Rocket borne Langmuir probe and plasma noise probe systems were developed to study some of the ionospheric plasma parameters. The Langmuir probe was developed to measure electron density in the range 10 electrons to \(10^6\) electrons/cc and electron temperature greater than 200°K. The plasma noise probe measures the electron density fluctuations in the frequency range 70 Hz to 1 KHz (of scale sizes ranging from one meter to 15 meters) and with amplitudes as low as 0.05% of the ambient level. The systems are described in forthcoming paragraphs.

4.1 The conventional Langmuir probe system: In the Langmuir probe experiment the sensor is a small section of the nose tip or a separate electrode projecting out from a suitable portion of the nose cone, which is well insulated from the rocket body. A voltage, varying around the floating potential, is applied to the sensor and the current drawn by it from the surrounding plasma is measured by a suitable electrometer amplifier. In the Smith's version the sensor stays at a potential well above the floating potential for a major portion of the cycle and the saturation electron current is measured for the electron density determination. During a part of the cycle the sensor potential varies linearly from a few volts negative to a few volts positive with respect to the floating
potential and electron temperature is determined in this portion of the cycle by retarding potential analysis of the probe current versus probe voltage curve.

The working of the above system is illustrated in fig. 6a. The sweep generator generates the voltage applied to the sensor and the electrometer amplifier measures the sensor current. It is necessary that the input impedance of the electrometer amplifier must be small so as to keep points A and A' very nearly at the same potential, the potential difference between the two points being less than 0.01 volt. The potential at A is not affected to any considerable extent by changes in the input current. It is customary to use amplifiers with 100% negative feed back for this purpose.

While the above system is straightforward, in practice, it involves many precautions. The sweep generating system requires a power supply which has one terminal in common with the rocket ground. The two batteries are therefore, independent and must be well insulated from one another. In fact, it is essential that the entire sweep generating system from the point S to the point A, be well insulated, and shielded from the rest of the payload with only two points G and G' having any connection with the rest of the system. The electrical shielding is connected to the rocket body at A'. Leakage currents between this section and the rest of the system must be much smaller than the sensor currents that are to be measured. The nature of the difficulty will be
CONVENTIONAL SYSTEM

PRESENT SYSTEM

FIG. 6
appreciated when one remembers that in a rocket payload any battery that supplies power to the circuitry must have associated relay systems and external batteries for pre-launch check-out procedure. Also if proper care is not taken even capacitive leakage between the systems can give rise to currents of the same order as the currents are to be measured. The distributed capacity of the sweep circuits further adds to the complication by modifying the probe current in that portion of the sweep cycle where the potential of the probe is varying. The probe current is modified most, after the voltage of the sensor is made to change suddenly from positive to negative. The charge collected in the distributed capacity disturbs measurements in a substantial portion of the sweep during which positive ion current is recorded.

4.2 **The present system:** An alternate system which is functionally similar to the conventional system, was used for the experiment, (Satya Prakash and Subbaraya 1967). This system is illustrated in fig.6 b. A wave form reverse to that which is to be applied to the sensor is generated and grounded to the rocket body. If the potential drop introduced by the electrometer is small (the difference is as before less than 0.01 volt), the sensor voltage varies with respect to the rocket body in a manner determined by the generator. In this system the leakage is reduced to a minimum as the input to the amplifier is directly connected to the sensor. If the payload is so situated inside the rocket nose cone that the sensor and the amplifier are separated by a large
distance, the leakage and distributed capacitances can be minimised by feeding the sensor through a cable and shield of which is kept at \( V_A \) since \( V_A \) differs from \( V_A' \) by 0.01 volts only. (\( V_A \) and \( V_A' \) represent the potentials at \( A \) and \( A' \) respectively.

The block diagram fig.7 describes the working of the system. Using a single floating power supply the voltages \( V_A = 18 \), \( V_A' = 9 \) are produced with respect to the rocket body, \( V_A' \) varying in a manner shown in fig.6. The electrometer amplifier works on these voltages and converts the sensor current into an analog voltage which can be telemetered by FM/FM telemetry system. The present system is much simpler. The frequency response of the system is high and depends primarily on the feedback element in the electrometer amplifier. Since electrometer amplifiers can be built with frequency response upto 20 KHz. Thus the system is ideal for studying the probe current fluctuations. Also the system works on single floating power supply. It facilitates the use of guard electrode without any additional electronics.

