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THE MULTIPLE IONOSPHERIC PROBE

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ABSTRACT

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The report constitutes a brief description of a Multiple Ionospheric Probe (M.I.P.) Nike Apache rocket payload. This payload includes five different types of probes. One of these, called the resonance relaxation probe, is designed to detect plasma resonances of the types seen on top-side sounder records. A second measurement is that of the impedance of a sphere as a function of frequency, and associated with this is the resonance rectification probe based on the resonant increase in d.c. current due to r.f. excitation. The fourth probe is the high frequency capacitance probe, which is a special case of the impedance probe. Finally, d.c. current measurements with three different collectors are also carried out. Data from one daytime and one nighttime launching at Wallops Island are desired under stable ionospheric conditions to permit quantitative comparison of the different techniques.

The principal theoretical and instrumental features of the different probes are presented in rather brief form; more complete descriptions will be published elsewhere. The auxiliary instrumentation is discussed in more detail in this report.

Author

ILLUSTRATIONS

I. INTRODUCTION

W. J. Heikkila

1.1 Historical Introduction

Ionospheric observations have been made with ground-based techniques since the beginning of this century, and with space instrumentation since 1945. The rocket and satellite techniques fall into two categories; those utilizing propagation paths ending at the vehicle, and those using probes for localized measurements. Propagation techniques suffer from many limitations, such as a dependence on spatial and temporal homogeneity. Consequently, probe techniques are often required for ionospheric observations.

The very earliest probe measurements in laboratory plasmas before the end of the last century involved the measurement of the voltage adopted by a small electrode placed in the plasma. Langmuir (1926) introduced a very significant advance by measuring the current-voltage characteristic to such an electrode when the potential was varied. From this characteristic he was able to obtain the value of the plasma potential, the electron concentration within the plasma, and the electron temperature.

For any non-zero probe potential, particles of one sign will be retarded or repelled on approaching the body and particles of the opposite sign will be attracted and accelerated. The resultant deficiency of particles of one sign constitutes a sheath covering the surface. An isolated body in equilibrium in the plasma must have zero net current flowing to it; consequently, it adopts a negative potential (of the order of $\frac{5kT}{e}$) in order to limit the current of the highly mobile electrons to equality with the ion current. An ion sheath is thus formed around the body. The total positive charge in the ion sheath is approximately equal to the negative charge on the body, and the distant plasma is almost perfectly shielded from the body potential. The Langmuir probe characteristic is not affected by the particle concentration profiles through the sheath provided certain broad conditions are met, but the radio frequency impedance of a probe may be greatly affected.

For application to a rocket or satellite experiment, the Langmuir probe requires a reference body from which potential is measured. Ideally, the reference body should be infinitely large so that it can provide a perfect potential reference. In practice, this body (generally the body of the rocket or satellite) is not infinitely large, and its potential will vary to a greater or lesser extent when the probe potential is varied. Since in equilibrium the total current to the system of probe plus rocket must be equal to zero, it is obvious that for positive potentials on the probe when a large electron current is collected, an equal ion current must flow to the vehicle, and this ion current cannot be collected unless the ion collection area is greater than the probe area by the ratio of the diffusion coefficients. If the ion collection area is not large enough, then the vehicle potential rather than the probe potential will change, leaving the probe still sufficiently negative with respect to the plasma to limit the electron current to the value of the ion current. This problem is often referred to as the current dumping problem for a probe on a space vehicle.

Several different geometries for Langmuir probes have been used. One of these is a sphere at the end of an insulated wire. A second is a long, thin cylinder (sometimes with a guard cylinder.) A third is planar, or at least approximately planar, such as an insulated part of the rocket or satellite surface. Another convenient geometry is that of the nose tip of the rocket, or an annular ring around the nose cone; this is particularly convenient because of its rigidity for D-region measurements where aerodynamic drag forces are high.

In the early radio wave propagation experiments with rockets, the antenna impedance was monitored during the flight (Kane, 1962). It was noticed that the impedance suffered regular changes associated with the varying electron concentration as the flight progressed. Subsequently, this effect was put to use by more careful measurements of the impedance which were then analyzed in terms of the apparent refractive index in the vicinity of the antenna; thus, a measurement of the local electron concentration was obtained. This result agreed fairly well with the results obtained by the propagation experiments except for a constant factor of about three; this factor was interpreted as an effect of an enhanced positive ion sheath about the antenna. Later measurements with varying transmitter powers demonstrated that the error was reduced by going to lower powers, thus corroborating this interpretation.

Two different methods have been used in studying this impedance. Kane measured the capacitance of the antenna by means of a variable capacitor which was swept through a range of values, noting the value of capacitance required to bring the antenna to resonance. The second method (utilized by Pfister, 1961) was to measure the standing wave ratio on the transmission line feeding the antenna. From this standing wave ratio, the impedance of the antenna could be deduced.

Rather than measuring antenna impedance at one frequency, it is possible to measure the impedance over a range of frequencies. At very low frequencies the antenna should be capacitive, the value of this capacitance being determined primarily by the thickness of the ion sheath. At somewhat greater frequencies, approaching the plasma frequency, the impedance would become inductive, and the imaginary part would be zero at some intermediate frequency. Above the plasma frequency, the impedance is again capacitive, and it approaches the free space capacitance at very high frequencies. Such an impedance measurement constitutes a very complete measurement on the plasma properties, and it may be the basis for a useful probe. The sampling time would be long for a complete sweep, but measurement at a few frequencies could be done in a shorter time.

Instead of using an antenna as the physical element of a probe, Sayers (1962) used the tip of the rocket insulated from the remainder of the rocket. This tip is a capacitor, provided the measurement of impedance is done at a frequency above the plasma frequency. Sayers used this capacitor in a resonant circuit and measured the resonant frequency of this circuit as the rocket penetrated the ionosphere. The resonant frequency was used as an indication of the dielectric constant of the ionospheric plasma and, therefore, of the electron concentration. This method has also been used by others with some variations in the method of capacitance measurements. Adey and Heikkila improved the method by using a larger capacitor and a larger separation between it and the rocket, thereby achieving greater sensitivity. Nisbet (1964), on the other hand, used a capacitance bridge for the measurement. Still another variation was designed by Forsyth and Kavadas (1961), using a feedback principle to keep the operating frequency at or near the plasma frequency.

It was found by Japanese workers (Miyazaki et al, 1960) that an r.f. excitation on a probe produces a rectified plasma current to the probe that is a function of the applied frequency. At frequencies well below the plasma frequency a constant value for this rectified current, independent of frequency, was measured; this current is dependent upon the electron temperature, and it is a good measure of this quantity. At a somewhat higher frequency a resonant increase occurs in the rectified current, and at still higher frequencies the rectified current drops to very low values. The frequency for maximum rectified current was taken to be the plasma frequency. Recent theoretical and experimental work (Fejer, 1963-1964) and by Harp (1963) indicates that in fact the frequency of resonance is below the plasma frequency by an amount which depends upon the ratio of the Debye length to the diameter of the probe. Subject to this correction, this resonance rectification method seems to be suitable for measuring both electron concentration and temperature above the E-region. Below the E-region collisions damp out the resonant effect.

When topside ionograms from the Alouette satellite were inspected it was found that resonances of long endurance were excited in the vicinity of the satellite at several discrete frequencies (Calvert and Goe, 1963). It has since been shown that these resonances are electrostatic resonances in the magnetoionic medium at frequencies that depend upon the plasma frequency and the gyro frequency (Fejer & Calvert, 1964).

The electrostatic resonances appear to provide a very reliable method for the measurement of electron concentration in the ionosphere. This conclusion is based upon the consideration that the resonances are set up in the medium over a considerable volume of the plasma and, therefore, should not be greatly affected by the presence of an ion sheath. A disadvantage of the method in practice is the requirement that a sweep in frequency over a considerable range is required. This complicates the instrumentation and also extends the time of one measurement. This method is referred to as a resonance relaxation method in this report.

Since many harmonics of the gyro frequency are observed, it may be possible to use the gyro resonances as a measure of the geomagnetic field. The method would have the advantage of averaging the value over a large volume, and disturbances due to fields generated on the spacecraft would, therefore, not be important.

1.2 The Multiple Ionospheric Probe Program

The Multiple Ionospheric Probe Program is a rocket program undertaken jointly by the Southwest Center for Advanced Studies and the Central Radio Propagation Laboratory to compare several different probe methods for measuring ionospheric properties. The main methods being used are radio frequency probes of the four different types considered above in addition to the simple Langmuir Probe. The objective of the program is to compare the different methods in order to permit verification of relevant theories and to provide an assessment of probes for use in different applications.

The arrangement of the main components in the payload is shown in Figures 1 and 2. A central programmer provides timing and synchronization signals to permit time sharing, with a basic frame period of 1.536 seconds.

Time sharing serves two purposes, the reduction or elimination of interference between experiments and an increase in telemetry capability for each experiment. The frame is divided into three equal periods of 512 ms. called Periods I, II and III. Some programming is actually done at half the basic rate, and sub-gates called A and B are provided for this.

During Period I a resonance relaxation experiment is performed, using a long dipole antenna that is extended from the midsection of the payload; this experiment actually utilizes a low power sounder. The frequency is swept over the range 3.0 to 0.1 MHz during sub-gate A, but is fixed at 4.0 MHz during sub-gate B. Pulses are 100 μs long and the repetition frequency is 500 per sec. A normal A-scan of the received signal is telemetered with a 10 kHz bandwidth.

The other RF probes use a large sphere as the sensing element with switching accomplished by reed relays. This sphere is protected by a clamshell nose cone during the early part of the flight; clamshell release is controlled by means of a timer actuated by altitude switches, located in the lower part of the payload.

The variable frequency impedance and the resonance rectification measurements are carried out during Period II, with the same frequency sweep as used in the relaxation experiment. During Period III the high frequency capacitance of the sphere is measured. The D.C. current to the sphere is also measured during this period, constituting the so-called electrostatic probe measurement. A complex bias program is played on the sphere during Period III.

Two Langmuir probes, one spherical, the other cylindrical, are operated alternately during all three periods. These are mounted at the top of the payload, and are also exposed after the clamshell is released.

A complete prototype payload was built and electrically tested during the early part of 1965. Three flight payloads will be ready for launch in August, 1965 at Wallops Island, Virginia.

2. RESONANCE RELAXATION PROBE

W. Calvert, J. Hugill, M. Field

2.1 Theory

The use of the topside sounder vehicles in the F-layer of the ionosphere has discovered the stimulation of plasma resonances by the transmitted pulse of R.F. energy from the sounder antennas. The frequencies at which these resonances occur are those where

$$X = 1$$

$$X = 1-Y^2 \qquad (1)$$

$$\text{and } Y = 1,\ 1/2,\ 1/3\ \ldots. ,$$

where, in the usual notation $X = f_N^2/f^2$ and $Y = f_H/f$ (f_N = plasma frequency, f_H = gyrofrequency.) These resonances are thought to be caused by the excitation of plasma waves which, under the conditions given in equation (1), have a very low group velocity (Fejer and Calvert 1964). Fields associated with the plasma oscillations remain close to the antenna and are detected for a certain time by the sounder receiver, appearing as a so-called 'spike' on the ionograms. Their duration depends partly on spatial spreading of the waves, and partly on the damping produced by electron collisions. The theory indicates that the frequencies of the spikes are very closely given by equation (1).

The purpose of the resonance relaxation probe incorporated in the M.I.P. payload is to use the plasma resonance effect to measure the electron density and gyrofrequency in the E-layer of the ionosphere to an accuracy of about 1%. A secondary purpose is to find the mechanism by which the resonances are excited by the sounder antennas, and to determine at what height electron collision damping limits their observation.

The closeness of coupling between the antenna and the surrounding plasma, whether for radiation of electromagnetic or plasma waves, can be investigated by measuring its impedance. This will be done during the periods of about 100μS when the pulsed transmitter is activated. The resistive part of its impedance is a measure of the rate of energy loss by the antenna, and the ratio of reactance to resistance determines how well the antenna and plasma are coupled. It will be of interest to observe how closely the frequencies of resonances in the antenna impedance which are known to occur, for example at the gyrofrequency, agree with the frequencies of the plasma resonances. There is some theoretical work (e.g. Wait, 1964) to indicate the ratio between the radiation resistances for electromagnetic radiation, R_r, and for plasma radiation, Rp, in the case where $f_H << f_N$. R_r is known, so by making a measurement of R_r + Rp this theory can be checked. The M.I.P. sounder receiver is designed and calibrated so that it will be able to make measurements of the electric field in the plasma. This will assist in the interpretation of the data obtained and afford a quantitative test of theory.

As the electron collision frequency ν increases the plasma oscillation relaxation time, τ decreases. In practice the receiver detecting the oscillation cannot be made fully sensitive until some time τR after the cessation of the transmitted R.F. pulse, because there are always certain transients associated with this which might be mistaken for plasma resonances.

When τ is such that

$$\tau << \tau_R$$

then the phenomenon can no longer be observed. The height in the ionosphere at which this condition occurs is of some interest. It will depend on ν, τ_R and the sensitivity of the receiver. Measurements of the variation of τ as ν changes will also provide a test of the theory outlined above.

2.2 Instrumentation

The resonance relaxation probe package consists of an antenna mechanism located above four stacked terminal boards containing the transmitter, receiver, and impedance measuring circuits.

The antenna, a 40 foot dipole, is made of beryllium copper spring tape, the relaxed form being an open sided tube of about 1/2 inch diameter. Two 20 foot sections of this material are opened out into flat strips and rolled onto spools along with another tape spring, a "negator" (Hunter Spring Company) motor. The antenna release is timed by a unijunction relaxation circuit initiated at 10,000 ft. during the rocket ascent through a series parallel connection of altitude switches. This circuit must be armed during preflight operations. At the end of the timer cycle a relay activated latching solenoid releases the antenna mechanism. Cam operated microswitches and a voltage source provide a telemetry signal for monitoring antenna extension as the negator spring motor and centripetal force pull the tape over guides which assist return to the tubular configuration. The negator springs roll up on take-up spools as the antenna is extended out through insulated ports in the payload shell. Mechanical counter discs engage to stop the rotation of the supply spools when the extension is complete. Electrical connection to the dipoles is through beryllium-copper spring fingers.

The resonance relaxation probe block diagram, figure 3, shows the main functions of the electronic circuitry. The operation is synchronized and controlled by pulses from the programmer (Chapter 6.1).

Pulses, approximately 200 volts peak to peak between the rocket body and one of the dipoles called the transmit dipole, are 100 microseconds in duration and occur at a rate of 500 pulses per second. During sub-gate A of gate Period I (512 milliseconds) the frequency transmitted varies from 3 MHz to 0.1 MHz; during sub-gate B of gate Period I (also 512 ms) the frequency is fixed at 4 MHz.

A portion of this energy is also applied to two phase detectors and a pulse amplitude monitor. The energy returning on the other dipole -- called the receive dipole -- produces a current which is decomposed into in-phase and quadrature components, each of which is then measured by a phase detector. The phase detector outputs are amplified and averaged to give telemetry signals representing the admittance of the antenna in the medium through which the vehicle is passing.

