal, used for the determination of the impedance, is superimposed on the D.C. voltage applied to the working electrode.

In this work a two-electrode system was used. Control of the working electrode potential and its measurement against a SCE reference electrode is discussed in the section on GaAs. This section will deal only with the A.C. signals.

A measurement circuit to which Eq. 33 can be applied is illustrated in principle in Fig. 7. All measurements of A.C. signals are made with the help of two phase-lock amplifiers with two D.C. outputs. One of those outputs is a D.C. voltage (V_{IN}) proportional to the part of the input A.C. voltage in phase with the reference signal, and the other is a voltage (V_{OUT}) proportional to that part of the input that is in quadrature of phase (advanced by 90°) with respect to the reference signal. Two such A.C. signals are measured, the voltage $\hat{V}$ across the cell, and the current through the cell as given by $\hat{V}_R/R$. In terms of the quantities defined in Fig. 7, Eq. 33 is written as:

$$Z = \frac{(V_{IN}^2 + V_{OUT}^2)^{1/2}}{(V_{RIN}^2 + V_{ROUT}^2)^{1/2}} \; R, \text{ and} \tag{51}$$

$$\tan \theta = \frac{(V_{OUT}V_{RIN} - V_{IN}V_{ROUT})}{(V_{IN}V_{RIN} + V_{OUT}V_{ROUT})} \tag{52}$$

The terminals of Fig. 7 are explicitly described as coaxial cables. The role of the shield (apart from electrostatic shielding) is to reduce to a small value the mutual inductance between the current carrying terminals (denoted HI CUR and LO CUR in Fig. 7) and the voltage terminals (denoted HI POT and LO POT in Fig. 7). This is achieved because the returning of the current goes through the shield. This, in principle, is the five-terminal technique.

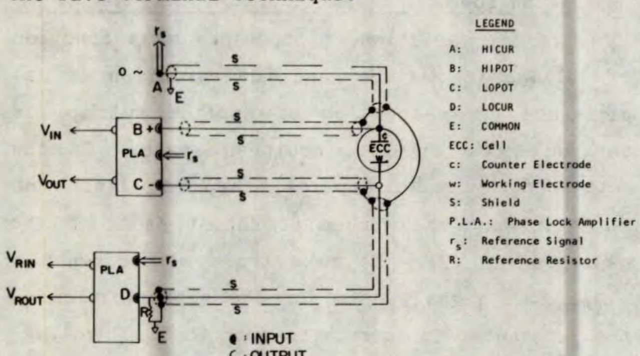


Fig. 7. Five terminal technique

There are two problems with this design in practice. Under certain conditions, the reference resistor R can degrade the small A.C. voltage applied and thus degrade the precision on the impedance. Also, good matching between two independent phase lock amplifiers is difficult to achieve.

The commercially available Hewlett-Packard Multi-Frequency LCR Meter #4274A used in the present investigation eliminates these two problems. A very useful feature of the device is its capacity to correct for the mutual inductance of the leads as well as their capacitive losses. The unit is computerized and these corrections are done numerically. The impedance (Eq. 51 and 52) is computed with the digitized values of the voltages discussed above. The corrections for the effect of the voltmeter leads and input impedance are carried out by software in another computer.

The measurement of the voltage (SCE) was done with a Hewlett-Packard digital voltmeter #3478A. Although the D.C. input resistance was very high (10^4 M Ω), it had some input capacitance. This was measured in the normal way with the LCR meter for all the frequencies used in the experiments. The impedance measured by the LCR meter was corrected numerically for voltmeter loading.

The LCR meter could provide, between the working and counterelectrode, a D.C. bias controlled by software in a HP - 85 computer (controller) through an IEEE-488 interface port. the voltmeter was also equipped with the same port and could be controlled by the external computer.

IV CAPACITANCE MEASUREMENTS OF n-GaAs ELECTRODES WITH THE (1 1 1) FACE EXPOSED TO SOLUTION

(a) <u>The ($\bar{1}\,\bar{1}\,\bar{1}$) Face of GaAs</u>

Two papers were published on capacitance measurements of GaAs with the ($\bar{1}\,\bar{1}\,\bar{1}$) face (arsenic side) exposed to the electrolyte (40,41). In these investigations and in measurements of capacitance of n-GaAs electrodes with the (100) face exposed to the electrolyte (42), two rather distinct regions in the C vs bias voltage or U_s were found. For bias voltages which would bring the Fermi level inside the gap, the capacitance of the surface states is of the same order as that of the space charge layer. Effects were found in that region where the capacitance depended on both

K_2SO_4 author corrected in French

the direction and rate of variation of the bias voltage. In this region, the Mott-Schottky relation did not apply. In the second region, with more anodic bias, the band bending, U_s, was positive enough to bring the Fermi level below the top of the valence band edge. In that region, the capacitance measured does not depend on either the direction or the rate of variation of bias voltage. This second region falls in the deep depletion region.

Measurements of n-GaAs electrodes with the (1 1 1) face (gallium side) exposed to the electrolyte should be of interest because, according to etching experiments (43), this face is the least reactive.

(b) Materials and Electrode Preparation

The semiconductor was Si-doped n-GaAs from Laser Diode with a resistivity between .0049 and .0039 Ω-cm and a doping density between 4.4 and 6.3×10^{17} cm^{-3}. The single crystal was cut along the (1 1 1) plane.

In order to distinguish between the (1 1 1) and the ($\bar{1}$ $\bar{1}$ $\bar{1}$) face an etching solution of 3:1:1 H_2SO_4:H_2O_2:H_2O was used at 80°C for 2 minutes. The ($\bar{1}$ $\bar{1}$ $\bar{1}$) face was shiny and the (1 1 1) face was slightly pitted.

A film of Au-Ge (88%-12%) alloy was deposited by evaporation onto the ($\bar{1}$ $\bar{1}$ $\bar{1}$) face in order to provide an ohmic contact. Its resistance was 0.05 Ω.

The crystal (with wire bound to the contact with lead solder) was mounted in a Teflon cylinder. The sides of the crystal and its contact were sealed with Scotch Cast epoxy. The assembly allowed polishing of the surface once the epoxy was cured. After polishing with carborundum abrasive paper #600, the sample was polished with 3 μm emery abrasive. This was followed with 0.3 μm and 0.05 μm alumina powder for a mirror finish.

Two etching formulae were used prior to immersion in the electrolyte. The first one was a mild wash with 2 M HCl followed by washing with 1 M KOH. The second etching procedure consisted of photoelectrochemical etching under short circuit conditions for 45 seconds in 1 M $(NH_4)_2S$ at pH 10.6 (NH_4OH). These etching treatments were used separately and never together. After etching, the surface was washed with distilled water.

The electrolyte was 0.5 M K00000$_4$ solution buffered to pH 9.2 with 0.01 M sodium tetraborate. It was found that phosphate buffers favored oxidation of the surface during the run whereas the borate buffer did not.

(c) Experimental Methods

(i) Electrode Stabilization with a Reversible Counter Electrode

In the present work, a two electrode system under non-potentiostatic conditions was used, the source of the D.C. bias to the working electrode being the built-in D.C. bias in the LCR meter. This is discussed further in Appendix I. In such a system in the absence of a redox couple, the rest potentials of the working as well as the platinum counterelectrodes were found to be unstable and undefined, causing fluctuations in the cell voltage and hence long durations for achieving equilibrium.

Further, the counterelectrode should also function as stable source or sink of small currents needed in the charging/discharging of the space charge in the Sc. This is not possible in the absence of a redox couple. Hence, if the platinum counterelectrode is immersed in an electrolyte containing $\sim 10^{-4}$-10^{-3} ML^{-1} of a redox couple, then its D.C. level would be stabilized. However, in the section before the last, it was pointed out that the capacitance measurements cannot be made with the working electrode in contact with a redox couple. Such a platinum electrode in contact with a redox couple will henceforth be called a reversible counterelectrode.

For the purpose of having a reversible counterelectrode and yet keeping the working electrode out of contact with the redox couple, a two compartment cell with a salt bridge with diaphragms was used to separate the two compartments. The saturated calomel electrode was in the working electrode compartment.

The variation of the GaAs electrode potential (SCE) as a function of bias voltage for the cases of reversible and irreversible counterelectrodes is shown in Fig. 8. The redox couple used was ferro-ferricyanide (5×10^{-4} ML^{-1}). Monitoring of the parallel A.C. resistance during the experiments indicated that the redox couple did not diffuse significantly into the working electrode compartment. No hysteresis occurred between the forward and reverse direction of the applied bias, in the modified method as shown in Fig. 8.

Without the redox couple the control of the working electrode potential was extremely poor. These experiments were run for both cases with the same working electrode, counterelectrode, and electrolyte solution (apart from the added redox couple). In both experiments the bias voltage was varied discretely by steps of 100 mV with a 10 minute interval between each step.

In Fig. 8 the intercept at the ordinate at zero bias (extrapolated value) agreed with the equilibrium electrode potential measured against SCE within a few mV. No such agreement was found without the redox couple. For the case where the redox couple was used, the slope is close to unity indicating that all the D.C. bias voltage appears across the working electrode (GaAs) whereas in the other case only 56% of the bias does so.

In order to avoid reactions with dissolved oxygen, ultrapure N_2 was bubbled through the electrolyte solution for 15 minutes before each experiment. The inert atmosphere was also maintained during the experiment by passing nitrogen at the top of the solution. The measurements were performed in a dark chamber, A 150W high pressure xenon lamp (Osram) was used for the measurement of the flat band potential of the working electrode by the rectified alternating photocurrent voltammetry (RAPV) method (44). The cell in this case had an optical quartz window. An inert atmosphere was maintained as before. The potentiostat used was a PAR 173. A light modulator (Roffin 7500) provided a reference signal that allowed detection and amplification of the photocurrent with a PAR 128A phase lock amplifier. The output of that amplifier (photocurrent) was traced as a function of voltage relative to SCE with a Hewlett-Packard #7004B X-Y recorder.

Most of the experiments were done with a settling time of 10 minutes to stabilize the capacitance. (This time was estimated by observing the measured impedance and voltage relative to SCE, at fixed bias with an irreversible counterelectrode as a function of time, and defining the conditions for stability as fluctuations in SCE voltage of 2 mV or less and in capacitance of 1% or less.) As pointed out earlier, the relaxation time was shortened with the reversible counterelectrode, but the same settling times were used for comparison purposes between the two types of counterelectrode.

Some of the experiments were done manually, without software control and with disconnection of the voltmeter during the measurement of the impedances, in order to assess the accuracy of the software. It was found that the software (acquisition and processing) was accurate. This was also shown when a combination of precision resistors and capacitors was used instead of an electrochemical cell.

Results were obtained with three samples of GaAs, using the (1 1 1) face.

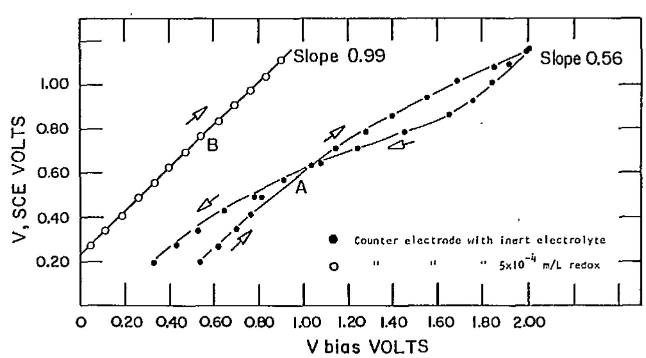


Fig. 8. n-GaAs electrode polarizability

(d) Results and Discussion

The capacitance of the cell was best described by the parallel combination, although in some cases the series capacitance was equal to the parallel capacitance. In Fig. 9 is shown a plot of inverse capacitance squared, as a function of voltage relative to SCE. In this case, the voltage scan was done only from the less positive to the more positive values (this registration sense will be referred to as "forward"). The frequency of the AC signal was 1 kH_z. The value of the fbp, -1.60 V SCE, was in agreement within 50 mV with that obtained by RAPV. The same value for fbp has been obtained by the $(\bar{1}\ \bar{1}\ \bar{1})$ face (41). In Fig. 9 the symbol V_v represents the top of the valence band edge. It can be seen in Fig. 9 that when the Fermi level is about 260 meV below the top of the valence band or lower, then the Mott-Schottky relation applies. With a value of 12.9 for the dielectric constant of GaAs (45), the donor density is calculated to be $5.8 \times 10^{17}\ cm^{-3}$, in good agreement with the manufacturer's value. For the $(\bar{1}\ \bar{1}\ \bar{1})$ face no such agreement was found (40). The surface for this experiment was prepared with the photoetchant.

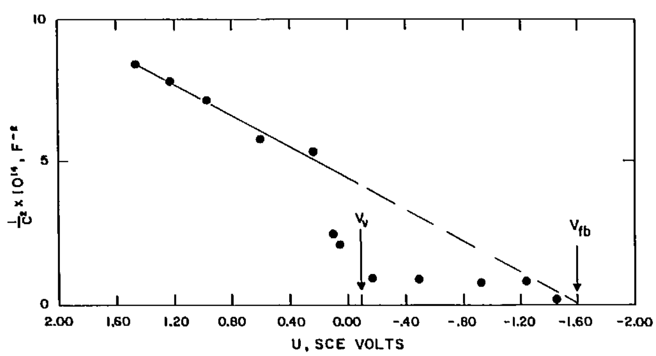


Fig. 9. Photoetched, single registration sense

In Fig. 10, the results of an experiment where the surface was treated with the mild etch (HCl, KOH) are shown. The two measuring frequencies were 1 and 10 kHz. The parallel shift towards the negative values of the fbp at the higher frequency suggests the presence of a thin foreign layer on the surface (32,46), presumably an oxide. This shift as a function of frequency does not appear in all the samples. For the $(\bar{1}\ \bar{1}\ \bar{1})$ face, the frequency dispersion pattern was a change in the slope without a change in fbp (40). This suggests that the dielectric relaxation, which is most probably responsible for the observed frequency dispersion, occurs in a layer as thick as the space charge layer (46). A microscopic examination of the surface after the experiment revealed that the surface had changed its appearance during the experiment from shiny to dull and rough.

Figure 10 also shows hysteresis in the Mott-Schottky plots obtained with forward and reverse directions of voltage scan. This hysteresis was found to be less on the same sample if the experiment was repeated without re-polishing or re-etching of the surface, with the same rate of voltage scan. In a separate experiment, it was further found that the hysteresis did not depend on the rate of voltage scan varying from 7 mV/min to 30 mV/min. Results in Fig. 10 correspond to a 7 mv/min scan rate.

The presently observed behaviour is distinct from the hysteresis with the $(\bar{1}\ \bar{1}\ \bar{1})$ face (As-face) that was observed by others (40) in the less anodic range, closer to the fbp and well above the top of the valence band edge (i.e., not in the deep depletion region). In our experiments with the (1 1 1) face (Ga-face), the hysteresis appears in the deep depletion region (far anodic). Also, on the $(\bar{1}\ \bar{1}\ \bar{1})$ face, the hysteresis depended on the scan rate. Thus the hysteresis observed here (Fig. 10), with the (1 1 1) face in the deep depletion region is not experienced with the $(\bar{1}\ \bar{1}\ \bar{1})$ face (40).

The V_{fbp} shown in Fig. 10 for both frequencies is the average value obtained from the forward and reverse scanning, as defined earlier. The V_{fbp} obtained from the Mott-Schottky plot with forward scanning alone, is found to be -1.60 V (SCE).

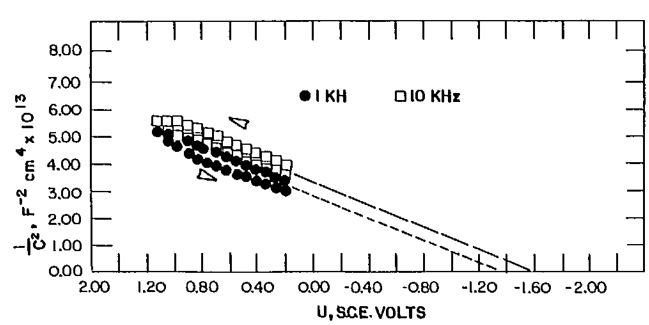


Fig. 10. Mild etch two-registration senses

The hysteresis on (1 1 1) face was also found to depend on whether the surface was highly polished, or dulled and roughened by the photoetching process. This was demonstrated by measurements made with the (1 1 1) surfaces polished and photoetched to a dull finish. The results obtained with two cycles, each with one forward and reverse scanning, at 30 mV/min and 1 kHz, are shown in Fig. 11. The hysteresis in this case was only 2% compared to ~ 30% (Fig. 10) obtained for the same face with a mirror finish obtained after fresh polishing and etching with the mild etch. Also, while the $(\bar{1}\ \bar{1}\ \bar{1})$ face (As-face) gave a shiny finish with the photoetch, the (1 1 1) face (Ga-face) was tarnished and roughened.

The effect of oxygen on the Mott-Schottky plots for the (1 1 1) face was also investigated by bubbling oxygen for one hour before the impedance measurements. The surface appeared blue after oxygen treatment. The results are shown in Fig. 12 for two frequencies (1 and 10 KHz), each with both forward and reverse scanning. The hysteresis observed when the surface was prepared with the mild etch does not appear in this case. The frequency dispersion involves the slope only and is of the same order of magnitude as that seen in experiments done with the $(\bar{1}\ \bar{1}\ \bar{1})$ face where efforts had been made to exclude oxygen (40,41).

In conclusion, a pure (1 1 1) face in the deep depletion region produces hysteresis in the capacitance measurements. Since this phenomenon is absent for the $(\bar{1}\ \bar{1}\ \bar{1})$ face, it can be concluded that this represents an irreversible change in the electrode surface involving Ga. The appearance of a parallel shift in the Mott-Schottky plot in the deep depletion region shows that this change occurs in a small depth compared to the depletion layer width (34).

Since this hysteresis appears in the deep depletion region, holes may have a role to play. The nature of that chemical change remains unknown.

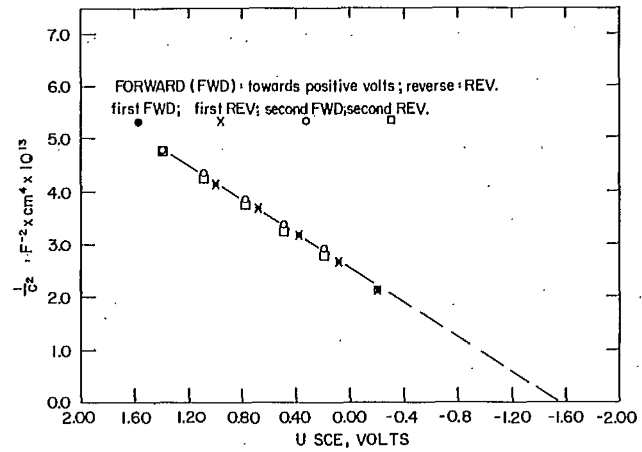


Fig. 11. Photoetched, four registration senses

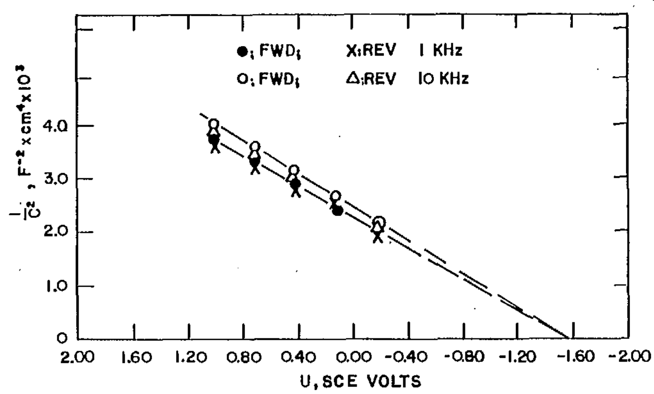


Fig. 12. Photoetched, bubbled oxygen, two registration senses

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APPENDIX I

DATA ACQUISITION AND CONTROL SOFTWARE

(a) The IEEE-488 Bus

This interface is specifically designed to control instruments or other peripheral devices close (a few meters at most) to the computer (47). It allows commands to be sent from the computer (software) to a device and data to be received from that device by the computer (if applicable). If there are more than one device on the bus, the computer can demand privacy between itself and a particular device and transmission speed is limited only by the device.

(b) The Software Three-Electrode System

The LCR meter can transform a floating point value, stored in the HP-85 computer and sent through the bus, into a bias voltage. Therefore a reading of the voltage (relative to SCE) with the voltmeter, which is sent to the computer, can be used to control the bias in such a way as to maintain the voltage (SCE) within narrow limits (± 2 mV). This is a software or soft three electrode system (a 'hard' three electrode system would be controlled by a potentiostat).

An illustration of this concept is given in principle in Fig. 13 in program description language, PDL (48). This is self-explanatory except for three aspects.

```
            PROCEDURE POTENTIOSTAT (REAL VALUE INPUT,PERIOD,
                                    REAL VALUE RESULT SERVO,
                                    BOOLEAN       RESULT OBEYED);

(*THESE ARRAYS FORM THE COMPLIANCE PANEL:THEY ARE INITIALIZED
  AND USED AS CONSTANTS THROUGHOUT*)
VAR DELAYS(1..8),GAINS(1..8),LIMITS(1..9):ARRAY OF REAL;

            PROCEDURE COMPLY(REAL VALUE ERR,
                             REAL RESULT RETARDATION,AMPLIFICATION);

BEGIN
I:=0;
REPEAT
I:=I+1
UNTIL ERR < = LIMITS(I);
RETARDATION:=DELAYS(I);AMPLIFICATION:=GAINS(I)
END; (*COMPLY*)

BEGIN (*THE ACTUAL INSTRUCTIONS TO THE INSTRUMENTS ARE IN ASSEMBLER*)
WRITELN(DMM)("SHUT ALL AUTO-CALIBRATIONS;MASK THE DATA READY
              SERVICE REQUEST");

RESET CLOCK;(*INTERNAL STOPWATCH*)
WHILE CLOCK <= PERIOD DO
  BEGIN
  WRITEFAST(DMM)("INITIATE SAMPLING"); (*SERVICE REQUEST INTERRUPT
                                         ENABLE AND DISABLE STEPS
                                         OMITTED*)
  READFAST(DMM)OUTPUT; (*CORE TO CORE FORMATTING STEPS OMITTED*)
  ERROR:=OUTPUT-INPUT;ERR:=ABS(ERROR);  (*ABSOLUTE VALUE*)
  OBEYED:=ERR < = LIMITS(9);
  IF NOT OBEYED THEN
       BEGIN
       COMPLY(ERR,RETARDATION,AMPLIFICATION);
       SERVO:=SERVO - AMPLIFICATION*ERROR;
       WRITEFAST(DMM)SERVO;
       WAIT(RETARDATION)  (*PREDEFINED PROCEDURE*)
       ENDIF
  ENDDO;

WRITELN(DMM)("CLEAR SERVICE REQUEST MASK;ENABLE AUTO-CALIBRATIONS")

END; (*POTENTIOSTAT*)
```

Fig. 13. Procedure potentiostat

The difference (ERROR) between the demanded and measured voltage (SCE), INPUT and OUTPUT respectively, is classified according to the classes defined by the array LIMITS. These classes are defined according to the absolute size of the difference, from 1 V to 2 mV (=LIMITS(9)). It was found that in order to eliminate rapid oscillations in the voltage (SCE) when the difference was small, a gain (AMPLIFICATION) applied to the difference for the bias correction (the bias is controlled by the variable SERVO) greater than 1 was needed. On the other hand when that difference was large (of the order of 100 mV or more) a large value of that gain led to overshoots and undershoots that were corrected slowly by the software. For those large values of the difference, gains close to unity were preferred. After the new variable of the bias is computed it is sent to the LCR meter. After the bias correction, there is a delay (RETARDATION) and the procedure is repeated. The values of the delay are predefined (array DELAYS) according to the sizes of the difference between measured and demanded voltage (SCE). These values were chosen empirically to ensure a minimum of overshoots, undershoots and oscillations in the control of the voltage (SCE). If the compliance flag OBEYED is set to TRUE the process is skipped.

