

# ROCKET BORNE INSTRUMENTATION FOR THE MEASUREMENT OF ELECTRON DENSITY—HEIGHT PROFILE IN THE IONOSPHERE

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## ABSTRACT

The present paper describes the construction and working of a high frequency capacitance rocket payload for the measurement of electron concentration in the ionosphere, designed and fabricated mostly with indigenous components. This payload was flight-tested in the first and second Indian Centaure test rocket launched on 26-2-1969 and 7-12-1969 from Thumba Equatorial Rocket Launching Station. The paper also presents the calibration procedures and some of the preliminary results obtained from the first flight to show the capabilities of the instrument.

## INTRODUCTION

RADIO frequency probes have been used in ionospheric research for many years now. Among the various probe techniques employed for the measurement of ionospheric parameters such as electron and ion densities and temperature, the high frequency capacitance probe (HFC) developed by Heikkila offers the possibility of determining the collision frequency also. In this paper we describe the HFC probe which we have developed in this laboratory using mostly indigenous components and which was successfully flight-tested on 26-2-1969 from Thumba Rocket Range near Trivandrum. We also describe the data reduction procedures and discuss some of the preliminary results part of which have been published elsewhere.<sup>1</sup> In paper II,<sup>2</sup> to be published later, we shall discuss, in detail, the results obtained by this probe during two rocket flights one in the afternoon and one in the early morning hours. The design considerations were similar in principle as those described by Heikkila *et al.*<sup>3</sup> In short, the tip of the nose cone insulated from the rest of the main rocket body is used as probe capacitance in the tank circuit of a clapp oscillator. The change in the capacitance of the probe as it goes through the plasma in the ionosphere is reflected as a change in the oscillator frequency which is tele-

metred down at suitable intervals of time. The change  $\Delta C$  in probe capacitance from its free space value  $C_0$  is linearly related to the electron density  $N$  according to the formula

$$\frac{\Delta C}{C_0} = \frac{kN}{f^2} \quad (1)$$

where  $k$  is constant and  $f$  is the operating frequency.  $N$  is calculated directly from the measurements of  $f$  using the following formula:

$$\frac{\Delta f}{f_0} = \frac{81 SKN}{2f^2} \quad (2)$$

where  $S$  = correction for ion sheath,  $f_0$  = operating frequency in free space and  $K = C_0/(C_0 + C_s)$  is the correction due to stray capacitance  $C_s$ . The choice of high operating frequency results in less sensitivity because of its inverse square law dependence while a low frequency requires a more elaborate analysis that takes ion-sheath and plasma resonance into account. A frequency two or three times the highest expected upper hybrid resonance frequency seems to be an appropriate choice for ionospheric measurements. Actually two separate frequencies, nominally 5 and 10 MHz, were selected and used alternately in a certain time sequence described later. As with any other probe, there are some advantages and disadvantages in using this technique which are enumerated below.

#### ADVANTAGES

The oscillator frequency provides a convenient measure of the dielectric constant of the plasma. A change in oscillator frequency is directly proportional to the change in electron concentration. The change in frequency or the frequency itself can be measured conveniently and precisely by simple digital counting techniques. Further, the capacitance probe measurements can be made very rapidly and its sensitivity and dynamic range permit both D and E region measurements with the same probe.

#### DISADVANTAGES

The high frequency capacitance probe, just like other ionospheric probes, is influenced by the ion sheath that forms about the probe. The ion sheath is dependent upon the potential of the probe with respect to the plasma, upon probe geometry, and to some extent upon the velocity and altitude of the rocket. The measurement does not depend very much on the rocket velocity, except for a decrease during descent that can be attributed to the wake

behind the rocket. The results during ascent appear to be reliable and accurate but the measurements need to be corrected for the stray capacitance and ion sheath effects. Comparison with ionograms taken during the rocket flights have been utilised to double check the accuracy of the evaluation of stray capacitance and sheath effects and calibration procedures.

#### INSTRUMENTATION

Figure 1 shows the schematic diagram of the portion of rocket nose cone where the HFC payload is housed. The stainless steel nose tip is conical in shape and has a length of three inches. It is separated from the main rocket body by teflon insulator. The oscillator and its control circuit with switching relays are housed in the teflon casing just below the nose tip. The amplifier, the frequency counting system, VCO and other electronic components are mounted on a deck of four cards made of fibre-glass and placed about half a metre below the nose tip. The teflon is coated with a special non-conducting metallic oxide paint to make it withstand temperature upto  $800^{\circ}\text{C}$  for a period of 10 minutes.

