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LABORATORY PLASMA PROBE STUDIES

Walter J. Heikkila
Plasma laboratory experiments and data reduction continued during this reporting period. This report summarizes some of the data obtained on electrostatic resonances observed in the plasma generated at The University of Texas at Dallas.

Dr. Rainer Kist* and UTD personnel utilized a UTD developed digital Langmuir probe plus RF probes to study resonances generated in a collisionless laboratory CO$_2$-plasma. Laboratory instrumentation, including the Langmuir probe output, were connected to the PDP 11/45 digital computer which automatically recorded and reduced probe data.

The main body of this report is presented in the following two papers written by Dr. Kist.

Appendix A: Plasma Probe Measurements in a Collisionless Laboratory CO$_2$-plasma.

Appendix B: Operation of a Digital Langmuir Probe on Line with a PDP 11/45 Digital Computer

*On leave at UTD, sponsored by the European Space Research Organization (ESRO), now European Space Agency (ESA).
Plasma Probe Measurements in a

Collisionless Laboratory CO₂-Plasma

by Rainer Kist

This memo describes diagnostic experiments performed in a collisionless plasma using CO₂ as working gas. In particular simultaneous measurements that have been performed by means of Langmuir- and RF-probes are presented. A resonance occurring above the parallel resonance in the frequency characteristic of a two electrode system is interpreted as being due to the resonant excitation of electroacoustic waves. The memo represents a part of the accomplishments achieved in the course of a laboratory plasma investigation at the University of Texas at Dallas (UTD).

+ On leave at UTD, sponsored by the European Space Research Organization (ESRSC), now European Space Agency (ESA).
Introduction:

Studies with diagnostic probes in laboratory plasmas have several important advantages as compared to space plasma investigations:

1) Systematic variation of the parameters involved with the possibility of measuring over large time intervals and of repeating the measurements.

2) Extensive testing of the performance of space plasma probes in a plasma environment prior to a space mission.

3) Systematic investigation of specific plasma phenomena with the aim of improving existing or developing new diagnostic methods.

4) Extensive investigation of various phenomena such as plasma wave mode generation and propagation, instable plasma states and nonlinear effects.

5) Relatively low cost and short time period needed for realizing a plasma experiment.

The results of such laboratory plasma investigations may provide data for checking on particular theories in plasma physics or have impact upon the understanding in fields like space plasmas (planetary ionospheres, magnetosphere, solar wind etc.) or even (after scaling up the results properly) fusion plasmas.

For the space plasma physicist the laboratory plasma is and will remain a very valuable tool even though in the coming space age the ionosphere itself may be used for particular investigations as a large scale "laboratory" plasma of low density and temperature.
In the piece of work presented here the influence of the electron temperature on the frequency characteristic of the plasma impedance of a two electrode system was investigated. Of particular interest was the resonant excitation of electro-acoustic waves within two RF electrodes for different geometries and plasma conditions.

**Experimental System**

A stainless steel vacuum chamber, 70 cm long and 50 cm in diameter, has been equipped with a plasma source which uses CO$_2$ as working gas. A turbomolecular pump together with a copper shroud which was cooled down to liquid nitrogen temperature provided a background vacuum of about 10$^{-6}$ Torr. Fig. 1 shows the source schematically. The general concept was to produce a discharge plasma in a separate volume $V_1$ (bell jar) and let it expand into the volume $V_2$ (chamber) through a diaphragm. During operation typical pressure values were 10$^{-2}$ Torr in volume $V_1$ and 10$^{-4}$ Torr in volume $V_2$. In order to control the pressure gradient and the plasma source performance the diaphragm was an iris which could be varied by means of a feedthrough mechanism. A heated tungsten cathode provides primary electrons for the discharge as well as neutralizing electrons for the ions moving from the discharge region into the tank. A paddle proved very useful in baffling high energetic electrons coming from the discharge.

A set of different plasma probes were installed in the tank, in particular

a) a conventional Langmuir probe (LP)

b) a retarding potential analyzer (RPA) and

c) electrode systems for RF impedance measurements.
Fig. 2 shows schematically the arrangement of the plasma source and the probes in the vacuum system. The probes were mounted on movable high vacuum feedthroughs in order to change their position and/or orientation within the tank.

The RF-measurements presented in this memo were performed with a cylindrical and a spherical two-electrode system $(E_1, E_2)$, as shown in Fig. 3. The principle of the RF-measurement is also shown. A swept frequency RF generator provides a signal of constant amplitude within the frequency interval of typically 1 to 25 MHz. The RF-reference voltage $U_R$ at $E_1$ as well as the test voltage $U_T$ at $E_2$ are measured and compared as to their complex ratio

$$\frac{U_T}{U_R} = E + jF$$

by means of a network analyzer hp 8407.

The signals provided by the network analyzer are magnitude

$$\alpha = \left| \frac{U_T}{U_R} \right| = \sqrt{E^2 + F^2}$$

in $dB$

and phase $\varphi = \arctan (F/E)$ in degrees. Magnitude and phase together are a measure for the complex plasma impedance $Z = X + jY$ between $E_1$ and $E_2$. In case of the spherical system half spheres were used as $E_1$ and $E_2$. Additional half spheres were operated as guard electrodes in order to reduce the influence of the tank walls.

In Fig. 4 are shown current-voltage characteristics of a spherical (diameter: 10 mm) stainless steel Langmuir probe.
The parameter of this set of curves is the bias voltage $U_1$ of the plasma source heating circuit. It can be seen that the velocity distribution and temperature $T_e$ of the electrons is markedly influenced by $U_1$. In the present case the distribution function is maxwellian in good approximation for $U_1$-values of $-2$ V, $-3$ V and $-4$ V. The corresponding $T_e$-values are $0.55$, $0.53$ and $0.52$ eV, respectively. For each of these Langmuir curves the magnitude $\alpha$ measured as function of frequency was plotted on a X-Y-recorder. Fig. 5 shows the corresponding set of curves, which reveals the following essential features:

a) above the parallel resonance $f_p$, which is in our case (no magnetic field) equal to the plasma frequency $f_N$, occurs an additional resonance $f_Z$, and

b) $f_Z$ is pronounced most clearly for the case of maxwellian distribution of the electrons with low electron temperature $T_e$ ($U_1 = -2$ V, $-3$ V, $-4$ V).

This resonance $f_Z$ can be understood in terms of electroacoustic waves (also called electron pressure or Landau waves) which are launched by an RF-source above the plasma frequency. Excitation of this electrostatic type of plasma wave, which is damped with increasing frequency by collisionless or Landau damping, is predominantly responsible for the real part of the impedance of an electrode system immersed into a plasma. For a single electrode this real part would decrease monotonically with increasing frequency. For a two electrode system ($E_1$, $E_2$) as used in our experiment, however, a characteristic electrode distance $d$ can be defined (distance between inner and outer cylinder or between two spheres). In this case the electroacoustic wave can produce a standing wave pattern between $E_1$ and $E_2$. This is expected to occur essentially at eigenfrequencies of the system electrodes-plasma, for which the wavelength $\lambda_{ea}$ (or integer multiples of it) matches the distance $d$. 