The radio frequency pulses after amplification are obtained by gating the output of a 4 MHz crystal oscillator. This pulse is mixed with the output of a voltage controlled oscillator (VCO) during sub-gate A, the frequency of the VCO going from 7 to 4.1 MHz. The sweep voltage controlling this oscillator is triggered by the leading edge of each gate pulse and the 100 microsecond pulser is triggered by 500 pps from the programmer. Both of these circuits will free run when not synchronized. During sub-gate B the 4 MHz pulses do not pass through the mixer and bypass the low pass filter on the mixer output.

The frequency sweeping oscillator (VCO) output is amplified and supplied to the variable frequency impedance and resonance rectification probe (Chapter 3). Frequency calibration is provided by feeding the VCO square wave signal through a 41.5 MHz crystal filter. Voltage pips are produced as the input frequency becomes equal to various subharmonics of 41.5 MHz.

A switch shorts the input to the receiver during and for about 10 microseconds following the transmitted pulse. One stage of the 4 MHz intermediate frequency amplifier is also shorted for 110 microseconds. During the receive time (1.9 ms) the signal passes through a low pass filter (0-3 MHz) to the mixer which is fed from the VCO. Receiver gain is such that 50 microvolt input produces a 1 volt detected output, modified by a detector filter which produces the required response. During Periods I and II the receiver amplitude vs. time (A-Scan) will be applied to the wide band telemetry channel (Channel H). During the Period III a signal of lowered bandwidth is applied to a 2 KHz channel (6 CW). The receiver output is shorted to ground for the duration of the transmit pulse.

3. RESONANCE RECTIFICATION AND VARIABLE FREQUENCY IMPEDANCE PROBES

J. A. Fejer and K. R. Tipple

3.1 Theoretical Considerations

The resonance rectification probe was originally proposed by Japanese workers (Miyazaki et al., 1960) as a method of measuring electron concentrations in the ionosphere. In the form originally proposed this was a probe to which a fixed dc voltage and a sweep-frequency rf voltage was applied. The dc current drawn by the probe was measured as a function of the radio frequency.

Early laboratory measurements (Miyazaki et al., 1960) indicated that a resonant peak in the dc current occurs at the plasma frequency. Recently, independent theoretical work by Fejer (1963-1964) and by Harp (1963) suggested, however, that the resonant maximum in the dc current is associated with a minimum in the rf impedance and that the two simultaneous resonant effects (in the dc current and in the impedance) occur at a frequency less than the plasma frequency. The results of laboratory experiments (Peter et al., 1963, Crawford and Harp, 1964) are in at least qualitative agreement with the predictions of the theory.

The purpose of the planned simultaneous measurements of rf probe impedance and of "rectified" current as functions of the frequency in the 0.1-3 MHz range will be partly to test the theories so far proposed and partly to obtain further experimental data. This data will also show the effects of an external magnetic field over a considerable range of values of the ratio of the plasma frequency to the electron cyclotron frequency.

A spherical conductor with a diameter of 4-1/2 inches will be used as a probe; the "floating" dc potential of the probe rather than the dc current will be measured simultaneously with the in-phase and out-of-phase components of the supplied rf current. An rf voltage of about 0.5V peak-to-peak will be applied to the probe and the radio frequency will be continuously varied between 3.0 MHz and 0.1 MHz.

An attempt will be made to refine previous theoretical calculations of the rf impedance of such a sphere (Fejer, 1964) and to compare the results of the experiments with the theory. It is realized that the presence of the earth's magnetic field and the motion of the rocket will affect the results of the measurements and that only qualitative theoretical predictions of these effects are available at present.

In the absence of an external magnetic field a resonant maximum of the impedance at the plasma frequency is expected as well as a resonant minimum at some frequency below the plasma frequency whose exact value depends on the electron temperature. In the presence of an external magnetic field (the actual situation in the ionosphere) resonant maxima are expected to occur at the plasma frequency, the upper hybrid frequency and at harmonics of the cyclotron frequency. These are also the resonant frequencies which should be detected by the resonance relaxation probe and their identification should, therefore, not be difficult if they are observable. It would, of course, be of considerable practical advantage to detect these resonances with the aid of a small probe rather than a large antenna.

3.2 Instrumentation

A simplified block diagram of the instrumentation is shown in Figure 4. The resonance rectification and the variable frequency impedance measurements are made simultaneously during Period II using a 4.5 inch diameter metallic sphere at the end of a 9-inch boom. During Period III this same sphere is used for the high frequency capacitance and electrostatic probe experiments; the reed relay switching required to accomplish this time sharing is located within an enlarged section of the boom, as are other circuit components with critical stray capacitance restrictions.

For the two experiments under consideration a radio frequency signal of constant amplitude 0.5 volts ptp is swept over the range 3.0 MHz to 0.1 MHz. The magnitude and phase of the r.f. current to the probe are measured for the determination of the impedance, and the d.c. potential of the probe is measured for the resonance rectification experiment.

3.2.1. Variable Frequency Impedance Experiment

The swept frequency signal is applied to the probe through a broadband transformer of rather critical design, and a voltage proportional to the probe current is developed across the capacitor C_2. The real and imaginary parts of the probe impedance are deduced from the outputs of two phase sensitive detectors operating at 10 KHz. The use of narrow band, low frequency detection circuits overcomes the difficulties associated with broadband devices, the broadband transformer being the only critical component.

The calibrated 7.0 MHz to 4.1 MHz sweep signal from the resonance relaxation probe is obtained by means of a coaxial cable connection. This signal is mixed in a ring diode switching mixer with a 4.000 MHz crystal oscillator which has a frequency stability of 0.001% over the estimated maximum temperature range of plus 20°C to plus 60°C. The resulting 3.0 MHz to 0.1 Mhz signal is passed through a low pass filter to remove 4 MHz and higher frequencies. The 3.0 MHz to 0.1 MHz signal is then amplified and applied to an emitter follower probe driver stage. The signal is also peak detected and the resulting d.c. signal is amplified and used as a level control for the crystal oscillator. This A.G.C. system maintains the signal applied to the probe driver stage constant within 0.5 db over the sweep frequency range. Similar circuitry is used with the 4.010 MHz crystal to develop the 2.99 MHz to 0.09 MHz sweep.

C_2 is a 390 pf capacitor used to develop a voltage proportional to the probe current. This value represents a compromise between the need to have sufficiently large reactance to develop an easily handled voltage at the high frequency end of the range and the need to have much less reactance at the low end of the frequency range than the input impedance of the succeeding amplifier. If the amplifier input impedance is not much higher than the reactance of the capacitor, the probe current will flow through a complex impedance rather than a purely imaginary one and the resulting voltage will undergo progressively greater changes in phase shift as the frequency is reduced toward 0.1 MHz. C_1, a 220 pf capacitor, serves as a d.c. blocking capacitor and also limits the maximum voltage developed across C_2 under conditions of very low probe impedance. The sweep signal from C_2 is mixed with the 2.99 MHz to 0.09 MHz swept frequency signal in a single ended switching type mixer to produce a 10 KHz signal, which then is filtered, amplified and fed to the amplitude-phase detectors. The 10 KHz reference signal for the detectors is developed in a mixer and filter system similar to that used for the signal channel. The d.c. outputs from the detectors are amplified by a factor of 10 and fed to the telemetry system. Since the detector output can be either positive or negative, while the telemetry system accepts only positive signals, an offset is introduced at the amplifier output equal to 50% of the telemetry range under conditions of zero detector output. The two outputs are telemetered on Channels 12 CW and 10 Cw.

3.2.2 Resonance Rectification Experiment

This experiment is done by a measurement of the d.c. potential developed on the probe throughout the period of the frequency sweep. A commercially available operational amplifier is used to match the high impedance probe circuit to the much lower impedance telemetry circuit. R_1 is a 5 megohm resistor used to block rf before the shielded cable connection to R_2. A value of 200 megohms was chosen for R_2; this value represents a compromise between the need to load the probe as lightly as possible and the limitations imposed on the circuit impedance by the input impedance and leakage currents of the operational amplifier. R_3 is a 400 megohm feedback resistor used to provide a voltage gain of two between the input to R_2 and the output of the operational amplifier. Because of the high voltage gain of the amplifier (30,000 minimum) combined with the high impedance associated with the amplifier input circuit it has been found necessary to shield the amplifier and its associated circuitry, including R_2 and R_3, in order to minimize stray pickup. The output is telemetered on channel 8 CW.

3.2.3 Programming and In-Flight Calibration

The resonance rectification and variable frequency impedance experiments will be operational for only one-third of the time. They will be activated for 512 msec followed by an off period of 1024 msec as described in Chapter 6.

The signal to turn the experiments on and hold them on is provided by "Gate 2," a 10-volt step which appears for the proper 512 msec period. This step is detected by a Schmidt trigger and used to apply B plus voltage to the crystal oscillators and the drivers for mixers #1 and #2. The output from the Schmidt trigger is also used to trigger a one shot multivibrator with a period of 15 msec. This 15 msec signal, which occurs at the beginning of each 512 msec operational period, is used to close normally open reed relays which shunt to ground the 10 KHz signal in the variable frequency impedance experiment and the d.c. from the probe in the resonance rectification experiment. This procedure provides a 15 msec zero level calibration period for each cycle so that any drift in the d.c. amplifiers, phase detectors and telemetry system can be observed. To improve the accuracy of the impedance measurements by increasing the effective dynamic range of the system, two gain positions are provided in the 10 KHz amplifier following mixer #3. The gain change is achieved with the aid of a reed relay which is energized every other operational period by a subgate which appears for 1536 msec every 3072 msec.

3.2.4 Pre-Flight Calibration

Pre-flight calibration of the variable frequency impedance instrumentation is performed by measuring the signal levels of the two output channels which result when the probe sphere is replaced by several known values of resistance and capacitance. These measurements are performed at a number of different fixed frequencies within the 3.0 MHz to 0.1 MHz range.

Pre-flight calibration of the resonance rectification instrumentation consists of measuring the output signal voltage which results from applying a known d.c. voltage to the probe sphere.

4. THE HIGH FREQUENCY CAPACITANCE PROBE

N. Eaker and W. Heikkila

4.1 Theory

At frequencies well above all resonance and gyro-frequencies the plasma may be considered a simple dielectric with relative dielectric constant slightly less than unity. The impedance of an isolated body, such as the 4.5 inch spherical probe, is then capacitive, with capacitance slightly below its free space value; this capacitance is a measure of the dielectric constant.

If the dielectric constant $\varepsilon = \varepsilon'\varepsilon_0$, with ε_0 being the value in free space and ε' being the relative dielectric constant of the plasma, then we may set $\varepsilon = 1 + \Delta$ with Δ a small quantity. It may be shown readily that the capacitance C of a sphere immersed in the plasma is given by the formula:

$$C = -4\pi\epsilon_0 \left[\int_{\infty}^{r_p} \frac{dr}{\epsilon' r^2} \right]^{-1}$$

If C_0 is the capacitance in free space and distance $x = r/r_p$ is measured in units of probe radius, the fractional change in capacitance, caused by the plasma is then given by the formula:

$$\frac{\Delta C}{C_0} = \frac{C - C_0}{C_0} \approx \int_1^{\infty} \frac{\Delta(x)}{x^2}\, dx$$

The variation of dielectric constant is part of the integrand since it is a function of position in the ion sheath. The formula shows that a net decrease in capacitance results from the introduction of the plasma, since Δ is then negative.

The dependence of the dielectric constant on electron collision frequency is given by the Appleton-Hartree magnetoionic formula (Ratcliffe, 1959) under the assumption that there is no dependence on electron energy. In fact the collision frequency has been shown to be a strong function of the energy, and a generalized magnetoionic theory (Budden, 1965) may be required for a proper interpretation of experimental results. In either case, both the electron concentration and the collision frequency can be evaluated by means of sufficiently accurate measurements of the probe capacitance at two frequencies. In the present instrument the two frequencies used are 5 and 10 MHz.

In the present instrument the probe is a 4.5 inch diameter sphere whose capacitance is used in an LC oscillator circuit, and the frequency of oscillation is measured. This frequency is given in terms of the free space probe capacitance C_p, stray capacitance C_c, inductance L, and relative dielectric constant ϵ' as

$$f = \frac{1}{2\pi\sqrt{L(C_c + \epsilon' C_p)}}$$

In practice the oscillator frequency may drift slowly due to a variety of causes, thus introducing error into the probe data. This drift may be allowed for by applying periodically a large negative bias to the probe; with the electrons repelled far away from the probe frequency returns towards its free space value f_o. Experience has shown that for low electron concentrations the return is essentially complete, and for high concentrations the errors due to oscillator drift are negligible in any case; therefore, the relative frequency change may be evaluated experimentally with good precision. Making the approximation that relative dielectric constant is near unity, as appropriate to a high operating frequency, the relative frequency change may be written as

$$\frac{\Delta f}{f_0} \approx K \frac{\Delta}{2}$$

The constant $K = \frac{C_p}{C_p + C_c}$ may be regarded as an instrumental merit factor since it is equal to unity for an ideal probe with no stray capacitance. It may be evaluated by calibration, as described below.

In the present experiments, N will be known from the results of the resonance relaxation experiment. Any departure of the high frequency capacitance probe result from this value may be interpreted as being due to the ion sheath effects.

4.2 Instrumentation

The instrument measures small changes in probe capacitance at two operating frequencies (5 MHz and 10 MHz) in order to provide a determination of both electron concentration and collision frequency. Several different values of probe bias potential are used, from near zero to -300 volts, in order to permit study of the ion sheath about the probe. All circuits are designed to provide 100 μs time resolution so that transient sheath effects may be observed.

4.2.1 Oscillator Circuit

The heart of the instrument is an oscillator whose frequency is determined in part by the probe capacitance. The frequency measurement was considered preferable to alternatives, such as bridge unbalance voltage or r.f. current measurements, from the points of view of sensitivity, accuracy, simplicity, and convenience.

The essential circuit configuration is shown in Figure 5. The sphere is connected through an inductance to the grid of a nuvister in a Clapp oscillator circuit. The inductance is actually in two parts; one being short circuited for operation at 10 MHz, while the combined inductance resonates at 5 MHz. The coil is located within the mast, and the series connection permits the connecting wire to be at a low impedance point in the circuit. In the Clapp oscillator, the two large capacitors C_A and C_B swamp out the stray capacities which are not in series with the inductance. The resonant frequency of this circuit is insensitive to large dc potentials applied to the probe. A feedback loop from the output amplifier maintains the amplitude of oscillation at less than 1 volt rms.

4.2.2 Programming

A complex bias voltage program is applied to the probe during Period III, as shown in Figure 6. With this program, it is hoped to study the effective ion sheath thickness as a function of potential. After each negative bias step the potential is returned to a small positive value (1.4 volts) with respect to the rocket, although it is to be expected that the large sphere will always remain slightly negative with respect to the plasma. Six fixed values of negative bias, from -1 to -300 volts were chosen, each being applied for 16 ms. A low voltage sweep is also included, without r.f. excitation on alternate sweeps, in an effort to check for any effect of the r.f. excitation on the plasma. The longer bias steps, of 64 ms. duration, permit a more accurate determination of the plasma parameters after transient sheath effects have disappeared. The operating frequency is 5 MHz during the whole bias program except during the last pair of bias values when the 10 MHz value is used. The frequency, which may increase by as much as 1 MHz under the influence of the ionospheric plasma, is measured by means of a discriminator and a counter as described below.