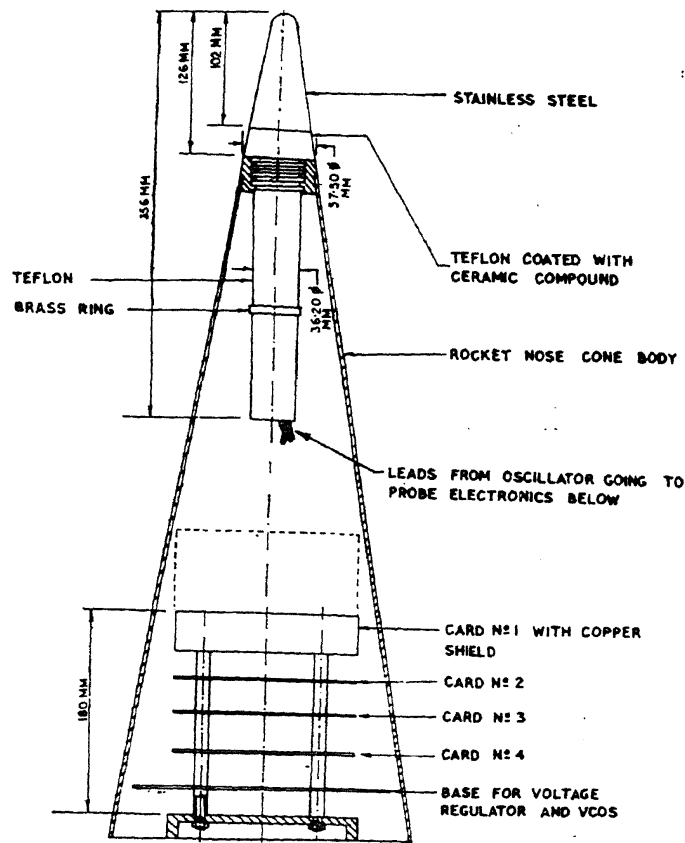


FIG. 1. Schematic diagram of HFC payload assembly in the Centaure rocket nose cone.

Figure 2 shows the block diagram of the payload. The output of a Clapp type oscillator is given to the oscillator control circuit which controls the amplitude of oscillations and is then amplified by a pulse amplifier and fed to a scaler consisting of chain of 18 flip-flops. With the same probe and a common inductance, the oscillator oscillates at two frequencies  $f_1$  and  $f_2$  (nominally 5 MHz and 10 MHz) depending on the relay which is programmed to alternately short or open the coil 2 of the inductance in series with the nose cone tip. The amplitude of the oscillation is kept low (25 mv) by feed-back mechanism, to minimise the disturbance caused to the ambient plasma. The pulse amplifier consists of two RC coupled amplifiers having a gain of about 200 thus giving a final output of about 5 volts for a 25 mv input pulse from the oscillator. The pulse counting is accomplished each time for only a period of 120 ms with the help of an accurate gate circuit which opens for the appropriate duration. The oscillator pulses are then scaled by a chain of scalars consisting of 18 flip-flops having 16 Mc/s response.