\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{fig5}
\caption{Corresponding set of curves showing essential features:}
\end{figure}
To check this interpretation we start with the Bohm/Gross (1959) dispersion relation for these plasma waves

$$\omega^2 = \omega_N^2 + (3KTe/m_e) \cdot k^2$$  \hfill (1)

Here $\omega$ is the angular RF-frequency, $\omega_N$ the angular plasma frequency, $K$ is Boltzmann's constant, $m_e$ the electron mass and $k = 2\pi/\lambda_{ea}$ the electroacoustic wave number. Equation (1) gives the wavelength $\lambda_{ea}$ at the resonance frequency $f_Z = \omega_Z/2\pi$:

$$\lambda_{ea}/m_e = 0.7263 \cdot \frac{\sqrt{KT_e/eV}}{f_Z/f_N} \cdot \frac{\sqrt{f_Z^2/f_N^2} - 1}{MHz}$$  \hfill (2)

Applied to the measurements of Fig. 5 we get the following table 1:

<table>
<thead>
<tr>
<th>$U_1/V$</th>
<th>$T_e/eV$</th>
<th>$f_Z/f_N$</th>
<th>$\lambda_{ea}/mm$</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1</td>
<td>.61</td>
<td>1.40</td>
<td>56</td>
</tr>
<tr>
<td>- 2</td>
<td>.55</td>
<td>1.34</td>
<td>54</td>
</tr>
<tr>
<td>- 3</td>
<td>.53</td>
<td>1.31</td>
<td>56</td>
</tr>
<tr>
<td>- 4</td>
<td>.52</td>
<td>1.30</td>
<td>52</td>
</tr>
<tr>
<td>- 5</td>
<td>.65</td>
<td>1.32</td>
<td>54</td>
</tr>
<tr>
<td>- 6</td>
<td>.85</td>
<td>1.38</td>
<td>54</td>
</tr>
</tbody>
</table>

The distance of the cylindrical electrodes is $d = 53$ mm. Due to the cylindrical geometry (equation (1) is strictly valid for plane waves), to the ion sheath, and possible inhomogeneous plasma distribution within the electrodes one cannot expect
an absolute agreement between $\lambda_{ea}$ and $d$. But we have as an essential result, that the ratio $\lambda_{ea}/d$ is constant within a few percent for all combinations ($f_N$, $f_Z$, $T_e$) that occur in the set of curves of Fig. 5.

Theoretical work done by Whale (1965), Balmain (1965) and Lin/Lei (1970) shows that excitation of electroacoustic waves is reduced by the presence of an ion sheath. On the other hand collapsing the ion sheath by changing the electrode bias potential to the plasma potential leads to electron absorption so that damping of the electroacoustic wave is to be expected, etc. Thus varying the electrode DC-potential $U_{DC}$ from negative (ion sheath extended) to positive (ion sheath "collapsed"), a value for $U_{DC}$ should occur for which the resonance at $f_Z$ is best pronounced.

The curves of Fig. 6, where the potential $U_{DC}$ of the test electrode $E_2$ was varied, exhibit exactly this behaviour and thus seem to confirm the interpretation for the $f_Z$-resonance suggested above.

Measurements with the spherical electrode system also show the resonance $f_Z = f_{Z1}$ as can be seen from Fig. 7. In this case the distance $d$ of the two spheres was varied. In case of the large distance $d = 92.8$ mm a second resonance $f_{Z2}$ above $f_{Z1}$ occurs. These measurements were analyzed on grounds of a theory by Chasseraux et al. (1972), in which the potential of an oscillating point charge in a warm isotropic plasma is calculated using kinetic plasma theory. The results predict resonances of the potential and hence of the plasma impedance of a spherical system essentially at those frequencies, at which the wavelength $\lambda_{ea}$ (or integer multiples) equals the distance $d$ between the spheres. As to our experiment we thus have to check, if the measured values for $d$, $f_{Z1}$ (and $f_{Z2}$) and $f_N$ lead to the same electron temperature. The result of this analysis is presented in Table 2.
Table 2

<table>
<thead>
<tr>
<th>d/\text{mm}</th>
<th>f_{Z1}/f_{N}</th>
<th>T_e/\text{eV}</th>
</tr>
</thead>
<tbody>
<tr>
<td>92.8</td>
<td>1.11</td>
<td>.44</td>
</tr>
<tr>
<td>83.8</td>
<td>1.11</td>
<td>.43</td>
</tr>
<tr>
<td>74.8</td>
<td>1.14</td>
<td>.45</td>
</tr>
<tr>
<td>65.8</td>
<td>1.20</td>
<td>.53</td>
</tr>
</tbody>
</table>

Again the essential result is that all cases lead in fact within a few percent to the same mean temperature $T_e = 46$ eV. In case of $d = 65.8$ mm the error in $T_e$ is relatively large due to the larger error in reading the resonance frequency $f_Z$. The mean value for $T_e$ is indicated by the straight line drawn into the corresponding Langmuir characteristic of Fig. 8. The additional resonance at $f_{Z2}$ leads, applying the theory of Chasserais et al., to the value $T_e = .51$ eV. This value still seems to be reasonable in view of several error sources like reading error for $f_{Z2}$, deviation of the velocity distribution of the electrons from maxwellian, presence of an ion sheath around the electrodes etc.

The experiments presented here show that a system of two RF-electrodes lead to additional resonances of the impedance characteristic above the plasma frequency which can be understood in terms of resonant excitation of electroacoustic waves.

Systematic and more detailed investigations of the plasma impedance of two electrode systems will be performed in the big plasma chamber at IPW$^+$/Freiburg. The importance of the additional resonance $f_Z$ relies on two aspects:

1) knowing the distance $d$ and the plasma frequency $f_N$, $f_Z$ allows in principle to deduce the electron temperature $T_e$.

$^+$ IPW = Institut für Physikalische Weltraumforschung.
2) This method would allow to determine $T_e$ with high temporal resolution ($10^{-1}$ to about $10^{-2}$ sec) which would be of particular value for diagnostic measurements in space plasmas as well as non stationary laboratory plasmas.