4.2.3 Data Handling and Calibration

The precise value of the oscillator frequency is the quantity to be measured and telemetered, with a time resolution of 100 μs. This is accomplished principally by means of a pulse averaging discriminator. Various mixer stages are used to heterodyne the frequency down to the range 0 to 1 MHz. The output is telemetered with two different sensitivities, as shown in Figure 5, on channels H and 12 CW. A second independent frequency measurement is made by counting cycles during specific gated periods shown in the bias program, Figure 6.

A laboratory calibration is required for determing the value of K. The circuit strays (neglecting for the moment fringing capacitance) are determined by connecting a calibrated micrometer capacitor to the oscillator inductor with the sphere removed. Several values of capacitance are adjusted into the circuit and the oscillator frequency is measured at each point. This information is plotted against $1/f^2$ and the amount of stray capacitance is deduced from the intercept on the C-axis. This capacitance will be called C_{cp} to indicate stray capacitance as measured from the inductor. Another method of measuring stray capacitance is to use two spheres of different sizes. The two sphere method allows the stray capacitance from the sphere to the mast and rocket body to be measured. The sphere sizes need to be slightly different, just enough to obtain different frequency readings. Due to the high sensitivity, these measurements must be made in a large, open area. Measurements taken on a model circuit have indicated stray capacitances in the order of 10 pf.

This gives a value for K of about 0.4. If there were no strays the value for K would be 1.

5. ELECTROSTATIC PROBES

W. J. Heikkila and N. Eaker

5.1 Theory

The recent complete theories of spherical electrostatic probes (Bernstein and Rabinowitz, Su and Lam, Cohen) predict both the concentration profiles throughout the sheath, as well as the magnitude of the current collected, as functions of the probe potential. Two independent checks on the theory are thus available through the r.f. impedance and d.c. current measurements, at least near the peak of the trajectory; at lower altitudes the rocket velocity may be a major factor in determining probe behavior, but no adequate theory exists to explain this quantitatively. The measurements should help in orienting any theoretical approach to the problem.

5.2 Instrumentation

D. C. probe measurements of two kinds are included in the MIP payload. These are: (a) the measurement of the ion current to the large sphere throughout the bias program that is applied during Period III (Figure 6), and (b) standard Langmuir probe measurements throughout each frame, using alternately a spherical and a cylindrical probe (Figure 7). The former is referred to as the electrostatic probe measurement to distinguish it from the Langmuir probe measurement.

5.2.1 Electrostatic Probe

The electrometer circuit consists of a high gain operational amplifier connected in series with the voltage programmer as shown in Figure 5. The effective electrometer input impedance is less than one ohm. The internal impedance of the voltage programmer is 150K ohms. An isolation resistor of 100K ohms is also in the circuit. A time resolution of 100 μs is achieved with this circuit. The dynamic range of the electrometer is 10^{-9} to 10^{-4} amperes, covered in five decades by means of an automatic ranging circuit. A positive output is maintained for either polarity of probe current. The main information is telemetered on channel 8 CW, and the range information on channel 10 CW.

5.2.2 Langmuir Probes

Standard Langmuir probes operating during all periods have been included to provide for further checks on consistency of data from all the probes, to provide measurements within the ion sheath surrounding the large spherical probe, and to permit determination of vehicle potential.

Two probes are used alternately during consecutive frames with the same electrometer, switching being accomplished by means of a reed relay. The radius of the spherical probe is 4.78 mm; it is gold plated aluminum, welded at the end of a 20.3 cm Monel wire. The cylindrical probe is gold plated Monel wire .445 mm in radius, located at the end of a 15.3 cm Monel wire. Both probes are exposed to the ionosphere when the clamshell nosecone is released.

The probe voltage is swept from -3.0 to +2.8 volts in 48 ms. and is then held constant for 16 ms. A calibration registor is switched in for one sweep during each frame. The electrometer is identical to the one described in section 5.1, and the information is telemetered on channel 14. Ranging information is telemetered during Period I on channel 8 CW and on channels 6 and 22 of the commutator.

6. AUXILIARY INSTRUMENTATION

6.1 The Main M.I.P. Programmer (R. L. Bickel)

The M.I.P. Programmer is required to provide the timing and synchronization signals to all experiments aboard the rocket payload. Since the various experiments operate on a time sharing basis, the programmer must provide gates and signals to each experiment to control its operation and in some cases its mode of operation. In addition, the programmer will switch the telemetry inputs to the proper experiments, thus allowing the experiments to share telemetry channels. Physically included in the programmer package are a 30 channel PAM commutator and a five pole, three position electronic switch.

The backbone of the programmer consists of a 2 KHz multivibrator oscillator driving a 13 stage flip-flop countdown chain (Figure 8). At two places along the flip-flop chain, free-running multivibrators are inserted to ensure against total failure of timing signals should the chain be broken by a flip-flop failure. Each free-running multivibrator is adjusted to operate at a lower frequency than normally encountered at its position, and it is forced to operate at the proper frequency by synchronization signals from the preceding flip-flop. If the timing chain should be broken, any experiment which is dependent upon signals preceding the break will be disabled, either partially or totally, but other experiments will continue to function at a slower rate.

The complete programmer is constructed on five circuit boards, each measuring four inches in length by three inches in width. Most of the individual circuits are contained in modules which are then soldered to the above mentioned circuit boards. Each module measures one inch by 0.65 inch, by 0.6 inch and contains two or three flip-flops, "and" circuits, or "nor" circuits. A total of 31 modules are used in the MIP Programmer. One of the circuit boards contains 34 emitter followers to provide isolation and low impedance outputs on all signal leads from the programmer. Each output lead is isolated so that the loading effect of one experiment will not affect the inputs to the other experiments. Another of the five circuit boards contains the regulated power supplies required by the programmer and the commutator timing and control signal sources. The third circuit board contains the time base while the last two boards contain the basic logic which provides the various gate signals which are required.

6.1.1 Time Base

The time base (Figure 8) is constructed of all silicon transistorized circuitry and is powered by a +5V power supply. The supply voltage is limited to 5 volts to prevent emitter to base breakdown of the various switching transistors which are driven into the cut-off condition through capacitors. The basic oscillator (Z25) is a free-running multivibrator operating at approximately 2 KHz. Its output (labeled "t") is used to drive two flip-flops in Z26. The two flip-flops ("a" and "b") divide the KHz signal down to 500 Hz. Since the basic rate of the telemetry commutator is set at 250 bits per second, and the commutator signals are invaluable in the event of experiment malfunction, a synchronized free running multivibrator is used to drive the next flip-flop in the chain. The multivibrator (Z27) is synchronized by the outputs of flip-flop "b" and will operate at 500 Hz as long as signals are received. The output of the multivibrator (Z27) is used to drive the flip-flop chain consisting of 8 flip-flops in the four modules Z28 through Z31. These flip-flops are labeled "c, d, e, f, g, h, i, and j" for convenience. Both the normal and the complementary outputs are supplied from flip-flop "f" through "j".

The basic MIP payload contains three separate experimental packages which operate sequentially on a shared time basis. Since the "ON" time for each experiment is to be 512 milliseconds, the timing chain must divide the output of flip-flop "j" by three to provide continuous operation of the payload. This division by three is accomplished by the Z33 and Z34 modules. Z33 contains two flip-flops ("k and l") which normally divide by four; however, at the beginning of the fourth period, the AND circuit in Z34 is activated and it, in turn, resets flip-flops "k" and "l" back to the first period conditions. The three resulting periods are labeled Period I, Period II, and Period III. Since the continued operation of the period counter is important to even partial success of the experiment, a synchronized free running multivibrator is inserted into the timing chain between flip-flop "j" and the divide-by-three flip-flops "k" and "l". In the event of a malfunction of the timing chain preceding the multivibrator in Z32, the multivibrator will freerun at a period longer than the normal 512 milliseconds and will continue to activiate the various experiments in turn, but at a slower rate.

The final requirement of the time base is to divide each three period cycle into alternate sub-periods which are called subgate A, and subgate B. The total cycle time for the complete time base is thus 3,072 milliseconds. The subgate signals will allow the various experiments to operate in different modes on alternate measurements.

Figure 9 is a timing chart which indicated the various waveforms and time relationships of the time base signals from flip-flop "h" through the subgate outputs. None of the signals generated in the time base are connected directly to the various experiments. They are used, by the remainder of the programmer, to generate the gates and signals (in a standardized voltage and impedance form) which are required elsewhere. The amplitudes of the signals generated by the time base are thus: the "1" signals must be positive at least two volts with respect to the common and the "o" levels must not be more than 0.3 volts positive with respect to the common lead.

6.1.2 Gate Generation

The gates required by the High Frequency Capacitance Probe package are shown on Figure 10 and at the upper part of Figure 11. These gates are produced by combining the outputs of various flip-flops in the timing chain through "and" and "nand" circuits in such a manner that the proper gates are generated. The general procedure used for the logic design was to express each gate function in terms of the minterm requirements. The minterm expressions were then entered on a Karnaugh map where they were analized to obtain the simplest possible logic equations for each gate. From these simplified logic equations, the actual circuitry was designed, using "and" and "nand" circuits as indicated. A typical example is shown in Figure 12.

Each output from the programmer must have an output of 10 volts minimum with an output impedance of 10K ohm. Each output must also be isolated from every other output so that if any line is grounded, no other outputs will be affected. The logic circuits are operated from an eleven volt power supply and are connected through emitter followers to the output lines. The typical emitter follower is shown in Figure 13.

6.1.3 Commutator

The 30 channel pulse amplitude modulated commutator is provided to allow monitoring of various voltages and functions during flight. Since the commutator would normally repeat its operation for every 30 clock pulses applied to it and it is desirable to maintain synchronism between the time base and the commutator, a special clock signal has to be generated which supplies only 30 pulses to the commutator for every 32 cycles of the timing chain. The wave form for the commutator clock signal is shown on the top part of Figure 14. The two missing pulses are placed after channel 28 since channels 29 and 30 constitute the master synchronization pulse of the commutator.

The commutator repeats its cycle every 128 milliseconds; therefore, four complete commutator scans are produced during each period.

6.2 Telemetry (N. Eaker)

The telemetry package is supplied by Goddard Space Flight Center, Beltsville, Maryland. The following is a brief description of the system.

The system is comprised of a Vector Engineering Transmitter TRPT-250, which produces 1/4 watt of power at 240.2 MHz. The transmitter is coupled by a phasing network to 60° sweep turnstile antennas. The data signals are fed to the transmitter by a set of eight Vector sub-carrier oscillators. The sub-carrier oscillators and the type of data input are listed in Table I, and the commutator channel assignments in Table 2.

TABLE I. TELEMETRY CHANNEL ASSIGNMENTS

CHANNEL	f_c	DEVIATION	MI	Δf	PERIOD I	PERIOD II	PERIOD III
H	165 KHz	±15%	2.5	10 KHz	A Scan	A Scan	HFC Counter and Discriminator
12 CW	104.2KHz	± 4 KHz	2.0	2 KHz	Ant Z_1	Probe Z_2	Discriminator Range
10 CW	87.5KHz	± 4 KHz	2.0	2 KHz	Ant Z_2	Probe Z_2	Electrostatic Range
8 CW	70.8KHz	± 4 KHz	2.0	2 KHz	Langmuir Range	Res.Recti. Volts	Electrostatic
6 CW	54.2KHz	± 4 KHz	2.0	2 KHz	Freq. Calibr.	Res.Relax. Sweep Level	Res.Relax. Receiver Out
4 CW	37.5KHz	± 4 KHz	2.0	2 KHz	Commutator (all periods)		
14	22.0KHz	±7.5%	5.0	330 Hz	Langmuir Probe (all periods)		
13	14.5KHz	±7.5%	5.0	220 Hz	Magnetic Aspect (all periods)		

TABLE 2. COMMUTATOR CHANNEL ASSIGNMENTS

CHANNEL	SIGNAL	CHANNEL	
1	Zero volts cal	17	-18V Monitor
2	+5 volts cal	18	Antenna position 2
3	Magnetometer Bias	19	Magnetometer Bias
4	Sweep 2 level	20	+5 volts cal
5	10 KHz level	21	Channel 6 cw
6	H.F.C. probe monitor	22	Langmuir range
7	Antenna position	23	H.F.C. probe monitor
8	Sphere temp.	24	+2.5V cal
9	Clamshell monitor	25	+6.3V monitor
10	+5 volts cal	26	Subgate A.
11	Channel H	27	Gate 1
12	Relax. sweep ramp	28	Gate 2
13	Transmitter power out	29	No pulse
14	Transmitter power supply	30	No pulse
15	+28v Monitor	31	Sync. pulse
16	+18V Monitor	32	Sync. pulse

A 6 volt regulator module and a mixer/amplifier module is also supplied with the system. Also provided in the telemetry system is a solid state calibrator which was designed by Goddard Space Flight Center. This calibrator is in series with the inputs to the sub-carrier oscillators, and will inject 0-5v calibrate pulses every 60 seconds into the sub-carrier oscillators. The calibrator steps from 0-5 volts in five 1 volt steps. Approximately 150 milliseconds are required to complete the calibration for each channel.

6.3 Power Supply (W. J. Odom and V. M. Wong)

The converter design for the M.I.P. Program is a conventional common collector design using a tape wound two mil toroidal core, silicon transistors, full wave diode bridges, one zener diode regulator, one series regulator and three unregulated outputs (Figures 15 and 16). In the high current supply a double diode full wave bridge is used. A zener diode is used for voltage reference in the low voltage regulated supply. It is basically an emitter follower type of series regulator and has a very low output resistance.

The design frequency of operation is 2Kz and an RC diode starting circuit provides positive starting under load. The battery leads are shielded from spikes from the switching transistors by an LC π filter and the low voltage outputs are current limited by saturated transistors in the common base configuration.

Primary power is obtained from 20 dry-charge silver zinc batteries, type Yardney HR1.5.

6.4 Aspect Instrumentation (N. Eaker)

The aspect of the payload will be determined by the use of a magnetometer. The magnetometer used is the HeliFlux Magnetic Aspect Sensor Type RAM-5C, manufactured by the Schonstedt Instrument Company, Silver Spring, Maryland. The RAM-5C has a sensitivity of .004 volts per millioersted and a range of plus and minus 600 millioersteds.

The field sensor is comprised of a permalloy core surrounded by two windings. An alternating current of approximately 8000 Hz is passed through one of the windings. The magnetic field associated with this current is of sufficient magnitude to cyclically drive the core into saturation. If there is a magnetic field, such as a component of the Earth's field, threading the core parallel with its long axis, a voltage at the second harmonic of the excitation frequency is induced in the tuned secondary winding. The second-harmonic signal is converted into a direct current signal in a phase-sensitive rectifier. A description of the RAM-5C may be found in the operating instructions for the magnetometer published by the Schonstedt Instrument Company.

The magnetometer sensor as used in the M.I.P. payload is mounted within the clamshell portion of the payload, with the associated electronics circuit being located on the battery deck. The sensor is mounted at approximately 54° with respect to the top surface of the payload, this mounting orientation being chosen because the spinning rocket carries the sensor consecutively into three mutually perpendicular directions, to permit in-flight calibration. Telemetry channel 13 is used for this aspect information.

6.5 Mechanical Design (R. Morgan)

The payload uses the GSFC-NASA standard Cajun-Apache type II structure. The load is carried by three aluminum struts 1" x 1/4", and one aluminum channel 2" x 1/2" x 1/8". Sub-assemblies are built on 1/4" thick aluminum deck plates which are attached to the struts with 8-32 screws. Any sub-assembly may be removed from the structure after the strut opposite the channel is removed. The channel is used for system interwiring.