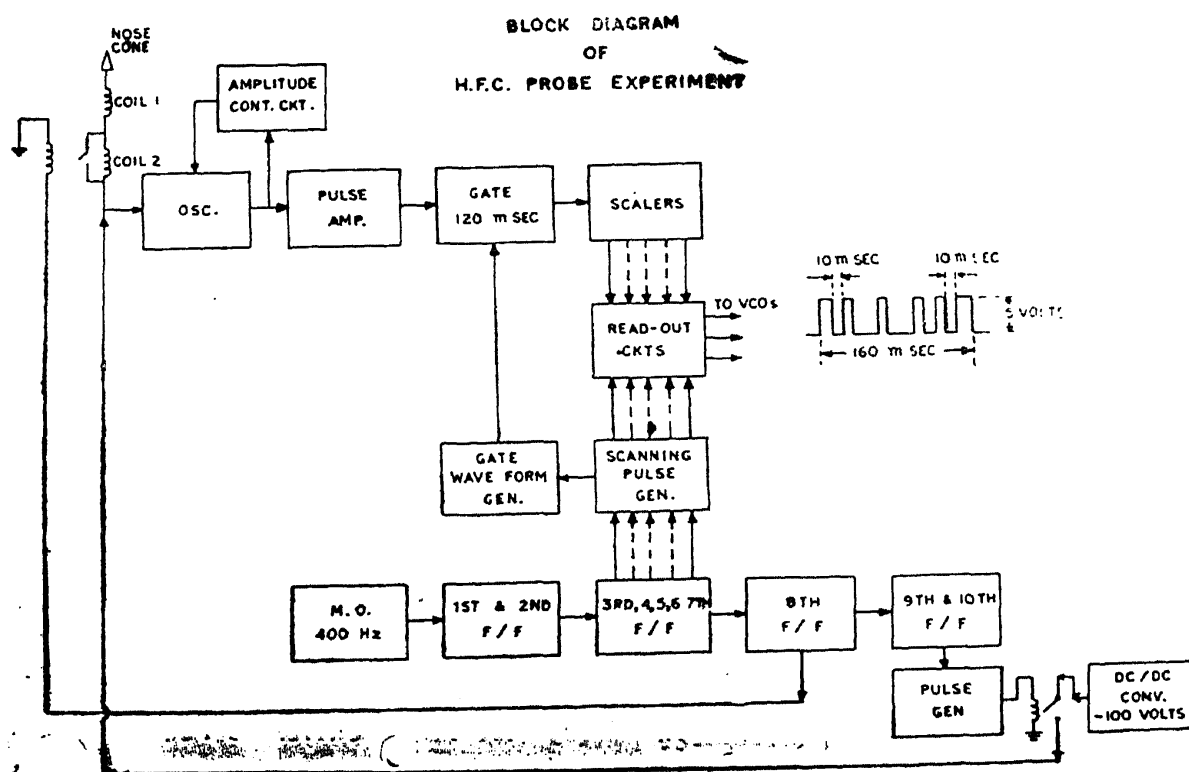
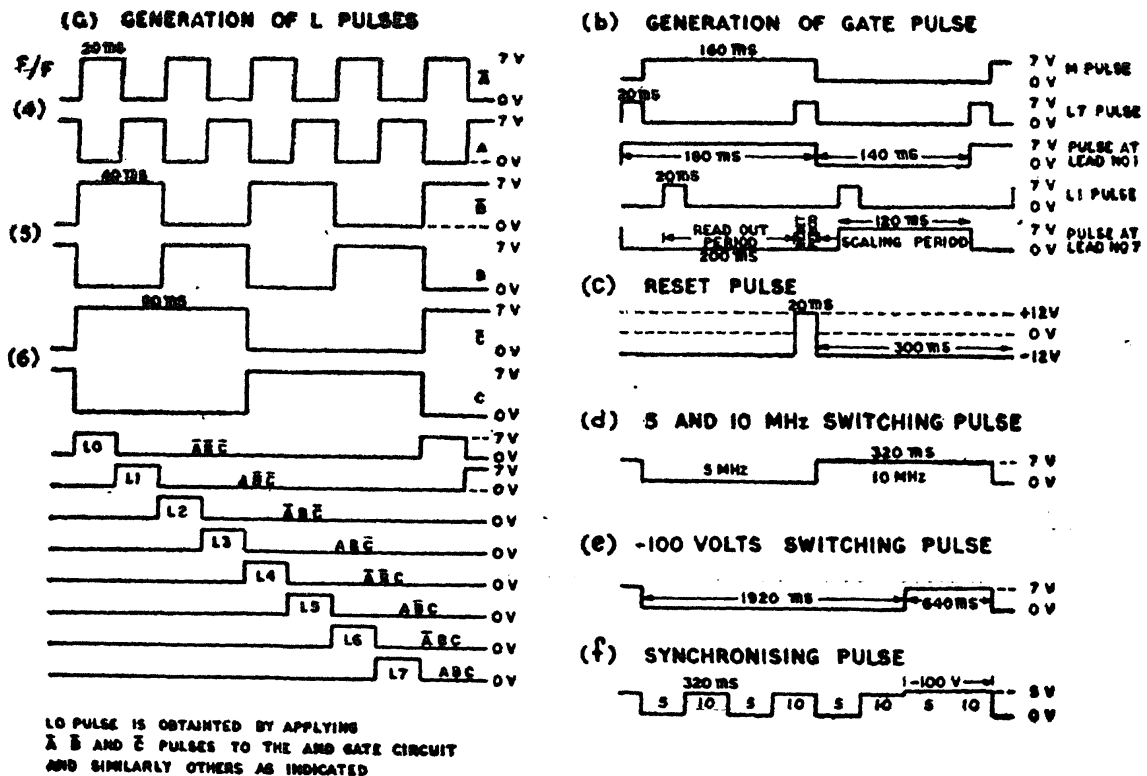