The second aspect is to make sure that when the procedure COMPLY is evoked, there is always time (the total time of execution is controlled by a computer timer, stopwatch, and the variable PERIOD) to push the data associated with its evocation out of (CPU) stack. Otherwise, the stack will fill up and this is a fatal run time error. This is not shown in Fig. 13.

The third aspect is a reference (PDL:READFAST,WRITEFAST) to a type of bus transaction (fast handshake transfer) which allows the fastest transmission rate.

A complete data acquisition and control program using this principle is illustrated in Fig. 14. The program listed in this appendix has other procedures which are not mentioned here for the sake of clarity. These omissions do not change the algorithmic structure.

What this algorithm describes is an experimental procedure in which the cell is maintained under potentiostatic control for a certain time (PERIOD). The values of the voltages relative to SCE (V_SCE) and of the impedances (Z and THETA) are measured at three frequencies (NU) chosen in advance by keyboard entry (procedure GET_MENU) after this waiting period. If the measured voltage (SCE) is insufficiently close to the demanded value the algorithm provides for a supplement of three-electrode control before measurement. During the measurement the system is a two-electrode system since the bias is not altered.

Since this is an automatic program, provisions must be made for checks on the status of the system. This is symbolized by the boolean function procedure CHECK_STATUS. In the actual program those status checks are distributed.

(c) The Two-Electrode System

The main acquisition loops are shown in Fig. 15a. The procedure ACQUIRE makes the measurements of the various quantities of interest as described above. It also (this is different from the above) sets the sampling timer (CLOCK #3) to the sampling period calculated in advance from keyboard inputs (not shown). It also, by accessing the master clock of the computer, measures its execution time (TIMEOUT). This also is different from the above. This is variable because the fluctuations of the cell have an influence on the balancing time of the LCR meter. The variation in bias is a triangular ramp which is in operation only if the procedure ACQUIRE is not evoked. In order to preserve the linearity of the variation of bias as a function of time, a correction pulse is sent after the evocation of the procedure by the procedure VERNIER_PULSE (Fig. 15b). When the procedure ACQUIRE is not evoked, the bias is incremented (forward stroke, STR=1) or decremented (reverse stroke, STR=2) by a value of 1mV (STEP) after waiting for a time equal to RAMP_PERIOD. This is chosen either as 1.5 or 3 seconds by keyboard entry. These values are nominal and are corrected for sources of delay originating either in the interface or in the interpreter.

```
CONSTANT NUMBER_OF_POINTS = 14,CHANCES = 5;

VAR ITEM,STROKE,I,J:INTEGER,
START,STEP,Z0,THETA0,V_SCE0,INPUT,PERIOD,SERVO,LAST_CHANCE:REAL,
ERROR_IN_STATUS,OBEYED:BOOLEAN,
NU(1..3),       (*FREQUENCIES*)
R_DMM(1..3), (*PARALLEL RESISTANCES OF  DMM FOR EACH FREQUENCY*)
C_DMM(1..3), (*PARALLEL CAPACITANCES OF DMM FOR EACH FREQUENCY*)
Z(1..2;1..3;1..NUMBER_OF_POINTS),(*MODULI OF THE IMPEDANCES*)
THETA(1..2;1..3;1..NUMBER_OF_POINTS), (*THEIR PHASES*)
V_SCE(1..2;1..3;1..NUMBER_OF_POINTS): (*APPLIED VOLTAGES*)
ARRAY OF REAL;

FUNCTION CHECK_STATUS:BOOLEAN;
FUNCTION GET_PERIOD:REAL;
PROCEDURE GET_SCE(REAL RESULT START,STEP);
PROCEDURE GET_MENU(NU(*),R_DMM(*),C_DMM(*));
PROCEDURE POTENTIOSTAT(REAL VALUE INPUT,PERIOD,
                       REAL VALUE RESULT SERVO,
                       BOOLEAN RESULT OBEYED);


BEGIN

(* INITIAL CHECKS;A.C. LEVEL SET AND CHECKED;EQUILIBRIUM APPLIED
   POTENTIAL MEASURED *)

PERIOD:=GET_PERIOD;LAST_CHANCE:=PERIOD/CHANCES;
GET_MENU(NU,FREQ,R_DMM,C_DMM); GET_SCE(START,STEP);
SERVO:=0;INPUT:=START;

STR:=0;
REPEAT
  I:=0;STR:=STR+1;
  REPEAT
    POTENTIOSTAT(INPUT,PERIOD,SERVO,OBEYED)
    ITEM;=0;
    REPEAT
      IF NOT OBEYED THEN
                    BEGIN
                    J:=0;
                    REPEAT
                      POTENTIOSTAT(INPUT,LAST_CHANCE,SERVO,OBEYED)
                      ERROR_IN_STATUS:=CHECK_STATUS;J:=J+1;
                    UNTIL OBEYED OR J=CHANCES OR ERROR_IN_STATUS
                    ENDIF;


    IF NOT ERROR_IN_STATUS THEN

      BEGIN
      ITEM:=ITEM+1;
      WRITEFAST(LCR)NU(ITEM);
      WRITELN(LCR,DMM) ("INITIATE SAMPLING");
      READFAST(LCR)Z0,THETA0;READFAST(DMM)V_SCE0;
      I:=I+1;
      Z(STR,ITEM,I):=Z0;THETA(STR,ITEM,I):=THETA0;V_SCE(STR,ITEM,I):=V_SCE0;
      ERROR_IN_STATUS:=CHECK_STATUS
      ENDIF

    UNTIL ERROR_IN_STATUS OR ITEM=3;

  INPUT:=INPUT + STEP
  UNTIL ERROR_IN_STATUS OR I=NUMBER_OF_POINTS;

STEP := -STEP
UNTIL ERROR_IN_STATUS OR STR=2;

(*INTERRUPT ALL INTERFACE ACTIVITIES*)
(*RETURN COMPUTER TO NORMAL*)
IF NOT ERROR_IN_STATUS THEN
  BEGIN
  (*PUT DATA ARRAYS IN A DATA FILE;PRINT THEM ON PAPER*)
  END
  ELSE
  BEGIN  (*PRINT STATUS DIAGNOSTICS*)ENDIF
END.
```

Fig. 14. Soft three electrode system:main (PDL)

Fig. 15. Two electrode system (PDL)
(a) Main; main loops and final
(b) Intercalated ramp pulse

```
ITEM:=0;
REPEAT
  ITEM:=ITEM + 1;STR:=0;WRITELN(LCR)NU(ITEM);
  REPEAT
    STR:=STR + 1;I:=0; TALLY:= 0.0;
    REPEAT
      I:=I + 1;
      IF I = 1 THEN
          BEGIN
          ACQUIRE(Z,THETA,V_SCE,CLOCK#3,TIMEOUT);
          VERNIER_PULSE(TIMEOUT,SERVO)  END
          ELSE
          BEGIN
          WHILE CLOCK#3 < = SAMPLING_PERIOD DO
            BEGIN
            SET CLOCK#2;
            WHILE CLOCK#2 < = RAMP_PERIOD DO;
            SERVO:=SERVO + STEP;
            WRITEFAST(LCR)SERVO

          ENDDO

      ENDIF;

      ACQUIRE(Z,THETA,V_SCE,CLOCK#3,TIMEOUT);
      VERNIER_PULSE(TIMEOUT,SERVO);
      ERROR_IN_STATUS:=CHECK_STATUS
      UNTIL ERROR_IN_STATUS OR I = NUMBER_OF_POINTS;


    STEP:= -STEP
    UNTIL ERROR_IN_STATUS OR STR = 2;

IF NOT ERROR_IN_STATUS THEN (*PRINT DATA ON TAPE;PRINT DATA ON PAPER*)
UNTIL ERROR_IN_STATUS OR ITEM = 3;

IF ERROR_IN_STATUS THEN (*PRINT DIAGNOSTICS*)

END.
```

(a)

```
PROCEDURE VERNIER_PULSE(REAL VALUE TIMEOUT,REAL VALUE RESULT SERVO);

(*GLOBAL INPUTS:TALLY AND EXECUTION_TIME (REFERS TO THIS PROCEDURE)*)


VAR CORRECTION,TEMP:INTEGER,FRACTION:REAL;

BEGIN

CORRECTION:= TIMEOUT DIV RAMP_PERIOD; (*INTEGER DIVISION*)
FRACTION:= TIMEOUT - CORRECTION*RAMP_PERIOD;
FRACTION:= FRACTION + TALLY + EXECUTION_TIME / RAMP_PERIOD;
TEMP:= FRACTION DIV RAMP_PERIOD;
CORRECTION:= CORRECTION + TEMP;FRACTION:= CORRECTION*RAMP_PERIOD;
TALLY:= TIMEOUT - FRACTION;
SERVO:= SERVO + STEP*FRACTION;
WRITEFAST(LCR)SERVO

END; (*VERNIER_PULSE*)
```

(b)

(d) The Two-Electrode and Software Three-Electrode Systems: Advantages and Disadvantages

The relaxation time is determined by a period of observation before either one of these measurement procedures is used. For cells that have slow relaxation (or settling) times a pure two electrode system would have no control over the voltage relative to SCE and numerical analysis requires that the impedance be measured in both the forward and reverse direction of voltage variation for the same set of SCE voltage values. Therefore for those cells the soft three electrode system is preferable. However, for those cells that settle only very slowly, the soft three electrode system will fail to provide these two identical sets of voltages (SCE). This is because this system reverts to being a two electrode system during measurement. For those cells that do relax quickly, the two electrode system is better since more points of data can be taken per unit time.

(e) Data Processing

Regression of the Mott-Schottky relation (Eq. 27) is carried out with Williamson's algorithm (49). This algorithm allows error in both the x and y axes and treats both variables on an equal statistical footing. The experimental errors are estimated by either one of the data acquisition programs. This is done for both the simple parallel and series analysis and for each frequency used.

Polarization analysis of the voltages (SCE) as a function of the bias voltages provided by the acquisition programs is also carried out with the same algorithm. This warns of abnormal conditions in the working electrode such as leaks, excessive relaxation effects and Fermi level pinning associated with deep traps (50).

The analysis of the impedances can be corrected for the bulk solution and contact resistance as well as for the presence of a thin foreign layer on the surface characterized by a voltage independent capacitance (34).

With a Hewlett-Packard #7470A printer plotter equipped with an IEEE-488 port, the program can generate appropriate Mott-Schottky plot graphics.

APPENDIX II

SOME NOTES ON THE HEWLETT-PACKARD BASIC

SOME NOTES ON THE HEWLETT-PACKARD BASIC

(a) Non-ANSI Features

This appendix will briefly discuss some of the non-ANSI features of the BASIC dialect used here in order to facilitate an understanding of the code.

(b) Multistatement Lines

In ANSI BASIC each statement is given a line number. In the dialect used here, it is possible to assign several statements to a single line number. The character @ is used as statement separator in the line.

(c) Input/Output

Corresponding to the PDL WRITTELN (device) is the statement OUTPUT device; which generates a carriage return and line feed character. The device is one of the external instruments, specified by an integer of the form 700 + primary address. The primary address of the LCR meter is 17 and that of the voltmeter is 23. For the other peripherals (CRT screen, internal printer and cassette) the corresponding expressions are DISP;, PRINT; and PRINT#(buffer number);. There are no carriage return and line feed characters generated for the cassette. Another variation of this statement is OUTPUT USING (line number);. The line number refers to a character formatting statement (IMAGE). Similarly, corresponding to the PDL statement READLN(device) is the statement ENTER device;.

(d) Symbolic Devices and Fast I/O

The PDL statement WRITEFAST(device) is not executed directly, but through the intermediary of a symbolic device residing in RAM. The device is created by the introduction of a character variable defined as a character queue with fill and empty registers with the IOBUFFER statement. The first step is to use the OUTPUT device; statement where device is the character variable name. The second step is to write the symbolic device on the real device with a statement of the form: TRANSFER symbolic device TO real device FHS. It is possible to control the value of the empty and fill registers outside of any symbolic device transaction. For example the statement CONTROL symbolic device, 0;1,0 empties the device of all characters. This is needed before some write operations on a symbolic device. Similarly the PDL statement READFAST(device) is stated: TRANSFER real device TO symbolic device FHS followed by ENTER symbolic device;.

(e) Vectored Interrupts

These are generated by statements of the form ON condition GOTO line number or ON condition GOSUB line number. They are disabled by the statement OFF condition.

The conditions involve keywords that are fairly explicit. The vectored interrupt is implemented after detection only after the line at which it occurs is executed.

The PDL CLOCK is written as TIMER#timer number, timer period. The TIMEOUT statements refer to the interface timer. The time unit for both types is the millisecond. The KEY statement refers to reserved keyboard keys used in menu driven programs.

(f) The Service Request Interrupt

On the IEEE-488 bus there is a special line called the service request (SRQ) line. This line is controlled by the devices on the bus. When one of the devices detects in itself a condition which is unusual, it can set that line to true. The value of the line is stored in the SRQ register of the interface (read by the statement STATUS 7,1;S, S being the value). The value of true of the SRQ line can be used to generate a vectored interrupt with the condition written as INTR 7 if the computer is enabled to respond to it with the statement ENABLE INTR 7;8.

An unusual condition can be read directly from the device with the predefined function SPOLL using as argument the device number defined above. The unusual condition may or may not cause the device to set the SRQ line to true. Depending on the device, certain conditions have to be masked in order for the SRQ line to be asserted as true when this condition exists. An example is the condition of having completed acquisition of a datum by the device.

(g) Device Codes

Commands (operands of the OUTPUT device; statement) are one to three byte opcodes that allow control of the settings. The setting of the D. C. bias (device:LCR meter) is of the form: "BI$\pm$d.ddE$\pm$ddV" where d is a digit. The operands between the 'BI' and 'V' opcodes correspond to the desired value of the D. C. bias. The actual value is the same within 1%. This corresponds in PDL to the variable SERVO.

(h) The TRIGGER Statement

The command to start sampling is written as TRIGGER (device list). The appropriate opcode (one byte) is automatically generated. Therefore there is no operand on the right of the device list.

APPENDIX III

BASIC LISTINGS: DATA ACQUISITION AND CONTROL SOFTWARE

INTERNAL DOCUMENTATION
SOFT THREE ELECTRODE SYSTEM

```
1000 ! ADMITTANCES▒CAPACITANCES
1010 ! HI RESOLUTION (LCR)
1020 ! PRODUCTION UNIT
1030 ! INTERNAL DOCUMENTATION
1040 ! FOR PROG Z8 ONLY
1050 ! FILE:Z8d
1060 ! UPDATED MAY 10/84
1070 ! RANDOMIZING MENU FREQU-
1080 ! ENCIES
1090 ! NEEDS 32K RAM
1100 ! LARGE STEPS
1110 ! SOFTWARE POTENTIOSTAT
1120 ! RELAXES THE CELL BEFORE
1130 ! EACH ACQUISITION
1140 ! MEASURES Urev AND ITS
1150 ! STANDARD DEVIATION
1160 ! (5 SAMPLINGS) BEFORE
1170 ! THE RUN
1180 ! THE STANDARD DEVIATIONS
1190 ! ARE BASED ON THE VARIA-
1200 ! TIONS BETWEEN THE FOR-
1210 ! WARD AND REVERSE STROKES
1220 ! THERE ARE THEREFORE A
1230 ! CLASS NUMBER OF STD
1240 ! DEV.'S PER MEASURED
1250 ! PARAMETER
1260 ! WITH HP#4274 LCR METER
1270 ! AND HP#3478A DMM
1280 ! FOLLOWED BY TAPE STORAGE
1290 ! OF THE DATA
1300 ! >FOR ELECTROLYTIC CELLS<
1310 ! SOME KEYBOARD INPUTS FOR
1320 ! DATA USED BY THE PROCES-
1330 ! SOR WILL BE ASKED
1340 ! AFTER THE CHOICE OF THE
1350 ! FREQUENCY MENU,THE USER
1360 ! IS INVITED TO INPUT
1370 ! A PERMUTATION OF 1,2,3
1380 ! (INCLUDING REPETITONS)
1390 ! THIS WILL HAVE THIS EF-
1400 ! FECT OF ALTERING THE
1410 ! SEQUENCE OF THE FREQUEN-
1420 ! CIES AND/OR OF INTRODU-
1430 ! DING REPETITIONS
1440 ! THIS FEATURE CAN BE TUR-
1450 ! NED OFF OR ON BY SETTING
1460 ! OR CLEARING FLAG R5 AT
1470 ! THE START OF MAIN
1480 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1490 ! JEAN LEDUC/CANMET/MSL
1500 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1510 !
1520 REM TIMERS
1530 !        IN MAIN
1540 ! #1:IN SR ACQUIRE
1550 ! WHICH CALLS THE FOLLO-
1560 ! WING SR'S WHERE THIS
1570 ! TIMER IS USED:
1580 ! START_METERS,GET_Urev &
1590 ! POTENTIOSTAT
1600 !    WILL DECLARE MTA
1610 !    ACKNOWLEDGE TIMEOUT
1620 !    PRIOR TO ORDERING
1630 !    THE GROUP EXECUTE
1640 !    TRIGGER COMMAND.
1650 !    THIS IS A FATAL RUN
1660 !    TIME ERROR:THE PRO-
1670 !    GRAM IS TERMINATED
1680 ! #3:POTENTIOSTAT OPERA-
1690 !    TING PERIOD
1700 !      SUBROUTINES
1710 !      ALL PROGRAM:
1720 !      TIMEOUT 7
1730 ! INTERFACE TIMER:GIVES
1740 ! TOTAL PROTECTION AGAINST
1750 ! CRASHES DUE TO BUS HANG-
1760 ! UPS FOR FORMATTED I/O
1770 ! AND FIRST HANDSHAKE PRO-
1780 ! TECTION AGAINST SAME FOR
1790 ! UNFORMATTED I/0
1800 ! (HP-85 vs LCR & DMM)
1810 ! THESE TIMEOUTS ARE FATAL
1820 ! RUN TIME ERRORS:THE PRO-
1830 ! GRAM TERMINATES
1840 ! THERE IS AN EXCEPTION:
1850 ! IN SR CHECK_DC,THE SE-
1860 ! COND TIMEOUT INDICATES
1870 ! THAT THE OPERATOR HAS
1880 ! TO PUT THE DC BIAS
1890 ! IN ITS PROPER POSITION.
1900 ! A WARNING IS ISSUED AND
1910 ! UPON RECTIFICATION,THE
1920 ! PROGRAM RESUMES.
1930 ! >>>>>>>>>>>>>>>>>>>>>>>>
1940 REM END TIMERS
1950 ! ◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀
1960 REM END-OF-LINE BRANCHES
1970 ! REQUEST FOR SERVICE
1980 ! INTERRUPT (BYTE 8)
1990 ! THIS CAN MEAN EITHER
2000 ! DATA READY (SERIAL POLL
2010 ! BYTE 65) OR MALFUNCTION
2020 ! IN THE LATTER CASE,THE
2030 ! PROGRAM IS TERMINATED
2040 !
2050 ! THE ERROR BRANCH
2060 ! IN MAIN,AT THE START,
2070 ! A HARDWARE SELF TEST IS
2080 ! MADE OF THE INTERFACE.
2090 ! FAILURE OF THE TEST IS
2100 ! A FATAL RUN TIME ERROR
2110 ! AND TERMINATES THE PRO-
2120 ! GRAM
2130 ! ALSO CONTINUES TO MONI-
2140 ! TOR THIS SITUATION
2150 ! THROUGHOUT THE PROGRAM
2160 !
2170 ! IN MAIN (ACQUIRE BLOCK),
2180 ! CHECKS THE ALIGNMENT OF
2190 ! THE I/O BUFFER AGAINST
2200 ! METERS FORMAT SPECS
2210 REM It was found that
2220 ! pick-up could severely
2230 ! mangle the throughput
2240 ! to the I/O buffer from
2250 ! the LCR meter ASCII
2260 ! queues
2270 REM An identical test is
2280 ! made when the LCR meter
2290 ! monitor ASCII queue is
2300 ! accessed by means of
2310 ! string logic (SR GET_AC)
2320 ! In SR GET_STATS,both LCR
2330 ! meter ASCII queues are
2340 ! accessed,and an iden-
2350 ! tical test is made
2360 ! This holds for the DMM
2370 ! ASCII queue as well.
2380 ! IF THIS MISALIGNMENT
2390 ! OCCURS,THIS IS A FATAL
2400 ! RUN TIME ERROR AND THE
2410 ! PROGRAM IS TERMINATED
2420 !
2430 ! ERROR BRANCH IN TAPE
2440 ! HANDLERS:
2450 ! SR GET_FILE_NAME
2460 ! THAT BRANCH ALLOWS
2470 ! RECOVERY FROM TAPE
2480 ! ERRORS SUCH AS:
2490 ! NO CASSETTE,IDENTIFIER
2500 ! CONFLICT,TAPE FULL,etc
2510 ! SR GET_TAPE:HERE A TAPE
2520 ! ERROR IS A FATAL RUN TI-
2530 ! ME ERROR AND THE PROGRAM
```

```
2540 ! IS TERMINATED
2550 ! ◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄
2560 REM END END-OF-LINE
2570 ! $$$$$$$$$$$$$$$$$$$$$$$$
2580 REM TAPE THROUGHPUT
2590 ! A FILE NAME IS ASKED AS
2600 ! AS KBD INPUT.THIS FILE
2610 ! NAME WILL BE THE IDENTI-
2620 ! FIER OF THE OUPUT FILE
2630 ! THE FILE HAS 3 LOGICAL
2640 ! RECORDS OF 1432 BYTES
2650 ! EACH;THIS CORRESPONDS
2660 ! TO 6 PRU'S.
2670 ! THIS GIVES A TOTAL OF 18
2680 ! PRU'S (4296 BYTES)
2690 REM FOR THE FORMAT DETAIL,
2700 REM SEE THE CODE IN FILE
2710 REM Z8
2720 ! $$$$$$$$$$$$$$$$$$$$$$$$
2730 REM END TAPE THROUGHPUT
2740 ! !!!!!!!!!!!!!!!!!!!!!!!!
2750 REM  VARS
2760 ! F9$:  OUTPUT FILE NAME
2770 ! U8,U9:REVERSIBLE POTEN-
2780 ! TIAL AND ITS STANDARD
2790 ! DEVIATION,RESPECTIVELY,
2800 ! IN VOLT
2810 ! S9:    INTERSAMPLING
2820 !        PERIOD,min
2830 ! D9:    SAME AS ABOVE,mS
2840 ! D7:    FRACTIONAL PERIOD
2850 !        OF POTENTIOSTATIC
2860 !        RELAXATION BEFORE
2870 !        ACQUISITION IF
2880 !        COMPLIANCE FLAG
2890 !        IS FALSE,mSEC
2900 !        D7:=D9/D4
2910 ! U4,U5:START & FINAL SCE
2920 !        VOLTS,RESPECTIVELY
2930 ! D0:    SIGNUM OF (U5-U4)
2940 ! U6:    SCE VOLT INCREMENT
2950 REM        POTENTIOSTAT
2960 !  COMPLIANCE PANEL
2970 REM THE FOLLOWING THREE
2980 !    CONSTANTS ARE [1:9]
2990 !    ARRAYS OF LONG REAL
3000 ! V3: VOLTAGE TOLERANCES,
3010 !      VOLT
3020 ! F5: GAINS
3030 ! P3: RETARDATIONS,mSEC
3040 DATA 1,.5,.25,.1,.05,.02,.0
     1, 005,.002
3050 FOR I=1 TO 9
3060 READ V3(I)
3070 NEXT I
3080 DATA 1.002,1.004,1.008,1.01
     6,1.032,1.064,1.128,1.128,1
     .05
3090 FOR I=1 TO 9
3100 READ F5(I)
3110 NEXT I
3120 DATA 200,400,800,1600,2000,
     2000,2000,2000,250
3130 FOR I=1 TO 9
3140 READ P3(I)
3150 NEXT I
3160 ! REM END PANEL
3170 ! U1:    DC BIAS (WE-CE)
3180 ! U0:    DEMANDED SCE VOLT
3190 ! D8:    INPUT VARIABLE:
3200 !        OPERATING PERIOD,
3210 !        mSEC
3220 ! U3:    Usce (MONITORED)
3230 ! D:     ERROR BETWEEN
3240 !        MONITORED & DEMAN-
3250 !        DED Usce
3260 ! V:     ITS ABSOLUTE VALUE
3270 ! C9:    COMPLIANCE FLAG:
3280 !        TRUE IF V LESS
3290 !        MINIMUM TOLERANCE
3300 !        (V3(9),see BELOW)
3310 ! P2:    RETARDATION CHO-
3320 !        SEN BY SR COMPLI-
3330 !        ANCE
3340 ! F6:    GAIN CHOSEN BY SR
3350 !        COMPLIANCE
3360 ! D5:    REMAINING OPERA-
3370 !        TING PERIOD AFTER
3380 !        EXECUTION OF SR
3390 !        COMPLIANCE
3400 REM SR COMPLIANCE CALLED
3410 !    FOR A FALSE COMPLIANCE
3420 !    FLAG
3430 ! I:RUNNING INTEGER
3440 REM  END POTENTIOSTAT
3450 ! U7,V: SCRATCH VARS
3460 ! I9:   STROKE COUNTER:1,2
3470 ! I8:   SAMPLING COUNTER:
3480 !       1,N8 (SEE CONS-
3490 !       TANSTS BELOW)
3500 ! F9:   MENU COUNTER:1,3
3510 ! I3:   1-3 FOR FORWARD,
3520 !       4-6 FOR REVERSE
3530 !       STROKE
3540 REM *(I3,I8):[1:6;1:14]
3550 !    ARRAYS OF LONG REAL
3560 !    *(F9,I8):[1:3;1:14]
3570 !    ARRAYS OF LONG REAL
3580 ! V5(I3,I8):
3590 ! V6(F9,I8):
3600 ! STD. DEV.'S OF ABOVE
3610 ! DC BIASES
3620 ! U(I3,I8):
3630 ! MEASURED SCE VOLTS
3640 ! B5:TEMPORARY STORAGE OF
3650 ! ONE COMPONENT OF ABOVE
3660 ! S0(F9,I8):
3670 ! STD. DEV.'S OF ABOVE
3680 ! Z(I3,I8):
3690 ! MODULI OF THE IMPEDAN-
3700 ! CES,Ω
3710 ! Z2:TEMPORARY STORAGE OF
3720 ! ONE COMPONENT OF ABOVE
3730 ! Z0(F9,I8):
3740 ! STD. DEV.'S OF ABOVE
3750 ! O(I3,I8): .
3760 ! PHASES OF THE IMPEDAN-
3770 ! CES,deg
3780 ! O2:TEMPORARY STORAGE OF
3790 ! ONE COMPONENT OF ABOVE
3800 ! O0(F9,I8):
3810 ! STD. DEV.'S OF ABOVE
3820 ! U$,V$,Z$:I/O BUFFERS
3830 ! S9$,S8$,F$:SETTINGS
3840 !             VARS
3850 ! V0.    AC VLT,mV;R.M.S.
3860 ! I8$:   ASCII VALUE OF
3870 !        AC OSCILLATOR
3880 !        LEVEL MULTIPLIER;
3890 !        OUTPUTTED BY SR
3900 !        GET_AC AND USED
3910 !        AS (PARTIAL) INPUT
3920 !        BY SR ECHO
3930 ! C0,G0:PARALLEL COR-
3940 !        RECTIONS FOR DMM
3950 !        LOADING
3960 !        C0:CAPACITANCE,nF;
3970 !        G0:CONDUCTANCE,nS
3980 !        BOTH:[1:3]ARRAYS
3990 !        OF LONG REAL
4000 ! F:     MENU VECTOR:
4010 !        [1:3] ARRAY OF
4020 !        INTEGER
```

```
4030 ! O5·    MENU ORDERING VEC-
4040 !        TOR;[1:3] ARRAY
4050 !        OF INTEGER
4060 ! F0:    ACTUAL FREQUENCIES
4070 !        CORRESPONDING TO
4080 !        THE MENU VECTOR,
4090 !        KHz.
4100 !        [1:3] ARRAY OF
4110 !        LONG REAL
4120 ! S:     INTERFACE AND/OR
4130 !        LCR METER REGISTER
4140 !        DECIMAL VALUE
4150 ! V1     DMM REGISTER,DECI-
4160 !        MAL VALUE.
4170 ! E1,C,E0:FLAGS
4180 REM END VARS
4190 ! !!!!!!!!!!!!!!!!!!!!!!!!
4200 REM CONSTANTS
4210 ! C1,G1:PARALLEL CORREC-
4220 ! FOR DMM COAX LOADING;
4230 ! C1:CAPACITANCE,nF
4240 ! G1:CONDUCTANCE,nS
4250 LET C1=.148
4260 LET G1=0
4270 LET N8=14 ! THIS IS THE
4280 ! NUMBER OF CLASSES OR
4290 ! POINTS PER STROKE
4300 LET Q=65 ! DATA RDY BYTE
4310 !           BOTH FOR THE
4320 !           DMM & LCR ME-
4330 !           TER:SERIAL RE-
4340 !           GISTER MASKED
4350 LET V7=1  ! SIMILAR FOR THE
4360 !           DMM,BUT WITH
4370 !           UNMASKED SERI-
4380 !           AL POLL REGIS-
4390 !           TER
4400 LET H1=360 ! FORMATTED I/O
4410 !             TIMEOUT,mSEC
4420 LET H2=50 ! UNFORMATTED
4430 !            I/OTIMEOUT,
4440 !            mSEC
4450 LET H3=260 ! GROUP EXECUTE
4460 !             TRIGGER
4470 !             MTA ACKNOW-
4480 !             LEDGE
4490 !             TIMEOUT,mSEC
4500 LET H4=600 ! DMM SELF-TEST
4510 !             TIMEOUT,mSEC
4520 LET D4=5 ! See definition
4530 !          above
4540 REM END CONSTANTS
4550 ! !!!!!!!!!!!!!!!!!!!!!!!!
```