Acknowledgement:

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PLASMA SOURCE

ORIGINAL PAGE IS OF POOR QUALITY

FIG 1
SPHERICAL RF-PROBE
DIAMETER OF BOTH SPHERES: 17.8 mm

CYLINDRICAL RF-PROBE

FIG 3
SPHERICAL LANGMUIR PROBE
STAINLESS STEEL
DIAMETER 10mm
VARIATION OF $U_1$

FIG 4
CYLINDRICAL RF-PROBE VARIATION OF $U_1$

FIG 5
SPHERICAL RF-PROBE
VARIATION OF PROBE DISTANCE d

2.9.74
EXPNO 05

f/MHz

FIG 7
SPHERICAL LANGMUIR PROBE
STAINLESS STEEL
DIAMETER 10mm
OPERATION OF A DIGITAL LANGMUIR PROBE
ON LINE WITH A PDP 11/45 DIGITAL COMPUTER

by

RAINER KIST*

This memo describes the concept and the performance of the
Digital Langmuir Probe (DLP) experiment, the necessary interface electronics
to the computer and the associated software. The system was set up to
provide a flexible diagnostic tool for the laboratory plasma facility
at the University of Texas at Dallas (UTD). The memo summarises a
part of the accomplishments achieved in the course of a project which
deals with production and diagnostics of collisionless laboratory plasmas
at UTD.

UTD, September 1974

*On leave at UTD, sponsored by the European Space Research Organization
(ESRO), now European Space Agency (ESA).
I. INTRODUCTION

Several diagnostic probes such as RF-probe, Retarding Potential Analyzer (RPA) and Langmuir Probes (LP) have been installed in the Laboratory plasma chamber at UTD. Langmuir Probes of different materials (Stainless Steel, Polymorphic carbon) and geometry (spherical, cylindrical) have been used. Fig. 1 shows the arrangement of the probes within the chamber. The detailed description and performance of the plasma source and the probes are the object of a separate memo.

A conventional Langmuir probe electronics makes use of an electrometer amplifier with either a nonlinear (diode) feedback resistor or a linear feedback resistor plus subsequent logarithmic amplifier. This allows to display the logarithm of the probe current over 3 to 4 orders of magnitude (current-voltage characteristic). This compressed form of current display, however, does not allow for a sufficient resolution of small current changes as they occur in time and/or space due to density fluctuations associated with electrostatic waves on instabilities present in a plasma.

In order to measure small electron density fluctuations in the F-region of the Equatorial Ionosphere a digital Langmuir Probe (DLP) was developed at UTD by D. Winningham and J. B. Smith for use in the EQUION rocket project. The unique feature of this experiment is to provide an absolute current resolution of $\approx 10^{-9}$ Amps and a maximum relative resolution of $\approx 10^{-4}$.

Since the investigation of electrostatic wave modes and instabilities is of special interest for laboratory plasma physics, this DLP was installed for use in the plasma chamber at UTD. In particular the digital output of the instrument allowed for a straightforward connection
to the computer (PDP 11/45). Therefore an interface electronics and a set of computer programs were set up to transfer the data to the computer and from there on to magnetic tape and process them for display on a Calcomp plotter.

A general diagram of the system DLP-Computer is shown in Fig. 2. The mean parts of the system are described below in more detail.

II. Properties of the DLP - Electronics*

A triangular bias waveform is applied at G (see Fig. 3) through the electrometer amplifier (1) to the Probe P. The laboratory version of the DLP allows for using the waveform of either the internal or an external bias generator. The range for the bias voltage is from -1 to +3 volts. The period $T$ of the internal bias generator is controlled by the bit rate fed into the experiment and can be varied between $.5 \, S \leq T \leq 200 \, S$. The relationship between $T$ and the bit rate $f_b$ is

$$\frac{T}{S} = \frac{23040}{f_b/Hz}$$

The electrometer amplifier is a 3420L BURR-BROWN with bias current of about 1 pA and frequency response better than 2 kHz.

The bias waveform at G also appears at A, B, and C. Therefore the bias is also introduced at J so that Amplifier 2 can see the bias as a common mode signal, and can reject it, making D independent of the bias and responsive only to the signal produced by the input current at A.

One of the important system tests consists of holding the input current

*This chapter is essentially the DLP electronics description that already had been prepared by D. Winningham and J. B. Smith for the EQUION-Project.
constant and letting the bias voltage cycle while observing the output code. If the system is properly adjusted, the output code will not change by more than 1 or 2 LSB's.

The principle of operation is obvious; only a few system constants will be specified here. The A/D converter is a 0 to -10 v full scale, 8 bit unit. Of the total range of 256 increments (called minor increments) only 200 are used, leaving an unused portion at the lower and upper edges of the 10 volt range. The limits of the 200 increment range are determined by voltage comparators. Actually the comparators defined a range of 200 increments plus a hysteresis band of a few increments in order to avoid an oscillatory condition when sitting at band edge. This means that certain values of current can be represented by two different code group differing by 200 minor increments and by 1 major increment. However, when the two code groups are decoded according to a fixed algorithm, exactly the same current results.

When a voltage comparator switches it changes the D/A converter code by one increment (called a major increment). The resulting output analog increment is fed into the system at J which resets the output D by 200 minor voltage increments.

The D/A is an 8 bit unit in which the 256 increments correspond to an output voltage from -10v to +10v. This range establishes the maximum measuring limits of the system, and $R_1$ is chosen so that the desired maximum current will cause a ± 10v change at B. However the bias voltage must be added to this which results in a range of -11 v to +13 v at B. With a ± 15 volt supply, the +13 v limit exceeds the linear range of operation of amplifiers 1 and 2. Therefore $R_1$ is chosen to be 786 KΩ.
which results in a maximum voltage at B of $7.86 \, V + 3V = 10.86 \, V$ for an
input current (electrons) of $10\mu A$. This means that the positive range
of the D/A will not all be used. In the negative direction (positive ion
current) the maximum current will be even smaller, and is not expected
to exceed 15% of the negative range capability.

The sense of the output code is arranged as follows: At the negative
limit (-10V of positive ion current at B, all code bits are zero. As the
current changes so as to move B in a positive direction, the code increases
and at +10V all bits are 1.

At zero current (0 V at B) the code is

<table>
<thead>
<tr>
<th>DAC</th>
<th>ADC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSB</td>
<td>LSB</td>
</tr>
<tr>
<td>0 1 1 1</td>
<td>1 1 0 0</td>
</tr>
</tbody>
</table>

Here the ADC code is 200. It cannot be 0 for zero current because the
upper level comparator excludes this point from the operating region.
Therefore a major increment is "subtracted" (the DAC LSB = 0) and the
ADC increased from 0 to 200.

The code/current algorithm is:

\[
    i = [(DAC - 127) \times 200 + ADC] \times (5 \times 10^{-10})
\]

where

- DAC = the decimal value of the D/a code
- ADC = the decimal value of the A/d code
- \( i \) = amperes (positive \( i \) means electrons flowing to the
  system. A negative \( i \) means positive ions flowing to
  the system).
- \( 5 \times 10^{-10} \) = the resolution or amps/minute increment
When applied to the above code the result is:

\[ i = [(126 - 127) \times 200 + 200] \times (5 \times 10^{-10}) = 0 \]

If the current increases by a few minor increments, say 15, the lower level comparator will trip and the resulting code will be:

0 1 1 1 1 1 1 1 0 0 0 0 1 1 1

Applying the algorithm

\[ i = 15 (5 \times 10^{-10}) = 75 \times 10^{-10} \text{ a.} \]

The algorithm applies to all values of current.