Plasma noise probe selects and amplifies the fluctuations in the probe current in the frequency range 70 Hz to 1 KHz. It can cover a dynamical range from 0.05% to 4% of total probe current. The fluctuations with frequencies smaller than 70 Hz can directly be seen on Langmuir probe current record.
BLOCK DIAGRAM OF LANGMUIR PROBE AND PLASMA NOISE PROBE

TO TRANSMITTER

MIXER

SCO 1

SCO 2

SCO 3

SCO 4

DETECTOR

A.C. AMPLIFIER

A.C. AMPLIFIER

FILTER

FILTER

AMPLIFIER

RELAY

SENSOR

REGULATED SUPPLY

FIG. 7

58 (a)
Description of the Langmuir probe and Plasma noise probe instruments: The mechanical system and electronic circuitry of L.P and Plasma noise probe were designed to withstand a wide range of temperature variation and high vibration levels. Temperature and vibration are the main considerations to be taken into account for rocket borne instrumentation. The mechanical layout of the system is such that after assembling the complete unit there is an easy accessibility for electronic components. Such that in case it becomes necessary, any component can be replaced without much difficulty.

The mechanical system was designed to withstand a thrust of about 50 g (g = acceleration due to gravity) with a vibration rate 3000/sec. Such conditions are likely to be encountered during Nike-Apache launch. The payload was subject to a linear acceleration of 50 g and at a frequency only 140 vibrations/sec. Shake table facility at Thumba was available for low vibration frequency i.e. maximum to 140 revolutions/sec.

The maximum temperature in the payload housing is expected to be around 60°C. Each electronic circuit was designed to withstand this temperature. Only those component i.e. transistors, diodes, capacitors and resistances which can stand high temperatures were used. The electronic circuits were kept at a temperature of 60°C for half an hour in an oven and tested for reliability and proper functioning.
Finally the assembled payload was kept at 60°C for half an hour and checked thoroughly for proper functioning. The operation of the assembled payload is continually evaluated during vibration and temperature test.

4.4 Electrode geometry: Electrodes of various geometries like planar, spherical and cylindrical have been used in rocket borne probes. But for the rocket borne probe, one of the most convenient shape of the sensor is the tip of the rocket nose cone. The sensor replaces the standard nose tip and does not require any modification in the geometry of the rocket and avoids use of any opening device. The conical shaped electrodes however, show marked aspect sensitivity of the sensor in probe current (Smith 1967). The aspect sensitivity of the sensor creates difficulties in the analysis of data and hence should be minimised. The conical nose tip was later replaced to an ogive shaped sensor by Smith and was found to be relatively insensitive to the aspect. This sensor was adopted for the present study. The electrode used had an ogive shape and included angle of 11°.

4.4.1 Guard electrode: The use of guard electrode greatly improves the performance of the sensor by rendering the electric field near the sensor normal to its surface and avoiding the edge effect. Since the guard electrode is kept nearly at the same potential as that of sensor hence the direct leakage current between the return electrode for the sensor is very much reduced. Thus it enhances the
function of the insulator which insulates the sensor from rest of the system. Any leakage between the guard and rest of the body does not affect the measurement.

Stainless steel was used for tip sensors because of its high work function (to reduce photoelectric effect), high melting point and low magnetic permeability as some of the probes were also flown along with proton precession magnetometers.

4.4.2 The insulator: The insulator material should be such that in addition to its ability to withstand high temperatures it should have high insulating property and good mechanical strength. Some of them which satisfy above requirements are boron nitride, teflon and ceramic (alumina). These materials were used in different flights for the insulator.

The guard electrode was insulated from the rocket body by teflon insulator. The photograph and drawing of the sensor is shown in fig. 8. To keep the probe sensor free from moisture the sensor is fitted at the tip of the rocket nose cone just before launching.

4.5 Probe Electronics: Fig. 7 illustrates the block diagram of probe electronics. The probe electronics consists of a sweep generator. An electrometer amplifier, plasma noise probe amplifier in frequency range 70 Hz to 1 kHz, subcarrier oscillators and band pass filters according to I.R.I.G. standards. The subcarrier oscillators and associated filters form the part of the probe electronics.
Figure-8: Nose tip electrode photograph.
electronics operates on floating power supply of voltages $V_A^+ = 18$, $V_A^- = 9$ volt. A battery and voltage regulator provides the required voltages. The a.c. output of the subcarrier oscillators is mixed by a resistance network and mixed output is fed to the transmitter. The transmitter operated on separate power supply. The electronic circuit of each unit will be described briefly in the following paragraphs.

4.6 **Sweep circuit:** A linear waveform was obtained by charging a condenser with a constant current. The waveform of the sweep voltage and the circuit diagram of the sweep generator is shown in figs. 11 & 10 respectively. The block diagram of sweep circuit is shown in fig. 9.