INTERNAL DOCUMENTATION: SUBROUTINES
TWO AND THREE ELECTRODE SYSTEMS

Note: This also contains the documentation for the two electrode system subroutines. File ZΘ: soft three electrode system; File Zδ*: two electrode system.

```
1000 ! ADMITTANCES▒CAPACITANCES
1010 ! SUBROUTINE DOCUMENTA-
1020 ! TION FOR PROG Z6* & Z0
1030 ! FREQUENCY MENU
1040 ! SHUFFLE (FLAG R5=0)
1050 ! FILE:Z‡SR
1060 ! UPDATED MAY 11/84
1070 REM FOR FURTHER DOCUMEN-
1080 ! TATION,SEE FILES Z6d &
1090 ! Z0d
1100 ! THE SUBROUTINES MARKED
1110 ! WITH A P REFER ONLY TO
1120 ! PROG Z0,THOSE MARKED
1130 ! WITH A R,TO PROG Z6*
1140 ! ONLY.THE UNMARKED SUB-
1150 ! ROUTINES ARE EITHER
1160 ! COMMON TO BOTH PROGS
1170 ! OR ACCOMPLISH SIMILAR
1180 ! TASKS
1190 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1200 ! JEAN LEDUC/CANMET/EMR/MSL
1210 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1220 DEFAULT OFF
1230 ! !!!!!!!!!!!!!!!!!!!!!!!!
1240 CLEAR @ DISP USING 1250 ;
1250 IMAGE "ADMITTANCES▒SR▒CAPAC
     ITANCES"
1260 DISP USING 1270 ;
1270 IMAGE "INTERNAL DOCUMENTATI
     ON",/,"OF THE SUBROUTINES",
     2/
1280 DISP USING 1290 ;
1290 IMAGE /,"FOR LISTING ONLY"
1300 DISP USING 1310 ;
1310 IMAGE 3/,3X,"FULL SYSTEM IM
     PLEMENTATION"
1320 IMAGE /5X,"FILES Z6* & Z0"
1330 DISP USING 1320 ;
1340 END
1350 !
1360 ! SUBROUTINES
1370 !
1380 ! SUBROUTINE START_METERS
1390 ! TRIGGERS BOTH METERS;
1400 ! CHECKS FOR MTA ACKNOW-
1410 ! DGE TIMEOUT;ENABLES
1420 ! THE DATA RDY BYTE INTER-
1430 ! RUPT
1440 ! FOR PROG Z6* ONLY:
1450 ! STARTS THE CLOCK FOR THE
1460 ! VERNIER PULSE CORRECTION
1470 RETURN
1480 END ! START_METERS
1490 !
1500 ! SUBROUTINE READ_&_CHECK
1510 ! UPON RECEIPT OF THE DATA
1520 ! RDY INTERRUPT FROM THE
1530 ! LCR METER,THIS SR READS
1540 ! IN THE DATA INTO AN I/O
1550 ! BUFFER AND CHECKS THE
1560 ! THROUGHPUT WITH RESPECT
1570 ! TO THE LCR METER SPECS;
1580 ! IT THEN (IF ALL IS WELL)
1590 ! FORMATS THE CONTENTS OF
1600 ! THE I/O BUFFER INTO NU-
1610 ! MERIC VARIABLES
1620 ! CALLS SR PULL_SCE (SEE
1630 ! BELOW)
1640 ! FOR PROG Z6* ONLY:
1650 ! CHECKS TO SEE IF /Z/
1660 ! FALLS BELOW THE CORRO-
1670 ! SION LIMIT.IF IT DOES
1680 ! IT FORCES AN ABORT VIA
1690 ! ITS ERROR FLAG
1700 RETURN
1710 END ! READ_&_CHECK
1720 !
1730 ! SUBROUTINE PULL_SCE
1740 ! SIMILAR TO ABOVE,FOR DMM
1750 RETURN
1760 END ! PULL_SCE
1770 !
1780 ! SUBROUTINE VERNIER_PULSE
1790 ! CASE A:PROG Z6*:
1800 ! MEASURES THE ACQUISITION
1810 ! TIME (INCLUDING HP-85
1820 ! TRANSACTIONS IN SR'S
1830 ! START_METER &
1840 ! READ_&_CHECK;COMPENSATES
1850 ! FOR THE RAMP TIMEOUT
1860 ! BY SENDING A CORRECTION
1870 ! PULSE TO THE DC BIAS
1880 ! DAC BEFORE RETURNING TO
1890 ! THE MAIN RAMP LOOP
1900 ! CASE B:PROG Z0
1910 ! IF THE COMPLIANCE FLAG
1920 ! IS TRUE,NOTHING HAPPENS;
1930 ! OTHERWISE,IT GIVES A TI-
1940 ! ME OF POTENTIOSTATIC
1950 ! RELAXATION TO THE CELL
1960 ! FOR A FRACTION OF THE
1970 ! INTERSAMPLING PERIOD
1980 RETURN
1990 END ! VERNIER_PULSE
2000 !
2010 ! SUBROUTINE GET_FREQUENCY
2020 ! WITH SOFT KEY ENTRY,GETS
2030 ! THE FREQUENCY MENU
2040 ! OUT:F,F0,C0,G0
2050 RETURN
2060 END ! GET_FREQUENCY
2070 !
2080 ! SUBROUTINE CHOOSE_ORDER
2090 ! INPUTS THE ORDER VECTOR
2100 ! (A PERMUTATION OF 1,2,3
2110 ! ,INCLUDING REPETITONS)
2120 ! AND PERMUTES ALL THE
2130 ! QUANTITIES ASSOCIATED
2140 ! WITH THE FREQUENCY MENU
2150 ! CAN BE DISABLED BY
2160 ! CLEARING FLAG R5 IN THE
2170 ! CODE
2180 RETURN
2190 END ! CHOOSE_ORDER
2200 !
2210 ! SUBROUTINE CHECK_DC
2220 ! MAKES THE SELF TEST ON
2230 ! THE DMM
2240 ! WARNS THE OPERATOR IF
2250 ! THE LCR METER DC BIAS
2260 ! SWITCH IS NOT IN THE
2270 ! PROPER POSITION.
2280 ! RECTIFICATION IS
2290 ! DEMANDED BEFORE THE PRO-
2300 ! GRAM IS ALLOWED TO
2310 ! RESUME
2320 ! OUT:E1:ABORT FLAG:SET
2330 ! ON TIMEOUT 7 IN CANCEL-
2340 ! LATION OF THE SERVICE
2350 ! REQUEST DATA READY BYTE
2360 RETURN
2370 END ! CHECK_DC
2380 !
2390 ! SUBROUTINE GET_AC
2400 ! WARNS THE OPERATOR IF
2410 ! THE AC VOLTAGE LEVEL IS
2420 ! BEYOND THE BOUNDS OF A
2430 ! PROPER ELECTROCHEMICAL
2440 ! PROTOCOL;DEMANDS RECTI-
2450 ! FICATION BEFORE THE PRO-
2460 ! GRAM IS ALLOWED TO RESUME
2470 ! OUT:V0,I8$
2480 !
2490 ! E1:ABORT FLAG:SET ON TI-
```

```
2500 ! MEOUT 7,BUS GARBLE OR
2510 ! DIGITAL OVERFLOW IN THE
2520 ! MONITOR ASCII QUEUE
2530 RETURN
2540 END ! GET_AC
2550 !
2560 !        ▒R▒
2570 ! SUBROUTINE SET_VOLTS
2580 ! THE PURPOSE OF THIS SUB-
2590 ! ROUTINE IS TO AVOID MO-
2600 ! VING THE CELL TOO RAPI-
2610 ! DLY FROM Usce=Urev TO
2620 ! THE DESIRED START SCAN
2630 ! VOLT
2640 ! A RAMP CONTROLLED BY
2650 ! THE OPERATOR GETS THE
2660 ! FROM Urev TO Ustart
2670 ! (SCE) AS GENTLY AS NEE-
2680 ! DED
2690 ! A RAMP RATE AS LOW AS
2700 ! 1 mV/S IS AVAILABLE
2710 ! ALSO PERFORMS DMM SELF-
2720 ! TEST
2730 RETURN
2740 END ! SET_VOLTS
2750 !
2760 ! SUBROUTINE GET_STATS
2770 ! CASE A PROG Z&*:
2780 ! TAKES 10 SAMPLES OF THE
2790 ! COMPLEX IMPEDANCES&Usce
2800 ! & COMPUTES THE STANDARD
2810 ! DEVIATIONS OF /Z/ AND θ
2820 ! KEEPS WATCH ON THE
2830 ! STATUS FLAGS OF BOTH
2840 ! ASCII QUEUES
2850 ! OUT:Z0,O0,S0,U8,U9
2860 ! E1:ERROR HALF NIBBLE
2870 ! 1:NO ERROR;2:MALFUNCTION
2880 ! SERVICE REQUEST;3:BUS
2890 ! GARBLE,TIMEOUT 7 OR
2900 ! GROUP EXECUTE TRIGGER
2910 ! MTA ACKNOWLEDGE TIMEOUT;
2920 ! 4:KEY#8 ABORT
2930 ! IS EXECUTED BEFORE
2940 ! THE REST OF THE ACQUI-
2950 ! SITION
2960 ! CASE B PROG Z0:
2970 ! COMPUTES FOR EACH CLASS
2980 ! A STANDARD DEVIATION
2990 ! BASED ON THE VARIATION
3000 ! BETWEEN FORWARD AND
3010 ! REVERSE STROKES
3020 ! THIS FOR Vbias,Usce
3030 ! (MEASURED),/Z/ AND θ
3040 ! EXECUTES LAST ACQUISI-
3050 ! TION
3060 RETURN
3070 END ! GET_STATS
3080 !
3090 ! SUBROUTINE SET_SAMPLES
3100 ! CASE A PROG Z&*:
3110 ! COMPUTES THE NUMBER OF
3120 ! SAMPLE POINTS,THE SAM-
3130 ! PLING PERIOD AND MAKES
3140 ! CONGRUENT WITH THE LATTE[
3150 ! THE SECOND END POINT (DC
3160 ! VOLT,BIAS MONITOR)
3170 ! IN:V (FROM SR GET_AC);
3180 ! OUT:U0:HERE=U2-U1 (U2 IS
3190 ! ALREADY CONGRUENT WITH
3200 ! THE SAMPLING PERIOD);
3210 ! U5,S9,D0,D
3220 REM As to D,it has the
3230 ! sign of D0
3240 ! CASE B PROG Z0:
3250 ! THE NUMBER OF POINTS IS
3260 ! FIXED.
3270 ! THE INITIAL AND FINAL
3280 ! DESIRED VALUES OF Usce
3290 ! ARE INPUTTED FROM THE
3300 ! KEYBOARD.IF THEIR
3310 ! ABSOLUTE DIFFERENCE IS
3320 ! LESS THAN 5*AC LEVEL,
3330 ! NEW KEYBOARD INPUT IS
3340 ! REQUESTED.
3350 ! MAKES THE FINAL Usce
3360 ! CONGRUENT WITH THE
3370 ! NUMBER OF POINTS
3380 ! OUT:U4,U5,U6,D0
3390 RETURN
3400 END ! SET_SAMPLES
3410 !
3420 ! SUBROUTINE ECHO
3430 ! CHECKS THE INTERNAL
3440 ! SETTINGS BYTE AND COM-
3450 ! PARE WITH THE DESIRED
3460 ! ONES;TERMINATES THE PRO-
3470 ! GRAM IN CASE OF A DIS-
3480 ! CREPANCY (E1=1,ABORT
3490 ! FLAG,TIMEOUT 7)
3500 ! IN:S9$,S8$,I8$,F$
3510 REM ONLY LCR METER
3520 RETURN
3530 END ! ECHO
3540 !
3550 ! SUBROUTINE EXPLAIN_SRQ
3560 ! IN CASE OF A SERVICE
3570 ! REQUEST FOR OTHER THAN
3580 ! THE DATA READY BYTE:
3590 ! DISPLAY OF THE SERIAL
3600 ! POLL BEFORE TERMINATION
3610 RETURN
3620 END ! EXPLAIN_SRQ
3630 !
3640 ! SUBROUTINE GET_FILE_NAME
3650 ! ASKS THE OPERATOR FOR
3660 ! FILE NAME
3670 ! CHECKS THE CATALOGUE AND
3680 ! REJECTS THE NAME
3690 ! IF INCLUDED IN DIRECTORY
3700 ! A NEW NAME MUST BE
3710 ! ENTERED FOR THE PROGRAM
3720 ! TO RESUME
3730 ! FOR FILE SPECS,SEE FILE
3740 ! Z0d OR Z&d
3750 RETURN
3760 END ! GET_FILE_NAME
3770 !
3780 ! SUBROUTINE GET_TAPE
3790 ! PRINTS ON TAPE THE DATA
3800 ! FOR PROCESSING.1 FILE
3810 ! RECORD PER MENU ITEM
3820 ! ERRORS HERE ARE NOT
3830 ! RECOVERABLE
3840 ! OUT:E1 ERROR BIT;SET
3850 ! SET FOR ABORT
3860 RETURN
3870 END ! GET_TAPE
3880 !
3890 ! SUBROUTINE EXPLAIN_ERROR
3900 ! THIS SUBROUTINE WILL
3910 ! DISPLAY THE ERROR CODES
3920 ! (INCLUDING THOSE OF THE
3930 !  INTERFACE AND ROM IF
3940 !  NEED BE) AND THE LINE
3950 !  NUMBER AT WHICH THE
3960 !  ERROR OCCURRED):
3970 !  GENERAL END_OF_LINE
3980 !  BRANCH OUTSIDE OF
3990 !  ACQUIRE BLOCK IN THE
4000 !  MENU LOOP;THIS BRAN-
4010 !  DOES NOT INVOLVE MIS-
4020 !  ALIGNED I/O BUFFERS
4030 RETURN
```

```
4040 END ! EXPLAIN_ERROR
4050 !
4060 !          ▒R▒
4070 ! SUBROUTINE WAIT_A_WHILE
4080 ! PURPOSE:TO OVERCOME
4090 ! THE 26 MINUTES LIMIT
4100 ! OF THE 'WAIT' FUNCTION
4110 ! IN:W0,W5,D7
4120 RETURN
4130 END ! WAIT_A_WHILE
4140 !
4150 !          ▒R▒
4160 ! SUBROUTINE GET_RELAXED
4170 ! DOES AN UPSTROKE-DOWN-
4180 ! STROKE WITHOUT ACQUISI-
4190 ! TION BEFORE ACQUISITION
4200 ! PURPOSE:TO ACQUIRE
4210 ! EQUILIBRIUM DURING
4220 ! ACQUISITION
4230 ! NUMBER OF THOSE PASSES
4240 ! ('CONDITIONNING PASSES')
4250 ! ASKED FOR AS WELL AS
4260 ! TOTAL NUMBER OF THOSE
4270 ! PASSES (v.g. IN A RE-
4280 ! LAXATION PROTOCOL).
4290 ! OUT:P8,P9
4300 RETURN
4310 END ! GET_RELAXED
4320 !
4330 ! SUBROUTINE MULT_IT
4340 ! WITH NUMERIC INPUTS
4350 ! 1,2, OR 3 GIVEN BY
4360 ! A KEY,PUTS THE AC
4370 ! OSCILLATOR MULTIPLIER
4380 ! AT .01,.1 OR 1
4390 ! CALLED BY SR GET_AC
4400 RETURN
4410 END ! MULT_IT
4420 !
4430 ! SUBROUTINE .01
4440 ! SETS THE INPUT OF SR
4450 ! MULT_IT (SEE ABOVE) AT
4460 ! 1 AND CALLS THE LATTER
4470 ! SR
4480 RETURN
4490 END ! .01
4500 !
4510 ! SUBROUTINE .1
4520 ! SIMILAR TO SR .01;INPUT
4530 ! OF SR MULT_IT SET AT 2
4540 RETURN
4550 END ! .1
4560 !
4570 ! SUBROUTINE 1
4580 ! SIMILAR TO SR .01;INPUT
4590 ! OF SR MULT_IT SET AT 3
4600 RETURN
4610 END ! 1
4620 !
4630 !          ▒R▒
4640 ! SUBROUTINE GET_RATE
4650 ! ALLOWS USER (WITH KEYS)
4660 ! TO CHOOSE EITHER A FAST
4670 ! (37 mV/min) OR SLOW
4680 ! (19 mV/min) SCAN RATE
4690 RETURN
4700 END ! GET_RATE
4710 !
4720 ! SUBROUTINE SHOW_DATA
4730 ! SHOWS ON CRT DATA AS
4740 ! THEY ARE ACQUIRED,EX-
4750 ! CLUSIVE OF THE DC
4760 ! BIASES
4770 RETURN
4780 END ! SHOW_DATA
4790 !
4800 ! SUBROUTINE PRINT_DATA
4810 ! CASE A PROG Z6*:
4820 ! PRINTS ON PAPER AFTER
4830 ! COMPLETION OF EACH ME-
4840 ! NU ITEM IN COLUMNS
4850 ! (STROKE BY STROKE) PT.
4860 ! #,Usce,/Z/,θ
4870 ! CASE B PROG Z8:
4880 ! AFTER COMPLETE ACQUISI-
4890 ! TION,EACH MENU ITEM
4900 ! HAS A PRINTING AS IN
4910 ! THE ABOVE,FOLLOWED BY
4920 ! A PRINTING OF THE STD.
4930 ! DEV.'S OF THOSE QUANTI-
4940 ! TIES,FOLLOWED BY A FULL
4950 ! PRINTING OF THE BIASES
4960 ! AND THEIR OWN STD.
4970 ! DEV'S.
4980 RETURN
4990 END ! PRINT_DATA
5000 !
5010 !          ▒P▒
5020 ! SUBROUTINE ACQUIRE
5030 ! CALLING SUBROUTINE;
5040 ! CALLS SR START_METERS,
5050 ! READ_&_CHECK,ECHO &
5060 ! SET_FREQUENCY
5070 RETURN
5080 END ! ACQUIRE
5090 !
5100 !          ▒P▒
5110 ! SUBROUTINE SET_FREQUENCY
5120 ! SETS THE LCR METER AT
5130 ! EACH OF THE THREE MENU
5140 ! FREQUENCIES BEFORE
5150 ! ACQUISITION
5160 ! OUTPUT:F$
5170 RETURN
5180 END ! SET_FREQUENCY
5190 !
5200 !          ▒P▒
5210 ! SUBROUTINE POTENTIOSTAT
5220 ! PLAYS THE ROLE OF A
5230 ! LOW COMPLIANCE,SMALL
5240 ! BAND PASS (10 Hz)
5250 ! SEQUENTIAL POTENTIOSTAT
5260 ! SETS THE COMPLIANCE
5270 ! FLAG TO FALSE IF MINI-
5280 ! MUM TOLERANCE BETWEEN
5290 ! MEASURED AND DEMANDED
5300 ! Usce NOT ACHIEVED
5310 ! IN:D8
5320 ! IN-OUT:U0,U1
5330 ! OUT:C9
5340 RETURN
5350 END ! POTENTIOSTAT
5360 !
5370 !          ▒P▒
5380 ! SUBROUTINE COMPLY
5390 ! CALLED BY SR POTENTIO-
5400 ! STAT
5410 ! ADJUSTS THE GAIN &
5420 ! RETARDATION ACCORDING
5430 ! TO THE ABSOLUTE ERROR
5440 ! BETWEEN  DEMANDED AND
5450 ! MEASURED Usce
5460 ! OUT:P2,F6
5470 RETURN
5480 END ! COMPLY
5500 !          ▒P▒
5510 ! SUBROUTINE GET_Urev
5520 ! WITH ZERO DC BIAS,
5530 ! TAKES 5 SAMPLINGS IN
5540 ! SUCCESSION OF Usce,
5550 ! TAKES AVERAGE AND STD.
5560 ! DEV. (EQUILIBRIUM
5570 ! POTENTIAL)
5580 ! OUT:U9,U8
5590 RETURN
5600 END ! GET_Urev
```