In reading the value of the analog channel only 1 fact is necessary:

The gain of Amplifier 3 is exactly -0.5. If D is -6 v, F is +3v, etc.

If the ADC code is known the voltage at D and F can be computed. The ADC increment is 10v/256 = 39.0625 m.v. (40 mv is close enough). Therefore

\[ V_D = - (ADC) \times 0.04 \text{ volts} \]

\[ V_F = (ADC) \times 0.02 \text{ volts} \]

or \( ADC = 50 V_F \)

from which the algorithm can be applied,

\[ i = [(DAC - 127) \times 200 + 50 \times F] \times (5 \times 10^{-10}) \text{ amps} \]

III. The Interface Electronics

The Interface Electronics (IE) provides matching of the experiment output signal to the driver assembly and allows for operation of the DLP in different modes. In more detail the following functions are realized; we partly follow the schematic diagram. Fig. 4 and the timing chart Fig. 5.

1) The bit rate is to be provided by an external pulse generator.

The word and frame rates are deduced from the bit rate.

2) The serial output signal DAC-ADC of the DLP is stored in a 16 bit storage register from where it will later be transferred
in parallel to the computer via 4 each quadruple 2-line to 1-line multiplexers.

3) The voltage of the internal or external bias generator is offset by +1.33V and then fed to an A/D-Converter. The A/D-Conversion is ordered by a strobe pulse generated in the programmer.

4) The converter is also used for A/D-Conversion of the probe position monitoring voltage (position sweep). This applies for the operation mode of the experiment, in which the probe is kept at constant bias voltage and moved within the plasma.

5) A set of eight toggle switches allows for monitoring the experiment number (EXPNO) or a coded STATUS in order to identify a particular data run (measurement).

6) Upon a select signal from the programmer the DAC/ADC data or the BIAS (or position)/EXPNO (or STATUS) data is alternately switched by the multiplexers to the driver assembly and then via optical couplers to the receiver section of the computer. Sixteen bits are transferred in parallel to the computer receiver but are not actually read into the computer until a cycle request pulse is generated by the programmer. The rate at which the data points are sampled is 366 per scan. It is independent from the scantime, since both, scantime and sampling period are fixed multiples of the bit period.

7) The programmer generated cycle request pulse commands the computer to read the data at its receiver inputs and to then follow the instructions given by the computer program for data storage and/or reduction.
IV. The Computer Software

At present the software for the I-P-Computer system consists of three programs:

1) Storage and Tape Transfer Program (PROBE), ASSEMBLER
2) Tape dumping Program (DLP), FORTRAN IV
3) Data Analysis Program (DIGITAL LANGMUIR PROBE), FORTRAN IV

PROBE handles the data flux that is coming from the DLP-experiment through the interface electronics IE to the receiver input of the computer. 16 bit data words are stored in the upper core memory and arranged in blocks of 8K Bytes. The part of memory used allows for storage of 22 blocks which form one file. One data block covers the data of 5.5 Scans of the Digital Langmuir Probe. As already mentioned the number of data samples taken per scan is 366 independently of the scantime. Thus with each run (measurement) practically 5 Langmuir Characteristics (each consisting of a full sweep upwards and a full sweep downwards) can be recorded. Prior to each measurement a computer attention button on the IE has to be pushed. This starts the computer to read 8 K bytes of data into the memory. A switch installed at the IE allows to interrupt the data flux.

Once up to 22 data blocks are stored they are transferred on to tape by executing PROBE with one label card for each block. The label card contains additional information (80 bytes) about the particular measurement such as file Number, block number, date and experimental conditions (pressure, probe used, etc). The data sequence on tape is thus:

label card information - data block label card information - data block - A.S.O. After each 22nd block an End of File (EOF) mark is written on the
tape. When executing PROBE for data transfer on to tape a 00 card
inserted right after the label cards takes care of reinitializing the
memory so that a new set of 22 measurements can be stored upon pushing
the computer intention button.

For short compilation of the procedure in handling the program PROBE
see the copy of the printer record in Appendix A.

The Program DLP reads the tape for a selected set of files and
blocks and prints the data in 32 columns of octal numbers. The sequence
of the data display is

EXPNO - ADC - DAC - BIAS

The selection of file Number (NF) and block (or record) number (NR) is
made via a data card which contains the number of records to be read
(MAXREX) in column 5, the number of records to be skipped (NRS) in column
10 and the number of files to be skipped (NFS) in column 15.

Fig. 6 shows the flow diagram for this program; a copy of the
printer record of DLP is included in appendix B.

The program DIGITAL LANGMUIR PROBE in its present version meets
the following objectives:

1) Skip a specified number of files and records and print label
(or header) card.

2) Identify bias and find first bias peak. The bias identification
relies on the fixed sequence of DAC/ADC/BIAS/EXPNO and the fact that
the experiment number (toggle switch setting at the IE) is constant
throughout one run.

3) Calculate current i out of DAC/ADC according to the algorithm
given in Chapter II.
4) Calculate the derivative \( T_G = 11606.9 \frac{\Delta U}{\Delta \log i} \)

5) Print EXPNO, Bias, \( \log i \) and \( T_G \)

6) Plot data for one cycle (scan) on CALCOMP - Plotter

A simplified flow chart of this program is shown as Fig. 7, a copy of the program is included as appendix C.

Figs. 8 and 9 show two examples of Langmuir characteristics as semilogarithmic plots produced by the system. The current for increasing bias voltage is marked by x-es, for decreasing bias by squares. The ion current is plotted as log of its absolute value. The probe used in the plasma was a stainless steel sphere of 5 mm diameter. The surface was discharge cleaned for 10 minutes in nitrogen at about 100\( \mu \) pressure. The Langmuir curves show almost no hysteresis. In Fig. 8 the floating potential is at +100 mV. In this experiment the plasma was clearly non-Maxwellian since the differential or "generalized temperature" \( T_G \) shows a monotonous increase. Here crosses are for the upward going and triangles for the downward going part of the curve. Fig. 9 shows a case where the distribution function of the electrons is close to Maxwellian. This shows up in the shoulder shaped part of the \( T_G \) curve, occurring between 1 and 1.4 Volts and corresponding to an electron temperature \( T_e \) of about 5000 K. For an ideally Maxwellian distribution the shoulder would have a horizontal plateau. A high value of \( T_e \) corresponds to a large, a low \( T_e \) value to a small horizontal extension of the plateau. The low \( T_G \) values on the left side reflect the drop of the measured total current due to the ion current which becomes significant with decreasing bias voltage. The high \( T_G \) values on the right side are due to the transition-knee from the retarding to the saturation regime of the
characteristic. This knee is influenced by the inhomogeneity of the work function over the probe surface. A perfectly homogeneous work function would produce a sharper knee of the electron current curve and a correspondingly straightened shape of the $T_G$-plateau.