![Fig.9 Block diagram of sweep generator](image)

As illustrated in block diagram fig. 9, R and C form a charging network and D is a high gain amplifier. $V_s$ is the supply voltage. With the increase of voltage at the condenser terminal $\Delta$, the output voltage of the dif-
erence amplifier will fall rapidly i.e. a negative going sweep will appear at the output. Let the decrease of voltage in time $\Delta t$ be $-\Delta V$ at the final output. If $g$ is the gain of the difference amplifier then $\frac{\Delta V}{g}$ is the input to difference amplifier. Thus the voltage across the condenser $C$ is $\Delta V(1 + \frac{1}{g})$ and charging current is $C \frac{\Delta V}{\Delta t} (1 + \frac{1}{g})$. The charging current through the resistance $R$ is $(Vs - \frac{\Delta V}{g})/R$ equating the two currents we get

$$C \frac{\Delta V}{\Delta t} = \frac{(Vs - \frac{\Delta V}{g})}{R(1+\frac{1}{g})} = \frac{Vs}{R} \left(1 - \frac{1}{g} - \frac{\Delta V}{gVs}\right)$$

On examining the above equation we can see that $\Delta V$ will vary linearly with time as long as $\frac{\Delta V}{g} < 1$. For the sweep used following were the values.

$$\Delta V_{\text{max}} = 5.0 \text{ volt}$$
$$Vs = 18.0 \text{ volt}$$
$$g = 100$$

so $\left(\frac{1}{g} + \frac{\Delta V}{gVs}\right) \approx 1.3 \times 10^{-2}$ obviously $\frac{1}{g} + \frac{\Delta V}{gVs} < 1$. The linearity of the sweep will be within 1.3%.

4.6.1 Working of sweep circuit: Referring to fig.10 the condenser $C$ is charged through a high resistance $R$, which form a charging network with a fairly large time constant. The other end of the condenser is returned to the final sweep output. The voltage at $A$ is fed to emitter follower $T_2$ and $T_3$ which in turn is fed to a difference amplifier $T_4$, through diode $D_1$. The negative end of the difference amplifier
is biased at +2.0V. The difference amplifier output is fed to emitter follower T₆. The diode D₁ and D₂ form a selective network. As long as the voltage at E is less than the voltage at terminal E the diode D₁ conducts and the output of the difference amplifier goes on decreasing and subsequently the voltage at E also goes on decreasing. As the voltage at the base of T₄ becomes more than the voltage at E, the diode D₂ becomes conducting and the difference amplifier no longer follows the voltage at the emitter of T₃ with the result the output voltage remains constant while the voltage $e_c$ rises. The voltage $e_c$ is fed to a difference amplifier T₁₁ and T₁₂ whose negative end is biased at +5.0 volt.

Divided signal from emitter follower T₆ is applied to T₇ and T₈. The final sweep output is returned to condensor terminal B.

4.6.2 Termination of sweep: The sweep is terminated when the voltage at $e_c$ becomes greater than 5 volts. The voltage $e_c$ is fed to a difference amplifier circuit T₁₁ & T₁₂. As soon as $e_c$ becomes more than +5.0 volt, the difference amplifier gives a positive pulse which triggers a monoshot. The monoshot T₉ and T₁₀ gives a +12 volt pulse for 50 m.sec. duration. The monoshot pulse makes the transistor T₉ fully conducting resulting in a shorting of the condensor C. The $e_c$ waveform and monoshot pulse wave forms are shown in fig.11. After 50 m.sec the short is removed and the sweep restarts.
VARIOUS WAVE FORMS AT DIFFERENT TERMINALS OF SWEEPCIRCUIT

FIG. 11
In order that the duration and the linearity of the sweep is not affected by the temperature change, the electronic components were selected carefully. Silicon transistors with $I_{co} < < 0.1 \text{ micro amp.}$ were used. The charging condenser $C$ was a low leakage current metallized paper capacitor with a leakage resistance more than ten thousand mega ohms.

Following is the specification of one of the sweeps used:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweep voltage levels</td>
<td>-1.0V to 4.0V</td>
</tr>
<tr>
<td>Variable voltage duration</td>
<td>0.6 sec.</td>
</tr>
<tr>
<td>Fixed voltage duration</td>
<td>0.50 sec.</td>
</tr>
<tr>
<td>Zero marker voltage duration</td>
<td></td>
</tr>
<tr>
<td>(monoshot pulse duration)</td>
<td>50 m. sec.</td>
</tr>
<tr>
<td>Total sweep cycle duration</td>
<td>1.15 sec.</td>
</tr>
</tbody>
</table>

### 4.7 Electrometer amplifier:

The probe current (in altitude region 55 to 180 km) that is to be measured ranges from $2 \times 10^{-9}$ amps to $3 \times 10^{-5}$ amps. The electrometer amplifier which can measure such currents should meet following requirements.

1) Should be able to handle currents of the order of $10^{-\mu}$ amp. and respond identically for both the polarities of input currents i.e. positive ion current and electron current.

2) Large dynamical range for input current should be about $1.5 \times 10^{4}$. 
3) Must be capable of giving output voltage from -5.0V to +10V to handle the positive ion as well as electron current and to satisfy telemetry requirements.

4) The frequency response should extend from D.C. to a few KHz and thus must be able to record audio frequency fluctuations present in the probe current. Frequency response should be upto 3 KHz.