BARE CODE
SOFT THREE ELECTRODE SYSTEM

MAIN

```
1000 ! ADMITTANCES▒CAPACITANCES
1005 ! HI RESOLUTION (LCR)
1010 ! FILE Z8 ----FULL SYSTEM
1015 ! REVISED MAY 4/84
1020 ! POTENTIOSTATIC CONTROL
1025 ! RELAXATION BEFORE EACH
1030 ! ACQUISITION AT STEADY
1035 ! VOLT SCE
1040 ! PRODUCTION UNIT:
1045 REM FOR FURTHER DOCUMEN-
1050 ! TATION,SEE FILE Z8d
1055 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1060 ! JEAN LEDUC/CANMET/EMR/MSL
1065 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1070 DEFAULT OFF
1075 OPTION BASE 1
1080 SHORT V3(9),P3(9),F5(9),D7,
     S9,H1,H2,H3,H4,V0,V,D9,F6,D
     ,P2,U1,U0,U3,D8,U4,U5,U6,D5
1085 REAL U7,R,U8,U9,Z2,O2,B5,C1
     ,G1
1090 INTEGER O5(3),F(3),I9,S,I8,
     Q,N8,F9,E1,C,R5,E0,V1,S7,V7
     ,D0,I,I3,C9,D4,I4
1095 DIM Z(6,14),Z0(3,14),O(6,14
     ),O0(3,14),U(6,14),S0(3,14)
     ,V5(6,14),F0(3),C0(3),G0(3)
1100 DIM V6(3,14)
1105 DIM V$[19],U$[21],Z$[42],S8
     $[9],S9$[13],F$[2],S7$[25],
     I8$[1]
1110 DIM F9$[5]
1115 IOBUFFER V$
1120 IOBUFFER U$
1125 IOBUFFER Z$
1130 ! !!!!!!!!!!!!!!!!!!!!!!!!
1135 ! BEGIN MAIN
1140 CLEAR @ DISP USING 1305 ;
1145 IF ERROM=0 THEN 1165
1150 DISP USING 1155 ;
1155 IMAGE "I/O ROM ERROR",/,"@@
     @ABORT@@@"
1160 GOTO 2150
1165 ON ERROR GOTO 1180
1170 RESET 7
1175 OFF ERROR @ GOTO 1195
1180 OFF ERROR @ DISP USING 1185
      ; @ GOTO 2150
1185 IMAGE "INTERFACE FAILS SELF
      DIAGNOSIS",/,"@@@ABORT@@@"
1190 ENABLE KBD 33
1195 N8=14 @ Q=65 @ V7=1 @ H1=36
     0 @ H2=50 @ H3=260 @ H4=600
1200 DATA 1,.5,.25,.1,.05,.02,.0
     1,.005,.002
1205 FOR I=1 TO 9
1210 READ V3(I)
1215 NEXT I
1220 DATA 1.002,1.004,1.008,1.01
     6,1.032,1.064,1.128,1.128,1
      05
1225 FOR I=1 TO 9
1230 READ F5(I)
1235 NEXT I
1240 DATA 200,400,800,1600,2000,
     2000,2000,2000,250
1245 FOR I=1 TO 9
1250 READ P3(I)
1255 NEXT I
1260 DATA 5
1265 READ D4
1270 DATA .148,0
1275 READ C1,G1
1280 C=0
1285 REM :RANDOMIZE MENU
1290 LET R5=0 ! 1=NOT RANDOM
1295 PRINT USING 1305 ;
1300 WAIT 2000
1305 IMAGE "ADMITTANCES▒HI▒CAPAC
     ITANCES",/,"LARGE STEPS",/,
     "POTENTIOSTAT"
1310 ! CALL GET_FILE_NAME
1315 GOSUB 3905
1320 ENABLE KBD 32
1325 ABORTIO 7 @ REMOTE 717,723
     @ LOCAL LOCKOUT 7
1330 ! CALL CHECK_DC
1335 GOSUB 3020
1340 IF E1 THEN 2095
1345 CLEAR
1350 ON TIMEOUT 7 GOTO 1365 @ SE
     T TIMEOUT 7;H1
1355 OUTPUT 723 ;"F1R0N5T4Z1D1"
1360 OFF TIMEOUT 7 @ GOTO 1370
1365 OFF TIMEOUT 7 @ DISP "TIMEO
     UT,DMM SETTING" @ GOTO 2095
1370 ENABLE KBD 1
1375 CLEAR @ DISP "INTERSAMPLING
      RELAXATION" @ DISP "TIME,m
     in"
1380 DISP "MINIMUM:1 minute"
1385 DISP "ENTER";
1390 INPUT S9
1395 IF S9>1 THEN 1410
1400 DISP "▒TOO SHORT" @ DISP
1405 GOTO 1375
1410 D9=S9*60000
1415 D7=D9/D4
1420 CLEAR @ DISP USING 1425 ; S
     9
1425 IMAGE "INTERSAMPLING RELAXA
     TION",/,"TIME:",3X,2D.D," m
     in"
1430 DISP @ DISP "Urev + STD. DE
     V"
1435 ON TIMEOUT 7 GOTO 1450 @ SE
     T TIMEOUT 7;H1
1440 OUTPUT 717 ;"I1"
1445 OFF TIMEOUT 7 @ GOTO 1460
1450 OFF TIMEOUT 7 @ DISP "DMM H
     ANG-UP,SETTINGS"
1455 GOTO 2095
1460 ! CALL GET_Urev
1465 GOSUB 3320
1470 IF E1 THEN 2095
1475 PRINT USING 1480 ; U8,U9
1480 IMAGE "Urev=",SD.3D," +/- "
     ,SD.3D,3/
1485 ON TIMEOUT 7 GOTO 1500 @ SE
     T TIMEOUT 7;H1
1490 OUTPUT 723 ;"T1"
1495 OFF TIMEOUT 7 @ GOTO 1505
1500 OFF TIMEOUT 7 @ DISP "TIMEO
     UT,DMM SETTINGS" @ GOTO 231
     0
1505 ENABLE KBD 32
1510 ! CALL GET_AC
1515 GOSUB 3140
1520 IF E1 THEN 2095
1525 I8$=VAL$(I8)
1530 ENABLE KBD 1
1535 ! CALL SET_SAMPLES
1540 GOSUB 3600
1545 ENABLE KBD 32
1550 ! CALL GET_FREQUENCY
1555 GOSUB 2490
1560 REM SETTINGS
1565 ON TIMEOUT 7 GOTO 1580 @ SE
     T TIMEOUT 7;H1
1570 OUTPUT 717 ;"A4B1C2D0H1R31S
     0T3"
1575 OFF TIMEOUT 7 @ GOTO 1600
1580 OFF TIMEOUT 7
1585 CLEAR @ BEEP 5,1000
```

```
1590 DISP USING 2015 ; @ DISP US
     ING 2020 ; @ DISP USING 202
     5 ; @ GOTO 2095
1595 REM S8$,S9$:FOR ECHO TEST
1600 S8$=" A4B1C2D0" @ S9$="H1I1
     M"&I8$&"R31S0T3"
1605 IMAGE "BI",S3De,"V"
1610 CLEAR
1615 ON KEY# 8."STOP" GOTO 1925
1620 KEY LABEL
1625 DISP USING 1305 ;
1630 PRINT USING 1635 ; S9
1635 IMAGE "INTERSAMPLING RELAXA
     TION",/,2D.D," min"
1640 E0=0
1645 CLEAR @ KEY LABEL @ DISP US
     ING 1305 ;
1650 BEEP 5,1000 @ WAIT 3000 @ C
     LEAR
1655 STATUS 7,1 ; S@ S=SPOLL(717
     ) @ V1=SPOLL(723)
1660 U0=U4 @ U1=0
1665 ! STROKE COUNT LOOP
1670 ! $$$$$$$$$$$$$$$$$$$$$$$$$
1675 FOR I9=1 TO 2
1680 CLEAR
1685 ! SAMPLING LOOP
1690 ! @@@@@@@@@@@@@@@@@@@@@@@@@
1695 FOR I8=1 TO N8
1700 ON ERROR GOTO 1975
1705 D8=D9
1710 ! CALL POTENTIOSTAT
1715 GOSUB 4960
1720 ON E1 GOTO 1730,2095,1925,1
     940
1725 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1730 ! MENU LOOP
1735 FOR F9=1 TO 3
1740 ! CALL VERNIER_PULSE
1745 GOSUB 5480
1750 ON E1 GOTO 1755,2095,1925,1
     940
1755 I3=I9+2*(F9-1)
1760 ! CALL ACQUIRE
1765 GOSUB 4780
1770 ON E1 GOTO 1775,2095,1925,1
     940
1775 U(I3,I8)=B5 @ V5(I3,I8)=U1
1780 Z(I3,I8)=Z2 @ O(I3,I8)=O2
1785 NEXT F9
1790 ! END MENU LOOP
1795 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1800 ! CALL SHOW_DATA
1805 GOSUB 2420
1810 IF I8=N8 THEN 1820
1815 U0=U0+U6
1820 NEXT I8
1825 ! @@@@@@@@@@@@@@@@@@@@@@@@@
1830 ! END SAMPLING LOOP
1835 OFF ERROR @ OFF INTR 7 @ OF
     F TIMER# 1 @ OFF TIMER# 3
1840 CLEAR @ DISP "END STROKE" @
      BEEP 5,3000 @ WAIT 2000
1845 U6=-U6
1850 NEXT I9
1855 ! END STROKE COUNT LOOP
1860 ! $$$$$$$$$$$$$$$$$$$$$$$$$
1865 REM :NORMAL ESCAPE
1870 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 1 @ OFF TIMER# 3
1875 ! GET_STATS
1880 GOSUB 5410
1885 CLEAR @ KEY LABEL @ DISP US
     ING 1305 ; @ DISP USING 189
     0 ;
1890 IMAGE 3/,"END OF ACQUISITIO
     N",/,"TAPE I/O AND PRINTING
     FOLLOW"
1895 ! CALL GET_TAPE
1900 GOSUB 4045
1905 IF E1 THEN 2095
1910 ! CALL PRINT_DATA
1915 GOSUB 4190
1920 C,E1=0 @ GOTO 2095
1925 REM KEY#8 ESCAPE
1930 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 1 @ OFF TIMER# 3
1935 C=1 @ GOTO 2095
1940 REM :ILLEGAL SRQ ESCAPE
1945 ! OUTSIDE OF ACQUISITION
1950 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 1 @ OFF TIMER# 3
1955 STATUS 7,1 ; S@ S=SPOLL(717
     )
1960 ! CALL EXPLAIN_SRQ
1965 GOSUB 3795
1970 C=1 @ GOTO 2095
1975 REM ERROR ESCAPE
1980 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 1 @ OFF TIMER# 3
1985 STATUS 7,1 ; S@ S=SPOLL(717
     )
1990 ! CALL EXPLAIN_ERROR
1995 GOSUB 4545
2000 C=1 @ GOTO 2095
2005 REM ERROR MESSAGES
2010 ! ◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀
2015 IMAGE "BUS HANG-UP IN"
2020 IMAGE "FORMATTED WRITE,"
2025 IMAGE "INITIAL,SETTINGS"
2030 IMAGE "DC BIAS STATUS CHECK
     "
2035 IMAGE "INITIAL DC BIAS CODE
     "
2040 IMAGE "UNFORMATTED WRITE,"
2045 IMAGE "RAMP LOOP"
2050 IMAGE "GRP EXEC TRIG",/,"MT
     A ACK TIMEOUT"
2055 IMAGE "UNFORMATTED READ,"
2060 IMAGE "ACQUIRE BLOCK"
2065 IMAGE "INTERCALATED PULSE"
2070 IMAGE "INTERFACE GARBLE,"
2075 IMAGE "OVER- OR UNDER-FLOW,
     LCR",/,"MAIN MEMORY"
2080 ! ◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀
2085 REM END ERROR MESSAGES
2090 REM :COM ESCAPE POINT
2095 ASSIGN# 7 TO *
2100 DISP "TERMINATE" @ BEEP
2105 STATUS 7,1 ; S@ S=SPOLL(717
     ) @ V1=SPOLL(723)
2110 OUTPUT 717 ;"BI000E00VI0"
2115 OUTPUT 723 ;"KM00"
2120 DISP USING 2125 ;
2125 IMAGE "DON'T FORGET TO SWIT
     CH OFF",/,"THE DC BIAS SWIT
     CH BEFORE",/,"REMOVING THE
     CELL"
2130 LOCAL 7 @ ABORTIO 7
2135 BEEP @ DISP "END OF" @ DISP
      USING 1305 ;
2140 DISP USING 2145 ;
2145 IMAGE "THE PROCESSOR FILE N
     AME IS:",/,10X,"Z8RC"
2150 END ! MAIN
```