Several packages utilize a so-called juke-box assembly. Such packages utilize four stainless steel rods 0.093 inches in diameter and appropriate spacers to fasten circuit boards to the 1/4 inch deck plates. To service the package (out of the rack structure) three of the rods are removed; the boards may then be pivoted about the fourth rod. All wiring from one board to another in the package is looped around the rod which serves as pivot.

The payload is surmounted by a two piece clamshell that is ejected at about 60 km altitude to expose the probes. The clamshell is approximately 27.4 inches long, including the 20° nosecone and a 9-inch cylindrical portion. The very tip is made of stainless steel.

Before release, the clamshell is held down by two heavy latches, and is held closed by a restraining bolt at the tip and a V-groove joint at the base adapter. The electrical control and monitor circuits described in the next section are connected by means of spring loaded contacts.

The altitude controlled timing circuit fires a redundant pair of pyrotechnic guillotine cutters to sever the upper restraining bolt. A spring pushes the clamshell tips apart, releasing the cables to the latches. A pair of springs at the base then completes the ejection.

6.6 Payload Wiring

6.6.1 System Wiring (N. Eaker)

The main "U" channel of the rack structure serves as the wiring channel for the payload system wiring. The wire used for payload wiring has an irradiated modified pololefin insulation. This wire may be used continuously (no insulation failure) in an ambient temperature from -55° to 125°C.

Payload connectors are of the Cannon series D type. Each connector floats in the wiring channel, and is fastened to the mating connector on the instrument packages by the use of a hold down screw, and a fixed nut on the instrument package connector. Each connector is potted to prevent wire breakage and short circuits.

The umbilical connector is a 19 pin Deutsch. The payload will be manually switched to internal power prior to breaking the umbilical connection. Since the umbilical connector is mounted in the telemetry section, a mating Cannon D type connector is used to connect the payload wiring to the umbilical connector. A one-to-one pin relationship is made from the umbilical connector to the D connector. The umbilical connection will be pulled apart a few minutes before launch.

Terminal blocks manufactured by Belling and Lee of England are used as tie points for power and ground connections as well as for resistor networks used for commutated data. The terminal blocks also provide accessible test points. These terminal blocks are made of flexible P.V.C. and have captive terminal screws. Each terminal is fully shrouded to protect against accidental contact. The terminal blocks are labeled TB-1 through TB-4.

6.6.2 Clamshell Electronics (K. Tipple)

The clamshell electronics package is divided into the two major areas of control circuitry and monitor circuitry. In addition to the airborne package, a checkout panel is provided in the ground checkout console for control and monitoring through the umbilical cable.

The clamshell release sequence cannot be initiated until the arming relay of Figure 17 is activated from the checkout panel. Once the arming relay contacts have been latched closed and the rocket has been launched, the release sequency will be initiated when the altitude switches close. There are four altitude switches, connected in series parallel for redundancy, which will close when the rocket reaches approximately 10,000 feet altitude. The closure of these switches activates the two timers which control the squib firing relays. The timers will be set to delay the squib firing sufficiently long to ensure that the rocket reaches a suitable altitude (about 60 km) before the clamshell releases. In addition to the redundancy provided by multiple altitude switches and two pairs of timers and squib firing relays, the squib assemblies each contain two explosive charges and firing circuits to ensure a highly reliable system.

The monitoring system provides an output channel which contains data in the form of a voltage level which varies from 0 to +5 volts. This level indicates timer state (set or fired) for both timers and clamshell state (clamshell on or off) for both halves of the clamshell as well as the sequence in which these events occur. The monitor channel information is fed to the main data commutator where it is sampled periodically and telemetered.

In addition to the telemetered monitor information which is available throughout the flight, information on timer state and arming relay state is obtained via the umbilical cable.

A meter on the checkout panel provides a monitor of timer state (set or fired for each timer) and arming relay state (safe or armed). The check-out panel includes control switches for arming relay control. Also, a timer reset control is provided on the checkout panel for laboratory testing of the clamshell electronics during system integration and preflight testing.

6.7 Checkout Console (N. Eaker)

The checkout console is shown on the right in the photograph, Figure 1. The equipment is assembled in a commercially available 19-inch wide rack with large rubber casters. The purpose of the console is to provide control functions needed for checkout and calibration of the payload through the umbilical cable. The console is of versatile design, adaptable to the checkout of other payloads with ease.

The heart of the console is an 820 contact patch panel with program board. All functions, including console switches, power supplies, etc. are connected to the patch panel. By means of the removable program board, any combination of switches, meters, etc. can be interconnected to perform a given function.

6.7.1 Power Supplies:

Three power supplies are used in the console for the present payload.

(1) Console power supply: This supply is used to supply power to console lamps, relays, and other internal circuits. The supply is patched into the patch panel to be used for any function internal to the console. The supply furnishes a nominal 25.7 volts, variable plus or minus 10%, at 6 amps.

(2) Payload power supply: This supply is also connected to the patch panel for the purpose of supplying power to the payload through the umbilical connector. This is used during preflight checkout and calibration of payload instrumentation. This supply provides for 0-36 volts D.C. at 10 amps. Controls and output are available on console front panel.

(3) Battery charging power supply: This is a 0-50 v D.C., 6 amp supply to be used for battery charging. This supply is not programmed through the patch panel. Since dry charged batteries will be used during the MIP firings, this supply will be needed only to charge the prototype battery pack. Associated with the basic power supply will be a constant current source, which will automatically stop charging once the batteries have reached their full charge. Interlock switches are provided on the console doors (top and rear) as safety devices. This ensures that power will be removed from the console if the program board is removed.

6.7.2 Oscilloscope

A Tektronix RM 504 is mounted at the top of the sloping front panel of the console. The oscilloscope input connections are available at the patch panel as well as on the front of the oscilloscope. The oscilloscope has a calibrated sensitivity from 5mv/cm to 20 v/cm with a passband from DC to 450 KHz. It has a calibrated sweep range from 1 usec/cm to 0.5 sec/cm.

6.7.3 Multimeter

A Simpson model 269 multimeter is mounted on the front panel of the console. The inputs to the meter are available either through the patch panel or from the front panel.

6.7.4 DC Voltmeter

A Weston model 1941, 0-50 DC voltmeter is located on the front panel. This meter is available only through the patch panel. During MIP checkout this meter will be used to monitor external payload power.

6.7.5 Running Time Meters

There are two General Electric running time meters located on the front panel. The meters are connected through the patch panel. During MIP checkout one meter will be used to monitor "ON" time for the flight payload. Since relays are used in the instruments it is desired to know their operating cycles. Also, during checkout one running time meter will be used to monitor time on internal power before firing.

6.7.6 General purpose switches

Pushbutton switches with red and green indicator lights are mounted on the front panel and are connected to the patch panel. There are four 3PDT switches with holding coils, two 3PDT momentary switches, and twelve 2PDT switches.

6.7.7 Automatic Telemetry Calibrator

The individual subcarrier oscillators of the telemetry may be calibrated during checkout, and during final pre-flight check by the use of an automatic calibrator built into the console. The controls for the calibrator are available on the front panel, and the calibrator is connected through the patch panel. The calibrator voltages may be monitored by the console meters if desired. The calibrator has three operating conditions as follows:

(1) Automatic: With the control set for automatic operation the calibrator will automatically step from 0 to plus 5v in half volt steps and then step back to zero. The calibrator will continue to cycle as long as the controls are left in the automatic position.

(2) Manual - Continuously variable: During this mode of operation the calibrating voltage may be adjusted continuously from 0 to plus 5v by using the front panel variable resistor.

(3) Manual - Stepped Variable: The calibrator may be set to three fixed steps of 0, 2.5 and 5 volts. This mode of operation allows the subcarrier oscillators to be calibrated for center frequency as well as band edges.

6.8 Telemetry Console (N. Eaker)

Some telemetry and data handling equipment is assembled into a large, enclosed rack, visible on the left of the photograph, Figure 1. This includes a Nems-Clarke 1301A receiver, a large cathode ray oscilloscope ITT Model 1735D, a Honeywell 1508 Visicorder with galvanometer amplifiers, and four Data Control Systems GFD-5 discriminators. This equipment permits complete systems checking and monitoring independently of range instrumentation, but it will not be used for primary data reception or recording.

REFERENCES

1. Bernstein, Ira B. and Rabinowitz, Irving N., "Theory of Electrostatic Probes in a Low-Density Plasma," Phys. Fluids 2, No. 2, 112-121 (1959)

2. Budden, K. G., "Effect of Electron Collisions on the Formulas of Magneto-Ionic Theory", Radio Science Journal of Research NBS/USNC-URSI, Vol. 69D, No. 2, 191-211, February 1965

3. Calvert, W. and Goe, G. B., "Plasma Resonances in the Upper Ionosphere" Journal of Geophysical Research, Vol. 68, No. 22, Nov. 15, 1963

4. Crawford, F. W., and Harp, R. S. "The Resonance Probe - A Tool for Ionospheric and Space Research", J. Geophys. Research, 70, 587-596, 1965.

5. Cohen, Ira M., "Asymptotic Theory of Spherical Electrostatic Probes in a Slightly Ionized, Collision-Dominated Gas," Phys. Fluids 6, 1492-1499 (1963).

6. Fejer, J. A., Calvert, W., "Resonance Effects of Electrostatic Oscillations in the Ionosphere", Journal of Geophysical Research, Vol. 69, No. 23, 5049-5062 (1964)

7. Fejer, J. A., "Interaction of an Antenna with a Hot Plasma and the Theory of Resonant Probes, Conference on Non-Linear Processes in the Ionosphere, December 16-17, 1963, NBS Technical Note No. 211, 101-118, and Radio Science, 68D, 1171-1176, 1964

8. Harp, R. S., "A Theory of the Resonance Probe, Microwave Lab. Report 1117, Stanford University, Stanford, California, November, 1963

9. Kane, J. A., Jackson, J. E., and Whale, H. A., Journal of Research of the National Bureau of Standards - D. Radio Propagation, Vol. 66D, No. 6, 641-648, November, December 1962

10. Kavadas, A. and Forsyth, P. A., "Falling Probe Electron Density Measurements" Reprinted from Canadian Aeronautical Journal, Vol. 7, No. 3, 105-108 (Mar., 1961)

11. Langmuir, I. and Mott-Smith, H., "Studies of Electric Discharges in Gases at Low Pressures," Gen. Elec. Rev. 27 (1924). "The Theory of Collectors in Gaseous Discharges," Phys. Rev. 28, 727-763 (1926).

12. Miyazaki, S., Hirao, K., Aono, Y., Takayama, K., Ikegami, H. and Ichimiya, T., "Resonance Probe - A New Probe Method for Measuring Electron Density and Electron Temperature in the Ionosphere", Rep. Ionos. Space Res., Japan, 14, 148-159, 1960

13. Nisbet, J. S., see Herman, J. R., "A Method for Determining D-Region Electron-Density Profiles Utilizing a Capacitive Impedance Rocket Probe", Journal of Geophysical Research, Vol. 69, No. 11, 2329-2336 (1964)

References (Continued)

14. Peter, G., Muller, G., and Rabben, H. H., "Measurements with the High Frequency Resonance Probe in a Caesium Plasma, Proc. Intern. Conf. Ionization Phenomena Gases, 6th, Paris, 1963, 4, 147-156 (1964)

15. Pfister, W., Ulwick, J. C., and Vancour, R. P., "Some Results of Direct Probing in the Ionosphere", Journal of Geophysical Research, Vol. 66, No. 4, 1293-1297 (April, 1961)

16. Ratcliff, J. A., "The Magneto-Ionic Theory & Its Applications to the Ionosphere", Cambridge University Press (1959)

17. Sayers, J., Rothwell, P. and Wager, J. H., "Evidence for a Further Ionospheric Ledge Above the F_2 Region" Reprinted from Nature, Vol. 1965, No. 4847, pp. 1143-1145, Sept. 22, 1962