FIG. 2. Block diagram of the electronics associated with HFC probe instrument.

The essential timings are completely defined by an on-board programmer which is a 400 cps multivibrator used as a master clock to generate the various pulses required to function in read out, gate, reset and switching circuits. Binary F/F circuits have been used to scale down the pulse rate and provide different timings needed for various operations. The collector voltages of the 3rd, 4th, 5th, 6th, and 7th flip-flops are used to generate sequentially a

number of pulses of duration 20 m seconds which are used in the read-out circuit. The output of the 8th flip-flop having a 320 m.sec. duration is used for switching between 5 and 10 MHz. Since the oscillator operating frequency is switched between 5 MHz and 10 MHz sequentially, it is advisable not to count the oscillator frequency in the beginning and end of each cycle. Hence no counting is done in the first 20 ms after the reset pulse. The 120 m.sec. wide gate opens only after 20 m.sec. after the beginning of each cycle, preserving the accuracy of frequency determination.

On board calibration of the oscillator free space frequency is extremely important to correct for any drifts in circuitry due to temperature changes or other environmental conditions associated with the take off the rocket. — 100 volts bias voltage from a DC/DC converter is switched on when the output is present at the collector of 9th and 10th flip-flops. Thus, as shown in Fig. 3 (b), the high negative potential is applied to the tip of the probe for 640 ms at intervals of 1920 m.sec. enabling us to have three cycles of regular data at both 5 MHz and 10 MHz followed by a cycle of data with the negative potential.



GENERATION AND FUNCTION OF VARIOUS PULSES AND PULSE WIDTH USED IN HFC PROGRAMMING CIRCUIT

FIG. 3. Timing sequences used in the operation of HFC instrument.

The frequency measured when the negative potential is applied gives the free space frequency of the oscillator.

Even though the oscillator oscillates sequentially at 5 MHz and 10 MHz for a period of 320 m. seconds each, the frequency is counted for only 120 m. second duration, 20 m. second after the start period. During the remaining period, the binary content of the scalers are read out to the telemetry. The read out of collector points of all 18 flip-flops of the scaler circuit is accomplished using the basic 20 m. second pulses from the programming scaler. The outputs are shaped into 10 m. second wide, 5 volt pulses and are fed to three VCO (Voltage Controlled Oscillator) channels of telemetry for transmission of data. Figure 4 shows the sample telemetry data obtained from the first rocket flight.