SUBROUTINES

```
2170 ! SUBROUTINE START_METERS
2175 E1=1
2180 ON KEY# 8,"STOP" GOTO 2245
2185 ON TIMER# 1,H3 GOTO 2200
2190 SEND 7 ; MTA UNL LISTEN 17,
     23
2195 STATUS 7,2 ; S@ IF BIT(S,0)
      THEN 2195 ELSE 2210
2200 OFF ERROR @ OFF INTR 7 @ OF
     F KEY# 8 @ OFF TIMER# 1
2205 DISP USING 2050 ; @ E1=2 @
     GOTO 2250
2210 OFF TIMER# 1 @ STATUS 7,1 ;
      S@ S=SPOLL(717) @ V1=SPOLL
     (723)
2215 OFF INTR 7 @ ON INTR 7 GOTO
      4855
2220 TRIGGER 717,723 @ RESUME 7
2225 WAIT 1000
2230 REM The RETURN to avoid
2235 REM timing problem
2240 ENABLE INTR 7;8 @ ON KEY# 8
     ,"STOP" GOTO 1925 @ RETURN
2245 OFF INTR 7 @ OFF KEY# 8 @ E
     1=3
2250 RETURN
2255 END ! START_METERS
2260 !
2265 ! SUBROUTINE READ_&_CHECK
2270 E1=1 @ ON KEY# 8,"STOP" GOT
     O 2400
2275 IF S=Q AND V1=V7 THEN 2285
2280 OFF KEY# 8 @ E1=4 @ E0=1 @
     GOTO 2405
2285 ! CALL PULL_SCE
2290 GOSUB 4415
2295 IF E1>1 THEN 2405
2300 CONTROL Z$,0 ; 1,0
2305 ON TIMEOUT 7 GOTO 2320 @ SE
     T TIMEOUT 7;H2
2310 TRANSFER 717 TO Z$ FHS
2315 OFF TIMEOUT 7 @ GOTO 2335
2320 OFF TIMEOUT 7 @ OFF KEY# 8
2325 DISP USING 2015 ; @ DISP US
     ING 2055 ; @ DISP USING 206
     0 ;
2330 E1=2 @ GOTO 2405
2335 ON ERROR GOTO 2355
2340 ENTER Z$ USING 2345 ; Z2,Q2
2345 IMAGE #,6X,D.5De,3X,2D.5De
2350 OFF ERROR @ GOTO 2370
2355 OFF ERROR @ OFF KEY# 8
2360 DISP USING 2070 ; @ DISP US
     ING 2060 ;
2365 E1=2 @ GOTO 2405
2370 REM Num ch in LCR main
2375 ! ASCII queue:34
2380 CONTROL Z$,0 ; 1,34
2385 IF Z$[4,4]&Z$[19,19]="NN" T
     HEN 2395
2390 OFF KEY# 8 @ DISP USING 207
     5 ; @ E1=2 @ GOTO 2405
2395 ON KEY# 8,"STOP" GOTO 1925
     @ GOTO 2405
2400 OFF ERROR @ OFF TIMEOUT 7 @
      OFF KEY# 8 @ E1=3
2405 RETURN
2410 END ! READ_&_CHECK
2420 ! SUBROUTINE SHOW_DATA
2425 IF RMD(I8-1,14)#0 AND RMD(I
     8-1,3)#0 THEN 2440
2430 CLEAR @ DISP USING 2435 ;
2435 IMAGE "F!","S!","pt#!","Usc
     e,V !","/Z/,Ω     !θ,deg"
2440 FOR F9=1 TO 3
2445 S=I9+2*(F9-1)
2450 DISP USING 2455 ; F9,I9,I8,
     U(S,I8),Z(S,I8),O(S,I8)
2455 IMAGE 2(D,"!"),2D,X,"!",SZ.
     3D," !",D.3De,"!",3D.D
2460 NEXT F9
2465 DISP
2470 RETURN
2475 END ! SHOW_DATA
2490 ! SUBROUTINE GET_FREQUENCY
2495 ON KEY# 1,"A" GOTO 2525 @ O
     N KEY# 2,"B" GOTO 2530 @ ON
      KEY# 3,"C" GOTO 2535
2500 ON KEY# 4,"D" GOTO 2540
2505 CLEAR @ DISP USING 2510 ; @
      DISP USING 2515 ; @ KEY LA
     BEL
2510 IMAGE "FREQUENCY MENUS"
2515 IMAGE "A:.2,2,20 KHz",/,"B:
     .4,4,40 KHz",/,"C:1,10,100
     KHz",/,"D:.4,1,2 KHz"
2520 GOTO 2520
2525 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ RE
     STORE 2550 @ E1=1 @ GOTO 25
     70
2530 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ RE
     STORE 2555 @ E1=2 @ GOTO 25
     70
2535 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ RE
     STORE 2560 @ E1=3 @ GOTO 25
     70
2540 OFF KEY# 4 @ OFF KEY# 1 @ O
     FF KEY# 2 @ OFF KEY# 3 @ RE
     STORE 2565 @ E1=4 @ GOTO 25
     70
2545 REM REMOTE CODES
2550 DATA 13,16,19
2555 DATA 14,17,20
2560 DATA 15,18,21
2565 DATA 14,15,16
2570 READ F(1),F(2),F(3)
2575 ON E1 GOTO 2580,2590,2600,2
     610
2580 RESTORE 2625
2585 GOTO 2615
2590 RESTORE 2630
2595 GOTO 2615
2600 RESTORE 2635
2605 GOTO 2615
2610 RESTORE 2640
2615 READ F0(1),F0(2),F0(3)
2620 REM FREQS,KHz
2625 DATA .2,2,20
2630 DATA .4,4,40
2635 DATA 1,10,100
2640 DATA .4,1,2
2645 ON E1 GOTO 2650,2660,2670,2
     680
2650 RESTORE 2720
2655 GOTO 2685
2660 RESTORE 2730
2665 GOTO 2685
2670 RESTORE 2740
2675 GOTO 2685
2680 RESTORE 2750
2685 READ C0(1),C0(2),C0(3)
2690 READ G0(1),G0(2),G0(3)
2695 REM DMM CORRECTIONS,
2700 REM PARALLEL;BY PAIRS OF
2705 REM DATA STMTS
2710 REM TOP OF PAIR:C,nF;
2715 REM BOTTOM OF PAIR:G,nS
2720 DATA .5187,.37946,.034914
2725 DATA 39.7,2819.7,9735.6
```

```
2730 DATA .5128,.21541,.025577
2735 DATA 156,6082,9998
2740 DATA .47558,.068393,.022641
2745 DATA 889,9108.8,10502
2750 DATA .5128,.47558,.37946
2755 DATA 156,889,2819
2760 IF R5=1 THEN 2775
2765 ! CALL CHOOSE ORDER
2770 GOSUB 2825
2775 PRINT USING 2780 ; F0(1),F0
     (2),F0(3)
2780 IMAGE "MENU FREQUENCIES,KHz
     ",/,3(3D.D,X)
2785 CLEAR
2790 FOR F9=1 TO 3
2795 C0(F9)=C0(F9)+C1
2800 G0(F9)=G0(F9)+G1
2805 NEXT F9
2810 RETURN
2815 END ! GET_FREQUENCY
2825 ! SUBROUTINE CHOOSE_ORDER
2830 CLEAR @ DISP "ENTER ORDER"
2835 ENABLE KBD 1
2840 DISP "▒";
2845 INPUT O5(1),O5(2),O5(3)
2850 FOR S=1 TO 3
2855 IF O5(S)>=1 AND O5(S)<=3 TH
     EN 2865
2860 GOTO 2875
2865 NEXT S
2870 GOTO 2880
2875 DISP "◀IMPROPER ENTRY◀" @ G
     OTO 2840
2880 ENABLE KBD 32
2885 FOR S=1 TO 3
2890 Z(1,S)=F0(O5(S))
2895 NEXT S
2900 FOR S=1 TO 3
2905 F0(S)=Z(1,S)
2910 NEXT S
2915 FOR S=1 TO 3
2920 Z(1,S)=C0(O5(S))
2925 NEXT S
2930 FOR S=1 TO 3
2935 C0(S)=Z(1,S)
2940 NEXT S
2945 FOR S=1 TO 3
2950 Z(1,S)=G0(O5(S))
2955 NEXT S
2960 FOR S=1 TO 3
2965 G0(S)=Z(1,S)
2970 NEXT S
2975 FOR S=1 TO 3
2980 O5(S)=F(O5(S))
2985 NEXT S
2990 FOR S=1 TO 3
2995 F(S)=O5(S)
3000 NEXT S
3005 RETURN
3010 END ! CHOOSE ORDER
3015 !
3020 ! SUBROUTINE CHECK_DC
3025 E1=0
3030 ON TIMEOUT 7 GOTO 3045 @ SE
     T TIMEOUT 7;H4
3035 CLEAR 723
3040 OFF TIMEOUT 7 @ GOTO 3055
3045 OFF TIMEOUT 7 @ E1=1 @ DISP
      "DMM FAILS SELF-TEST"
3050 GOTO 3125
3055 ON TIMEOUT 7 GOTO 3070 @ SE
     T TIMEOUT 7;H1
3060 OUTPUT 717 ;"I0"
3065 OFF TIMEOUT 7 @ GOTO 3080
3070 OFF TIMEOUT 7 @ E1=1 @ DISP
      USING 2015 ; @ DISP USING
     2020 ; @ DISP USING 2025 ;
3075 GOTO 3125
3080 OFF KEY# 1 @ S=SPOLL(717)
3085 ON TIMEOUT 7 GOTO 3100 @ SE
     T TIMEOUT 7;H1
3090 OUTPUT 717 ;"BI000E00V"
3095 OFF TIMEOUT 7 @ GOTO 3125
3100 OFF TIMEOUT 7
3105 CLEAR @ BEEP 5,1000 @ ON KE
     Y# 1 GOTO 3080
3110 IMAGE "PUT THE DC BIAS SWIT
     CH",/,"IN 'int' POSITION,PL
     EASE",/,"WHEN DONE,PUSH KEY
     #1"
3115 DISP USING 3110 ;
3120 GOTO 3120
3125 RETURN
3130 END ! CHECK_DC
3140 ! SUBROUTINE GET_AC
3145 E1=0
3150 I8=1
3155 ! CALL MULT_IT
3160 GOSUB 4610
3165 IF E1 THEN 3235
3170 ON KEY# 7,"READY" GOTO 3185
3175 CLEAR @ KEY LABEL @ DISP "A
     C LEVEL ADJUST"
3180 IF E1 THEN 3235 ELSE 3180
3185 OFF KEY# 7
3190 ON TIMEOUT 7 GOTO 3205 @ SE
     T TIMEOUT 7;H1
3195 OUTPUT 717 ;"LV"
3200 OFF TIMEOUT 7 @ GOTO 3215
3205 OFF TIMEOUT 7
3210 GOTO 3235
3215 CONTROL Z$,0 ; 21,20@ ON TI
     MEOUT 7 GOTO 3230 @ SET TIM
     EOUT 7;H2
3220 TRANSFER 717 TO Z$ FHS
3225 OFF TIMEOUT 7 @ GOTO 3240
3230 OFF TIMEOUT 7
3235 DISP USING 2015 ; @ GOTO 32
     60
3240 E1=Z$[21,21]=" " @ S=Z$[22,
     22]="N" @ IF E1 AND S THEN
     3270
3245 CLEAR @ IF S THEN 3255
3250 DISP USING 2070 ; @ GOTO 32
     60
3255 DISP "BUS GARBLE"
3260 DISP "◀AC LEVEL ROUTINE◀"
3265 GOTO 3305
3270 ENTER Z$ USING 3275 ; V0
3275 IMAGE 3X,2D.2De
3280 IF V0>=.004 AND V0<=.006 TH
     EN 3295
3285 DISP "READJUST" @ WAIT 1000
3290 E1=0 @ GOTO 3170
3295 V=V0 @ V0=V0*1000 @ DISP US
     ING 3300 ; V0 @ WAIT 4000 @
      CLEAR @ E1=0
3300 IMAGE "AC OK DON'T TOUCH",/
     ,"AC VLT:",3D.D," mV R.M.S.
     "
3305 OFF KEY# 7 @ OFF KEY# 1 @ O
     FF KEY# 2 @ OFF KEY# 3 @ RE
     TURN
3310 END ! GET_AC
3315 !
3320 ! SUBROUTINE GET_Urev
3325 E1=0
3330 U8,U9=0
3335 ON TIMER# 1,D9 GOTO 3345
3340 GOTO 3340
3345 OFF TIMER# 1
3350 ON TIMEOUT 7 GOTO 3365 @ SE
     T TIMEOUT 7;H1
3355 OUTPUT 723 ;"KM01"
```

```
3360 OFF TIMEOUT 7 @ GOTO 3375
3365 OFF TIMEOUT 7 @ E1=1 @ DISP
      "HANG-UP,Urev ROUTINE"
3370 GOTO 3580
3375 STATUS 7,1 ; S@ S=SPOLL(723
     )
3380 FOR I8=1 TO 10
3385 SEND 7 ; MTA UNL LISTEN 23
3390 STATUS 7,2 ; S@ IF BIT(S,0)
      THEN 3390 ELSE 3400
3395 DISP USING 2050 ; @ E1=1 @
     GOTO 3580
3400 STATUS 7,1 ; S@ S=SPOLL(723
     )
3405 ON INTR 7 GOTO 3420 @ ENABL
     E INTR 7;8
3410 TRIGGER 723 @ RESUME 7
3415 GOTO 3415
3420 OFF INTR 7 @ STATUS 7,1 ; S
     @ WAIT 500 @ S=SPOLL(723)
3425 IF S=Q THEN 3440
3430 DISP "ILLEGAL SERVICE REQUE
     ST" @ DISP "Urev ROUTINE"
3435 E1=1 @ E0=1 @ GOTO 3580
3440 CONTROL U$,0 ; 1,0
3445 ON TIMEOUT 7 GOTO 3460 @ SE
     T TIMEOUT 7;H2
3450 TRANSFER 723 TO U$ FHS
3455 OFF TIMEOUT 7 @ GOTO 3480
3460 OFF TIMEOUT 7 @ OFF KEY# 8
3465 DISP USING 2015 ; @ DISP US
     ING 2055 ; @ DISP "DMM"
3470 E1=1
3475 GOTO 3580
3480 ON ERROR GOTO 3500
3485 ENTER U$ USING 3490 ; U7
3490 IMAGE #,SD.5De
3495 OFF ERROR @ GOTO 3515
3500 OFF ERROR @ DISP USING 3505
      ;
3505 IMAGE "GARBLE,BUS◄DMM"
3510 E1=1 @ GOTO 3580
3515 IF U7<9999990000 THEN 3530
3520 DISP "※DMM OVLD※"
3525 E1=1 @ GOTO 3580
3530 U8=U8+U7
3535 U9=U9+U7^2
3540 NEXT I8
3545 U8=U8/10
3550 U9=SQR(U9-U8^2*10)/3
3555 ON TIMEOUT 7 GOTO 3570 @ SE
     T TIMEOUT 7;H1
3560 OUTPUT 723 ;"KM00"
3565 OFF TIMEOUT 7 @ GOTO 3580
3570 OFF TIMEOUT 7 @ E1=1
3575 DISP "BUS HANG-UP,Urev ROUT
     INE"
3580 RETURN
3585 END ! GET_Urev
3595 !
3600 ! SUBROUTINE SET_SAMPLES
3605 U7=10*V
3610 CLEAR
3615 DISP "START SCE VLT",
3620 INPUT U4
3625 DISP "FINAL SCE VLT";
3630 INPUT U5
3635 V=U5-U4 @ D0=SGN(V) @ V=ABS
     (V)
3640 IF V>U7 THEN 3650
3645 DISP "IMPROPER VALUES" @ DI
     SP @ GOTO 3615
3650 S=FLOOR(1000*V+.5) @ S=S\N8
      @ U6=S/1000
3655 S=FLOOR(1000*U4+.5) @ U4=S/
     1000
3660 U7=U6
3665 IMAGE "ADJUSTED END SCE PTS
      :",/,2(SZ.3D,X),"VOLT",/,"
     BY STEPS OF:",SZ.3D," VOLT"
3670 U6=D0*U6
3675 U5=U4+(N8-1)*U6
3680 PRINT USING 3665 ; U4,U5,U7
3685 PRINT USING 3690 ; V0
3690 IMAGE "AC VLT:",2D.D," mV R
     .M.S."
3695 RETURN
3700 END ! SET_SAMPLES
3705 !
3710 ! SUBROUTINE ECHO
3715 E1=0
3720 ON TIMEOUT 7 GOTO 3735 @ SE
     T TIMEOUT 7;H1
3725 OUTPUT 717 ;"K"
3730 OFF TIMEOUT 7 @ ON TIMEOUT
     7 GOTO 3750 @ SET TIMEOUT 7
     ;H1 @ GOTO 3740
3735 OFF TIMEOUT 7 @ GOTO 3755
3740 ENTER 717 ; S7$
3745 OFF TIMEOUT 7 @ GOTO 3765
3750 OFF TIMEOUT 7 @ CLEAR @ BEE
     P 5,1000
3755 DISP USING 2015 ; @ DISP "*
     **ECHO TEST***"
3760 E1=1 @ GOTO 3780
3765 IF S7$=S8$&"F"&F$&S9$ THEN
     3780
3770 E1=1 @ DISP USING 3775 ;
3775 IMAGE "ERROR IN SETTINGS"
3780 RETURN
3785 END ! ECHO
3790 !
3795 ! SUBROUTINE EXPLAIN_SRQ
3800 CLEAR @ BEEP 5,1000 @ DISP
     "ILLEGAL SERVICE REQUEST"
3805 IF E0 THEN 3815
3810 S=SPOLL(717) @ STATUS 7,1 ;
      E1
3815 IF S=0 OR S=Q THEN 3850
3820 DISP @ DISP "LCR METER"
3825 FOR I8=3 TO 1 STEP -1
3830 IF BIT(S,I8) THEN 3840
3835 NEXT I8
3840 DISP USING 3845 ; I8
3845 IMAGE "MOST SEVERE BIT ASSE
     RTED IS# ",D
3850 IF E0 THEN 3860
3855 V1=SPOLL(723) @ STATUS 7,1
     ; E1
3860 IF V1=0 OR V1=Q OR V1=V7 TH
     EN 3890
3865 DISP @ DISP "DMM"
3870 FOR I8=5 TO 2 STEP -1
3875 IF BIT(V1,I8) THEN 3885
3880 NEXT I8
3885 DISP USING 3845 ; I8
3890 RETURN
3895 END ! EXPLAIN_SRQ
3905 ! SUBROUTINE GET_FILE_NAME
3910 CLEAR @ BEEP 5,1000 @ DISP
     "ENTER FILE NAME (5 CH MAX)
     ";
3915 ON ERROR GOTO 3930
3920 INPUT F9$
3925 OFF ERROR @ GOTO 3940
3930 OFF ERROR
3935 DISP "INPUT ERROR" @ WAIT 3
     000 @ GOTO 3910
3940 ON ERROR GOTO 3955
3945 REWIND
3950 OFF ERROR @ GOTO 3960
3955 OFF ERROR @ DISP "NO CASSET
     TE" @ WAIT 5000 @ GOTO 3910
```

```
3960 ON ERROR GOTO 3975
3965 CREATE F9$,3,1432
3970 OFF ERROR @ ASSIGN# 7 TO F9
     $ @ GOTO 4020
3975 OFF ERROR
3980 IMAGE "NAME IN CATALOGUE",/
     ,"CHOOSE ANOTHER"
3985 IMAGE "NOT ENOUGH ROOM TO C
     REATE",/,"A NEW FILE",/,"US
     E ANOTHER TAPE",/,"PAUSE"
3990 IF ERRN=63 THEN 4010
3995 DISP USING 3985 ; @ BEEP 20
     ,4000
4000 PAUSE
4005 GOTO 3960
4010 BEEP @ DISP USING 3980 ; @
     WAIT 3000
4015 GOTO 3910
4020 PRINT "FILE NAME:-";F9$
4025 CLEAR
4030 RETURN
4035 END ! GET_FILE_NAME
4040 !
4045 ! SUBROUTINE GET_TAPE
4050 U6=ABS(U6)
4055 ON ERROR GOTO 4165
4060 REWIND
4065 FOR F9=1 TO 3
4070 I3=2*F9-1 @ I=I3+1
4075 PRINT# 7,F9 ; N8,S9,F0(F9),
     V0,U4,U5,U6,U8,U9
4080 PRINT# 7 ; C0(F9)
4085 PRINT# 7 ; G0(F9)
4090 FOR S=1 TO N8
4095 PRINT# 7 ; U(I3,S),U(I,S),Z
     (I3,S),Z(I,S),O(I3,S),O(I,S
     )
4100 NEXT S
4105 FOR S=1 TO N8
4110 PRINT# 7 ; S0(F9,S),Z0(F9,S
     ),O0(F9,S)
4115 NEXT S
4120 FOR S=1 TO N8
4125 PRINT# 7 ; V5(I3,S),V5(I,S)
4130 NEXT S
4135 FOR S=1 TO N8
4140 PRINT# 7 ; V6(F9,S)
4145 NEXT S
4150 NEXT F9
4155 OFF ERROR @ CLEAR @ DISP @
     DISP "END TAPE WRITE"
4160 E1=0 @ GOTO 4175
4165 OFF ERROR @ E1=1 @ DISP USI
     NG 4170 ;
4170 IMAGE /,"※※TAPE I/O ERROR※※
     "
4175 RETURN
4180 END ! GET_TAPE
4190 ! SUBROUTINE PRINT_DATA
4195 IMAGE "pt#|","Usce,V |","/Z
     /,Ω      |θ,deg"
4200 IMAGE 2D,X,"|",SZ.3D," |",D
     .3De,"|",3D.D
4205 IMAGE "pt#|","δUsce,V|","δ/
     Z/,Ω    |δθ,deg"
4210 FOR F9=1 TO 3
4215 PRINT USING 4220 ; F0(F9)
4220 IMAGE /,"FREQUENCY:",3D.D,"
      KHz"
4225 PRINT @ PRINT "VALUES"
4230 FOR I9=1 TO 2
4235 S=I9+2*(F9-1)
4240 IF I9=1 THEN PRINT "FORWARD
      STROKE" ELSE PRINT "REVERS
     E STROKE"
4245 PRINT USING 4195 ;
4250 FOR I8=1 TO N8
4255 PRINT USING 4200 ; I8,U(S,I
     8),Z(S,I8),O(S,I8)
4260 NEXT I8
4265 NEXT I9
4270 PRINT @ PRINT "STANDARD DEV
     IATIONS"
4275 PRINT USING 4205 ;
4280 FOR I8=1 TO N8
4285 PRINT USING 4200 ; I8,S0(F9
     ,I8),Z0(F9,I8),O0(F9,I8)
4290 NEXT I8
4295 NEXT F9
4300 PRINT @ PRINT "DC BIAS VOLT
     S AND" @ PRINT "STANDARD DE
     VIATIONS"
4305 PRINT "FROM LEFT TO RIGHT I
     N ORDER" @ PRINT "OF THE AP
     PEARING FREQUENCIES" @ PRIN
     T
4310 PRINT "THE VOLTS"
4315 IMAGE "V#1    |V#2    |V#3"
4320 IMAGE SZ.3D,2("|",SZ.3D)
4325 FOR I9=1 TO 2
4330 IF I9=1 THEN PRINT "FORWARD
      STROKE" ELSE PRINT "REVERS
     E STROKE"
4335 PRINT USING 4315 ;
4340 FOR I8=1 TO N8
4345 ON I9 GOTO 4350,4360
4350 PRINT USING 4320 ; V5(1,I8)
     ,V5(3,I8),V5(5,I8)
4355 GOTO 4365
4360 PRINT USING 4320 ; V5(2,I8)
     ,V5(4,I8),V5(6,I8)
4365 NEXT I8
4370 NEXT I9
4375 PRINT "STANDARD DEVIATIONS"
4380 PRINT USING 4315 ;
4385 FOR I8=1 TO N8
4390 PRINT USING 4320 ; V6(1,I8)
     ,V6(2,I8);V6(3,I8)
4395 NEXT I6
4400 RETURN
4405 END ! PRINT_DATA
4410 !
4415 ! SUBROUTINE PULL_SCE
4420 ON KEY# 8,"STOP" GOTO 4525
4425 CONTROL U$,0 ; 1,0
4430 ON TIMEOUT 7 GOTO 4445 @ SE
     T TIMEOUT 7;H2
4435 TRANSFER 723 TO U$ FHS
4440 OFF TIMEOUT 7 @ GOTO 4460
4445 OFF TIMEOUT 7 @ OFF KEY# 8
4450 DISP USING 2015 ; @ DISP 27
     96;@ DISP 2830;@ E1=2
4455 GOTO 4530
4460 ON ERROR GOTO 4480
4465 ENTER U$ USING 4470 ; U7
4470 IMAGE SD.5De
4475 OFF ERROR @ GOTO 4495
4480 OFF ERROR @ OFF KEY# 8
4485 DISP USING 2070 ; @ E1=2
4490 GOTO 4530
4495 IF U7<9999990000 THEN 4515
4500 DISP "※DMM OVLD※"
4505 E1=2
4510 GOTO 4530
4515 B5=U7
4520 GOTO 4530
4525 OFF KEY# 8 @ E1=3
4530 ON KEY# 8,"STOP" GOTO 1925
     @ RETURN
4535 END ! PULL_SCE
4545 ! SUBROUTINE EXPLAIN_ERROR
4550 IF ERROM=0 THEN 4560
4555 DISP USING 1155 ;
4560 IF ERRSC=0 THEN 4575
```

```
4565 DISP USING 4570 ;
4570 IMAGE "INTERFACE ERROR";
4575 S=ERRN @ V1=ERRL
4580 DISP USING 4585 ; S,V1
4585 IMAGE "ERROR CODE IS:",3D,/
     ,"AT LINE#",4D
4590 RETURN
4595 END ! EXPLAIN_ERROR
4600 !
4605 !
4610 ! SUBROUTINE MULT_IT
4615 IMAGE "M",D
4620 ON TIMEOUT 7 GOTO 4635 @ SE
     T TIMEOUT 7,H1
4625 OUTPUT 717 USING 4615 ; I8
4630 OFF TIMEOUT 7 @ GOTO 4640
4635 OFF TIMEOUT 7 @ E1=1 @ GOTO
      4645
4640 ON KEY# 1,".01" GOSUB 4660
     @ ON KEY# 2,".1" GOSUB 4700
      @ ON KEY# 3,"1" GOSUB 4740
4645 RETURN
4650 END ! MULT_IT
4655 !
4660 ! SUBROUTINE .01
4665 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3
4670 I8=1
4675 ! CALL MULT_IT
4680 GOSUB 4610
4685 RETURN
4690 END ! .01
4695 !
4700 ! SUBROUTINE .1
4705 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3
4710 I8=2
4715 ! CALL MULT_IT
4720 GOSUB 4610
4725 RETURN
4730 END ! .1
4735 !
4740 ! SUBROUTINE 1
4745 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3
4750 I8=3
4755 ! CALL MULT_IT
4760 GOSUB 4610
4765 RETURN
4770 END ! 1
4780 ! SUBROUTINE ACQUIRE
4785 ! CALL SET_FREQUENCY
4790 GOSUB 4895
4795 IF NOT E1 THEN 4805
4800 E1=2 @ GOTO 4880
4805 ! CALL ECHO
4810 GOSUB 3710
4815 IF NOT E1 THEN 4840
4820 E1=2 @ GOTO 4880
4825 REM This SR has the data
4830 ! ready byte SRQ interrupt
4835 ! enabled
4840 ! CALL START_METERS
4845 GOSUB 2170
4850 IF E1=1 THEN 4850 ELSE 4880
4855 OFF INTR 7
4860 WAIT 500
4865 STATUS 7,1 ; S@ S=SPOLL(717
     ) @ V1=SPOLL(723)
4870 ! CALL READ_&_CHECK
4875 GOSUB 2265
4880 RETURN
4885 END ! ACQUIRE
4890 !
4895 ! SUBROUTINE SET_FREQUENCY
4900 E1=F(F9)
4905 ON TIMEOUT 7 GOTO 4920 @ SE
     T TIMEOUT 7;H1
4910 OUTPUT 717 USING 4925 ; E1
4915 OFF TIMEOUT 7 @ GOTO 4940
4920 OFF TIMEOUT 7 @ CLEAR @ BEE
     P
4925 IMAGE "F",2D
4930 DISP USING 2015 ; @ DISP US
     ING 2020 ; @ DISP USING 202
     5 ;
4935 E1=1 @ GOTO 4945
4940 F$=VAL$(E1) @ E1=0
4945 RETURN
4950 END ! SET_FREQUENCY
4960 ! SUBROUTINE POTENSTIOSTAT
4965 OFF KEY# 8
4970 CONTROL U$,0 ; 1,0
4975 OUTPUT U$ USING 4980 ; U0
4980 IMAGE #,"S.C.E.-",SZ.3D
4985 ON TIMEOUT 7 GOTO 5000 @ SE
     T TIMEOUT 7,H1
4990 OUTPUT 723 ;"N3Z0M01D3"&U$
4995 OFF TIMEOUT 7 @ GOTO 5015
5000 OFF INTR 7 @ OFF TIMEOUT 7
     @ OFF KEY# 8 @ OFF TIMEP# 1
      @ OFF TIMER# 3 @ E1=3
5005 STATUS 7,1 ; S@ S=SPOLL(723
     )
5010 DISP USING 2015 ; @ DISP US
     ING 2020 ; @ DISP "POTENTIO
     STAT" @ E1=2 @ GOTO 5290
5015 CONTROL U$,0 ; 1,0
5020 ON KEY# 8,"STOP" GOTO 5280
5025 ON TIMER# 3,D8 GOTO 5265
5030 SETTIME 0,100
5035 F6=1 @ C9=0
5040 ! HUNTING LOOP
5045 ON TIMER# 1,H3 GOTO 5060
5050 SEND 7 ; MTA UNL LISTEN 23
5055 STATUS 7,2 , S@ IF BIT(S,0)
      THEN 5055 ELSE 5075
5060 OFF KEY# 8 @ OFF TIMER# 1
5065 DISP "DMM HANG UP" @ DISP "
     POTENSTIOSTAT" @ E1=2
5070 GOTO 5290
5075 OFF TIMER# 1
5080 STATUS 7,1 ; S@ S=SPOLL(723
     )
5085 ON INTR 7 GOTO 5100 @ ENABL
     E INTR 7,8
5090 TRIGGER 723 @ RESUME 7
5095 GOTO 5095
5100 OFF INTR 7 @ STATUS 7,1 ; S
     @ S=SPOLL(723)
5105 IF S=Q THEN 5130
5110 OFF KEY# 8 @ OFF TIMER# 1 @
      OFF TIMER# 3 @ E1=4
5115 DISP "POTENTIOSTAT"
5120 GOTO 5290
5125 ON TIMEOUT 7 GOTO 5140 @ SE
     T TIMEOUT 7;H2
5130 TRANSFER 723 TO U$ FHS
5135 OFF TIMEOUT 7 @ GOTO 5160
5140 OFF TIMEOUT 7 @ OFF KEY# 8
     @ OFF TIMER# 1 @ OFF TIMER#
      3
5145 STATUS 7,1 ; S@ S=SPOLL(723
     )
5150 DISP USING 2015 ; @ DISP US
     ING 2035 ; @ DISP "POTENTIO
     STAT"
5155 E1=2 @ GOTO 5290
5160 ENTER U$ USING "D.3De" ; U3
5165 D=U3-U0 @ V=ABS(D)
5170 C9=V<=V3(9)
5175 IF C9 THEN 5255
5180 P2=P3(9) @ F6=F5(9)
5185 ! CALL COMPLY
```

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5190 GOSUB 5345
5195 IF E1 THEN 5265
5200 ON TIMEOUT 7 GOTO 5215 @ SE
     T TIMEOUT 7;H2
5205 U1=U1-F6*D @ OUTPUT V$ USIN
     G 5235 ; U1 @ TRANSFER V$ T
     O 717 FHS
5210 OFF TIMEOUT 7 @ GOTO 5240
5215 OFF TIMEOUT 7 @ OFF KEY# 8
     @ OFF TIMER# 1 @ OFF TIMER#
      3
5220 STATUS 7,1 ; S@ S=SPOLL(723
     )
5225 DISP USING 2015 . @ DISP US
     ING 2040 , @ DISP "POTENTIO
     STAT"
5230 E1=2 @ GOTO 5290
5235 IMAGE #,"EI",S3De,"V"
5240 ON TIMER# 1,P2 GOTO 5250
5245 GOTO 5245
5250 OFF TIMER# 1
5255 GOTO 5045
5260 ! END HUNTING LOOP
5265 OFF INTR 7 @ OFF TIMEOUT 7
     @ OFF KEY# 8 @ OFF TIMER# 1
      @ OFF TIMER# 3
5270 STATUS 7,1 ; S@ S=SPOLL(723
     )
5275 E1=1 @ GOTO 5290
5280 OFF INTR 7 @ OFF TIMEOUT 7
     @ OFF KEY# 8 @ OFF TIMER# 1
      @ OFF TIMER# 3 @ E1=3
5285 STATUS 7,1 ; S@ S=SPOLL(723
     )
5290 ON TIMEOUT 7 GOTO 5305 @ SE
     T TIMEOUT 7,H1
5295 OUTPUT 723 ;"M00D1N5Z1K"
5300 OFF TIMEOUT 7 @ GOTO 5325
5305 OFF TIMEOUT 7
5310 IF E1=1 THEN E1=2
5315 DISP USING 2015 . @ DISP US
     ING 2020 : @ DISP "POTENTIO
     STAT"
5320 IF E1>1 THEN 5330
5325 ON KEY# 8,"STOP" GOTO 1925
     @ RETURN
5330 RETURN
5335 END ! POTENSTIOSTAT
5345 ! SUBROUTINE COMPLY
5350 OFF TIMER# 3 @ E1=0 @ D5=D8
-1000*TIME @ ON TIMER# 3,D5 GOTO
 5390
5355 FOR I=1 TO 8
5360 IF V<=V3(I) THEN 5375
5365 F2=P3(I) @ F6=F5(I)
5370 GOTO 5385
5375 NEXT I
5380 OFF TIMER# 3
5385 D5=D8-1000*TIME @ ON TIMER#
 3,D5 GOTO 5265 @ RETURN
5390 OFF TIMER# 3 @ E1=1
5395 RETURN
5400 END ! COMPLY
5410 ! SUBROUTINE GET_STATS
5415 FOR F9=1 TO 3
5420 S=2*F9-1 @ I=S+1
5425 FOR I8=1 TO N8
5430 I3=N8-I8+1
5435 Z0(F9,I8)=ABS(Z(S,I8)-Z(I,I
     3))/2
5440 O0(F9,I8)=ABS(O(S,I8)-O(I,I
     3))/2
5445 S0(F9,I8)=ABS(U(S,I8)-U(I,I
     3))/2
5450 V6(F9,I8)=ABS(V5(S,I8)-V5(I
     ,I3))/2
5455 NEXT I8
5460 NEXT F9
5465 RETURN
5470 END ! GET_STATS
5475 !
5480 ! SUBROUTINE VERNIER_PULSE
5485 D8=D7
5490 FOR I4=1 TO D4
5495 IF C9 THEN 5520
5500 ! CALL POTENTIOSTAT
5505 GOSUB 4960
5510 IF E1 THEN 5520
5515 NEXT I4
5520 RETURN
5525 END ! VERNIER_PULSE
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TWO ELECTRODE SYSTEM
BASIC LISTING