Above 2.5 V bias the data are meaningless since in this case the current exceeded the upper current limit ($10^{-5}$ amperes) to which the electronics of the Digital Langmuir Probe was set.

ACKNOWLEDGEMENT: The author is highly indebted to Dr. D. Winningham for providing the DLP back up electronics of the EQUION-project. Many thanks go to N. Eaker and C. Thompson for designing and building the interface electronics. The outstanding help from Dr. J. Midgley, L. Wadel and D. Beck in providing parts of the necessary software is particularly appreciated. The author finally wishes to express his gratitude to B. Milam for his engineering assistance.
DLP tape dumping program

Fortran II

Reads tape, prints data in 32 columns of octal numbers - when decoded, disregard most significant binary digit.
APPENDIX A

1) LIST TMM
2) TITLE PAGE
3) PHODE OPERATES SIMULTANEOUSLY WITH NORMAL BATCH PROCESSING.
4) IT ACCEPTS 16 BIT DATA WORDS, IN BLOCKS OF 4K WORDS, STORING THEM
5) IN UPPER MEMORY, AND (WHEN INSTRUCTED) DUMPING THEM ON TAPE AS A FILE
6) A MAXIMUM OF 22 SUCH BLOCKS MAY BE STORED BETWEEN DUMPS.
7) WHEN PHODE IS RUN, ONE DATA (LABEL) CARD MUST BE INCLUDED FOR EACH
8) BLOCK TO BE WRITTEN. THE CONTENTS OF THE CARD ARE WRITTEN AS AN 80
9) BYTE LABEL RECORD PRECEDING THE 4K endless DATA RECORD. THE FIRST TWO
10) DIGITS ON THE FIRST CARD SPECIFY THE FILE NUMBER IN WHICH THE
11) BLOCKS ARE WRITTEN. A 80 CARD (CARD WHOSE FIRST TWO COLUMNS ARE ZERO)
12) FOLLOWING THE LAST LABEL CARD CLOSES THE FILE AND REINITIALIZES
13) MEMORY TO STORE ANOTHER 22 BLOCKS.
14) PROCEDURE: 1) EXECUTE PHODE WITH ONLY A 80 CARD TO INITIAL MEMORY
15) 2) PUSH ATTENTION BUTTON TO START A DATA BLOCK
16) 3) START DATA AND STOP IT AFTER 4K WORDS ON CARD
17) 4) REPEAT 2) AND 3), BUT NO MORE THAN 22 TIMES.
18) 5) EXECUTE PHODE WITH ONE LABEL CARD FOR EACH BLOCK TO BE
19) RECORDED ON TAPE, AND A 80 CARD TO REINITIALIZE MEMORY.
20) 6) REPEAT 2)-5) AS OFTEN AS DESIRED, INCREASING FILE
21) NUMBER ON LABEL CARDS BY ONE EACH TIME.

GLOBAL TAPE
CALL INIT, READ, WAIT, RLSE, EXIT

FILING
THE ADDRESS WHERE INT IS STORED

PROBE1 INIT $LACKR
161 HEAD $LACKR,$CARD READ ONE DATA CARD
WALT $LACKR

080174

1180 BR 28
1280 BH 128

281 RQM 85

284 CLSP 118
285 DEC 49
287 BLE 31

41 P0726 210267 000726 MOV 49, NF
42 P0766 004567 000000 JSR 45,TAPE SKIP NF FILES
43 P0726 00497 BR 36
44 P0744 0216794, WORD ONE
45 P0708 0216714, WORD IC
46 P0710 0216744, WORD IN
47 P0712 021632, WORD ZERO
48 P0714 021603, WORD HM
49 P0716 001624, WORD HF
51 P0722 0216127 001457 1281 RQM 65
52 P0722 001276 000672 364 MOV 129, NB
53 P0710 021268 000000 00044G RIC #11,TAPE #64 SET MEM EXTENSION BITS
54 P07136 021767 000000 000472 RIC #60,TAPE #72
55 P0722 004567 000000 JSR 45,TAPE WRITE LABEL
56 P07150 002495 49 BL 49
57 P07152 001039, WORD TWO
58 P07154 001026, WORD IC
<table>
<thead>
<tr>
<th>Line</th>
<th>Instruction</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>MOV @136, 000674</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>MOV @136, 001721</td>
<td></td>
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<tr>
<td>61</td>
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<tr>
<td>62</td>
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<td>63</td>
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<tr>
<td>64</td>
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<tr>
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<tr>
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<tr>
<td>114</td>
<td>MOV @136, 000620</td>
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</tbody>
</table>

**Note:** The above code snippet is a typical assembly language program, possibly for a microcomputer, and includes various operations such as moving data to memory, setting interrupt addresses, and setting buffer addresses. The commands include `MOV`, `ADD`, `SUB`, `INC`, `DEC`, `JMP`, `JMPA`, `JZ`, `JNZ`, `JSR`, and `BIT`. The purpose of the program seems to be related to memory management or file I/O operations, possibly for a tape drive or similar peripheral device.
115 020466 012122
116 020470 077022
117 020472 025037 177572
118 020474 003233
119 020526 012737 001600 172354
120 020526 012737 000100 172434
121 020514 000000
122
123 020156 012737 000001 177572
124 020154 003131 000536
125 020137 025037 177572
126 020135 000000
127 020136 012737 020000 172343
128 020144 011775
129 020145 012737 000100 172434
130 020154 002137 000116
131 020154 012737 020000 172434
132 020155 021774
133 020155 026127 000222 000072
134 020155 023566
135 020155 026767 000222 000218
136 020155 026772 000204
137 020155 010001
138 020154 042771 177760
139 020152 015528
140 020152 021227 000204
141 020152 010137 172432
142 020152 012737 170000 172430
143 020145 042772 177717
144 020155 026742 000101
145 020155 012037 172434
146 020154 020737
147 020158 000703
148 020155 014720
149 020152 003021
150 020152 026750
151 020256 002122 000000 000000
152 020154 026774
153 020158 000203
154 020154 000000
155 020152 001122 001123
156 020152 020000
157 020152 000454
158 020152 007777
159 020158 000000
160 020152 177777
161 020158 000000
162 020152 020000
163 020200
TITLE: DLP

DLP DIRECTIONS:
USE DATA CARD TO SPECIFY RECORD READING
PUT REC, COL. 5, NO. REC, SKIP COL, 10, FILE. SKIP COL, 15
REPEAT CARD, USE 0 FOR MAXREX IN LAST CARD.