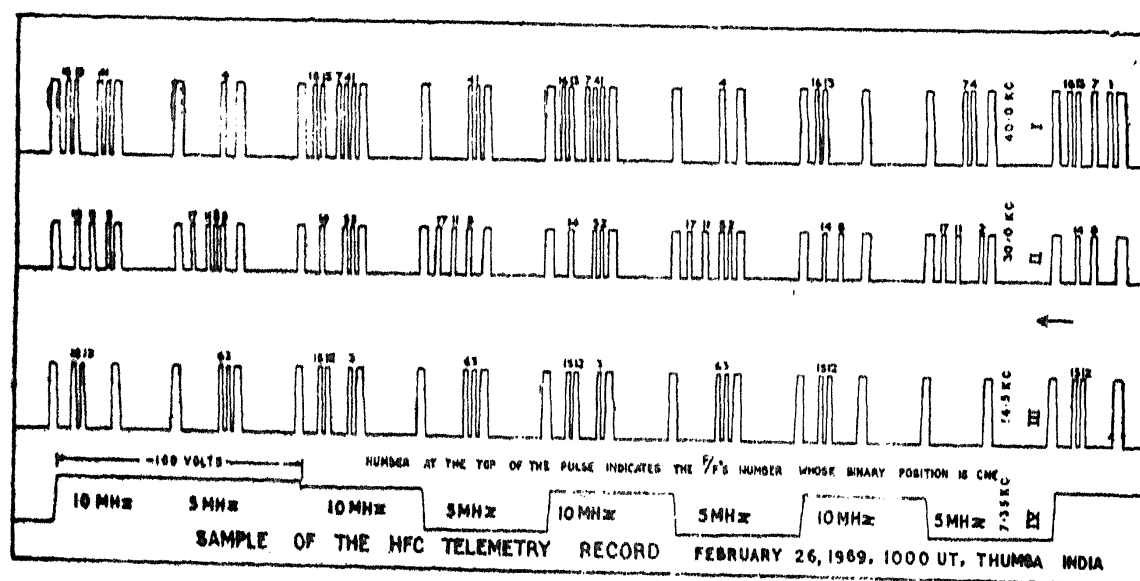


FIG. 4. Sample telemetry record showing digital data in three VCO channels and the house-keeping information in the fourth channel.

### DATA ANALYSIS

Knowing the number of resets that have occurred during each accumulation time of 120 m. secs. the actual oscillator frequencies are calculated from the binary read-outs of the flip-flops. Figure 5 shows the trajectory of the rocket derived from the radar data. In Fig. 6 is plotted the oscillator frequency at 10 MHz as a function of time after rocket take-off.

The measured oscillator frequency shows a sharp departure from the free space frequency at around 85 seconds after the launch (equivalent to an altitude of about 85 km.) indicating the presence of plasma. The change in the dielectric causes a decrease in the capacitance of the probe thereby increasing the frequency of the oscillator. This sharp gradient corresponds to the E

region over Thumba. The maximum deviation corresponding to E layer peak occurs at about 112 km. The small ripple mounted on the data having a period from 2.5 to 2.8 seconds appears to be due to the modulation of switching sequence which is 2.65 cycles per second. The frequency curve under  $-100$  volt bias condition also shows sudden small jumps in sympathy with the  $f$  variation. As  $f_{100}$  is not expected to change abruptly but rather slowly, we have interpolated between start and the end points by a smooth dashed curve to represent true free space frequency  $f_0$ . This may be considered as corrected calibration curve, the reduction being 15 per cent of average of  $\Delta f$  in one case and about 18 per cent in the other. On the whole, it can be seen that the instrument has behaved sensibly well. Below 85 km. we see very little, if any, frequency deviation due to the small electron concentration (less than 100 electron per c.c.). The maximum deviation in frequency  $f$  of 104 KHz at 10 MHz and 87 KHz at 5 MHz is observed at 112 km. altitude, both during the upward and downward leg of the trajectory.