18. Su, C. H. and Lam, S. H., "Continuum Theory of Spherical Electrostatic Probes," Phys. Fluids, 6, 1479-1491 (1963).

19. Wait, J. R., "Theory of a Slotted Sphere Antenna Immersed in a Compressible Plasma," J. Res. NBS 68D, 1127 (1964)

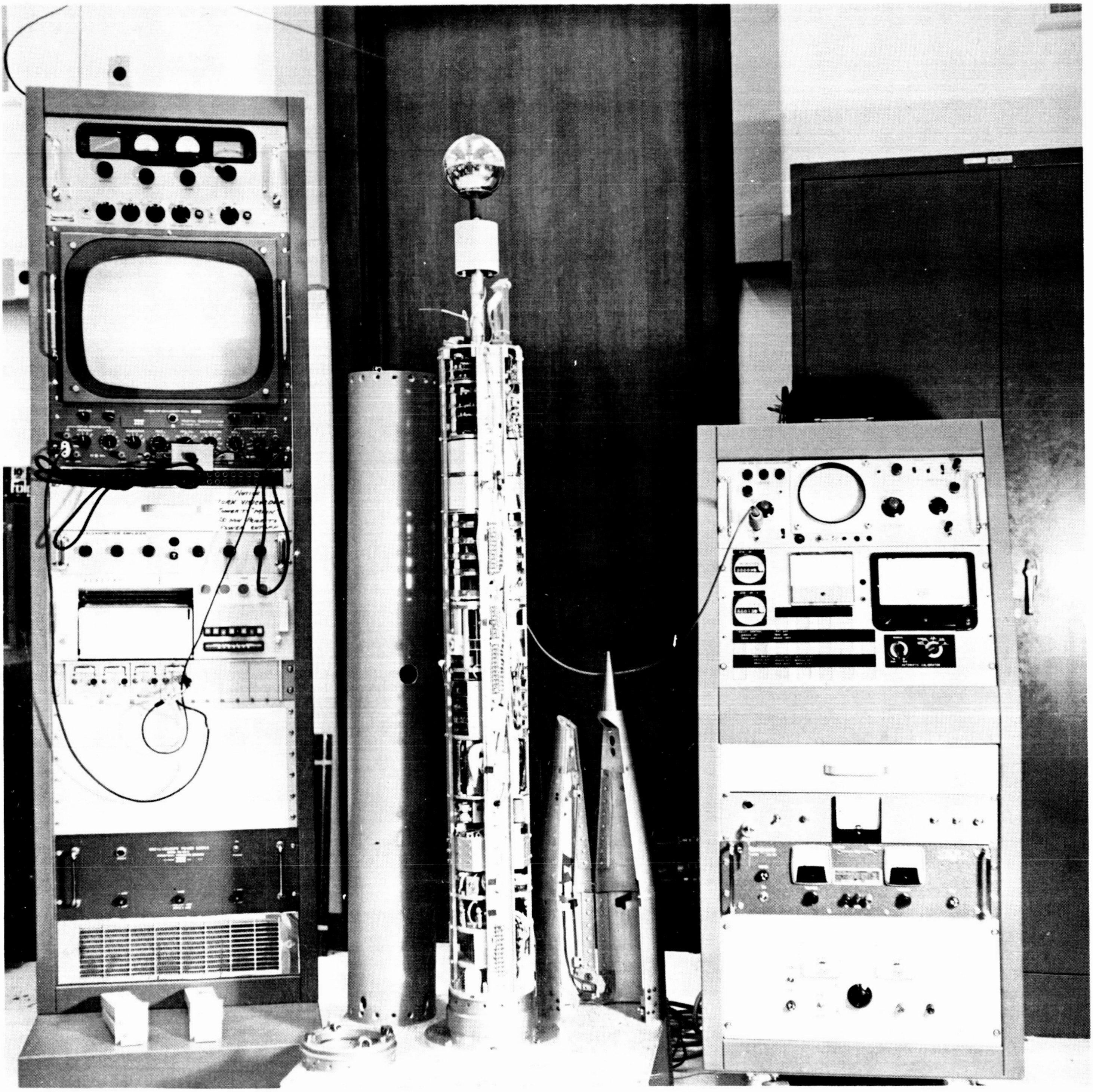


Figure 1. MIP Payload and Checkout Instrumentation

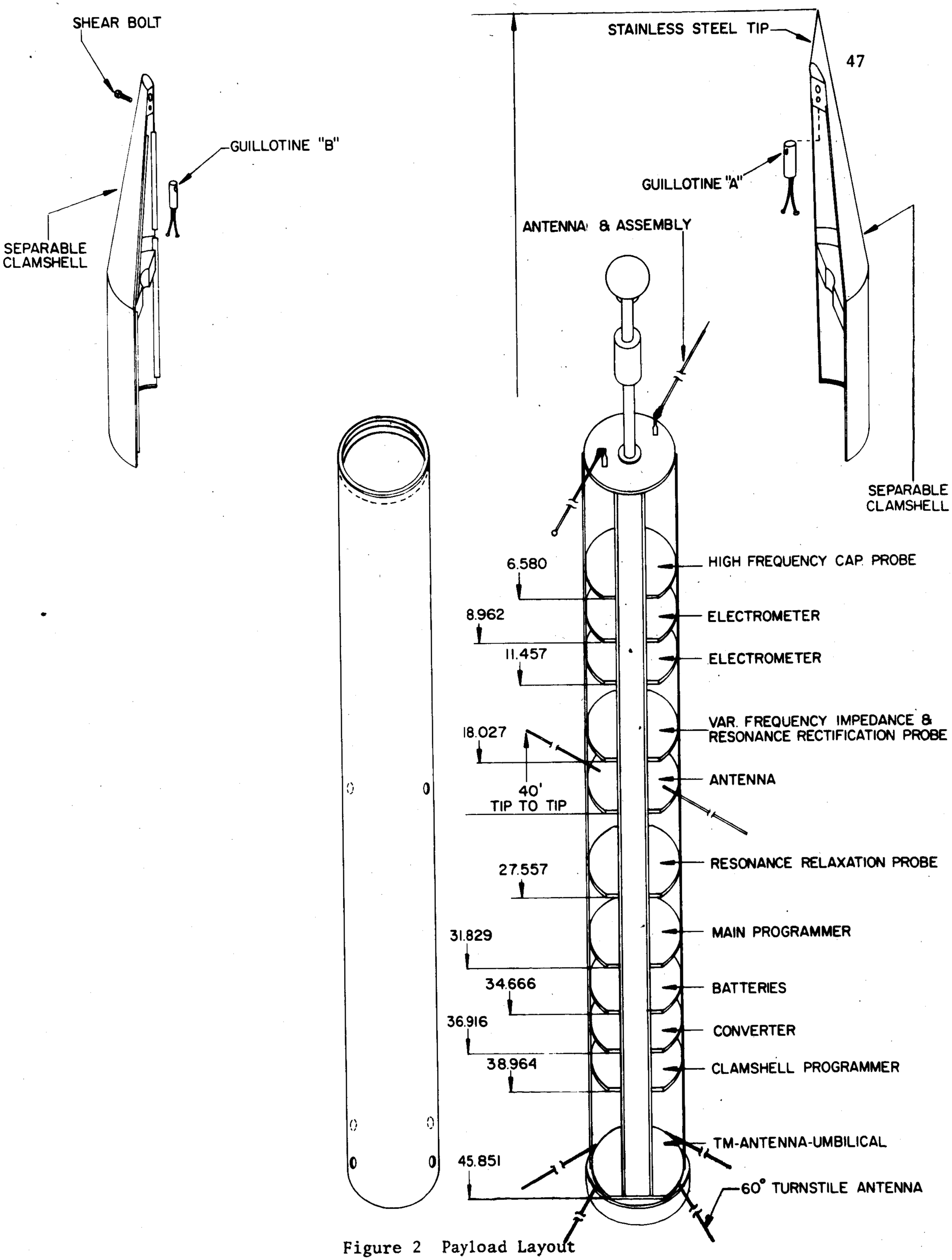


Figure 2 Payload Layout

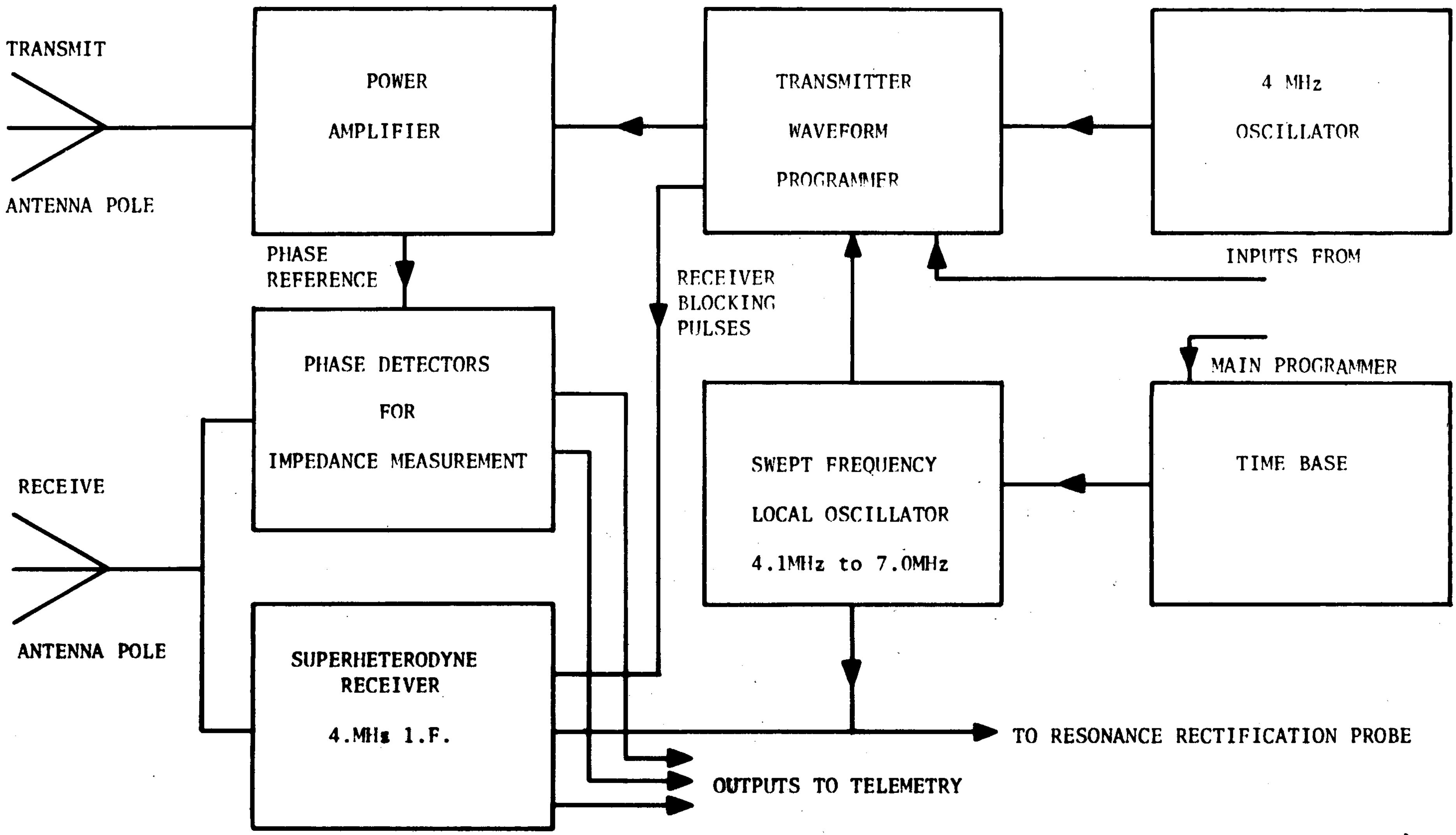