5) D.C. Voltage drift must not exceed 100 m.volt due to temperature or supply voltage change.

Fig. 12 Representation of a feed back amplifier.

The amplifier in Fig. 12 has gain A and R_f is the feedback element. i and E_o represent the input current and output voltage respectively. If z_1 is the input impedance the amplifier and if i is the current flows into the
amplifier then,

\[(i - \Delta i) R_F = Z_1 \Delta i - (-\Delta Z_1 \Delta i)\]

\[= \Delta Z_1 \Delta i (1 + \frac{1}{\Delta})\]

\[= -E_0 (1 + \frac{1}{\Delta}) \text{ where } E_0 = -\Delta Z_1 \Delta i\]

\[i R_F = -E_0 (1 + \frac{1}{\Delta} + \frac{R_F}{\Delta Z_1})\]

For a typical circuit \(\Delta = 10^3\)

Feedback resistance \(R_F = 40\) meg. ohm

Grid leak resistance \(Z_1 = 10^6\) meg. ohm

Hence \(\frac{R_F}{AZ_1} < < 1\)

Thus the amplifier output is approximately given by

\[E_0 = -i R_F\] within 0.1\% and the input current

is given by \(i = -\frac{E_0}{R_F}\) \(\text{(9)}\)

Input current is given by output voltage divided by the feedback resistance. Thus it is independent of the amplifier characteristics.

Input impedance of the amplifier = \(\frac{R_F}{A} = 40 \times 10^6\) \(\text{ohms}\)

= 40 \(K\) ohms, which is much less than the value of \(Z_1\).

Referring to fig.13 the input stage of the electrometer amplifier is an electrometer tube Raytheon CK 587 which has a maximum leakage current of \(10^{-13}\) amp. The output voltage of the electrometer tube is fed to a difference amplifier \(T_2\) & \(T_3\) through emitter follower \(T_1\). The difference
ELECTROMETER AMPLIFIER

FIG. 13
amplifier at its negative input is connected to a potential divider. Potentiometer P is used to adjust the zero level of the amplifier. The difference amplifier output is followed by emitter followers T5 and T6. Output of T6 is fed back to the input stage through the feedback network circuit. The condenser C is connected to limit the frequency response of the amplifier and to prevent high frequency oscillations.

4.7.2 Large dynamical range for input current: The large dynamical range of currents is achieved by using a nonlinear resistive element for large currents, a pure resistance for small currents. Thyrites and silicon diodes were used as nonlinear resistance elements. The feedback network used in some of the flights is shown in the amplifier circuit fig.13. The feedback network consists of thyrite, pure resistance and diodes. The resistance and thyrite form the feedback network for electron current while diodes for positive ion current. The resistance can cover a dynamical range of $10^2$ while the thyrite covers a dynamical range of $1.5 \times 10^2$. Thus the total dynamical range of $1.5 \times 10^4$ is achieved for electron current. While diodes cover dynamical range of $10^3$ for positive ion currents.

For low electron current from one milli micro amp. to 0.25 μamp a resistance of 40 meg. ohm is used. The switching from resistance to thyrite is done by the circuit shown in fig.14. The amplifier output is fed to a T8 and T9
TRANSISTORS: 2N532 NPN & 2N2906 PNP

CIRCUIT FOR ZERO MARKER & THYRITE SWITCH RELAY

FIG. 24
which gives a pulse of +15 volt when the amplifier output exceeds 10 volts. The bistable $T_8$ and $T_9$ gives a pulse which is fed to $T_{10}$ which puts on the relay No.2 thus the thyrite gets connected parallel to the 40 meg. resistance. After each sweep cycle a monoshot pulse (from the sweep circuit) of 50 m.sec duration resets the bistable. The current range between $10^{-3}$ μ amp to 0.25 μ amp. is used for electron temperature determination. Any uncertainty caused by using a non-linear element like thyrite as feedback element is avoided.

4.7.3 Zero current marker: The circuit diagram of zero current marker is shown in fig. 14. At the beginning of every sweep cycle a calibration mark is obtained for 50 m.sec. at the amplifier output. This is achieved by shorting the feedback network for 50 m.sec. during each cycle with relay no.1 which is driven by a monoshot. The shorting of the feedback element gives a more reliable zero mark compared to disconnecting the input to the amplifier. From the expression it can be seen for $i = 0$, $E_0 = 0$. Also $E_0 = 0$ when $R_f = 0$. Thus a output corresponding to $i = 0$ can be got by shorting $R_f$. The zero mark can also be obtained by disconnecting the input from tip sensor. Zero mark obtained by shorting the $R_f$ becomes independent of any leakage taking place within amplifier output and the sensor. While in the other method the zero mark will not be free from leakage in the amplifier. Leakage in the amplifier and the sensor are expected during the prelaunch.
period due to the moisture. This leakage is reduced very much as the ambient pressure decreases during the flight.