INTERNAL DOCUMENTATION

```
1000 ! ADMITTANCES▒CAPACITANCES
1010 ! HI RESOLUTION (LCR)
1020 ! PRODUCTION UNIT
1030 ! INTERNAL DOCUMENTATION
1040 ! FOR PROG Z&* ONLY
1050 ! FILE:Z&d
1060 ! UPDATED MAY 9/84
1070 ! RANDOMIZING MENU FREQU-
1080 ! ENCIES
1090 ! NEEDS 32K RAM
1100 ! EXTRA RELAX TIME AFTER
1110 ! FREQUENCY SWITCHING
1120 ! BEFORE THE MENU,MEASURES
1130 ! Urev AND ITS STANDARD
1140 ! DEVIATION
1150 ! DOUBLE LINEAR RAMP &
1160 ! IMPEDANCE ACQUISITION
1170 ! WITH HP#4274 LCR METER
1180 ! AND HP#3478A DMM
1190 ! FOLLOWED BY TAPE STORAGE
1200 ! OF THE DATA
1210 ! >FOR ELECTROLYTIC CELLS<
1220 ! SOME KEYBOARD INPUTS FOR
1230 ! DATA USED BY THE PROCES-
1240 ! SOR WILL BE ASKED
1250 ! AFTER THE CHOICE OF THE
1260 ! FREQUENCY MENU,THE USER
1270 ! IS INVITED TO INPUT
1280 ! A PERMUTATION OF 1,2,3
1290 ! (INCLUDING REPETITONS)
1300 ! THIS WILL HAVE THIS EF-
1310 ! FECT OF ALTERING THE
1320 ! SEQUENCE OF THE FREQUEN-
1330 ! CIES AND/OR OF INTRODU-
1340 ! DING REPETITIONS
1350 ! THIS FEATURE CAN BE TUR-
1360 ! NED OFF OR ON BY SETTING
1370 ! OR CLEARING FLAG R5 AT
1380 ! THE START OF MAIN
1390 ! CHOICE OF TWO SCAN
1400 ! RATES:FAST:37 mV/min
1410 ! AND SLOW:19 mV/min
1420 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1430 ! JEAN LEDUC/CANMET/MSL
1440 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1450 !
1460 REM TIMERS
1470 !      IN MAIN
1480 ! #1:IN ACQUIRE BLOCK:
1490 !     WILL DECLARE MTA
1500 !     ACKNOWLEDGE TIMEOUT
1510 !     PRIOR TO ORDERING
1520 !     THE GROUP EXECUTE
1530 !     TRIGGER COMMAND.
1540 !     THIS IS A FATAL RUN
1550 !     TIME ERROR:THE PRO-
1560 !     GRAM IS TERMINATED
1570 ! #2:RAMP LOOP;CONTROLS
1580 !     DC BIAS UPDATE
1590 ! #3:CONTROLS THE SAMPLING
1600 !     PERIOD
1610 !       SUBROUTINES
1620 !       GET_STATS
1630 ! #1:SAME FUNCTION AS IN
1640 !     MAIN
1650 ! #2:HAS A PERIOD OF 30
1660 !     SEC.CONTROLS SAM-
1670 !     PLING OF 10 VALUES
1680 !     OF IMPEDANCES IN OR-
1690 !     DER TO GET THE STAN-
1700 !     DARD DEVIATIONS
1710 !       SET_VOLTS
1720 ! #2:SAME AS IN MAIN
1730 !       GET_RELAXED
1740 ! #2:SAME AS IN MAIN
1750 !       ALL PROGRAM:
1760 !       TIMEOUT 7
1770 ! INTERFACE TIMER:GIVES
1780 ! TOTAL PROTECTION AGAINST
1790 ! CRASHES DUE TO BUS HANG-
1800 ! UPS FOR FORMATTED I/O
1810 ! AND FIRST HANDSHAKE PRO-
1820 ! TECTION AGAINST SAME FOR
1830 ! UNFORMATTED I/O
1840 ! (HP-85 vs LCR & DMM)
1850 ! THESE TIMEOUTS ARE FATAL
1860 ! RUN TIME ERRORS:THE PRO-
1870 ! GRAM TERMINATES
1880 ! THERE IS AN EXCEPTION:
1890 ! IN SR CHECK_DC,THE SE-
1900 ! COND TIMEOUT INDICATES
1910 ! THAT THE OPERATOR HAS
1920 ! TO PUT THE DC BIAS
1930 ! IN ITS PROPER POSITION.
1940 ! A WARNING IS ISSUED AND
1950 ! UPON RECTIFICATION,THE
1960 ! PROGRAM RESUMES.
1970 ! >>>>>>>>>>>>>>>>>>>>>>>
1980 REM END TIMERS
1990 ! ◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄
2000 REM END-OF-LINE BRANCHES
2010 ! REQUEST FOR SERVICE
2020 ! INTERRUPT (BYTE 8)
2030 ! THIS CAN MEAN EITHER
2040 ! DATA READY (SERIAL POLL
2050 ! BYTE 65) OR MALFUNCTION
2060 ! IN THE LATTER CASE,THE
2070 ! PROGRAM IS TERMINATED
2080 !
2090 ! THE ERROR BRANCH
2100 ! IN MAIN,AT THE START,
2110 ! A HARDWARE SELF TEST IS
2120 ! MADE OF THE INTERFACE.
2130 ! FAILURE OF THE TEST IS
2140 ! A FATAL RUN TIME ERROR
2150 ! AND TERMINATES THE PRO-
2160 ! GRAM
2170 ! ALSO CONTINUES TO MONI-
2180 ! TOR THIS SITUATION
2190 ! THROUGHOUT THE PROGRAM
2200 !
2210 ! IN MAIN (ACQUIRE BLOCK),
2220 ! CHECKS THE ALIGNMENT OF
2230 ! THE I/O BUFFER AGAINST
2240 ! METERS FORMAT SPECS
2250 REM It was found that
2260 ! pick-up could severely
2270 ! mangle the throughput
2280 ! to the I/O buffer from
2290 ! the LCR meter ASCII
2300 ! queues
2310 REM An identical test is
2320 ! made when the LCR meter
2330 ! monitor ASCII queue is
2340 ! accessed by means of
2350 ! string logic (SR GET_AC)
2360 ! In SR GET_STATS,both LCR
2370 ! meter ASCII queues are
2380 ! accessed,and an iden-
2390 ! tical test is made
2400 ! This holds for the DMM
2410 ! ASCII queue as well.
2420 ! IF THIS MISALIGNMENT
2430 ! OCCURS,THIS IS A FATAL
2440 ! RUN TIME ERROR AND THE
2450 ! PROGRAM IS TERMINATED
2460 !
2470 ! ERROR BRANCH IN TAPE
2480 ! HANDLERS:
2490 ! SR GET_FILE_NAME
2500 ! THAT BRANCH ALLOWS
2510 ! RECOVERY FROM TAPE
2520 ! ERRORS SUCH AS:
2530 ! NO CASSETTE,IDENTIFIER
```

```
2540 ! CONFLICT,TAPE FULL,etc
2550 ! SR GET_TAPE:HERE A TAPE
2560 ! ERROR IS A FATAL RUN TI-
2570 ! ME ERROR AND THE PROGRAM
2580 ! IS TERMINATED
2590 ! ◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀◀
2600 REM END END-OF-LINE
2610 ! $$$$$$$$$$$$$$$$$$$$$$$$
2620 REM TAPE THROUGHPUT
2630 ! A FILE NAME IS ASKED AS
2640 ! AS KBD INPUT.THIS FILE
2650 ! NAME WILL BE THE IDENTI-
2660 ! FIER OF THE OUPUT FILE
2670 ! THE FILE HAS 3 LOGICAL
2680 ! RECORDS OF 2170 BYTES
2690 ! EACH;THIS CORRESPONDS
2700 ! TO 9 PRU'S.
2710 ! THIS GIVES A TOTAL OF 27
2720 ! PRU'S (6912 BYTES)
2730 REM FOR THE FORMAT DETAIL,
2740 REM SEE THE CODE IN FILE
2750 REM Z6
2760 ! $$$$$$$$$$$$$$$$$$$$$$$$
2770 REM END TAPE THROUGHPUT
2780 ! !!!!!!!!!!!!!!!!!!!!!!!!
2790 REM  VARS
2800 ! F9$:   OUTPUT FILE NAME
2810 ! U8,U9:REVERSIBLE POTEN-
2820 ! TIAL AND ITS STANDARD
2830 ! DEVIATION,RESPECTIVELY,
2840 ! IN VOLT
2850 ! U1,U2:VOLTAGE LIMITS
2860 !        RAMP (WE-CE),VLT
2870 ! D0:    THE SIGNUM OF
2880 !        THEIR DIFFERENCE
2890 ! U3:    SINCE U1 & U2 ARE
2900 !        ESTIMATES,THIS
2910 !        STORES THE REMOTE
2920 !        CODES OF DC BIAS
2930 !        AT THE START AND
2940 !        THE END OF EACH
2950 !        STROKE,FOR EACH
2960 !        MENU ITEM
2970 !        [1:3;1:2]ARRAY OF
2980 !        LONG REAL
2990 ! U7,V:  SCRATCH VARS
3000 ! U0:    INSTANTANEOUS DC
3010 !        BIAS,(WE-CE),VLT
3020 ! U:     Usce (DC) (VLT):
3030 !        [1:2;1:42] ARRAY
3040 !        OF LONG REAL
3050 ! S0:    STANDARD DEV OF
3060 !        ABOVE,VLT
3070 ! R0:    RAMP COURSE COR-
3080 !        RECTION TALLY
3090 ! U$,V$,Z$:I/O BUFFERS
3100 ! S9$,S8$,F$:SETTINGS
3110 !               VARS
3120 ! V0:    AC VLT,mV;R.M.S.
3130 ! I8$:   ASCII VALUE OF
3140 !        AC OSCILLATOR
3150 !        LEVEL MULTIPLIER;
3160 !        OUTPUTTED BY SR
3170 !        GET_AC AND USED
3180 !        AS (PARTIAL) INPUT
3190 !        BY SR ECHO
3200 ! Z:     MODULI OF
3210 !        THE IMPEDANCES,Ω:
3220 !        [1:2;1:42] ARRAY
3230 !        OF LONG REAL
3240 ! O:     PHASE (DEG) OF
3250 !        THE IMPEDANCES:
3260 !        [1:2;1:42] ARRAY
3270 !        OF LONG REAL
3280 ! Z0,O0:STD. DEV. OF ABOVE
3290 !        QUANTITIES
3300 ! O3:           IF /Z/ FALLS
3310 !               BELOW THIS
3320 !               VALUE,THIS
3330 !               WILL BE TAKEN
3340 !               AS A SIGN OF
3350 !               MASSIVE COR-
3360 !               ROSION;THIS
3370 !               IS A FATAL
3380 !               RUN TIME
3390 !               ERROR
3400 ! C0,G0:PARALLEL COR-
3410 !        RECTIONS FOR DMM
3420 !        LOADING
3430 !        C0:CAPACITANCE,nF;
3440 !        G0:CONDUCTANCE,nS
3450 !        BOTH:[1:3]ARRAYS
3460 !        OF LONG REAL
3470 ! S9:    SAMPLING PERIOD,
3480 !        mSEC
3490 ! R8:    NOMINAL RAMP
3500 !        PERIOD,mSEC
3510 ! R3:    NOMINAL SCAN RATE,
3520 !        mV/min
3530 ! R9:    RAMP PERIOD,COR-
3540 !        RECTED FOR RAMP
3550 !        PULSE WIDTH,mSEC
3560 ! I9:    STROKE COUNTER
3570 ! I8:    SAMPLING COUNTER
3580 ! F9:    MENU COUNTER
3590 ! F:     MENU VECTOR:
3600 !        [1:3] ARRAY OF
3610 !        INTEGER
3620 ! O5:    MENU ORDERING VEC-
3630 !        TOR;[1:3] ARRAY
3640 !        OF INTEGER
3650 ! F0:    ACTUAL FREQUENCIES
3660 !        CORRESPONDING TO
3670 !        THE MENU VECTOR,
3680 !        KHz:
3690 !        [1:3] ARRAY OF
3700 !        LONG REAL
3710 ! N8:    NUM. PTS/STROKE
3720 ! S:     INTERFACE AND/OR
3730 !        LCR METER REGISTER
3740 !        DECIMAL VALUE
3750 ! V1     DMM REGISTER,DECI-
3760 !        MAL VALUE
3770 ! E1,C,E0:FLAGS
3780 ! T4:    RAMP TIMEOUT,SEC
3790 ! D9    :INTERMENU RELAXA-
3800 !        TION PERIOD,min
3810 ! W0:    BOOLEAN:IF THE
3820 !        WAITING PERIOD
3830 !        IS LESS THAN 26
3840 !        MINUTES,SET TO
3850 !        TRUE
3860 ! W5:    FOR W0 FALSE,NUM-
3870 !        BER (INTEGER) OF
3880 !        TIMES THAT D9 GOES
3890 !        INTO 26 MINUTES
3900 ! D7:    IF W0 TRUE:=D9
3910 !        ELSE REMAINDER
3920 !        OF D9 MODULO 26
3930 !        MINUTES
3940 ! P8:    NUM OF CONDITIO-
3950 !        NING CYCLES BEFORE
3960 !        THAT PARTICULAR
3970 !        RUN
3980 ! P9:    CUMULATIVE NUMBER
3990 !        OF CONDITIONING
4000 !        CYCLES
4010 REM END VARS
4020 ! !!!!!!!!!!!!!!!!!!!!!!!!
4030 REM CONSTANTS
4040 ! C1,G1:PARALLEL CORREC-
4050 ! FOR DMM COAX LOADING;
4060 ! C1:CAPACITANCE,nF
4070 ! G1:CONDUCTANCE,nS
```

```
4080 LET C1= 148
4090 LET G1=0
4100 LET N0=42 ! BASIC ARRAY
4110 !           DIMENSION
4120 LET D=.001 ! 1mV INCREMENT
4130 LET T5=.111 ! RAMP PULSE
4140 !             WIDTH,SEC
4150 LET Q=65 ! DATA RDY BYTE
4160 !          BOTH FOR THE
4170 !          DMM & LCR ME-
4180 !          TER:SERIAL RE-
4190 !          GISTER MASKED
4200 LET V7=1 ! SIMILAR FOR THE
4210 !          DMM,BUT WITH
4220 !          UNMASKED SERI-
4230 !          AL POLL REGIS-
4240 !          TER
4250 LET H1=360 ! FORMATTED I/O
4260 !            TIMEOUT,mSEC
4270 LET H2=50 ! UNFORMATTED
4280 !           I/OTIMEOUT,
4290 !           mSEC
4300 LET H3=260 ! GROUP EXECUTE
4310 !            TRIGGER
4320 !            MTA ACKNOW-
4330 !            LEDGE
4340 !            TIMEOUT,mSEC
4350 LET H4=600 ! DMM SELF-TEST
4360 !            TIMEOUT,mSEC
4370 LET P=.002 ! CPU STACK
4380 !            PUSH-PULL DE-
4390 !            LAY,SEC
4400 LET H5=26 ! MAXIMUM
4410 !            ARGUMENT OF
4420 !            'WAIT' IN
4430 !            MINUTES
4440 REM END CONSTANTS
4450 ! !!!!!!!!!!!!!!!!!!!!!!!!
```