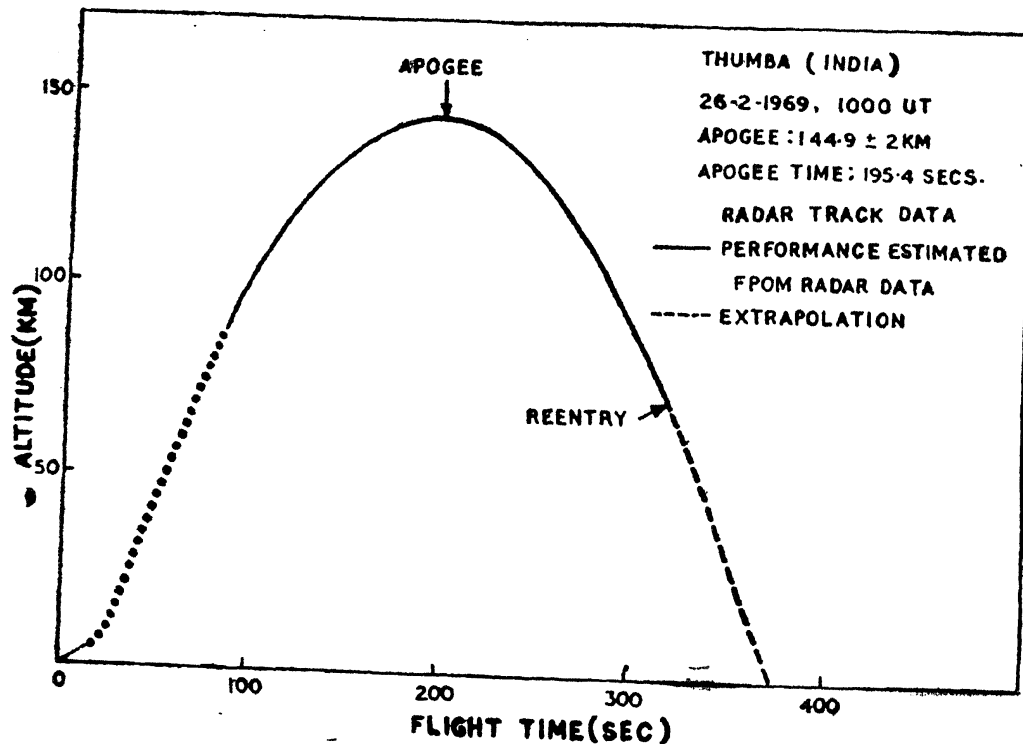


FIG. 5. Rocket trajectory.

As described earlier, it is very important to evaluate the effects due to stray capacitance and the presence of ion sheath. Following Heikkila *et al.* we have calculated  $C_0$ ,  $C_s$  and  $K$  for our probe geometry, which is given in Table I.

TABLE I

Frequency MHz	$c_0$ pf	$c_2$ pf	K
5	4.445	7.554	0.370
10	4.445	3.555	0.555

The sheath correction factor  $S$  has been evaluated by comparing the peak electron density obtained from the ionogram taken at the time of the rocket flight with that obtained by the High Frequency Capacitance probe. The ionogram shown in Fig. 7 was taken at 0955 UT. It shows the presence of equatorial type  $E_s$  which is usually present throughout the day. Because of  $E_s$ , the normal E trace is not seen clearly. However, the  $f_{min} F$  trace shows a cusp at 3.3 MHz due to the critical frequency  $f_0 E$  of the lower E layer and hence  $f_0 E$  may be taken as 3.3 MHz, which corresponds to  $N_{max} E = 1.2 \times 10^5$  per  $cm^3$ . Comparing the peak value obtained by the probe with the value obtained from the ionogram and attributing the difference

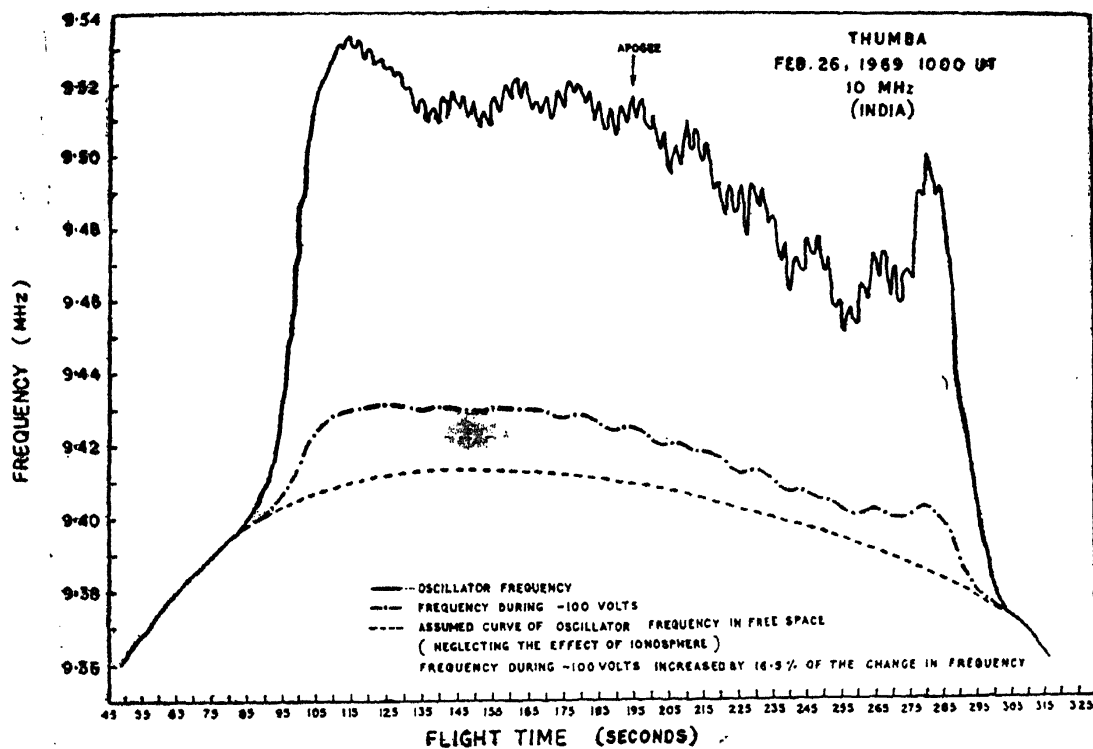


FIG. 6. Oscillator frequency  $f_2$  plotted against flight time in seconds from the rocket take-off. Similar data exist for  $f_1$  mode.