4.7.4 **The switching relays:** Reed switches of G.E. Co. U.S.A. were used for relay No.1, and relay No.2. The reed switch coils were wound on a plastic spool of \( \frac{1}{2} '' \) length and outer diameter \( \frac{1}{4} '' \).

The amplifier was tested for temperature variations. The drift at the amplifier output was less than 0.1 volt for supply voltage variation \( V_0' + 21 \) to \( V_0' + 15 \) V and temperature variation from 27°C to 60°C.

The standard resistances and standard mercury cadmium cells were used for amplifier calibration.

Typical calibration curves are given in fig.15, curve (A) for electron current with resistance feed back network, curve (B) for thyrite feed back, and curve (C) for positive ion current with diodes as feed back network.

4.8 **Plasma noise amplifier:** An audio frequency amplifier shown in fig.16 was designed to study fluctuations in the probe current from 0.05% to 4.0% of total probe current. It consists of a band pass filter, a signal divider circuit and an amplifier.

The band pass filter has a band width from 70 Hz to 1 KHz, and is a combination of high pass and low pass filter, tuned at 100 Hz and 800 Hz respectively. The toroidal cores manufactured by Arnold Eng. Co. were used for inductance coils.
AMPLIFIER OUTPUT VOLTS
(OPTIONAL CURRENT)
CALIBRATION CURVE
ELECTRO METER
AMPLIFIER

FEEDBACK NETWORK

AMPLIFIER OUTPUT VOLTS
(ION CURRENT)

CALIBRATION CURVE
ELECTRO METER
AMPLIFIER

FIG. 15
NOISE PROBE AMPLIFIER
CIRCUIT. BAND WIDTH
70Hz TO 1kHz
FIG. 16
The filter output is divided in the ratio 1:12 every alternate sweep cycle to cover a large dynamical range. The change of gain (division) is obtained by the flip flop shown in the circuit diagram. The flip flop is triggered by a negative pulse fed from sweep circuit. The divider circuit consists of 22 K ohm resistance and 2 K ohm resistance in series with the transistor $T_4$. When a positive pulse from flip flop is applied to base of $T_4$ the transistor remains non conducting and almost full signal appears at terminal $A$. But for a negative pulse it conducts fully and no voltage appears across the transistor $T_4$. The terminal $B$ is shorted to -9V and the signal at $A$, i.e. across 2.0 K is divided in the above ratio.

The filter output is fed to a feedback amplifier. The amplifier can handle a signal of 0.4 volt peak to peak at its input. It has a voltage gain of twenty with feedback and one thousand without feed back.

In two rocket flights plasma noise signals were studied within a narrow band of frequencies. For this purpose narrow band pass filters were employed. In one flight filter frequency was 680 Hz ±15%. In another flight filters of 400 Hz and 960 Hz each of band width of ± 7.5% were employed. The amplifier output used was same as described earlier. The a.c output of the amplifier was detected and telemetered.

The circuit diagram of phase inverter and diode detector is shown in fig.17. The a.c output voltage of the
amplifier is fed to phase inverter $T_1$. The voltage at collector and emitter are $180^\circ$ out of phase. The diode $D_1$ and $D_2$ form the diode detector circuit. The rectified output voltage is fed to $T_2$. The condenser $C$ is connected across the emitter resistance of $T_2$ for filtering. The filtered output is fed to an emitter follower and then to subcarrier oscillator.

4.9. **Electronic differentiation of J-V Langmuir probe characteristics:** In one of the flights electron temperature was determined by differentiating the J-V characteristic curve. The theoretical treatment of this method is given on page 110. The electronic circuit used for this purpose was similar as shown in fig.17. A signal of about 2 m volt of 800 Hz frequency was superimposed on sweep voltage, with the help of a transformer. The signal at 800 Hz was selected at the output of the electrometer amplifier and amplified. The amplifier signal was then detected and telemetered. The a.c amplitude at 800 Hz will be maximum at space potential where the J-V characteristic has maximum curvature.

4.10 **Subcarrier oscillators:** The d.c outputs of the electrometer amplifier and a.c signal output of the plasma noise amplifier are fed to subcarrier oscillators (S.C.O) of FM/FM telemetry system. The oscillators are transistorised multivibrators designed for various 1R1G standard subcarrier channels with a band width of $\pm 7.5\%$ of the centre frequency.
The channel selected to telemeter the particular information depends upon the intelligence frequency of the channel. The intelligence frequency is 10% of the channel bandwidth. The frequency of the signal should not exceed the intelligence frequency. For example, to telemeter plasma noise of 1 KHz frequency 70 KHz ± 7.5% channel which has intelligence frequency 1.00KHz is needed. In case it becomes necessary to telemeter the signal which has frequency more than a few KHz, then the signal must be spectrum analyzed in the payload itself and the detected signal should be telemetered. Subcarrier oscillators were designed for centre-frequency of 10.5, 22, 40, 70 KHz with ± 7.5% bandwidth. The circuit diagram of the S.C.O is shown in fig.18. It consists of a voltage controlled oscillator, a limiter circuit and band pass filter.