BYTE BUFFER (.1912), HEADER(.80)
EQUVALENT (BUFFER(1), HEADER(1))
CONTINUE
N = 2
C
SKIP MODULE
READ (8,1001) MAXREX, NRS, NFS
1001 FORMAT (3I5)
IF (MAXREX LE 0) GO TO 7000
IF (NFS LE 0) GO TO 5
NB = 0
NR = 50
NF = 1
CALL TAPE(-1,0,BUFFER,NB,NR,NF)
NFS = NFS - 1
GO TO 2
5 CONTINUE
6 IF (NRS LE 0) GO TO 10
NB = 0
NR = 2
NF = 1
CALL TAPE(-1,0,BUFFER,NB,NR,NF)
NRS = NRS - 1
GO TO 6
12 CONTINUE
18 NR = 80
NR = 1
IF (N GT MAXREX) GO TO 55
3 CALL TAPE (-1, 0, HEADER, NB, NR, NF)
IF (NF EQ 0) GO TO 20
IF (NB) 21, 28, 23
20 WRITE (5, 541)
541 FORMAT(1E10D FILE')
GO TO 22
21 WRITE (5,542) N
542 FORMAT(1TAPE READ ERROR ON HEADER, RECORD=GROUP', 17)
GOTO 2200
23 WRITE (5,543) NB, N, HEADER
543 FORMAT('HEADER RECORD SHORT BY', 13, ', RECORD=GROUP', 17)
1 (A01), 80A1
GOTO 200
28 WRITE (5,555) HEADER, N
555 FORMAT('10, 80A1, 20X, 'HEADER RECORD GROUP', 17)
C
TEMPORARY: PRINTS OUT OCTAL FORM FOR DIAGNOSIS OF TAPE
C
WRITE (5,955) HEADER
0243      955 FORMAT (’0’, 3204)

C
0244      202 CONTINUE
0245      NB = 8192
0246      NR = 1
0247      NF = 1
0248      CALL TAPE (-1, 0, BUFFER, NB, NR, NF)
0249      IF (NF .EQ. 0) GO TO 20
0250      IF (NB) 221, 228, 223
0251      221 WRITE (5, 221) N
0252      5221 FORMAT (’TAPE READ-ERROR ON DATA, RECORD-GROUP’, I7)
0253      GO TO 1
0254      223 WRITE (5, 523) NB
0255      5223 FORMAT (’DATA RECORD SHORT BY’, I7)
0256      228 CONTINUE
0257      WRITE (5, 5228) N
0258      5228 FORMAT (’DATA, RECORD-GROUP’, I7 //)
0259      WRITE(5,5229)(BUFFER(I),I=1,8000) //
0260      5229 FORMAT (’ ’, 3204)
0261      N = N+1
0262      GO TO 1
0263      55 CONTINUE
0264      WRITE (5,5555)MAXREX
0265      5555 FORMATA(0)PROCESSED NUMBER OF RECORDS-GROUPS SPECIFIED’,I5)
0266      22 CONTINUE
0267      CALL TAPE (4, 0)
0268      GO TO 4
0269      7000 CONTINUE
0270      STOP
0271      END

#END

Routines called:
TAPE

Block length
Main, 4880 (023040)

Compiler ---- CORE
Phases used free
Declarations 00456 13834
Executables 00637 12983
Assembly 01471 14936
APPENDIX C

DATA CARD #1

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-12</td>
<td>NOMINAL MAX PEAK VPE (E/F FORMAT)</td>
</tr>
<tr>
<td>13-24</td>
<td>MIN (E/F)</td>
</tr>
<tr>
<td>25-36</td>
<td>TOLERANCE (E/F)</td>
</tr>
<tr>
<td>37-41</td>
<td>DATA POINTS BETWEEN POS PEAKS (I FORMAT)</td>
</tr>
<tr>
<td>42-46</td>
<td>DATA POINTS POS TO NEG (I)</td>
</tr>
</tbody>
</table>

DATA CARD #2

<table>
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<tr>
<th>COLUMN</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>NUMBER OF FILES TO SKIP (I FORMAT)</td>
</tr>
<tr>
<td>6-10</td>
<td>NUMBER OF RECORDS TO SKIP AFTER ANY FILE SKIPPING (COUNT BOTH HEADING RECORDS AND DATA RECORDS)</td>
</tr>
<tr>
<td>11-15</td>
<td>NUMBER OF RECORDS TO PROCESS (COUNT ONLY DATA RECORDS)</td>
</tr>
<tr>
<td>16-20</td>
<td>NUMBER OF CYCLES TO PROCESS (LEAVE BLANK IF WANT ALL) IN EACH RECORD</td>
</tr>
<tr>
<td>21-25</td>
<td>1 IF PLUT WANTED, ELSE 0 OR BLANK</td>
</tr>
</tbody>
</table>

REAL* CCHLOG (500), BYAS (500), TE (500), F (500)
INTEGER* IDATE (3), IHUF (4096)
INTEGER* NOX (2), INTE (2), INTEN, INTEG (2), MAXIM (40)
BYTE HUFFEN (192), BUF (192), INTERB (2), MDH (72)
BYTE POUR (400)

C EQUIVALENCE (HUFFEN(1), BUF(1)), (INTEH, INTERB(1)),
  (MDH(1), HUFFEN(1))
C EQUIVALENCE (BUF(1), IHUF(1))

DATA NAV / 3 /
DATA ISW / 0 /
DATA HSCALE / 1.95312E-2 /
DATA INTEH / 0/, KMEC / 0 /
DATA TSCALE / 1.16654E-4 /
DATA PEAK / 1, 1, 1, 1 /
DATA OFFSET / 1.33 /