to the sheath effect, we get  $S = 0.3$ . This may be compared with  $S = 0.5$  obtained by Heikkila *et al.* Knowing the values of  $K$  and  $S$  we have computed the electron density *versus* height profile which is shown in Fig. 8. It may be seen that the profile shows a sharp gradient in electron density below the peak but not so sharp beyond the peak.

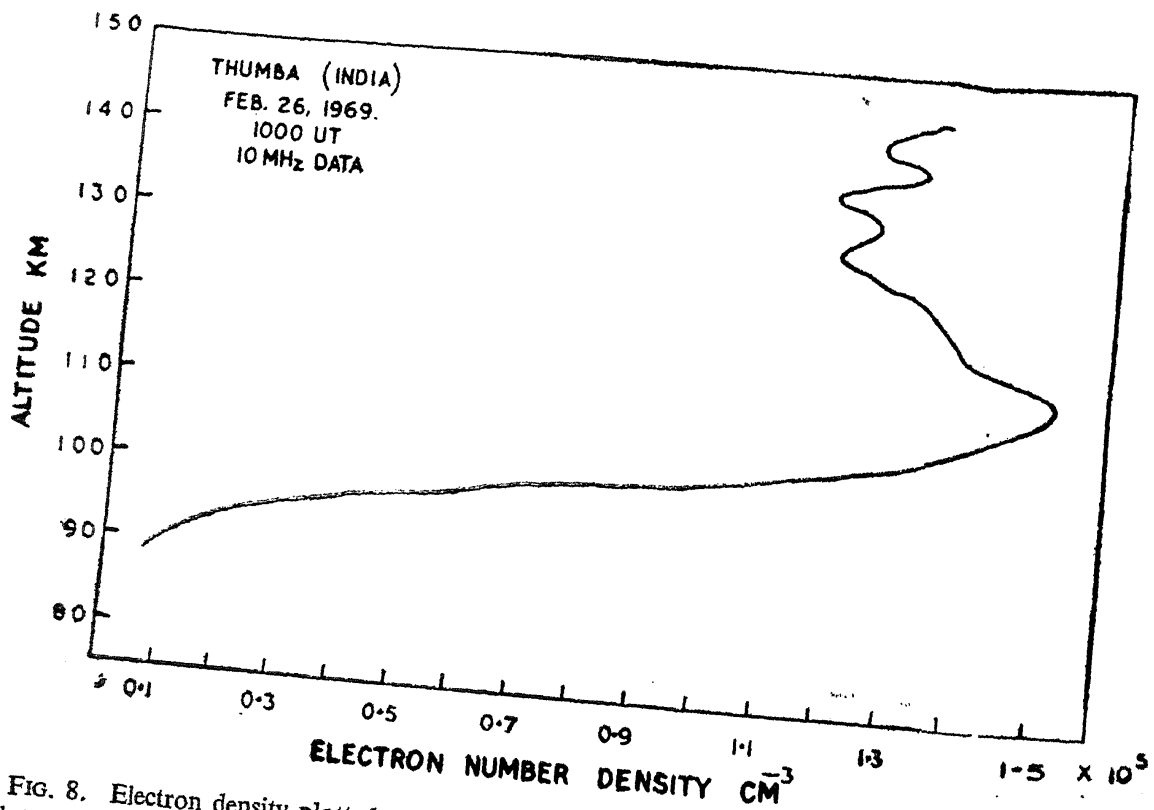


FIG. 8. Electron density plotted as a function of altitude. The electron density has been calculated after making correction for the stray capacitance and ion sheath effects. Note the wave-like structure above 120 km.