(a) Voltage controller oscillator: The VCO is a multivibrator whose oscillation frequency varies with input voltage. The frequency of a stable multivibrator is given by

$$f = \frac{1}{2\pi R_b C \left(1 + \frac{V_C}{V_b}\right)}$$

Where $R_b$ is base resistance and $C$ is coupling condenser. $V_C$ is collector voltage and $V_b$ is the bias voltage. In present circuit $\frac{V_C}{V_b}$ was about 1, $V_b$ varies from $V_a - 0.6$ Volt to $V_a + 2$ Volt. The V.C.O were designed for the frequencies of I.R.I.G channels. The base resistance $R_b$ was taken 100 K ohm and the approximate value of the condenser needed for a given centre frequency was calculated from above equation. In order to
improve the recovery time of the multivibrator pulse the collector resistance used was less than one tenth of the base resistance and the collector voltage was clamped at one third of the total supply voltage. It also makes the frequency of multivibrator less sensitive to supply voltage variations.

The oscillating frequency was found to increase by one percent when the supply voltage is increased from +24 V to +30V. With temperature change from 27°C to 60°C the frequency increase was +1.5% of the central frequency. Typical curve showing the relation between input voltage and oscillation frequency are shown in fig.19.

(b) Limiter circuits: The V.C.O. frequency varies by ±7.5% of its central frequency for input variation of 2.6 Volt. In order that the input voltage variation should not exceed the desired voltage limit, diode limiter circuits (fig.18) were used to limit the input voltage levels.

(c) Band pass filters: The square wave output from V.C.O. is filtered to provide a sine wave input to telemetry transmitter. Band pass filter were designed for bandwidth ± 7.5% centered at 10.5, 22, 40 and 70 KHz. The circuit diagram of the band pass filter is shown in fig.18.

It consists of three independent tuned circuits. The two parallel tuned circuits are coupled by a series tuned circuit. All the three networks were tuned at nearly same
Frequency vs Voltage Characteristic

**Figure 19**

- **Central Frequency**
- **Diode Limiters**
  - $V_A' = +2.0$ VOLT
  - $V_A' = -0.6$ VOLT

**Diagram Details**
- **Frequency (kHz)**
  - Ranges from 19 to 24 kHz
- **Input Volts**
  - Ranges from -1.2 to 2.4 V

Frequency vs Voltage Characteristic

FIG. 19
frequency. The inductance were wound on toroidal cores (Arnold Eng.Co.U.S.A.). The inductance values were chosen to get coil about twenty. The bandwidth of the filter is governed by the coefficient of coupling between coils (1) and (2) as well as between coil (2) and coil (3). The filter provides an output voltage with nearly constant amplitude around the resonance frequency and a sharp fall in amplitude at frequencies away from resonance by more than $\pm 7.5\%$. The frequency response of the filter is shown in fig.20. Specifications of the filter, frequency bandwidth $\pm 7.5\%$, attenuation at 2nd harmonic and subharmonic 40 db.

4.11 Power supply: The power supply consists of a battery and a regulator. A 40.5 volt battery pack was used which can give 100 m.a. current for ten hours. Six Burgess 135 R mercury cells each of 6.75 volt were used which have an ampere hour capacity with maximum current drain of 100 m.a. When the batteries are loaded by 100 m.a. the voltage drops to 36.0 volt because of the internal impedance of the cells which is about 45 ohms.

The probe electronics operated on floating power supplies at voltage $V_A^{1+18}$ volt and $V_A^{1-9}$ volt and requires 100 m.a. current. A voltage regulator was designed for these requirements. It had an output impedance of the order of ten milli ohms. The circuit diagram of the voltage regulator is shown in fig.21. The transistor $T_1$ and the power Transistor $T_2$ form a series control circuit. Transistor $T_3$ and $T_4$ form
FILTER OUTPUT db
RESPONSE CURVE OF PRL MADE FILTER

F = 22 ± 7.5 kHz

FREQUENCY KHz
RESPONSE CURVE OF PRL MADE FILTER

FIG. 20
comparator and amplifier circuit. The zener diode of 9.0 volt is used for reference voltage. The condenser C is used to suppress oscillations in the power supply.

The power regulator provides regulated voltage of 27 volt. It is divided as +18 V and -9V with respect to $V_{1h}^1$. The divider circuit is also shown in the same figure. The resistance $R_3$ and $R_4$ divide the 27.0 volt in the ratio 2:1. The divider output is taken through emitter followers $T_5$ and $T_6$. $T_6$ is a power transistor. $T_6$ output taken as reference voltage $V_{1h}^1$. The circuit provides two voltage as $V_{1h}^1 - 9V & V_{1h}^1 + 18V$.