REAL (8.8000) PMAX, PMIN, TOL, LMAX, LMIN
8008 FORMAT (3E12.0, 215)
917 FORMAT (5F7.0) PMAX, PMIN, TOL, LMAX, LMIN
5705 FORMAT (4II, 4F8.3, 4F8.3, 4F8.3, 4F8.3, 4TOLERANCE = *,F8.3,)
1 * ASSUMED MAX TO MIN, IS = MAX TO MIN, 15)
HEAD (8) 1005H, NF, N4, MAXHEX, KX, IPIOL
8015 FORMAT (5F5.1)
IF (X <= 0) KX = 19
IF (X > 19) KX = 19
IF (1.IPLT 44.0) 1
CALL CALCMH (IHFU, 4000, 53, 0)
917 FORMAT (5F7.0) NF
5727 FORMAT (10IFILES SKIPPED*, 14)
IF (NF <= 0) GO TO 2
N = 32000
CALL TAPE (-1C, HUFFEN, NR, MR, NF)
    WITF (5, 4703)
IF(INF,NF,0) STOP
2 CONTINUE
WRITE (5,5701) MAXREX, NH, KA, IFLT
5701 FORMAT(13,5X, 'MAX RECORDS=', 15, 5X, 'RECORDS SKIPPED=', 15, 5X)
1 'MAX CYCLES PROCESSED PER RECORD=', 15, 5X, 'PLOT CODE=', 13)
KA = 2 * KA - 1
C
IF (NH .LE. 0) GO TO 5
NR = 0
NF = 1
CALL TAPE (-1, 0, BUFFER, NB, NR, NF)
WRITE (5,5702) NH
5702 FORMAT(15,5X, 'DECREASED TO=', 13)
S CONTINUE
IF (KREC .LE. MAXHEX) GO TO 888
C
HEAD HDH.RECORD; WAIT FOR COMPLETION
KREC = KREC + 1
NR = 60
NF = 1
CALL TAPE (-1, 0, BUFFER, NB, NR, NF)
C
IF (INF .NE. 1) GO TO 999
C
READ EHHEU ON SHORT RECORD?
C
IF (NH) 10, 20, 30
C
GOOD RECORD
20 CONTINUE
WRITE(3,5005) HDH, KREC
5005 FORMAT(15,5X, 'RECORD NO.', 15, '//' )
C
SAVE DATE FROM HEADER.RECORD TO PLOT
DO 25 I = 1, 3
25 JDATE (1) = IJUF (I+1)
C
HEAD DATA RECORD; WT FOR COM\
300 CONTINUE
NH = 6192
NR = 1
NF = 1
CALL TAPE (-1, 0, BUFFER, NB, NR, NF)
C
IF (INF .NE. 1) GOTO 999
C
READ EHHEU ON SHORT RECORD?
C
IF (NH) 310, 320, 330
C
GOOD RECORD
320 CONTINUE
C
FIND PHASE
J = 3
DO 40 I = 8, 18 +
 IF (IUF (2) .NE. BUF (I) ) GO TO 50
40 CONTINUE
\n DO 45 I = 802, 982 +
 IF (IUF (2) .NE. BUF (I) ) GO TO 50
45 CONTINUE
\n DO 50 I = 6
50 CONTINUE
J = 5
\n DO 55 I = 6, 23 +
 IF (IUF (4) .NE. BUF (I) ) GO TO 70
55 CONTINUE
\n DO 60 I = 62, 72 +
 IF (IUF (4) .NE. BUF (I) ) GO TO 70
60 CONTINUE
\n DO 70 I = 60
70 CONTINUE
CONTINUE

INTER(1) = BUF(I-1)
EXPNR(1) = INTER
WRITE (5, 5015) EXPNR(1)

C

5015 FORMAT('DEPEAK NOT FOUND')
C

DO 80 I = 1, N)
INTERA (1) = BUF (I-3)
IF (INTER.** EXPNR(1) ) GO TO 120
INTERA (1) = BUF (I-2)
BIAS(1) = INTER
BYE = BS.CALE*BIAS(1)
IF (BYE .GE. (PHRAX-TOL)) GO TO 100
80 CONTINUE
120 CONTINUE
WRITE (5, 5020)
5020 FORMAT('PEAK NOT FOUND')
C

DO 10 I = 1, N)
IF (INTER.**LT. BIAS (1)) GO TO 110
BIAS (1) = INTER
I = 1
GO TO 100
110 CONTINUE
MAXI(N) = 1 + 2
DO 8 I = 1, N
MAXI(N) = MAXI(N-1) + 4 - LMIN
ITEM = MAXI(N-1) + 4 - LMAX
IF (ITEM .GE. HLV1) GO TO 230
INTERH(1) = BUF (ITEM+1)
IF (INTER .EQ. EXPNR (1) ) GO TO 240
INTERH(1) = BUF (ITEM + 1)
IF (INTER .NE. EXPNR (1) ) GO TO 230
240 MAXI(N+1) = ITEM
230 CONTINUE

C

TABULATE BIAS* DAC. ADC, F STARTING AT FIRST POSITIVE PEAK
C

DAC IS IN BUF(1+5) ADC = BUF(1+4)
C

BIAS = BUF(1+6)
EXPNR = BUF(1+7)
C

DO 200 K = 1, KK+2
KU = MAXI (K+2)
IF (KU .LE. 0) GO TO 5
KM = MAXI (K+1)
KL = MAXI (K)
LCTR = 99
N = 0
DO 400 KK = KL, KU, 4
N = N + 1
IF (KK .LE. KM) NMD = N
INTERH(1) = BUF (KK-2)
ADC = INTER
INTERH(1) = BUF (KK-1)
DAC = INTER
F(N) = (DAC - 127) * 200 + ADC * 5.E-10
FABS = AES (F(N) )
IF (FABS .EQ. 0) FABS = 1.E-35
CUMLOG (N) = ALOG10 (FABS)
INTERH(1) = BUF (KK)
400 CONTINUE
200 CONTINUE
PROCESSED MAXEX RECORDS

STOP

END

SUBROUTINE PLCUR (CURLOG, HYAS, NMID, NMAX)

REAL*8 CURLOG(500), HYAS(500)

DATA C / 1.25 / 
DATA D / 3.0 / 
DATA ISYMND / 91 / 
DATA ISYMUP / 95 / 
DATA A / 1.5 / 
DATA H / 10.5 / 

DO 100 I = 1, NMAX

TRANSFORM ALL HYAS AS MAY NEED IN SUBRTN PLTEM

HYAS(I) = C * HYAS(I) + D

IF (HYAS(I) .LT. 1.75) OR (HYAS(I) .GT. 6.75) GO TO 100

IF ((CURLOG(I) .GT. -4.0) OR (CURLOG(I) .LT. -9.7)) GO TO 100

CURLOG(I) = A * CURLOG(I) + B

ISYM = ISYMND

IF (I .GT. NMID) ISYM = ISYMUP

CALL SYMUL (HYAS(I), CURLOG(I), 0.05, ISYM, 0, -1)

100 CONTINUE

RETURN

END

SUBROUTINE PLTEM (TE, HYAS, NMID, NMAX)

REAL*8 TE(500), HYAS(500)

DATA ISYMND / 93 / 
DATA ISYMUP / 94 / 
DATA A / 5.0 / 
DATA H / -1.0 / 
DATA CUT / 6.5 / 

CUT MUST CHANGE IF C, D IN SUBRTN PLCUR CHANGE

HYAS HAS BEEN TRANSFORMED BY IMMEDIATELY PREVIOUS CALL PLCUR

CC 100 I = 1, NMAX

IF (HYAS(I) .GT. CUT) GO TO 100

IF ((TE(I) .GT. 3.000000E+0) OR (TE(I) .LT. 100.0)) GO TO 100

TE(I) = A * ALUV10 (TE(I)) + B

ISYM = ISYMND

IF (I .GT. NMID) ISYM = ISYMUP

CALL SYMUL (HYAS(I), TE(I), 0.05, ISYM, 0, -1)