Figure 3 The Resonance Relaxation Probe

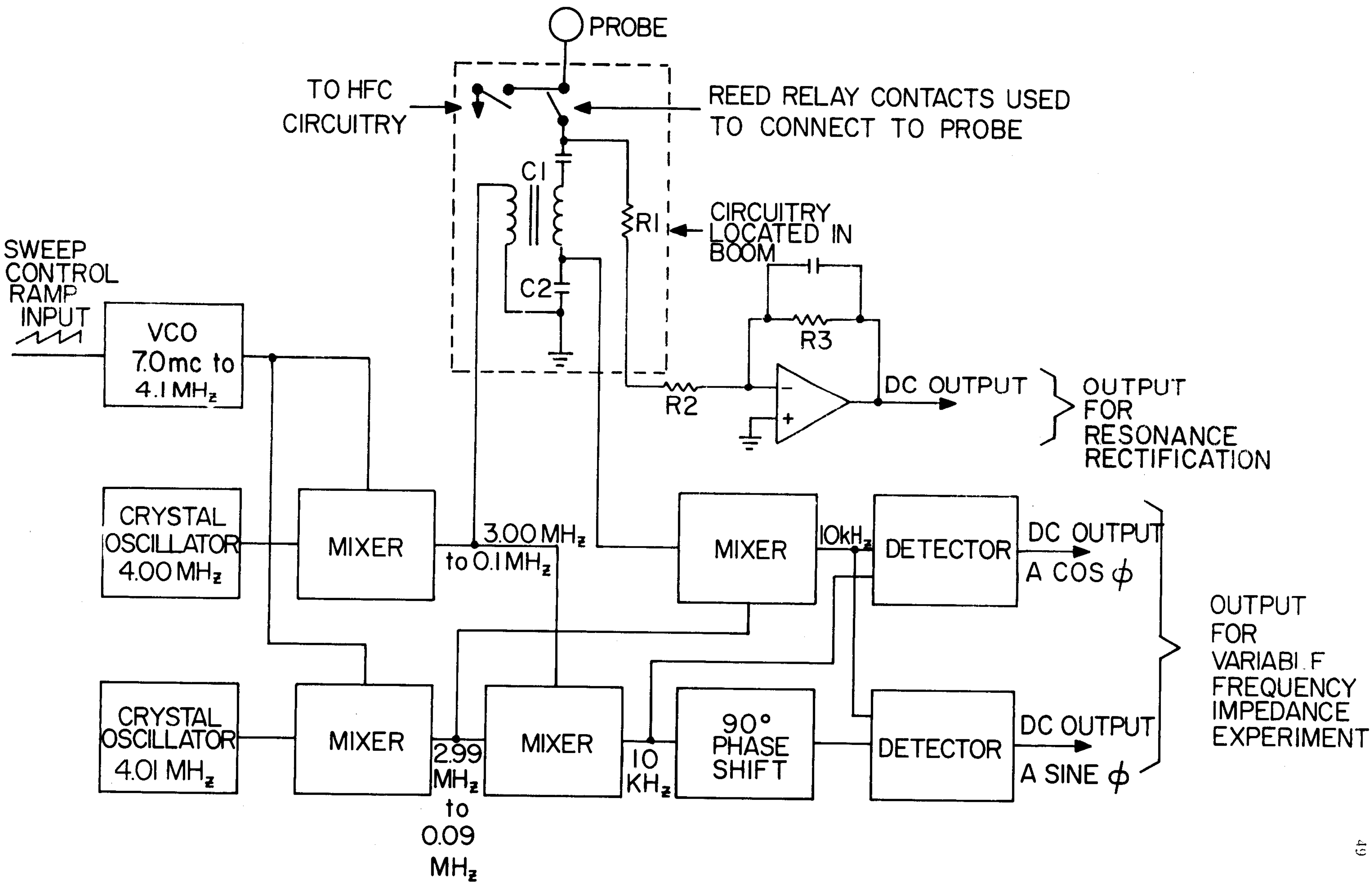


FIG. 4 RESONANCE RECTIFICATION AND VARIABLE FREQUENCY IMPEDANCE EXPERIMENT

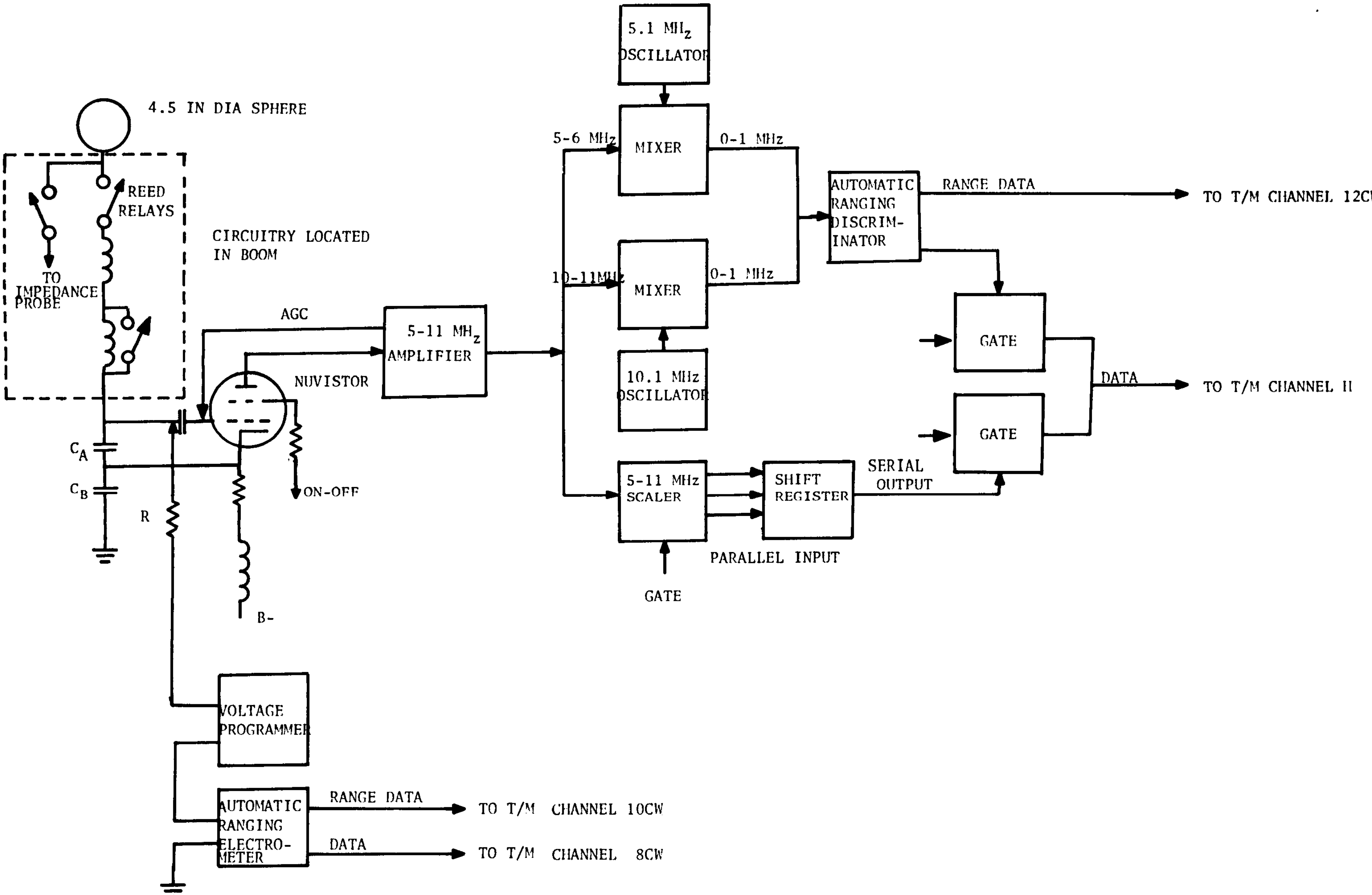


FIGURE 5 HIGH FREQUENCY CAPACITANCE AND ELECTROSTATIC PROBES

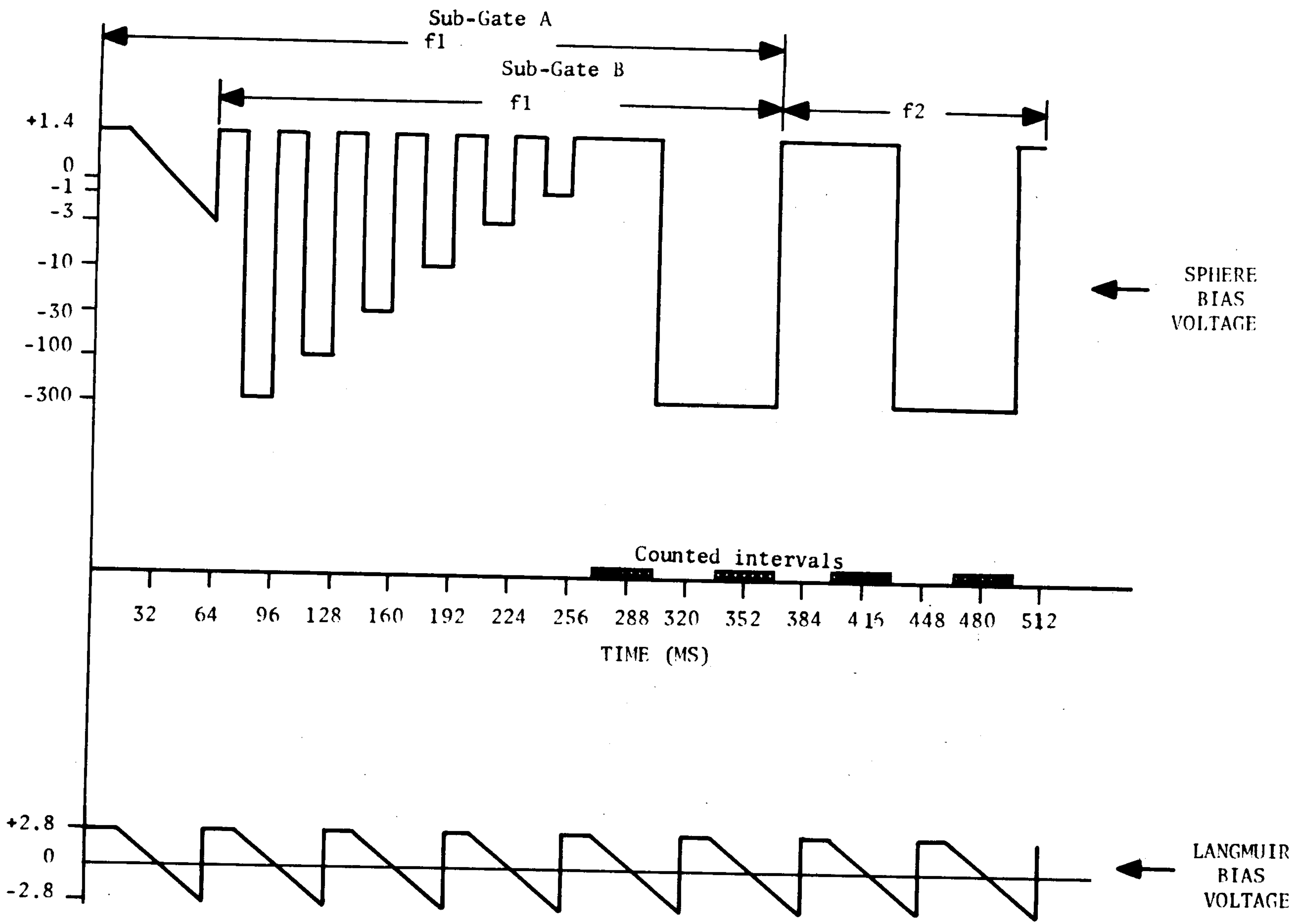
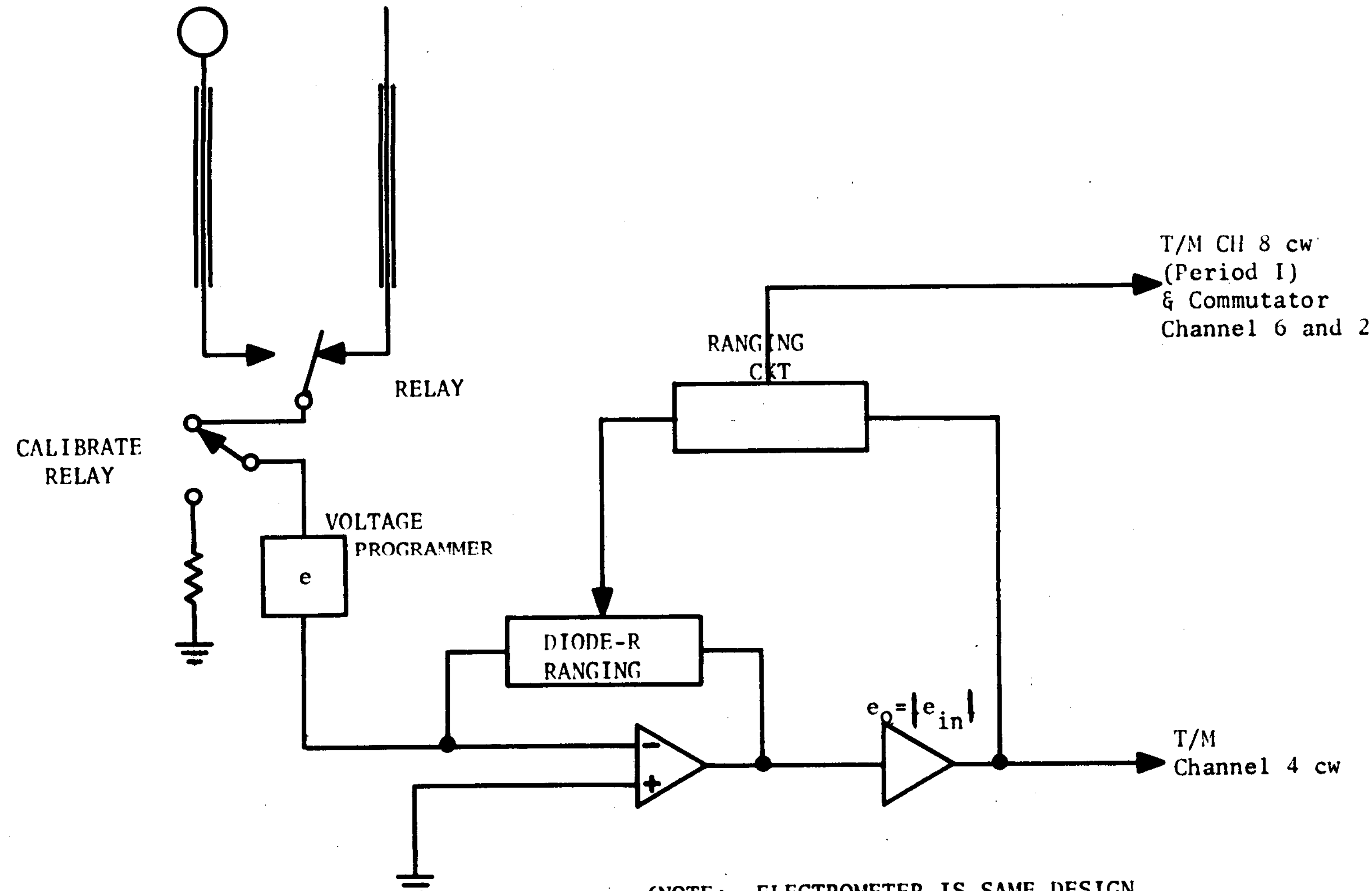


Figure 6 HFC Sphere and Langmuir Voltage Programs



(NOTE: ELECTROMETER IS SAME DESIGN AS THAT USED IN ELECTROSTATIC)