In addition to the main peak at 112 km., we can also see small crests and troughs above 120 km. These crests and troughs are spaced at about 7 to 8 km. in the vertical and appear to be due to horizontally stratified sub-layers. This is the first time that such stratified ionized layers which may be field-aligned over the geomagnetic equator have been experimentally observed. Rao *et al.* have hinted that the physical mechanism which might be responsible for this may be the gravity wave mechanism. In Paper 2, we shall compare the results presented here with the electron density measurements during morning hours obtained from another successful rocket launch on December 7, 1969 from Thumba and discuss the theoretical implications of the horizontal stratification observed in E region ionization.

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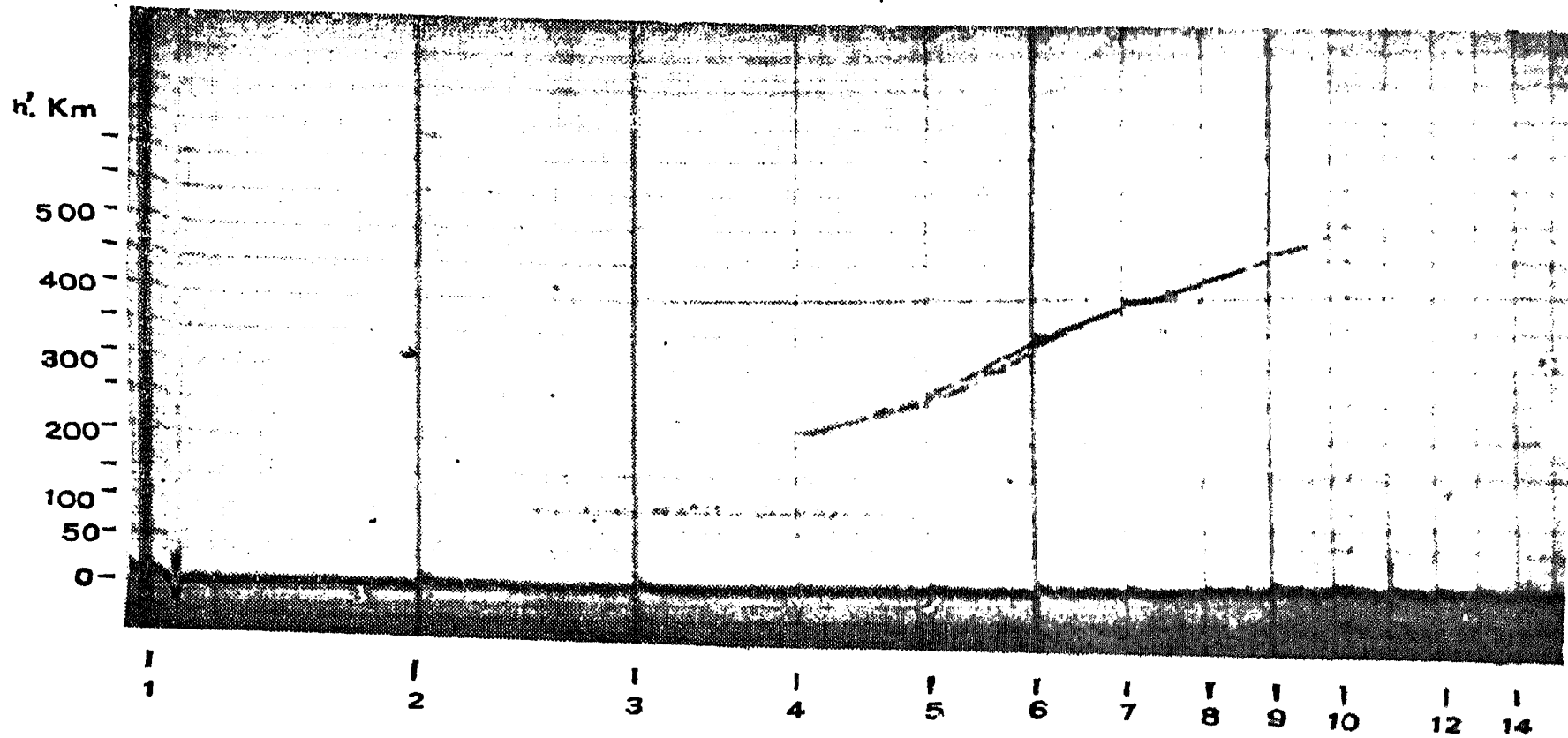


FIG. 7. Ionogram taken by C4 ionosonde just before the rocket launch.

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