100 CONTINUE

RETURN

END
! I

\[
\text{INACTION} (3)
\text{INTEG} (2) \text{ NOD} (5)
\text{DATA} \text{ ISYM} / 31 /
\text{DATA} \text{ AL} / 1.75 /
\text{DATA} \text{ YB} / 3 /
\text{DATA} \text{ ASCALE} / 0.125 /
\text{DATA} \text{ AX} / 0.75 /
\text{DATA} \text{ TSCALE} / 3 /
\text{DATA} \text{ CSSCALE} / 1.5 /
\text{DATA} \text{ TL} / 0.301033 / 0.477121 / 0.602060 / 0.698970 / 0.778151 /
\]

\[
1 / 0.845098 / 0.903090 / 0.954243 /
\]

\[
\text{FPN} = -1.
\text{CALL} \text{ NUMBER} \ (X L - 0.100, \ Y H - 0.500, \ 0.250, \ F P N, \ 0, -1)
\]

\[
\text{DUPLICATE} \ \text{TO} \ \text{ENSURE} \ \text{INK} \ \text{START}
\text{CALL} \text{ NUMBER} \ (X L - 0.100, \ Y H - 0.500, \ 0.250, \ F P N, \ 0, -1)
\]

\[
K = 0
\text{CALL} \text{ CALCM3} \ (X L, \ Y H, \ 0, -1)
\]

\[
\text{DO} \ 22 \ I = 1, 4
\text{DO} \ 18 \ J = 1, 9
K = K + 1
X = X L \ + \ K \ \times \ \text{ASCALE}
\]

\[
\text{CALL} \text{ SYMBOL} \ (X + \ Y H, \ 0.14, \ \text{ISYM}, \ 0, -2)
\text{CONTINUE}
\]

\[
K = K + 1
X = X L \ + \ K \ \times \ \text{ASCALE}
\]

\[
\text{CALL} \text{ SYMBOL} \ (X + \ Y H, \ 0.28, \ \text{ISYM}, \ 0, -2)
\text{FPN} = 1 - 1
\text{CALL} \text{ NUMBER} \ (X - 0.100, \ Y H - 0.500, \ 0.250, \ F P N, \ 0, -1)
\text{CALL} \text{ CALCM3} \ (X L, \ Y H, \ 0, -1)
\]

\[
\text{CONTINUE}
\text{FPN} = 10
\]

\[
\text{CALL} \text{ NUMBER} \ (X + 0.25, \ Y H, \ 0.25, \ F P N, \ 0, -1)
\text{FPN} = 2
\text{CALL} \text{ NUMBER} \ (999, \ Y H, \ 0.125, \ 0.15, \ F P N, \ 0, -1)
\text{CALL} \text{ CALCM3} \ (X + \ Y H, \ 0, -1)
\]

\[
\text{DO} \ 28 \ I = 1, 3
\text{JJ} = 8
\text{IF} \ 1 \ + \ \text{EU}, \ 3 \ \text{JJ} = 2
\text{DO} \ 28 \ J = 1, \ \text{JJ}
Y = Y H \ + \ \text{TSCALE} \ \times \ (T L(J) \ + \ I - 1)
\text{CALL} \text{ SYMBOL} \ (X + \ Y, \ 0.1, \ \text{ISYM}, \ 90, -2)
\]

\[
\text{CONTINUE}
\text{IF} \ 1 \ + \ \text{EQ}, \ 3 \ \text{GO} \ \text{TO} \ 28
\]

\[
Y = Y H \ + \ 1 \ \times \ \text{TSCALE}
\text{CALL} \text{ SYMBOL} \ (X + \ Y, \ 0.28, \ \text{ISYM}, \ 90, -2)
\text{FPN} = 10
\text{CALL} \text{ NUMBER} \ (X + 0.25, \ Y, \ 0.25, \ F P N, \ 0, -1)
\text{FPN} = 1 - 1
\text{CALL} \text{ NUMBER} \ (999, \ Y, \ 0.125, \ 0.15, \ F P N, \ 0, -1)
\text{CALL} \text{ CALCM3} \ (X + \ Y, \ 0, -1)
\]

\[
\text{CONTINUE}
\]

\[
\text{YSY} = Y
\text{FPN} = 0
\]

\[
\text{CALL} \text{ NUMBER} \ (X L - 0.75, \ Y H, \ 0.25, \ F P N, \ 0, -1)
\text{CALL} \text{ CALCM3} \ (X L + \ Y H, \ 0, -1)
\]

\[
\text{DO} \ 36 \ I = 1, 3
\text{DO} \ 36 \ J = 1, \ 8
Y = Y H \ + \ \text{CSSCALE} \ \times \ (T L(J) \ + \ I - 1)
\text{CALL} \text{ SYMBOL} \ (X + \ Y, \ 0.14, \ \text{ISYM}, \ 90, -2)
\]

\[
\text{CONTINUE}
\text{Y} = Y H \ + \ 1 \ \times \ \text{CSSCALE}
\text{CALL} \text{ SYMBOL} \ (X L + \ Y, \ 0.28, \ \text{ISYM}, \ 90, -2)
\text{FPN} = 1 - 9
\text{CALL} \text{ NUMBER} \ (X L - 0.75, \ Y, \ 0.25, \ F P N, \ 0, -1)
\]
38 CONTINUE
K = 0
DO 42 I = 1, 4
ON 48 J = 1, 9
K = K + 1
X = XL * K * XSCALE
CALL SYMBOL (X, Y, 0.14, ISYM, 0., -2)
48 CONTINUE
K = K + 1
X = XL * K * XSCALE
CALL SYMBOL (X, Y, 0.28, ISYM, 0., -2)
42 CONTINUE
CALL CALCNP (XH, YS, 1., 1)
CALL SYMBOL (XL-1.2, YH-3.0, 0.30, 'LOG I', 90., 5)
CALL SYMBOL (XL-1.9, YH-1.0, 0.25, 'HIAS', 0., 4)
CALL SYMBOL (XH+1.35, YH+0.5, 0.30, 'GENERALIZE TEMPERATURE', 1, 90., 23)
CALL SYMBOL (XL, YH-1.5, 0.250, IDATE(1), 0., 2)
CALL SYMBOL (999., YH-1.5, 0.250, 'X', 0., 1)
CALL SYMBOL (999., YH-1.5, 0.250, IDATE(2), 0., 2)
CALL SYMBOL (999., YH-1.5, 0.250, 'X', 0., 1)
CALL SYMBOL (999., YH-1.5, 0.250, IDATE(3), 0., 2)
E=CODE (10, 7000, NCO) NEXP
7000 FORMAT(TEAM_NUM, 14)
CALL SYMBOL (XH-2.5, YB-1.5, 0.250, NCO, 0., 14)
RETURN
END