Figure 7 Langmuir Probe Block Diagram

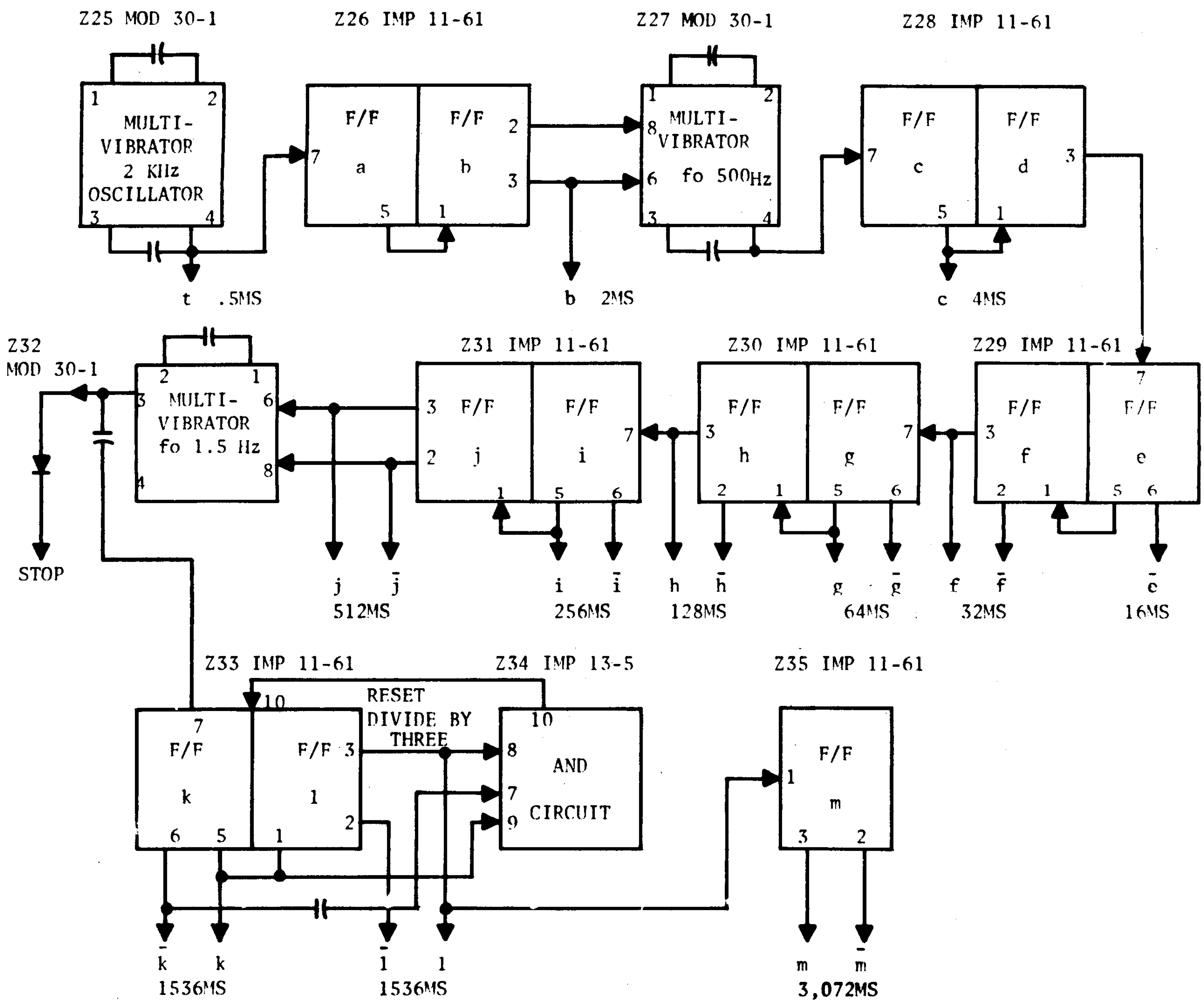


Figure 8 MIP Programmer Time Base Block Diagram

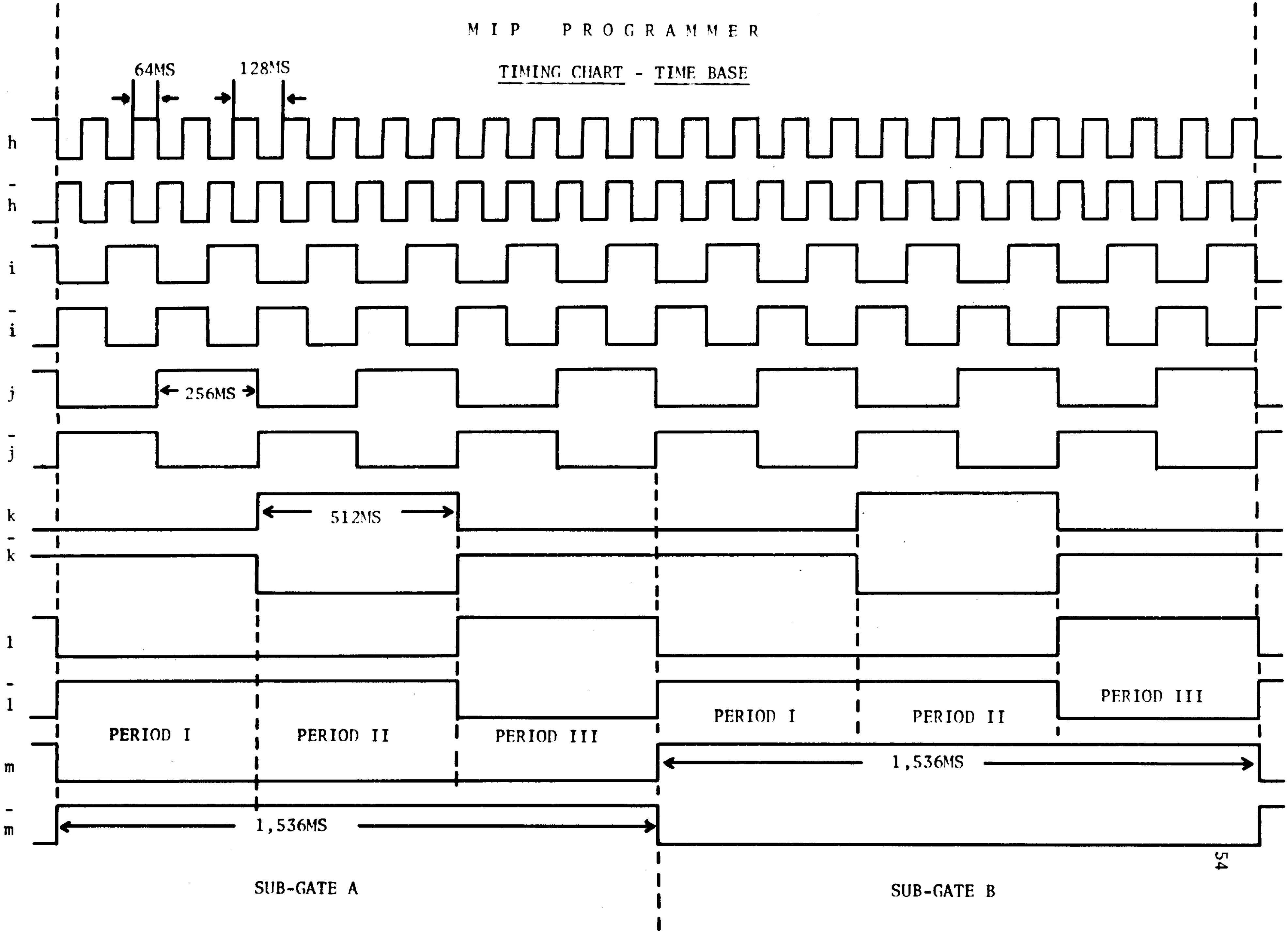


Figure 9 M I P Timing Chart

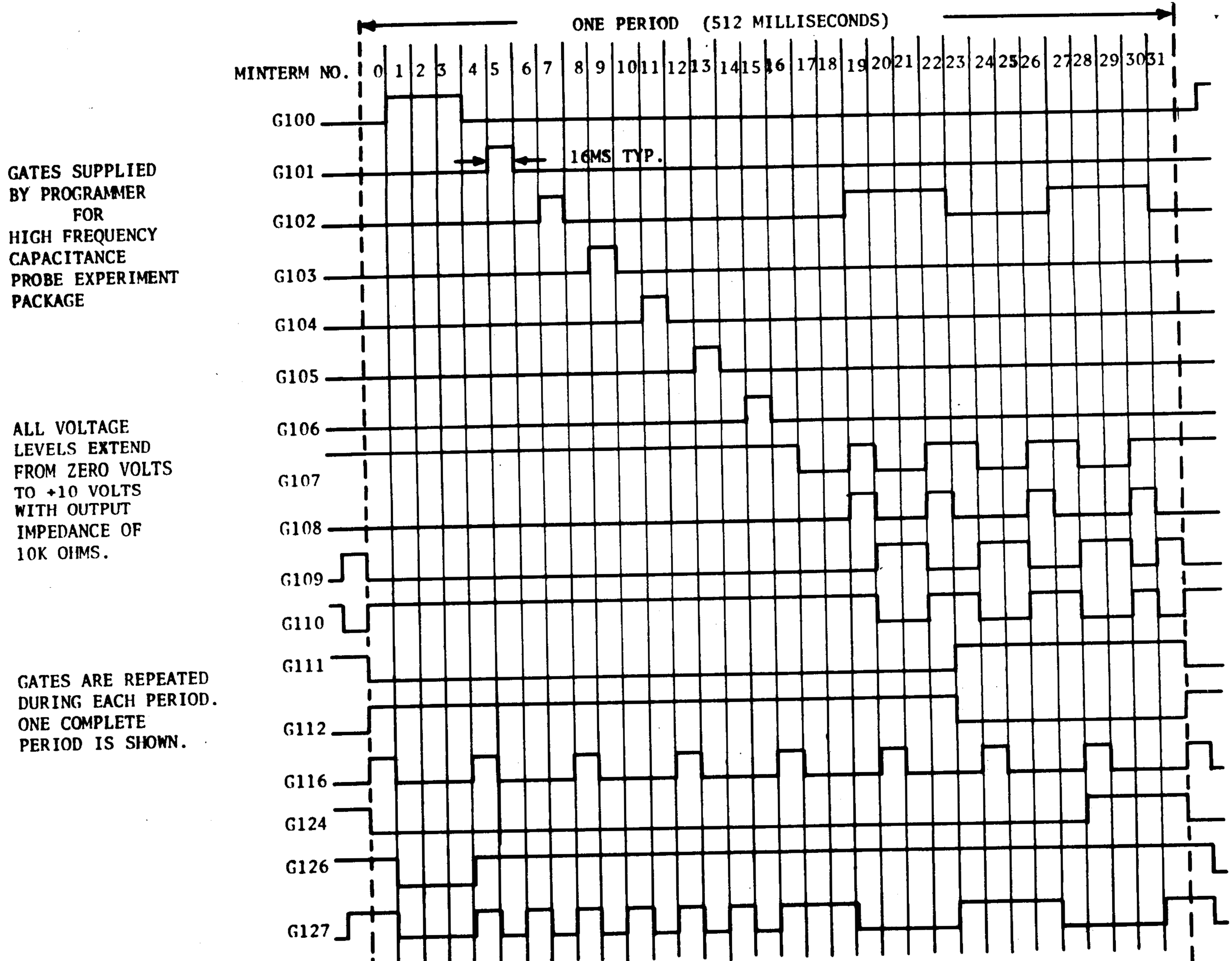
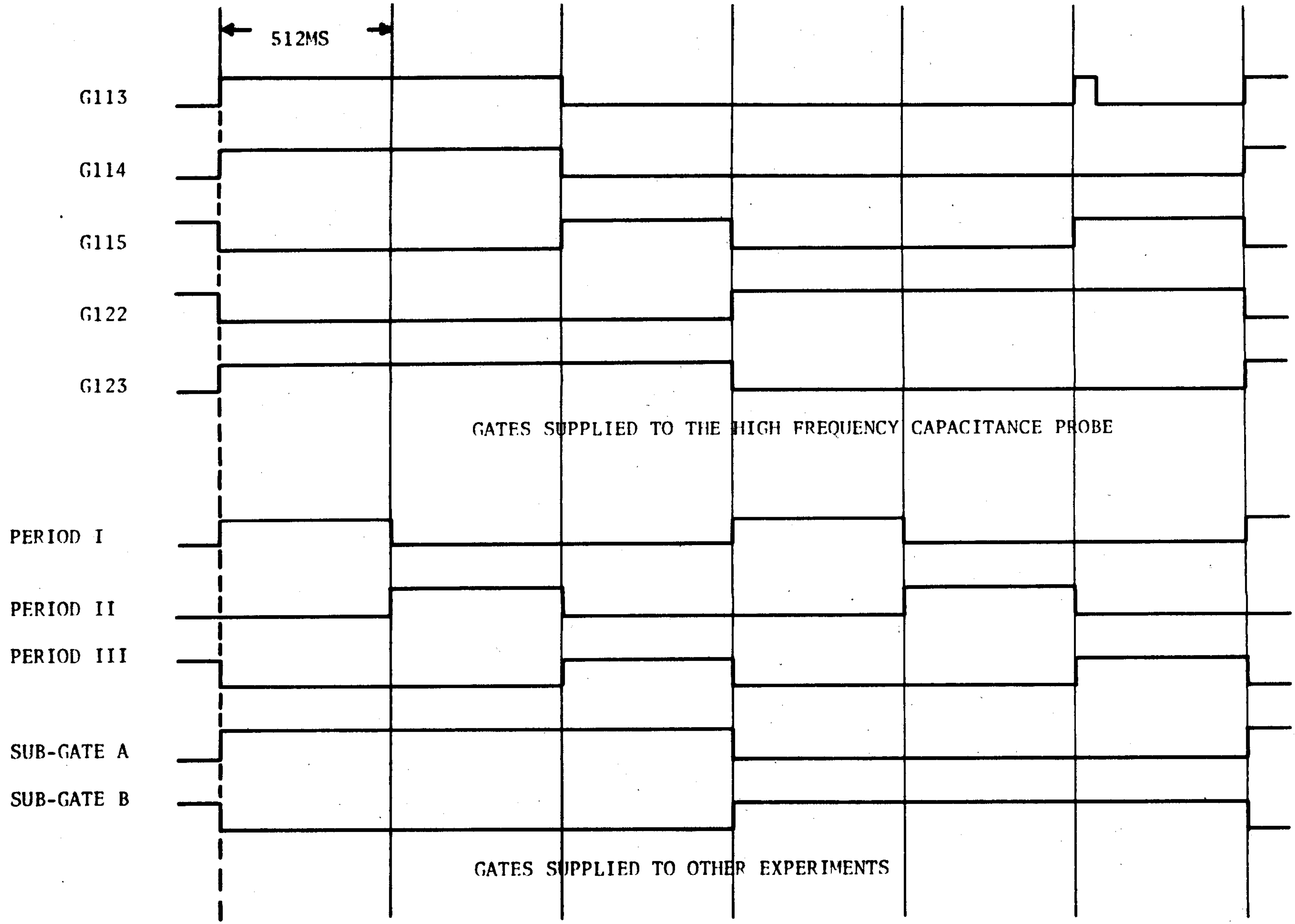


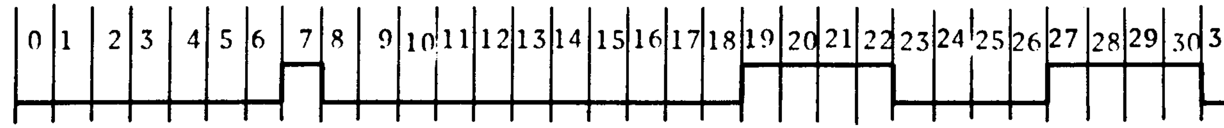
Figure 10 High Frequency Capacitance Probe Gates



ALL VOLTAGE LEVELS EXTEND FROM ZERO VOLTS TO +10 VOLTS WITH AN OUTPUT IMPEDANCE OF 10K OHMS.

Figure 11 Gates Supplied by Programmer

MINTERM NO.
G102



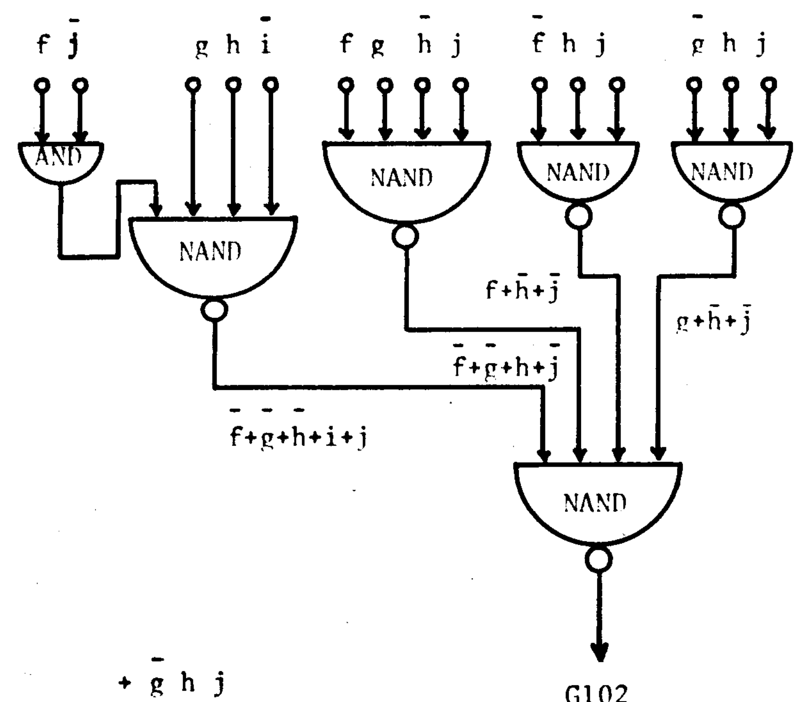
GATE WAVEFORM TO BE GENERATED

MINTERM EXPRESSION

$$G102 = m_7 + m_{19} + m_{20} + m_{21} + m_{22} + m_{27} + m_{28} + m_{29} + m_{30}$$

KARNAUGH MAP

	$\bar f\bar g$	$f\bar g$	fg	$\bar f g$	$\bar f g$	fg	$f\bar g$	$\bar f\bar g$
$\bar h\bar i$	0	1	3	2	18	19	17	16
$h\bar i$	4	5	7	6	22	23	21	20
hi	12	13	15	14	30	31	29	28
$\bar h i$	8	9	11	10	26	27	25	24
	$\bar j$				j			



SIMPLIFIED EXPRESSION FROM MAP

$$G102 = \underset{(m_7)}{f\,g\,h\,\bar i\,j} + \underset{(m_{19}+m_{27})}{f\,g\,\bar h\,j} + \underset{(m_{20}+m_{22}+m_{28}+m_{30})}{\bar f\,h\,j} + \underset{(m_{20}+m_{21}+m_{28}+m_{29})}{\bar g\,h\,j}$$