BARE CODE

MAIN

```
1000 ! ADMITTANCES▒CAPACITANCES
1005 ! HI RESOLUTION (LCR)
1010 ! FILE:Z6*----FULL SYSTEM
1015 ! TESTED FEB 29/84
1020 ! MAINTENANCE:MAY/3/84
1025 ! SLOW FREQUENCY MENU
1030 ! DOCUMENTS THE CUMULATIVE
1035 ! NUMBER OF CONDITIONNING
1040 ! PASSES
1045 ! CHOICE OF SCAN RATES:
1050 ! 37 mV/min OR 19 mV/min
1055 ! PRODUCTION UNIT:
1060 REM FOR FURTHER DOCUMEN-
1065 ! TATION,SEE FILE Z6d
1070 ! EXTRA WAIT BEFORE Urev
1075 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1080 ! JEAN LEDUC/CANMET/EMR/MSL
     1036 ! CHOICE OF SCAN RATES
     :
1085 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1090 DEFAULT OFF
1095 OPTION BASE 1
1100 SHORT R,D,T9,S9,R9,D0,H1,H2
     ,H3,H4,H5,R8,V0,V,R0,P,D9,D
     7,R3
1105 REAL U1,U2,T4,U0,U7,Z0,O0,S
     0,U8,U9,O3,C1,G1
1110 INTEGER O5(3),F(3),I9,S,I8,
     N0,Q,N8,F9,E1,C,R5,E0,V1,S7
     ,V7,W0,W5,P9,P8
1115 DIM Z(2,42),O(2,42),U(2,42)
     ,U3(3,2),F0(3),C0(3),G0(3)
1120 DIM V$[19],U$[21],Z$[42],S8
     $[9],S9$[13],F$[2],S7$[25],
     I8$[1]
1125 DIM F9$[5]
1130 IOBUFFER V$
1135 IOBUFFER U$
1140 IOBUFFER Z$
1145 ! !!!!!!!!!!!!!!!!!!!!!!!!!
1150 ! BEGIN MAIN
1155 CLEAR @ DISP USING 1250 ;
1160 IF ERROM=0 THEN 1180
1165 DISP USING 1170 ;
1170 IMAGE "I/O ROM ERROR",/,"@@
     @ABORT@@@"
1175 GOTO 2440
1180 ON ERROR GOTO 1195
1185 RESET 7
1190 OFF ERROR @ GOTO 1210
1195 OFF ERROR @ DISP USING 1200
      ; @ GOTO 2440
1200 IMAGE "INTERFACE FAILS SELF
      DIAGNOSIS",/,"@@@ABORT@@@"
1205 ENABLE KBD 33
1210 N0=42 @ D=.001 @ T9=.111 @
     R8=1500 @ Q=65 @ V7=1 @ H1=
     360 @ H2=50 @ H3=260 @ H4=6
     00
1215 P=.002 @ H5=26 @ R3=37
1220 C1=.148 @ G1=0
1225 C=0
1230 REM :RANDOMIZE MENU
1235 LET R5=0 ! 1=NOT RANDOM
1240 PRINT USING 1250 ;
1245 WAIT 10000
1250 IMAGE "ADMITTANCES▒HI▒CAPAC
     ITANCES",/,"CONDITIONING",/
     ,"RATES"
1255 ! CALL GET_FILE_NAME
1260 GOSUB 4795
1265 ENABLE KBD 32
1270 ABORTIO 7 @ REMOTE 717,723
     @ LOCAL LOCKOUT 7
1275 ! CALL CHECK_DC
1280 GOSUB 3385
1285 IF E1 THEN 2380
1290 ! CALL GET_RATE
1295 GOSUB 5800
1300 R9=R8-T9*1000
1305 CLEAR
1310 ON TIMEOUT 7 GOTO 1325 @ SE
     T TIMEOUT 7;H1
1315 OUTPUT 723 ;"F1R0N5T3Z1D1"
1320 OFF TIMEOUT 7 @ GOTO 1330
1325 OFF TIMEOUT 7 @ DISP "TIMEO
     UT,DMM SETTING" @ GOTO 2380
1330 CLEAR @ DISP "INTERMENU REL
     AXATION TIME,min";
1335 ENABLE KBD 1
1340 INPUT D9
1345 W0=D9<=H5
1350 IF W0 THEN 1370
1355 W5=D9\H5
1360 D7=H5*FP(D9/H5)
1365 H5=H5*60000 @ GOTO 1375
1370 D7=D9
1375 D7=D7*60000 @ D9=D9*60000
1380 CLEAR @ DISP USING 1385 ; D
     9/60000
1385 IMAGE "Urev:PRELIMINARY REL
     AXATION:-",/,3X,2D.D," min"
1390 ! CALL WAIT_A_WHILE
1395 GOSUB 5315
1400 DISP "Urev + STD. DEV" @ DI
     SP "5min"
1405 ON TIMEOUT 7 GOTO 1420 @ SE
     T TIMEOUT 7;H1
1410 OUTPUT 717 ;"I1"
1415 OFF TIMEOUT 7 @ GOTO 1430
1420 OFF TIMEOUT 7 @ DISP "DMM H
     ANG-UP,SETTINGS"
1425 GOTO 2380
1430 ! CALL GET_STATS
1435 GOSUB 3680
1440 ON E1 GOTO 1445,2250,2380,2
     215
1445 U9=S0 @ U8=U(1,2)
1450 PRINT USING 1455 ; U8,U9
1455 IMAGE "Urev=",SD.3D," +/- "
     ,SD.3D,3/
1460 ON TIMEOUT 7 GOTO 1475 @ SE
     T TIMEOUT 7;H1
1465 OUTPUT 723 ;"T1"
1470 OFF TIMEOUT 7 @ GOTO 1480
1475 OFF TIMEOUT 7 @ DISP "TIMEO
     UT,DMM SETTINGS" @ GOTO 260
     0
1480 ENABLE KBD 33
1485 ! CALL SET_VOLTS
1490 GOSUB 4055
1495 ON E1 GOTO 1500,2380,2230
1500 ENABLE KBD 32
1505 ! CALL GET_AC
1510 GOSUB 3505
1515 IF E1 THEN 2380
1520 I8$=VAL$(I8)
1525 ENABLE KBD 0
1530 ! CALL SET_SAMPLES
1535 GOSUB 4500
1540 ENABLE KBD 32
1545 ! CALL GET_FREQUENCY
1550 GOSUB 2855
1555 REM SETTINGS
1560 ON TIMEOUT 7 GOTO 1575 @ SE
     T TIMEOUT 7;H1
1565 OUTPUT 717 ;"A4B1C2D0H1R31S
     0T3"
1570 OFF TIMEOUT 7 @ GOTO 1595
1575 OFF TIMEOUT 7
1580 CLEAR @ BEEP 5,1000
1585 DISP USING 2305 ; @ DISP US
     ING 2310 ; @ DISP USING 231
     5 ; @ GOTO 2380
```

```
1590 REM S8$,S9$:FOR ECHO TEST
1595 S8$=" A4B1C2D0" @ S9$="H1I1
     M"&I8$&"R31S0T3"
1600 IMAGE "BI",S3De,"V"
1605 ENABLE KBD 32
1610 CLEAR
1615 ON KEY# 8,"STOP" GOTO 2215
1620 KEY LABEL
1625 DISP USING 1250 ; @ DISP
1630 DISP USING 1640 ; D9/60000
1635 PRINT USING 1640 ; D9/60000
1640 IMAGE "PRE MENU CELL RELAXA
     TION",/,2D.D," min"
1645 ! CALL WAIT_A_WHILE
1650 GOSUB 5315
1655 E0=0 @ U0=U1-D
1660 ENABLE KBD 33
1665 ! CALL GET_RELAXED
1670 GOSUB 5360
1675 IF E1 THEN 2380
1680 ENABLE KBD 32
1685 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
1690 ! MENU LOOP
1695 FOR F9=1 TO 3
1700 PRINT
1705 CLEAR @ KEY LABEL @ DISP US
     ING 1250 ;
1710 BEEP 5,1000 @ WAIT 3000 @ C
     LEAR
1715 E1=F(F9)
1720 ON TIMEOUT 7 GOTO 1735 @ SE
     T TIMEOUT 7;H1
1725 OUTPUT 717 USING 1740 ; E1
1730 OFF TIMEOUT 7 @ GOTO 1755
1735 OFF TIMEOUT 7 @ CLEAR @ BEE
     P
1740 IMAGE "F",2D
1745 DISP USING 2305 ; @ DISP US
     ING 2310 ; @ DISP USING 231
     5 ;
1750 GOTO 2380
1755 CLEAR
1760 DISP USING 1765 ; F9,D9/600
     00
1765 IMAGE "MENU ITEM#",D,/,"REL
     AXATION:",2D.D," min"
1770 ! CALL WAIT_A_WHILE
1775 GOSUB 5315
1780 F$=VAL$(E1)
1785 ! CALL ECHO
1790 GOSUB 4600
1795 IF E1 THEN 2380
1800 CLEAR @ DISP USING 1805 ; F
     9,F0(F9)
1805 IMAGE "FREQ #",D,X,3D.D," K
     Hz",X,"STD. DEV.'S",/,"5 mi
     n"
1810 ! CALL GET_STATS
1815 GOSUB 3680
1820 ON E1 GOTO 1825,2250,2380,2
     215
1825 PRINT USING 1830 ; F9,F0(F9
     )
1830 IMAGE /,"MENU ITEM#:",D," F
     REQ.",3D.D," KHz",/
1835 PRINT USING 1840 ; Z0,O0
1840 IMAGE "STD. DEV. [/Z/]=",2D
     .3De," Ω",/,"STD. DEV. [θ]=
     ",D.D," deg"
1845 O3=Z(1,2)/5
1850 PRINT USING 1855 ; O3
1855 IMAGE "MIN /Z/ FOR CORROSIO
     N ABORT:",/,D.2De," Ω"
1860 PRINT USING 1865 ; S0
1865 IMAGE "STD. DEV. [Usce]=",Z
     .3D," VOLT"
1870 STATUS 7,1 ; S@ S=SPOLL(717
     ) @ V1=SPOLL(723)
1875 ! STROKE COUNT LOOP
1880 ! $$$$$$$$$$$$$$$$$$$$$$$$$
1885 FOR I9=1 TO 2
1890 R0=0
1895 U3(F9,I9)=U0
1900 CLEAR
1905 ! SAMPLING LOOP
1910 ! @@@@@@@@@@@@@@@@@@@@@@@@@
1915 FOR I8=1 TO N8
1920 ON INTR 7 GOTO 2240 @ ENABL
     E INTR 7;8
1925 ON ERROR GOTO 2265
1930 IF I8=1 THEN 2000
1935 ! RAMP LOOP
1940 ! &&&&&&&&&&&&&&&&&&&&&&&&&
1945 OFF TIMER# 2
1950 ON TIMEOUT 7 GOTO 1970 @ SE
     T TIMEOUT 7;H2
1955 U0=U0+D @ OUTPUT V$ USING 1
     965 ; U0 @ TRANSFER V$ TO 7
     17 FHS
1960 OFF TIMEOUT 7 @ GOTO 1980
1965 IMAGE #,"BI",S3De,"V"
1970 OFF INTR 7 @ OFF TIMEOUT 7
     @ OFF KEY# 8 @ OFF TIMER# 3
1975 DISP USING 2305 ; @ DISP US
     ING 2330 ; @ DISP USING 233
     5 ; @ GOTO 2380
1980 ON TIMER# 2,R9 GOTO 1945
1985 GOTO 1985
1990 ! END RAMP LOOP
1995 ! &&&&&&&&&&&&&&&&&&&&&&&&&
2000 ! ACQUIRE BLOCK
2005 ! *************************
2010 OFF TIMER# 3 @ OFF TIMER# 2
      @ SETTIME 0,317
2015 REM This SR has the data
2020 ! ready byte SRQ interrupt
2025 ! enabled
2030 ! CALL START_METERS
2035 GOSUB 2460
2040 ON E1 GOTO 2040,2380,2215
2045 OFF INTR 7 @ SETTIME 0,317
2050 STATUS 7,1 ; S@ S=SPOLL(717
     ) @ V1=SPOLL(723)
2055 ! CALL READ_&_CHECK
2060 GOSUB 2555
2065 ON E1 GOTO 2070,2380,2215,2
     230
2070 ! CALL SHOW_DATA
2075 GOSUB 2730
2080 ! CALL VERNIER_PULSE
2085 GOSUB 2775
2090 ON E1 GOTO 2095,2380,2215
2095 ON TIMER# 3,S9 GOTO 2000
2100 ! END ACQUIRE
2105 ! *************************
2110 NEXT I8
2115 ! @@@@@@@@@@@@@@@@@@@@@@@@@
2120 ! END SAMPLING LOOP
2125 OFF ERROR @ OFF INTR 7 @ OF
     F TIMER# 2 @ OFF TIMER# 3
2130 CLEAR @ DISP "END STROKE" @
      BEEP 5,3000
2135 D=-D @ D0=-D0
2140 WAIT S9
2145 NEXT I9
2150 ! END STROKE COUNT LOOP
2155 ! $$$$$$$$$$$$$$$$$$$$$$$$$
2160 ! CALL GET_TAPE
2165 GOSUB 4935
2170 IF E1 THEN 2380
2175 ! CALL PRINT_DATA
2180 GOSUB 5050
2185 NEXT F9
2190 ! END MENU LOOP
```

```
2195 ! ▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒▒
2200 REM :NORMAL ESCAPE
2205 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 2 @ OFF TIMER# 3
2210 C,E1=0 @ GOTO 2380
2215 REM KEY#8 ESCAPE
2220 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 2 @ OFF TIMER# 3
2225 C=1 @ GOTO 2380
2230 REM :ILLEGAL SRQ ESCAPE
2235 ! OUTSIDE OF ACQUISITION
2240 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 2 @ OFF TIMER# 3
2245 STATUS 7,1 ; S@ S=SPOLL(717
     )
2250 ! CALL EXPLAIN_SRQ
2255 GOSUB 4685
2260 C=1 @ GOTO 2380
2265 REM ERROR ESCAPE
2270 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT# 7 @ OFF KEY# 8 @
     OFF TIMER# 2 @ OFF TIMER# 3
2275 STATUS 7,1 ; S@ S=SPOLL(717
     )
2280 ! CALL EXPLAIN_ERROR
2285 GOSUB 5255
2290 C=1 @ GOTO 2380
2295 REM ERROR MESSAGES
2300 ! ◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄
2305 IMAGE "BUS HANG-UP IN"
2310 IMAGE "FORMATTED WRITE,"
2315 IMAGE "INITIAL,SETTINGS"
2320 IMAGE "DC BIAS STATUS CHECK
     "
2325 IMAGE "INITIAL DC BIAS CODE
     "
2330 IMAGE "UNFORMATTED WRITE,"
2335 IMAGE "RAMP LOOP"
2340 IMAGE "GRP EXEC TRIG",/,"MT
     A ACK TIMEOUT"
2345 IMAGE "UNFORMATTED READ,"
2350 IMAGE "ACQUIRE BLOCK"
2355 IMAGE "INTERCALATED PULSE"
2360 IMAGE "INTERFACE GARBLE,"
2365 IMAGE "OVER- OR UNDER-FLOW,
     LCR",/,"MAIN MEMORY"
2370 ! ◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄◄
2375 REM END ERROR MESSAGES
2380 REM :COM ESCAPE POINT
2385 ASSIGN# 7 TO *
2390 DISP "TERMINATE" @ BEEP
2395 STATUS 7,1 ; S@ S=SPOLL(717
     ) @ V1=SPOLL(723)
2400 OUTPUT 717 ;"BI000E00VI0"
2405 OUTPUT 723 ;"KM00"
2410 DISP USING 2415 ;
2415 IMAGE "DON'T FORGET TO SWIT
     CH OFF",/,"THE DC BIAS SWIT
     CH BEFORE",/,"REMOVING THE
     CELL"
2420 LOCAL 7 @ ABORTIO 7
2425 BEEP @ DISP "END OF" @ DISP
      USING 1250 ;
2430 DISP USING 2435 ;
2435 IMAGE "THE PROCESSOR FILE N
     AME IS:",/,10X,"Z6RC*"
2440 END ! MAIN
```