High value capacitors are connected across these two voltages to bypass high frequencies or transients.

4.12 Spectrum analyser: For spectrum analysis of the composite plasma noise a spectrum analyser was designed which consists of six band pass filters. The filters are centered at frequencies 110, 170, 260, 400, 600 and 900 Hz each with a bandwidth $\pm$ 20% of centre frequency. The block diagram of spectrum analyser and recording systems is shown in fig. 22. The composite plasma noise is fed to a driver stage and the driver output is fed to the six filter sections. The filter outputs are amplified and fed to a recorder. Frequency response of spectrum analyser is shown in fig. 23.

4.13 Wiring of the payload circuits: The complete electronic circuitry was wired on six fibreglass cards. A photograph of one of the wired cards is shown in fig. 24. The
PLASMA NOISE PROBE DATA RECORDING USING SPECTRUM ANALYSER

FIG. 22

MAGNETIC TAPE UNIT

DISCRIMINATOR

BAND PASS FILTER HZ

70 TO 135

135 TO 205

205 TO 310

310 TO 470

470 TO 710

710 TO 1078

AMPLIFIER

AMPLIFIER

AMPLIFIER

AMPLIFIER

AMPLIFIER

RECORDER
RESPONSE CURVE OF SIX CHANNEL SPECTRUM ANALYSER

FREQUENCY Hz

SPECTRUM ANALYSER OUTPUT VOLTS

PEAK TO PEAK
electronic components were mounted and soldered on one side while interconnections were made on the other side. To assemble all the cards of one payload, four brass rods of 3/16" diameter and length 6½" were used. Spacers of about 1" height were used between the two successive cards. The assembled payload photograph is shown in fig. 25. The assembled unit is tested for proper performance. After proper checking and adjustment the unit was given a conformal coating.

4.14 Potting of the payload: The payload undergoes a certain amount of acceleration and vibration during rocket launching. Hence it is necessary that each electronic component should be tested up to certain specified condition. Mechanical support is necessary for bigger components. The payload cards were potted to give firm support to the components.

First an araldite layer was put on both the sides of the card. After the araldite is cured the units were potted with eccofoam. For potting an aluminium mould was designed. The material used for potting was the FPH Resin and 12-4H catalyst manufactured by Emerson and Cumming Co. of U.S.A. The Resin and catalyst were mixed in the ratio 4:3 by weight. The mixed compound is poured on card kept in the mould. The mould is then closed by an aluminium plate. After about ten minutes the potted card is taken out from the mould. The card acquired a solid shape with thickness about 3/4". All the electronic components are completely covered by the
Figure-24: Photograph of wired circuit.
Figure-25: Photograph of Langmuir probe and Plasma noise probe payload.
potting compound. The silastic R.T.V. rubber was used to cover the intercard connection terminals and other points where potting compound cannot be used. The R.T.V. rubber does not require a mould and hence is quite convenient to use. However, the resistance of the material remains low till it gets completely cured. Hence care should be taken not to use rubber to cover terminals where high resistances are used.

4.15 Telemetry requirements: A FM/FM standard telemetry system was employed. The mixed output from subcarrier channels modulates the transmitter frequency. The transmitters used had a carrier frequency in the vicinity of 240 MHz. Following were the specifications of one of the telemetry system.

Transmitter:

<table>
<thead>
<tr>
<th>Frequency</th>
<th>244.3 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>2 Watt</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>100 KHz/volt r.m.s</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>500 KHz</td>
</tr>
<tr>
<td>Output impedance</td>
<td>50 Ohms</td>
</tr>
</tbody>
</table>

Antennas:

The transmitter output is fed to the pair of circularly polarised turnstile antennas. The characteristics impedance of the antenna was 50 Ohms, and length about λ/4. Where λ is wavelength of the electromagnetic wave.

4.15.1 Transmitter supply: The transmitter operates on separate power supply whose one terminal is grounded to rocket body. A D.C to D.C converter was used to supply proper volt-

<table>
<thead>
<tr>
<th>/U</th>
<th>56.0</th>
<th>0.56</th>
<th>0.60</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>114 KHz</td>
<td>1.14 V</td>
<td>1.42</td>
<td>120 KHz</td>
<td></td>
</tr>
</tbody>
</table>
ages to the transmitter. The D.C - D.C converter operates at 6.0 Volts. Yardney silver cells HR-3 were used for converter supply. In one of the flight DC-DC converter operated on 30.0 Volts.

4.15.2 **Mixing of subcarrier channels:** A linear taper law was adopted for setting the carrier deviation to correspond to different subcarrier channels so that the signal to noise ratio remains equal in all the subcarrier channels. This presumes that the signal strength at the receiver is more than 100 microvolt and no receiver noise is added to the signal. Foster (1965). However if weaker signal is expected then the channel voltages should be mixed in proportion of $f^{3/2}$ law.