Figure 12 **Development of Typical Gate Function**

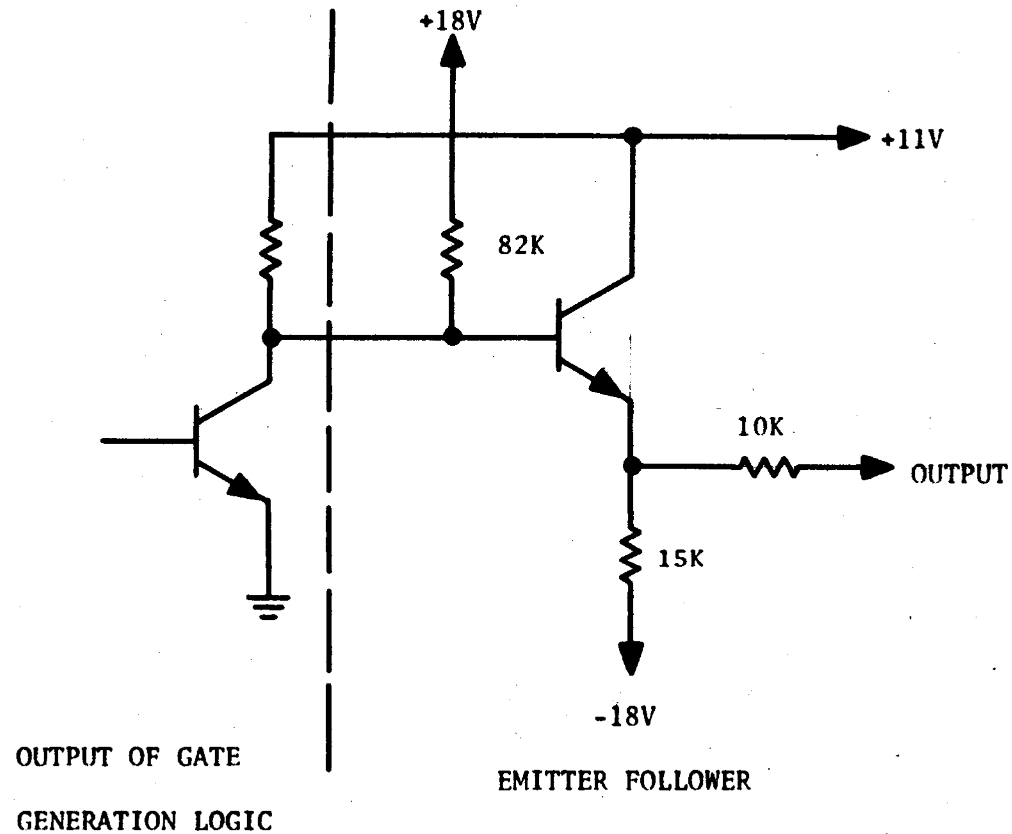


Figure 13 Typical Logic Output Circuit

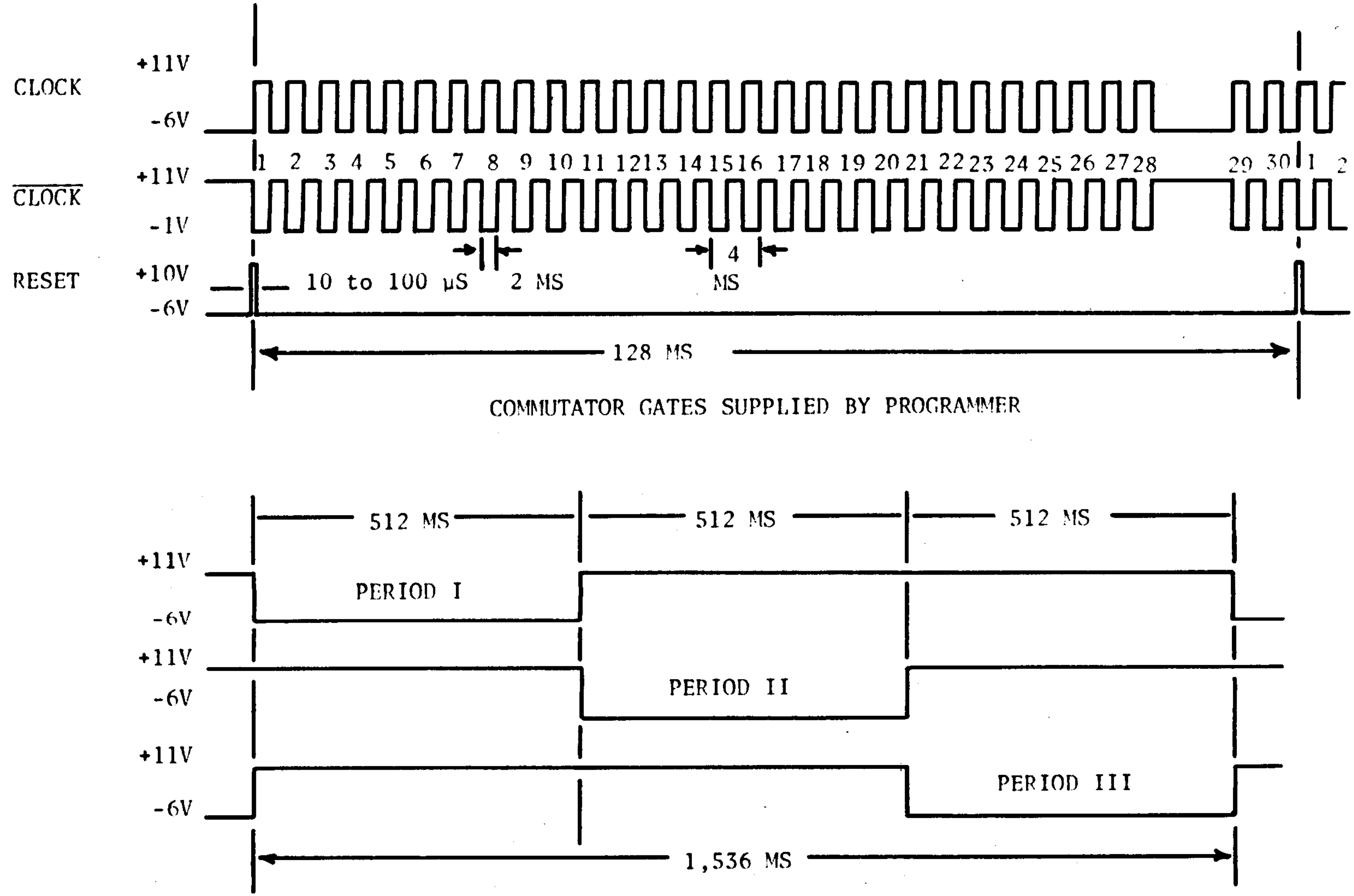


Figure 14 Commutator and Switch Gates

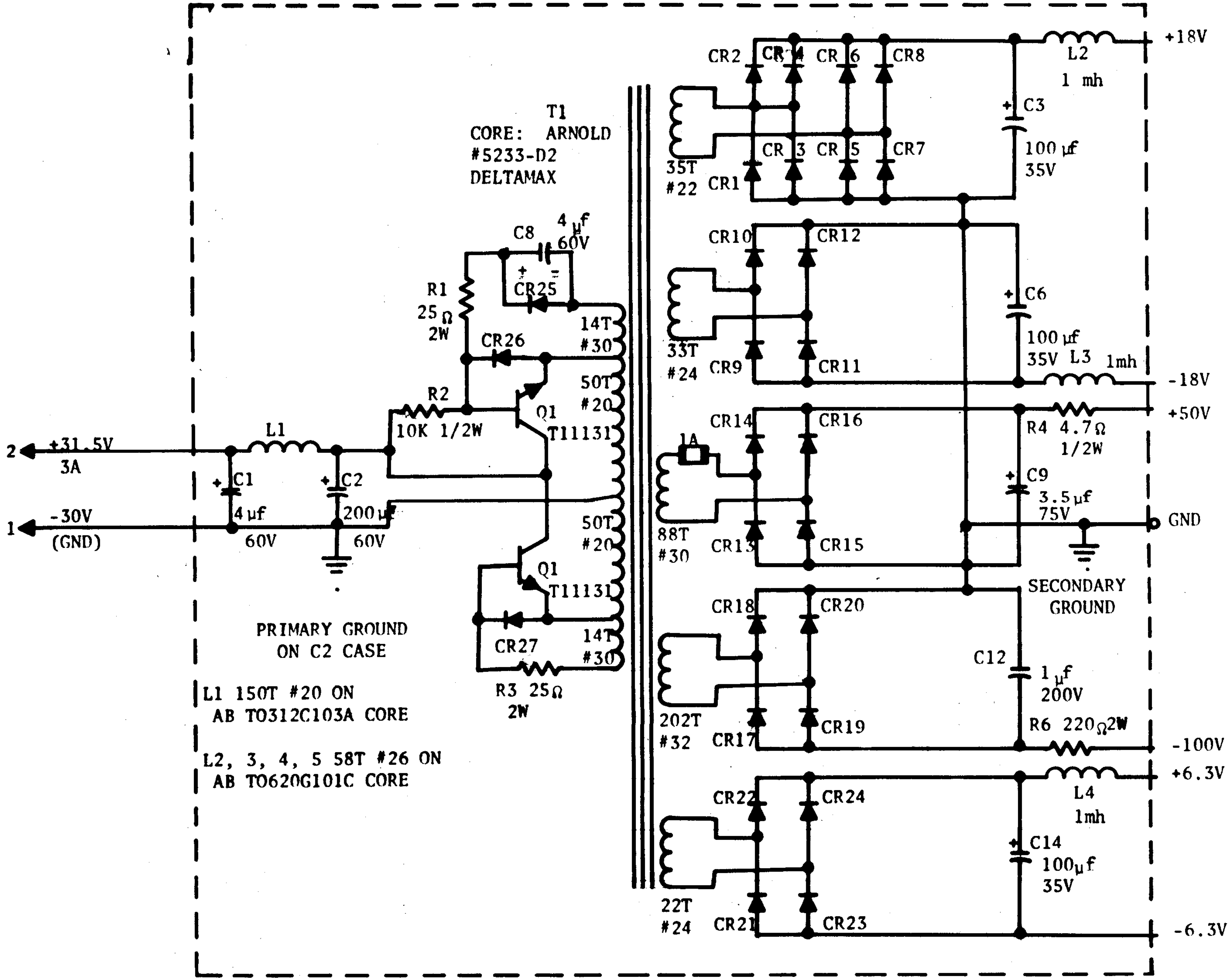


Figure 15 MIP Power Supply (Shielded Section)

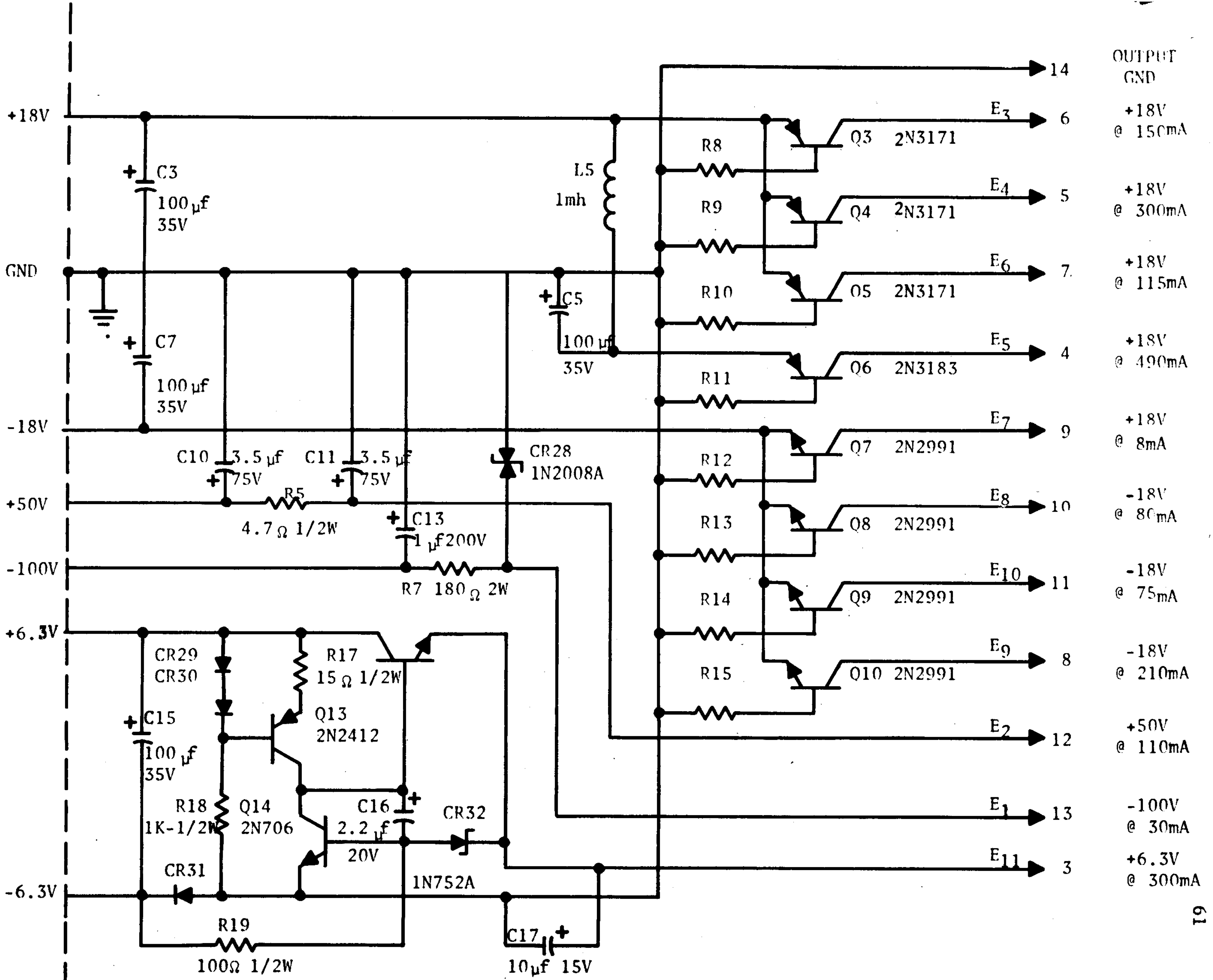


Figure 16 Power Supply - MIP - Regulator and Limiter Section

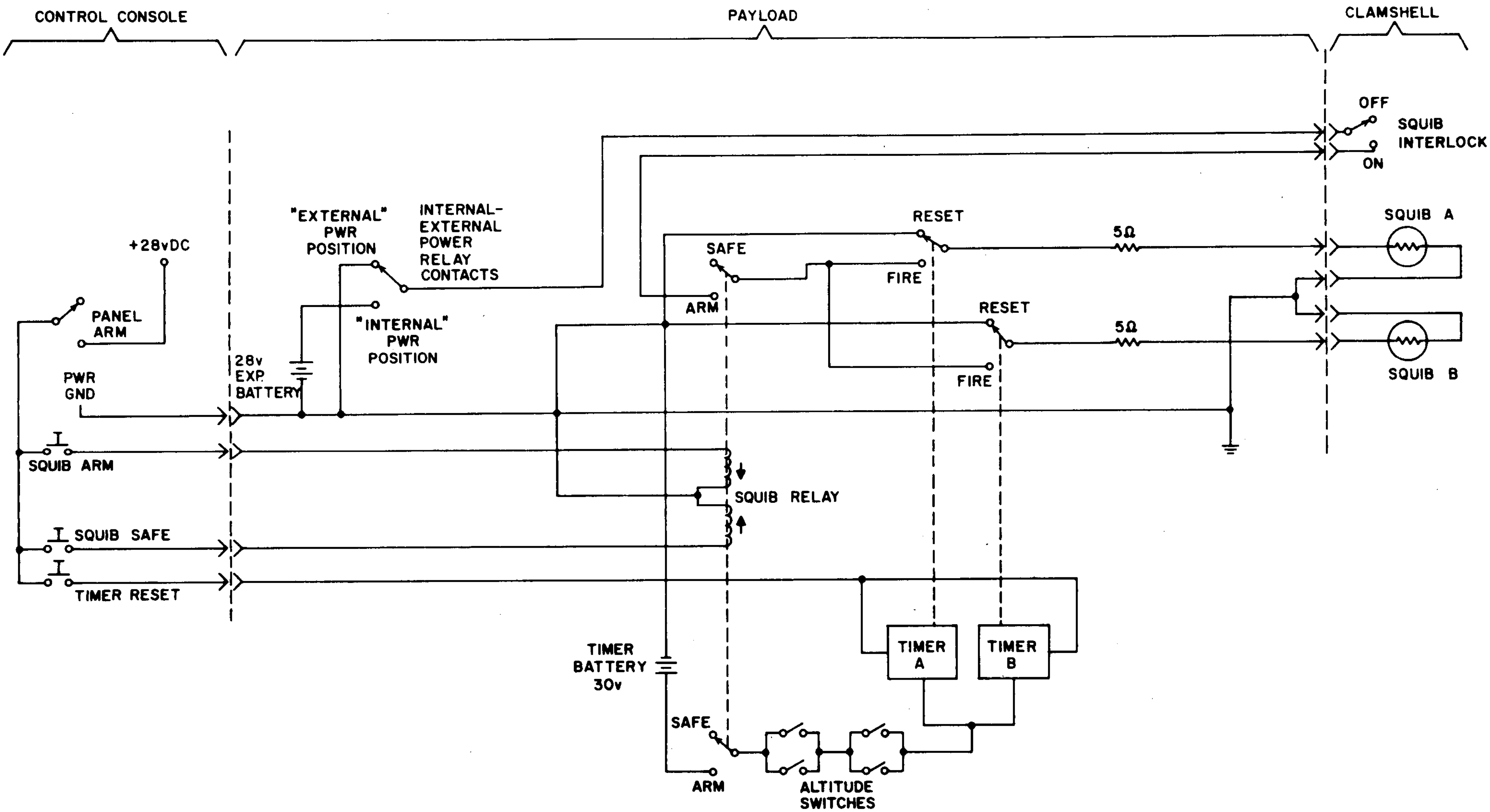


Figure 17 Simplified Diagram of Squib Control Circuits