SUBROUTINES

```
2460 ! SUBROUTINE START_METERS
2465 E1=1
2470 ON KEY# 8,"STOP" GOTO 2535
2475 ON TIMER# 1,H3 GOTO 2490
2480 SEND 7 , MTA UNL LISTEN 17,
     23
2485 STATUS 7,2 ; S@ IF BIT(S,0)
      THEN 2485 ELSE 2500
2490 OFF ERROR @ OFF INTR 7 @ OF
     F KEY# 8 @ OFF TIMER# 1
2495 DISP USING 2340 ; @ E1=2 @
     GOTO 2540
2500 OFF TIMER# 1 @ STATUS 7,1 ;
      S@ S=SPOLL(717) @ V1=SPOLL
     (723)
2505 OFF INTR 7 @ ON INTR 7 GOTO
      2045
2510 TRIGGER 717,723 @ RESUME 7
2515 WAIT 1000
2520 REM The RETURN to avoid
2525 REM timing problem
2530 ENABLE INTR 7;8 @ ON KEY# 8
     ,"STOP" GOTO 2215 @ RETURN
2535 OFF INTR 7 @ OFF KEY# 8 @ E
     1=3
2540 RETURN
2545 END ! START_METERS
2555 ! SUBROUTINE READ_&_CHECK
2560 E1=1 @ ON KEY# 8,"STOP" GOT
     O 2710
2565 IF S=Q AND V1=V7 THEN 2575
2570 OFF KEY# 8 @ E1=4 @ E0=1 @
     GOTO 2715
2575 ! CALL PULL_SCE
2580 GOSUB 5125
2585 IF E1>1 THEN 2715
2590 CONTROL Z$,0 ; 1,0
2595 ON TIMEOUT 7 GOTO 2610 @ SE
     T TIMEOUT 7;H2
2600 TRANSFER 717 TO Z$ FHS
2605 OFF TIMEOUT 7 @ GOTO 2625
2610 OFF TIMEOUT 7 @ OFF KEY# 8
2615 DISP USING 2305 ; @ DISP US
     ING 2345 ; @ DISP USING 235
     0 ;
2620 E1=2 @ GOTO 2715
2625 ON ERROR GOTO 2645
2630 ENTER Z$ USING 2635 ; Z(I9,
     I8),O(I9,I8)
2635 IMAGE #,6X,D.5De,3X,2D.5De
2640 OFF ERROR @ GOTO 2660
2645 OFF ERROR @ OFF KEY# 8
2650 DISP USING 2360 ; @ DISP US
     ING 2350 ;
2655 E1=2 @ GOTO 2715
2660 REM Num ch in LCR main
2665 ! ASCII queue:34
2670 CONTROL Z$,0 ; 1,34
2675 IF Z$[4,4]&Z$[19,19]="NN" T
     HEN 2685
2680 OFF KEY# 8 @ DISP USING 236
     5 ; @ E1=2 @ GOTO 2715
2685.IF Z(I9,I8)>03 THEN 2705
2690 OFF ERROR @ OFF INTR 7 @ OF
     F TIMEOUT 7 @ OFF KEY# 8 @
     OFF TIMER# 2 @ OFF TIMER# 3
2695 DISP "MASSIVE CORROSION"
2700 E1=2 @ GOTO 2715
2705 ON KEY# 8,"STOP" GOTO 2215
     @ GOTO 2715
2710 OFF ERROR @ OFF TIMEOUT 7 @
      OFF KEY# 8 @ E1=3
2715 RETURN
2720 END ! READ_&_CHECK
2730 ! SUBROUTINE SHOW_DATA
2735 IF RMD(I8-1,14)#0 THEN 2750
2740 CLEAR @ DISP USING 2745 ;
2745 IMAGE "F|","S|","pt#|","Usc
     e,V |","/Z/,Ω     |θ,deg"
2750 DISP USING 2755 ; F9,I9,I8,
     U(I9,I8),Z(I9,I8),O(I9,I8)
2755 IMAGE 2(D,"|"),2D,X,"|",SZ.
     3D," |",D.3De,"|",3D.D
2760 RETURN
2765 END ! SHOW_DATA
2775 ! SUBROUTINE VERNIER_PULSE
2780 E1=1 @ ON KEY# 8,"STOP" GOT
     O 2830
2785 T4=TIME @ T4=T4+T9+P
2790 T4=T4*1000+R0 @ R0=FP(T4) @
      V=FLOOR(T4)/R8
2795 IF V<1 THEN 2835
2800 U0=U0+D0*V/1000
2805 ON TIMEOUT 7 GOTO 2820 @ SE
     T TIMEOUT 7;H2
2810 OUTPUT V$ USING 1965 ; U0 @
      TRANSFER V$ TO 717 FHS
2815 OFF TIMEOUT 7 @ U0=U0+D @ G
     OTO 2835
2820 OFF TIMEOUT 7 @ OFF KEY# 8
2825 E1=2 @ GOTO 2840
2830 OFF TIMEOUT 7 @ OFF KEY# 8
     @ E1=3 @ GOTO 2840
2835 ON KEY# 8,"STOP" GOTO 2215
2840 RETURN
2845 END ! VERNIER PULSE
2855 ! SUBROUTINE GET_FREQUENCY
2860 ON KEY# 1,"A" GOTO 2890 @ O
     N KEY# 2,"B" GOTO 2895 @ ON
      KEY# 3,"C" GOTO 2900
2865 ON KEY# 4,"D" GOTO 2905
2870 CLEAR @ DISP USING 2875 ; @
      DISP USING 2880 ; @ KEY LA
     BEL
2875 IMAGE "FREQUENCY MENUS"
2880 IMAGE "A:.2,2,20 KHz",/,"B:
     .4,4,40 KHz",/,"C:1,10,100
     KHz',/,"D:.4,1,2 KHz"
2885 GOTO 2885
2890 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ RE
     STORE 2915 @ E1=1 @ GOTO 29
     35
2895 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ RE
     STORE 2920 @ E1=2 @ GOTO 29
     35
2900 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ RE
     STORE 2925 @ E1=3 @ GOTO 29
     35
2905 OFF KEY# 4 @ OFF KEY# 1 @ O
     FF KEY# 2 @ OFF KEY# 3 @ RE
     STORE 2930 @ E1=4 @ GOTO 29
     35
2910 REM REMOTE CODES
2915 DATA 13,16,19
2920 DATA 14,17,20
2925 DATA 15,18,21
2930 DATA 14,15,16
2935 READ F(1),F(2),F(3)
2940 ON E1 GOTO 2945,2955,2965,2
     975
2945 RESTORE 2990
2950 GOTO 2980
2955 RESTORE 2995
2960 GOTO 2980
2965 RESTORE 3000
2970 GOTO 2980
2975 RESTORE 3005
2980 READ F0(1),F0(2),F0(3)
```

```
2985 REM FREQS,KHz
2990 DATA .2,2,20
2995 DATA .4,4,40
3000 DATA 1,10,100
3005 DATA .4,1,2
3010 ON E1 GOTO 3015,3025,3035,3
     045
3015 RESTORE 3085
3020 GOTO 3050
3025 RESTORE 3095
3030 GOTO 3050
3035 RESTORE 3105
3040 GOTO 3050
3045 RESTORE 3110
3050 READ C0(1),C0(2),C0(3)
3055 READ G0(1),G0(2),G0(3)
3060 REM DMM CORRECTIONS,
3065 REM PARALLEL;BY PAIRS OF
3070 REM DATA STMTS
3075 REM TOP OF PAIR:C,nF;
3080 REM BOTTOM OF PAIR:G,nS
3085 DATA .5187,.37946,.034914
3090 DATA 39.7,2819.7,9735.6
3095 DATA .5128,.21541,.025577
3100 DATA 156,6082,9998
3105 DATA .47558,.068393,.022641
3110 DATA 889,9108.8,10502
3115 DATA .5128,.47558,.37946
3120 DATA 156,889,2819
3125 IF R5=1 THEN 3140
3130 ! CALL CHOOSE ORDER
3135 GOSUB 3190
3140 PRINT USING 3145 ; F0(1),F0
     (2),F0(3)
3145 IMAGE "MENU FREQUENCIES,KHz
     ",/,3(3D.D,X)
3150 CLEAR
3155 FOR F9=1 TO 3
3160 C0(F9)=C0(F9)+C1
3165 G0(F9)=G0(F9)+G1
3170 NEXT F9
3175 RETURN
3180 END ! GET_FREQUENCY
3190 ! SUBROUTINE CHOOSE_ORDER
3195 CLEAR @ DISP "ENTER ORDER"
3200 ENABLE KBD 1
3205 DISP "※";
3210 INPUT O5(1),O5(2),O5(3)
3215 FOR S=1 TO 3
3220 IF O5(S)>=1 AND O5(S)<=3 TH
     EN 3230
3225 GOTO 3240
3230 NEXT S
3235 GOTO 3245
3240 DISP "◀IMPROPER ENTRY◀" @ G
     OTO 3205
3245 ENABLE KBD 32
3250 FOR S=1 TO 3
3255 Z(1,S)=F0(O5(S))
3260 NEXT S
3265 FOR S=1 TO 3
3270 F0(S)=Z(1,S)
3275 NEXT S
3280 FOR S=1 TO 3
3285 Z(1,S)=C0(O5(S))
3290 NEXT S
3295 FOR S=1 TO 3
3300 C0(S)=Z(1,S)
3305 NEXT S
3310 FOR S=1 TO 3
3315 Z(1,S)=G0(O5(S))
3320 NEXT S
3325 FOR S=1 TO 3
3330 G0(S)=Z(1,S)
3335 NEXT S
3340 FOR S=1 TO 3
3345 O5(S)=F(O5(S))
3350 NEXT S
3355 FOR S=1 TO 3
3360 F(S)=O5(S)
3365 NEXT S
3370 RETURN
3375 END ! CHOOSE ORDER
3385 ! SUBROUTINE CHECK_DC
3390 E1=0
3395 ON TIMEOUT 7 GOTO 3410 @ SE
     T TIMEOUT 7;H4
3400 CLEAR 723
3405 OFF TIMEOUT 7 @ GOTO 3420
3410 OFF TIMEOUT 7 @ E1=1 @ DISP
      "DMM FAILS SELF-TEST"
3415 GOTO 3490
3420 ON TIMEOUT 7 GOTO 3435 @ SE
     T TIMEOUT 7;H1
3425 OUTPUT 717 ;"I0"
3430 OFF TIMEOUT 7 @ GOTO 3445
3435 OFF TIMEOUT 7 @ E1=1 @ DISP
      USING 2305 ; @ DISP USING
     2310 ; @ DISP USING 2315 ;
3440 GOTO 3490
3445 OFF KEY# 1 @ S=SPOLL(717)
3450 ON TIMEOUT 7 GOTO 3465 @ SE
     T TIMEOUT 7;H1
3455 OUTPUT 717 ;"BI000E00V"
3460 OFF TIMEOUT 7 @ GOTO 3490
3465 OFF TIMEOUT 7
3470 CLEAR @ BEEP 5,1000 @ ON KE
     Y# 1 GOTO 3445
3475 IMAGE "PUT THE DC BIAS SWIT
     CH",/,"IN 'int' POSITION,PL
     EASE",/,"WHEN DONE,PUSH KEY
     #1"
3480 DISP USING 3475 ;
3485 GOTO 3485
3490 RETURN
3495 END ! CHECK_DC
3505 ! SUBROUTINE GET_AC
3510 E1=0
3515 I8=1
3520 ! CALL MULT_IT
3525 GOSUB 5630
3530 IF E1 THEN 3600
3535 ON KEY# 7,"READY" GOTO 3550
3540 CLEAR @ KEY LABEL @ DISP "A
     C LEVEL ADJUST"
3545 IF E1 THEN 3600 ELSE 3545
3550 OFF KEY# 7
3555 ON TIMEOUT 7 GOTO 3570 @ SE
     T TIMEOUT 7;H1
3560 OUTPUT 717 ;"LV"
3565 OFF TIMEOUT 7 @ GOTO 3580
3570 OFF TIMEOUT 7
3575 GOTO 3600
3580 CONTROL Z$,0 ; 21,20@ ON TI
     MEOUT 7 GOTO 3595 @ SET TIM
     EOUT 7;H2
3585 TRANSFER 717 TO Z$ FHS
3590 OFF TIMEOUT 7 @ GOTO 3605
3595 OFF TIMEOUT 7
3600 DISP USING 2305 ; @ GOTO 36
     25
3605 E1=Z$[21,21]=" " @ S=Z$[22,
     22]="N" @ IF E1 AND S THEN
     3635
3610 CLEAR @ IF S THEN 3620
3615 DISP USING 2360 ; @ GOTO 36
     25
3620 DISP USING 3895 ;
3625 DISP "◀AC LEVEL ROUTINE◀"
3630 GOTO 3665
3635 ENTER Z$ USING 3905 ; V0
3640 IF V0>=.004 AND V0<=.006 TH
     EN 3655
3645 DISP "READJUST" @ WAIT 1000
```

```
3650 E1=0 @ GOTO 3535
3655 V=V0 @ V0=V0*1000 @ DISP US
     ING 3660 ; V0 @ WAIT 4000 @
      CLEAR @ E1=0
3660 IMAGE "AC OK DON'T TOUCH",/
     ,"AC VLT:",3D.D," mV R.M.S.
     "
3665 OFF KEY# 7 @ OFF KEY# 1 @ O
     FF KEY# 2 @ OFF KEY# 3 @ RE
     TURN
3670 END ! GET_AC
3680 ! SUBROUTINE GET_STATS
3685 OFF KEY# 8 @ ON KEY# 8 GOTO
      4030
3690 Z(1,2),O(1,2),U(1,2),Z0,O0,
     S0=0
3695 E1=1
3700 FOR I8=1 TO 10
3705 ON TIMER# 2,30000 GOTO 3715
3710 GOTO 3710
3715 OFF TIMER# 2 @ ON TIMER# 1,
     H3 GOTO 3730
3720 SEND 7 ; MTA UNL LISTEN 17,
     23
3725 STATUS 7,2 , S@ IF BIT(S,0)
      THEN 3725 ELSE 3740
3730 OFF KEY# 8 @ OFF TIMER# 1
3735 DISP USING 2340 ; @ E1=3 @
     GOTO 4040
3740 OFF TIMER# 1 @ S=SPOLL(717)
      @ V1=SPOLL(723) @ STATUS 7
     ,1 ; S7
3745 ON INTR 7 GOTO 3760 @ ENABL
     E INTR 7;8
3750 TRIGGER 717,723 @ RESUME 7
3755 GOTO 3755
3760 OFF INTR 7 @ STATUS 7,1 ; S
     @ S=SPOLL(717) @ V1=SPOLL(7
     23)
3765 WAIT 1000
3770 IF S=Q AND V1=V7 THEN 3780
3775 E1=2 @ E0=1 @ OFF KEY# 8 @
     GOTO 4040
3780 CONTROL Z$,0 ; 1,0@ ON TIME
     OUT 7 GOTO 3795 @ SET TIMEO
     UT 7;H2
3785 TRANSFER 717 TO Z$ FHS
3790 OFF TIMEOUT 7 @ GOTO 3800
3795 OFF TIMEOUT 7 @ OFF KEY# 8
     @ GOTO 3870
3800 E1=Z$[1,1]=" " @ S=Z$[4,4]&
     Z$[19,19]="NN" @ IF E1 AND
     S THEN 3820
3805 CLEAR @ IF S THEN 3815
3810 DISP USING 3895 ; @ GOTO 39
     00
3815 DISP USING 2360 ; @ DISP US
     ING 2365 ; @ GOTO 3900
3820 ENTER Z$ USING 2635 ; Z(1,1
     ),O(1,1)
3825 Z(1,2)=Z(1,2)+Z(1,1) @ O(1,
     2)=O(1,2)+O(1,1) @ Z0=Z0+Z(
     1,1)^2 @ O0=O0+O(1,1)^2
3830 ON TIMEOUT 7 GOTO 3845 @ SE
     T TIMEOUT 7;H1
3835 OUTPUT 717 ;"LA"
3840 OFF TIMEOUT 7 @ GOTO 3850
3845 OFF TIMEOUT 7 @ OFF KEY# 8
     @ OFF TIMER# 2 @ GOTO 3870
3850 CONTROL Z$,0 ; 21,20@ ON TI
     MEOUT 7 GOTO 3865 @ SET TIM
     EOUT 7;H2
3855 TRANSFER 717 TO Z$ FHS
3860 OFF TIMEOUT 7 @ GOTO 3875
3865 OFF TIMEOUT 7 @ OFF KEY# 8
     @ OFF TIMER# 2
3870 DISP USING 2305 ; @ DISP US
     ING 2345 ; @ DISP "STD. DEV
     .'S" @ GOTO 3900
3875 E1=Z$[21,21]=" " @ S=Z$[22,
     22]="N" @ IF E1 AND S THEN
     3910
3880 CLEAR @ IF S THEN 3890
3885 DISP USING 2360 ; @ GOTO 39
     00
3890 DISP USING 3895 ;
3895 IMAGE "UNDER OR OVER FLOW",
     /,"LCR,MONITOR QUEUE"
3900 E1=3 @ GOTO 4040
3905 IMAGE #,3X,2D.2De
3910 CONTROL U$,0 ; 1,0
3915 ON TIMEOUT 7 GOTO 3930 @ SE
     T TIMEOUT 7;H2
3920 TRANSFER 723 TO U$ FHS
3925 OFF TIMEOUT 7 @ GOTO 3950
3930 OFF TIMEOUT 7 @ OFF KEY# 8
3935 DISP USING 2305 ; @ DISP US
     ING 2345 ; @ DISP "DMM"
3940 E1=3
3945 GOTO 4040
3950 ON ERROR GOTO 3970
3955 ENTER U$ USING 3960 ; V
3960 IMAGE #,SD.5De
3965 OFF ERROR @ GOTO 3985
3970 OFF ERROR @ OFF KEY# 8 @ DI
     SP USING 3975 ;
3975 IMAGE "GARBLE,BUS◀DMM"
3980 E1=3 @ GOTO 4040
3985 IF V<9999990000 THEN 4000
3990 DISP "※DMM OVLD※"
3995 E1=3 @ GOTO 4040
4000 U(1,2)=U(1,2)+V
4005 S0=S0+V^2
4010 NEXT I8
4015 Z(1,2)=Z(1,2)/10 @ O(1,2)=O
     (1,2)/10 @ U(1,2)=U(1,2)/10
4020 Z0=SQR(Z0-Z(1,2)^2*10)/3 @
     O0=SQR(O0-O(1,2)^2*10)/3 @
     S0=SQR(S0-U(1,2)^2*10)/3
4025 WAIT 4000 @ CLEAR @ GOTO 40
     35
4030 OFF KEY# 8 @ E1=4 @ GOTO 40
     40
4035 ON KEY# 8,"STOP" GOTO 2215
4040 RETURN
4045 END ! GET_STATS
4055 ! SUBROUTINE SET_VOLTS
4060 E1=1 @ E0=0
4065 CLEAR @ U0=0 @ DISP USING 4
     070
4070 IMAGE "NOW THE CELL IS AT U
     rev"
4075 WAIT 2000
4080 IMAGE "CHOOSE SCAN DIRECTIO
     N",/,"TO GET AT START VOLT"
4085 ON KEY# 1,"+" GOTO 4095 @ O
     N KEY# 2,"-" GOTO 4100 @ KE
     Y LABEL @ DISP USING 4080 ;
4090 GOTO 4090
4095 OFF KEY# 1 @ OFF KEY# 2 @ U
     7=1 @ GOTO 4105
4100 OFF KEY# 2 @ OFF KEY# 1 @ U
     7=-1
4105 ON KEY# 1,"1" GOTO 4120 @ O
     N KEY# 2,"10" GOTO 4125 @ O
     N KEY# 3,"50" GOTO 4130
4110 ON KEY# 4,"100" GOTO 4140 @
      CLEAR @ KEY LABEL @ DISP "
     CHOOSE SCAN RATE,mV/S"
4115 GOTO 4115
4120 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3 @ OFF KEY# 4 @ U7
     =.001*U7 @ GOTO 4145
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4125 OFF KEY# 2 @ OFF KEY# 1 @ O
     FF KEY# 3 @ OFF KEY# 4 @ U7
     =.01*U7 @ GOTO 4145
4130 OFF KEY# 3 @ OFF KEY# 1 @ O
     FF KEY# 2 @ OFF KEY# 4 @ U7
     =.05*U7 @ GOTO 4145
4135 IMAGE "CHOOSE SCAN DIRECTIO
     N",/,"TO GET AT START VOLT"
4140 OFF KEY# 4 @ OFF KEY# 1 @ O
     FF KEY# 2 @ OFF KEY# 3 @ U7
     =.1*U7
4145 ON KEY# 1,"HALT" GOTO 4225
     @ CLEAR @ KEY LABEL @ DISP
     USING 4150 ;
4150 IMAGE "NOW WATCH THE DMM"
4155 OFF TIMER# 2 ! RAMP LOOP
4160 CONTROL V$,0 ; 1,0
4165 U0=U0+U7 @ OUTPUT V$ USING
     1965 ; U0
4170 ON TIMEOUT 7 GOTO 4185 @ SE
     T TIMEOUT 7;H2
4175 TRANSFER V$ TO 717 FHS
4180 OFF TIMEOUT 7 @ GOTO 4205
4185 OFF TIMEOUT 7 @ E1=2
4190 CLEAR @ DISP USING 2305 ; @
      DISP USING 2325 ;
4195 DISP USING 2330 ; @ DISP US
     ING 2335 ;
4200 GOTO 4485
4205 ON TIMER# 2,1000 GOTO 4155
4210 GOTO 4210
4215 ! END RAMP LOOP
4220 CONTROL V$,0 ; 1,0
4225 OFF KEY# 1 @ OFF TIMER# 2
4230 ON KEY# 1,"RERUN" GOTO 4085
      @ ON KEY# 2,"OK" GOTO 4250
4235 CLEAR @ KEY LABEL @ DISP US
     ING 4240
4240 IMAGE "CHOOSE OPTION"
4245 GOTO 4245
4250 OFF KEY# 2 @ OFF KEY# 1
4255 ON TIMEOUT 7 GOTO 4270 @ SE
     T TIMEOUT 7;H1
4260 OUTPUT 723 ;"T4KM01"
4265 OFF TIMEOUT 7 @ GOTO 4285
4270 OFF TIMEOUT 7
4275 DISP USING 2305 ; @ DISP US
     ING 2310 ; @ DISP USING 231
     5 ;
4280 E1=2 @ GOTO 4485
4285 SEND 7 ; MTA UNL LISTEN 23
4290 ON TIMER# 1,H1 GOTO 4305
4295 STATUS 7,2 ; S@ IF BIT(S,0)
      THEN 4295
4300 OFF TIMER# 1 @ GOTO 4320
4305 OFF TIMER# 1
4310 DISP USING 2340 ;
4315 E1=1 @ GOTO 4485
4320 V1=SPOLL(723) @ STATUS 7,1
     ; S
4325 ON INTR 7 GOTO 4340 @ ENABL
     E INTR 7;8
4330 TRIGGER 723
4335 GOTO 4335
4340 V1=SPOLL(723) @ STATUS 7,1
     ; S
4345 IF V1=Q THEN 4355
4350 E0=1 @ E1=3 @ GOTO 4485
4355 ON TIMEOUT 7 GOTO 4375 @ SE
     T TIMEOUT 7;H2
4360 CONTROL U$,0 ; 1,0
4365 TRANSFER 723 TO U$ FHS
4370 OFF TIMEOUT 7 @ GOTO 4390
4375 OFF TIMEOUT 7
4380 DISP USING 2305 ; @ DISP US
     ING 2345 ; @ DISP USING 232
     5
4385 E1=2 @ GOTO 4485
4390 ON ERROR GOTO 4405
4395 ENTER U$ USING 5180 ; V
4400 OFF ERROR @ GOTO 4415
4405 OFF ERROR @ E1=2 @ DISP USI
     NG 2360 ; @ DISP "DMM"
4410 GOTO 4485
4415 IF V<9999990000 THEN 4425
4420 DISP "DMM OVLD" @ E1=2 @ GO
     TO 4485
4425 U1=U0
4430 CLEAR @ DISP "OTHER (SCE) V
     OLT LIMIT";
4435 INPUT U7
4440 U7=U7-V
4445 U2=U1+U7
4450 ON TIMEOUT 7 GOTO 4465 @ SE
     T TIMEOUT 7;H1
4455 OUTPUT 723 ;"KM00"
4460 OFF TIMEOUT 7 @ GOTO 4485
4465 OFF TIMEOUT 7
4470 DISP USING 2305 ; @ DISP US
     ING 2310 ; @ DISP USING 232
     5 ;
4475 E1=2
4480 CONTROL U$,0 ; 1,0@ CONTROL
      V$,0 ; 1,0
4485 RETURN
4490 END ! SET_VOLTS
4500 ! SUBROUTINE SET_SAMPLES
4505 U7=2*V
4510 U0=U2-U1 @ D0=SGN(U0) @ N8=
     ABS(U0)\U7
4515 IF N8<=N0 THEN 4525
4520 N8=N0 @ U7=1000*ABS(U0)/(N0
     -1) @ U7=IP(U7)/1000
4525 U2=U1+U7*D0*(N8-1)
4530 D=D*D0 @ S9=R8*U7*1000*N8/(
     N8-1)
4535 PRINT USING 4540 ; N8
4540 IMAGE "NUM PTS/STROKE:",2D,
     /,"ADJUSTED VALUES,(BIAS,VL
     T)"
4545 IF R3>20 THEN 4565
4550 PRINT USING 4555 ; U1,U2,S9
     /60000
4555 IMAGE "END PTS,DC BIAS:",SD
     .3D,",",SD.3D,/,"SAMPLING P
     ERIOD:",3D.D," min"
4560 GOTO 4575
4565 PRINT USING 4570 ; U1,U2,S9
     /1000
4570 IMAGE "END PTS,DC BIAS:",SD
     .3D,",",SD.3D,/,"SAMPLING P
     ERIOD:",3D.D," SEC"
4575 PRINT USING 4580 ; V0
4580 IMAGE "AC VLT:",2D.D," mV R
     .M.S."
4585 RETURN
4590 END ! SET_SAMPLES
4600 ! SUBROUTINE ECHO
4605 E1=0
4610 ON TIMEOUT 7 GOTO 4625 @ SE
     T TIMEOUT 7;H1
4615 OUTPUT 717 ;"K"
4620 OFF TIMEOUT 7 @ ON TIMEOUT
     7 GOTO 4640 @ SET TIMEOUT 7
     ;H1 @ GOTO 4630
4625 OFF TIMEOUT 7 @ GOTO 4645
4630 ENTER 717 ; S7$
4635 OFF TIMEOUT 7 @ GOTO 4655
4640 OFF TIMEOUT 7 @ CLEAR @ BEE
     P 5,1000
4645 DISP USING 2305 ; @ DISP "*
     **ECHO TEST***"
4650 E1=1 @ GOTO 4670
```

```
4655 IF S7$=S8$&"F"&F$&S9$ THEN
     4670
4660 E1=1 @ DISP USING 4665 ;
4665 IMAGE "ERROR IN SETTINGS"
4670 RETURN
4675 END ! ECHO

4685 ! SUBROUTINE EXPLAIN_SRQ
4690 CLEAR @ BEEP 5,1000 @ DISP
     "ILLEGAL SERVICE REQUEST"
4695 IF E0 THEN 4705
4700 S=SPOLL(717) @ STATUS 7,1 ;
     E1
4705 IF S=0 OR S=Q THEN 4740
4710 DISP @ DISP "LCR METER"
4715 FOR I8=3 TO 1 STEP -1
4720 IF BIT(S,I8) THEN 4730
4725 NEXT I8
4730 DISP USING 4735 ; I8
4735 IMAGE "MOST SEVERE BIT ASSE
     RTED IS# ",D
4740 IF E0 THEN 4750
4745 V1=SPOLL(723) @ STATUS 7,1
     ; E1
4750 IF V1=0 OR V1=Q OR V1=V7 TH
     EN 4780
4755 DISP @ DISP "DMM"
4760 FOR I8=5 TO 2 STEP -1
4765 IF BIT(V1,I8) THEN 4775
4770 NEXT I8
4775 DISP USING 4735 ; I8
4780 RETURN
4785 END ! EXPLAIN_SRQ
4795 ! SUBROUTINE GET_FILE_NAME
4800 CLEAR @ BEEP 5,1000 @ DISP
     "ENTER FILE NAME (5 CH MAX)
     ";
4805 ON ERROR GOTO 4820
4810 INPUT F9$
4815 OFF ERROR @ GOTO 4830
4820 OFF ERROR
4825 DISP "INPUT ERROR" @ WAIT 3
     000 @ GOTO 4800
4830 ON ERROR GOTO 4845
4835 REWIND
4840 OFF ERROR @ GOTO 4850
4845 OFF ERROR @ DISP "NO CASSET
     TE" @ WAIT 5000 @ GOTO 4800
4850 ON ERROR GOTO 4865
4855 CREATE F9$,3,2178
4860 OFF ERROR @ ASSIGN# 7 TO F9
     $ @ GOTO 4910
4865 OFF ERROR
4870 IMAGE "NAME IN CATALOGUE",/
     ,"CHOOSE ANOTHER"
4875 IMAGE "NOT ENOUGH ROOM TO C
     REATE",/,"A NEW FILE",/,"US
     E ANOTHER TAPE",/,"PAUSE"
4880 IF ERRN=63 THEN 4900
4885 DISP USING 4875 ; @ BEEP 20
     ,4000
4890 PAUSE
4895 GOTO 4850
4900 BEEP @ DISP USING 4870 ; @
     WAIT 3000
4905 GOTO 4800
4910 PRINT "FILE NAME:-";F9$
4915 CLEAR
4920 RETURN
4925 END ! GET_FILE_NAME
1975 ! SUBROUTINE GET_TAPE
4940 OFF KEY# 8
4945 ON ERROR GOTO 5025
4950 REWIND
4355 PRINT# 7,F9 ; N8,P9,S9,D9,F
     0(F9),V0,Z0,O0,S0,U8,U9
4960 FOR S=1 TO 2
4965 PRINT# 7 ; U3(F9,S)
4970 NEXT S
4975 PRINT# 7 , C0(F9)
4980 PRINT# 7 ; G0(F9)
4985 FOR S=1 TO N8
4990 PRINT# 7 ; U(1,S),U(2,S),Z(
     1,S),Z(2,S),O(1,S),O(2,S)
4995 NEXT S
5000 PRINT# 7 , R3
5005 OFF ERROR @ CLEAR @ DISP US
     ING 5010 , F9,F0(F9)
5010 IMAGE "END TAPE FOR MENU IT
     EM#",D,/,"FREQ:",3D D," KHz
     "
5015 BEEP @ WAIT 3000 @ CLEAR
5020 ON KEY# 8,"STOP" GOTO 2215
     @ E1=0 @ GOTO 5035
5025 OFF ERROR @ E1=1 @ DISP USI
     NG 5030 ;
5030 IMAGE "※TAPE I/O ERROR※"
5035 RETURN
5040 END ! GET_TAPE

5050 ! SUBROUTINE PRINT_DATA
5055 IMAGE /,"pt#|","Usce V |","
     /Z/,Ω      :θ,deg'
5060 IMAGE 2D,X,"|",SZ 3D," |",D
     .3De,"|",3D D
5065 PRINT
5070 FOR I9=1 TO 2
5075 PRINT
5080 IF I9=1 THEN PRINT "FORWARD
      STROKE" ELSE PRINT "REVERS
     E STROKE"
5085 PRINT USING 5055 ;
5090 FOR I8=1 TO N8
5095 PRINT USING 5060 ; I8,U(I9,
     I8),Z(I9,I8),O(I9,I8)
5100 NEXT I8
5105 NEXT I9
5110 RETURN
5115 END ! PRINT_DATA
5125 ! SUBROUTINE PULL_SCE
5130 ON KEY# 8,"STOP" GOTO 5235
5135 CONTROL U$,0 ; 1,0
5140 ON TIMEOUT 7 GOTO 5155 @ SE
     T TIMEOUT 7,H2
5145 TRANSFER 723 TO U$ FHS
5150 OFF TIMEOUT 7 @ GOTO 5170
5155 OFF TIMEOUT 7 @ OFF KEY# 8
5160 DISP USING 2305 ; @ DISP 27
     90;@ DISP 2830;@ E1=2
5165 GOTO 5240
5170 ON ERROR GOTO 5190
5175 ENTER U$ USING 5180 ; V
5180 IMAGE SD.5De
5185 OFF ERROR @ GOTO 5205
5190 OFF ERROR @ OFF KEY# 8
5195 DISP USING 2360 ; @ E1=2
5200 GOTO 5240
5205 IF V<9999990000 THEN 5225
5210 DISP "※DMM OVLD※"
5215 E1=2
5220 GOTO 5240
5225 U(I9,I8)=V
5230 GOTO 5240
5235 OFF KEY# 8 @ E1=3
5240 ON KEY# 8,"STOP" GOTO 2215
     @ RETURN
5245 END ! PULL_SCE
5255 ! SUBROUTINE EXPLAIN_ERROR
5260 IF ERROM=0 THEN 5270
5265 DISP USING 1170 ;
5270 IF ERRSC=0 THEN 5285
5275 DISP USING 5280 ;
5280 IMAGE "INTERFACE ERROR";
5285 S=ERRN @ V1=ERRL
```

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5290 DISP USING 5295 ; S,V1
5295 IMAGE "ERROR CODE IS:",3D,/
     ,"AT LINE#",4D
5300 RETURN
5305 END ! EXPLAIN_ERROR

5315 ! SUBROUTINE WAIT_A_WHILE
5320 IF W0 THEN 5340
5325 FOR E1=1 TO W5
5330 WAIT H5
5335 NEXT E1
5340 WAIT D7
5345 RETURN
5350 END ! WAIT_A_WHILE
5360 ! SUBROUTINE GET_RELAXED
5365 E1=0
5370 CLEAR @ DISP "CONDITIONING"
5375 DISP "CUMULATIVE NUMBER OF
     PASSES";
5380 INPUT P9
5385 DISP "NUMBER OF PASSES FOR
      THIS RUN";
5390 INPUT P8
5395 IF P8>=1 THEN 5410
5400 PRINT "NO CONDITIONING"
5405 GOTO 5615
5410 PRINT USING 5415 ; P9
5415 IMAGE "NUM. CONDITIONING PA
     SSES:",2D
5420 ON TIMEOUT 7 GOTO 5430 @ SE
     T TIMEOUT 7;H1
5425 OUTPUT 723 ;"KM00T1"
5430 OFF TIMEOUT 7 @ GOTO 5445
5435 OFF INTR 7 @ OFF TIMEOUT 7
     @ OFF KEY# 8 @ OFF TIMER# 3
5440 DISP USING 2305 ; @ DISP US
     ING 2330 ; @ DISP USING 233
     5 ; @ E1=1 @ GOTO 5615
5445 DISP USING 5450 ;
5450 IMAGE "PRELIMINARY ELECTROD
     E CHECK:",/"SEE IF δUsce α
     δVbias"
5455 FOR F9=1 TO P8
5460 FOR I9=1 TO 2
5465 FOR I8=1 TO N8
5470 ON TIMER# 3,S9 GOTO 5535
5475 ! RAMP LOOP
5480 ! &&&&&&&&&&&&&&&&&&&&&&&&&
5485 OFF TIMER# 2
5490 ON TIMEOUT 7 GOTO 5505 @ SE
     T TIMEOUT 7;H2
5495 U0=U0+D @ OUTPUT V$ USING 1
     965 ; U0 @ TRANSFER V$ TO 7
     17 FHS
5500 OFF TIMEOUT 7 @ GOTO 5515
5505 OFF INTR 7 @ OFF TIMEOUT 7
     @ OFF KEY# 8 @ OFF TIMER# 3
5510 DISP USING 2305 ; @ DISP US
     ING 2330 ; @ DISP USING 233
     5 ; @ E1=1 @ GOTO 5615
5515 ON TIMER# 2,R9 GOTO 5485
5520 GOTO 5520
5525 ! END RAMP LOOP
5530 ! &&&&&&&&&&&&&&&&&&&&&&&&&&
5535 OFF TIMER# 3 @ OFF TIMER# 2
5540 NEXT I8
5545 CLEAR @ DISP "END STROKE:CO
     NDITIONING" @ BEEP 5,3000
5550 D=-D @ D0=-D0
5555 WAIT S9
5560 NEXT I9
5565 NEXT F9
5570 ON KEY# 1,"SHUT UP" GOTO 55
     80 @ CLEAR @ KEY LABEL @ DI
     SP "END OF CONDITIONING"
5575 BEEP 5,1000 @ WAIT 1000 @ G
     OTO 5575
5580 OFF KEY# 1 @ DISP USING 558
     5 ;
5585 IMAGE 2/,"!PAUSE!",/"PUSH [
     CONT] TO RESUME"
5590 PAUSE
5595 ON TIMEOUT 7 GOTO 5610 @ SE
     T TIMEOUT 7;H1
5600 OUTPUT 723 ;"KM00T4"
5605 OFF TIMEOUT 7 @ GOTO 5615
5610 OFF TIMEOUT 7 @ DISP "BUS H
     ANGUP" @ E1=1
5615 RETURN
5620 END ! GET_RELAXED
5630 ! SUBROUTINE MULT_IT
5635 IMAGE "M",D
5640 ON TIMEOUT 7 GOTO 5655 @ SE
     T TIMEOUT 7;H1
5645 OUTPUT 717 USING 5635 ; I8
5650 OFF TIMEOUT 7 @ GOTO 5660
5655 OFF TIMEOUT 7 @ E1=1 @ GOTO
      5665
5660 ON KEY# 1,".01" GOSUB 5680
     @ ON KEY# 2,".1" GOSUB 5720
      @ ON KEY# 3,"1" GOSUB 5760
5665 RETURN
5670 END ! MULT_IT

5680 ! SUBROUTINE .01
5685 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3
5690 I8=1
5695 ! CALL MULT_IT
5700 GOSUB 5630
5705 RETURN
5710 END ! .01

5720 ! SUBROUTINE .1
5725 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3
5730 I8=2
5735 ! CALL MULT_IT
5740 GOSUB 5630
5745 RETURN
5750 END ! .1

5760 ! SUBROUTINE 1
5765 OFF KEY# 1 @ OFF KEY# 2 @ O
     FF KEY# 3
5770 I8=3
5775 ! CALL MULT_IT
5780 GOSUB 5630
5785 RETURN
5790 END ! 1

5800 ! SUBROUTINE GET_RATE
5805 ON KEY# 1,"FAST" GOTO 5815
     @ ON KEY# 2,"SLOW" GOTO 582
     0 @ CLEAR @ KEY LABEL @ DIS
     P "CHOOSE RATE"
5810 GOTO 5810
5815 OFF KEY# 1 @ OFF KEY# 2 @ G
     OTO 5830
5820 OFF KEY# 1 @ OFF KEY# 2
5825 R3=R3/2 @ R8=R8*2
5830 PRINT USING 5835 ; R3
5835 IMAGE /,"SCAN RATE:",2D," m
     V/min",/
5840 RETURN
5845 END ! GET_RATE
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