Following table shows R.f deviation required for linear taper and also r.m.s modulation voltage for each channel for a transmitter described above.

<table>
<thead>
<tr>
<th>Central frequency channel KHz</th>
<th>R.F deviation required KHz</th>
<th>R.M.S voltage</th>
<th>Experimental values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Input to r.f mixer r.m.s volts</td>
<td>r.f deviation observed in KHz</td>
</tr>
<tr>
<td>10.5</td>
<td>8.40</td>
<td>0.084</td>
<td>0.13</td>
</tr>
<tr>
<td>22</td>
<td>17.6</td>
<td>0.176</td>
<td>0.26</td>
</tr>
<tr>
<td>40</td>
<td>32.0</td>
<td>0.32</td>
<td>0.43</td>
</tr>
<tr>
<td>70</td>
<td>56.0</td>
<td>0.56</td>
<td>0.60</td>
</tr>
<tr>
<td>114 KHz</td>
<td>1.14 V</td>
<td>1.42 R.M.S</td>
<td>1.42 R.M.S</td>
</tr>
</tbody>
</table>
4.16 Mounting & fixing of the payload and probe: The Langmuir probe and plasma noise probe including telemetry are accommodated in the cylindrical portion of the rocket nose-cone. In one rocket flight a part of conical portion of the rocket nosecone was also used. The whole payload is mounted in a rack. Fibreglass racks were used for flights accompanied by magnetometers. While for other flights the aluminium racks were used. Mounting procedure of the payload for one of the flight accompanied by T.M.A payload is described below, and the photograph of integrated payload including telemetry is shown in fig.26.

In the photograph the nosecone A, cylindrical portion B (a part of apoche body) and the integrated payload C is shown with sensor electrode. The sensor electrode is screwed at the tip of the nosecone. The cylinder B encloses the integrated payload C and is screwed at the telemetry housing portion. Above this the nose cone is fitted.

The rack used in one of the flight consists of four aluminium strips of length twelve inches. Three strips of width one inch while the 'raceway' strip had a width of two inches. The base and top plates of the rack were also of aluminium.

The rack is mounted on the telemetry housing region which encloses the D.C to D.C converter and extend upto the region where it is screwed with the T.M.A payload housing
Figure-26: Installation of Langmuir Probe, Plasma noise probe and Telemetry system in a Nike - Apache rocket.
portion of rocket. The D.C to D.C converter connections are brought through the bottom plate, through a connector. The transmitter, antenna bases and rocket umbilical is mounted on the bottom portion of this rack. In the upper portion the Langmuir probe and plasma noise probe payload is fitted. The battery box, consists of a pack of batteries for D.C to D.C converter and is mounted on the top plate of the rack. The top plate is provided with a hole, so the cable coming from the tip sensor is connected to the electrometer amplifier input.

4.17 Prelaunch testing: Prior to launching extensive tests are carried out while the rocket is on the launch pad. This includes horizontal checks and vertical checks. The block diagram/payload control and monitoring is shown in fig.27. The payload mounting points are brought from rocket umbilical to block house through cables. All the testing is carried out on external power. The payload performance is checked at ground based telemetry station while the payload and transmitter voltage supply is monitored from block house. The FM/FM telemetry station at Thumba confirms the IRIG standard (TARLS hand book 1967). The telemetry station, subcarrier discriminator and recording oscillograph levels are properly adjusted before final calibration.

The control box was built to monitor the payload from block house whose circuit diagram is shown in fig. 28.
FIG. 57: BLOCK DIAGRAM OF INTEGRATED PAYLOAD MOUNTED INSIDE THE NOSE CONE
The control box consists of driver circuits of transistor $T_1$, $T_2$ and $T_3$, $T_4$. The voltmeter $V_1$ indicates the external power supply $P_1$ voltage. $G_1$ and $G_2$ galvanometers indicate amplifier output and sweep voltages respectively. Ammeter $A_1$ indicates the current drawn by the payload, when it operates on external supply. Switches are shown for changing the supply from external to internal.

The transmitter supply $P_2$ and relay control supply $P_3$ with ammeter $A_2$ and $A_3$ are also shown. The push button switches are shown by $S_1$, $S_2$ and $S_3$. The transmitter and the probe electronics can be switched separately. Indicating meters are fixed in the test box to indicate sweep voltage and also Langmuir probe amplifier output. The transfer of payload to internal power is also indicated by the same meters.

Just before launch calibration of the amplifier and sweep is carried out. Known resistances are put between the sensor and rocket body and the discriminator outputs are recorded. Calibration is done while the instrument operates on internal batteries.

The telemetered signal i.e receiver output is tape recorded. At the same time a real time record is obtained at a chart speed of $10''$/sec. Slow speed, record is prepared by playing back the tape at a chart speed $1''$/sec and $0.16''$/sec. The slow speed record is used for quick look of electron density profile.