A technique for measurement of electrical potential of a balloon-borne gondola

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During electrical conductivity measurements using balloon-borne probes, the gondola was observed to acquire an electrical potential of the order of a few tens of volts. Such an effect was found to occur mainly during balloon ascent and also to a lesser extent during balloon float and descent periods. A technique has been developed at the Physical Research Laboratory (Ahmedabad, India) for the direct measurement of potential acquired by the gondola during the course of its flight. Such measurement has relevance when we interpret the data obtained from the balloon-borne conductivity and electric field probes.

I. INTRODUCTION

Balloon-borne measurements of electrical parameters of the atmospherelike polar conductivity and electric fields are affected by charge accumulation on the balloon and the gondola. During the period 1984–1988, several balloon flights were conducted from Hyderabad (India) for the measurement of atmospheric conductivity and electric field at stratospheric altitudes.[1] In all these flights, the telemetry data channels were observed to get saturated during the ascent and part of the float period (at the ceiling altitude) of the balloon flight. This saturation of the data channels indicates that the reference ground potential or the gondola potential had changed to a value outside the range of supply voltages used. An estimation of the gondola potential done with the help of decay curves obtained from the conductivity experiment indicated gondola potential values of a few tens of volts. We used this estimate as a guideline for developing an instrument at the Physical Research Laboratory which would carry out a direct measurement of gondola potential. This instrument was used for measurement of gondola potential during one of the balloon flights (IMAP-C6). The values of gondola potential obtained during this flight are presented here.

II. DESCRIPTION OF THE BALLOON-BORNE SYSTEM

Figure 1 depicts a typical configuration of the balloon-borne system. In this configuration, a load line is attached to a plastic film balloon, and various packages are attached to the load line at different points along its length. At the apex of the balloon, there is a valve known as the "Apex valve" which can let out hydrogen gas from the balloon on a given command from the ground. The main packages along the load line are (1) a cutoff device situated just below the balloon, (2) a parachute, (3) a radiosonde, and (4) a radar reflector. The gondola is situated at the lowermost end of the load line which is typically 70 m away from the balloon. Some of the earlier balloons were not fitted with apex valves.

The gondola consists of the instrument package (or packages), a telemetry unit, a telecommand unit, and a ballast container. Except for the radiosonde all other packages including a cutoff device and an apex valve are electrically connected to the gondola. (This fact has to be considered in appraising the situation.) The wires used for telecommand operation have a leakage resistance of the order of 10^{17} Ω and a capacitance of the order of 100 pf. The balloon film has resistivity of the order of 10^{16} Ω cm. The relevant parameters for different balloon flights are listed in Table I. A detailed description of the balloon-borne system has been given by Narayan[2] and Gupta.[2]

III. PRINCIPLE OF MEASUREMENT OF GONDOLA POTENTIAL

The measurement of electrical potential of the gondola with respect to the ambient medium becomes necessary because the electric circuit for measurement of any atmospheric electrical parameter involves the probe, the return electrode (which is the gondola body in the present case), as well as the ambient medium.

Large dc shifts in the telemetry records from earlier balloon flights suggest that the gondola might be acquiring a large electrical potential with respect to the ambient medium through some mechanism which is not yet identified. Thus the aim is to find out the potential of the gondola with respect to the ambient medium. Since it is impossible to determine this potential difference, we do the following instead. A conducting probe is kept in the ambient medium. After some time it acquires a steady-state electric potential with respect to the medium. Measurement of the potential difference between the probe and the gondola will give us an idea of the gondola potential provided we know the probe potential with respect to the ambient medium under a steady-state condition.

Thus we have to first define when the steady-state condition is reached. A probe kept in the ambient medium, having a nonzero potential with respect to it, will attract ions of opposite polarity and its potential will change or decay exponentially to the steady-state value. The time constant of decay of this potential is a measure of the atmospheric conductivity, which is given by the following expression,

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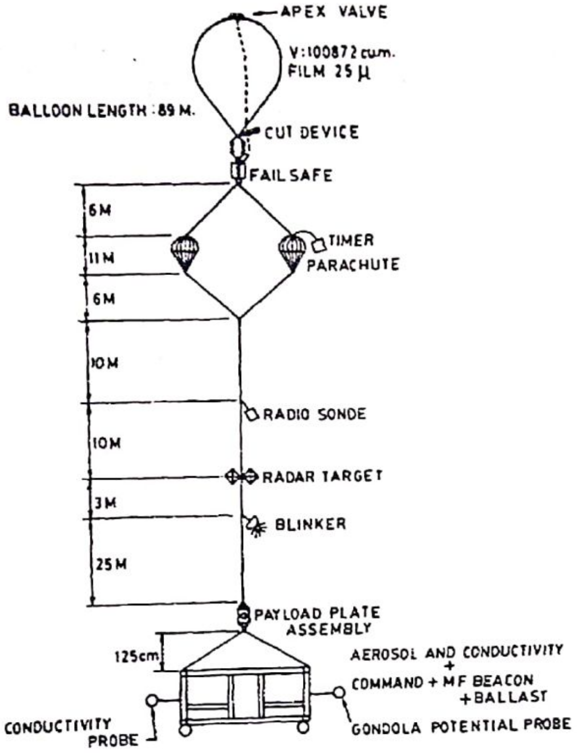

FIG. 1. Sketch of IMAP C-06 balloon payload train.

$$\tau_{+} = \epsilon_0/\sigma_{\pm},$$

where $\tau_{\pm}$ is the voltage decay time, ϵ_0 is the permittivity of ambient medium, and $\sigma_{\pm}$ is the polar conductivity. The + and − subscripts denote the fact that air conductivity is due to positive as well as negative ions. The positive ions are involved when the initial probe potential is negative with respect to the equilibrium voltage, while the negative ions are involved when the initial voltage is positive. After a period of four time constants, the probe potential is less than 2% of its initial value, so that after four to five time constants we can assume that the probe is at a steady-state potential.

The next important point for consideration is the following. The quantity which we measure is the potential difference between the probe and the gondola. The probe may not be at the same potential as the ambient medium. Let us examine how good a measure of the gondola potential is the potential difference between the probe and the gondola. The probe and the ambient potentials may differ because of following reasons:

(1) When a conducting probe is kept in plasma, it acquires eventually a floating potential due to difference in positive and negative carrier mobilities.

(2) A surface potential barrier is present at the probe surface which is equal to the work function of the probe surface material.

(3) There is a possibility of frictional or triboelectric charging of the probe.

(4) The possibility of the presence of external electric field around the probe-gondola system due to the proximity of a highly charged balloon.

All these factors can affect the measurement of gondola potential and are possible error sources. So let us examine these points one by one.

The first point refers to the observation of a floating potential for any Langmuir-probe type of system. This floating potential has been observed during rocket-borne mesospheric ionization measurements to be of the order of 1 V.[3] It is caused because of a difference in electron and ion mobili-

TABLE I. Technical details of balloon experiments carrying conductivity payloads launched from Hyderabad (India) during 1984–88 period.

Serial No.	Flight No.	Date and Time of Launch	Balloon Volume (m^3)	Ascent Rate (m/s)	Float Altitude* (km)
1	IMAP 4	18.04 1984 0.610 h	64533	2.6	35
2	IMAP 7	29.12 1985 01.00 h	50962	4.7	34
3	IMAP 9	22.10 1985 0.600 h	29262	5.0	32
4	IMAP C2	08.04 1987 01.00 h	50962	3.5	34
5	IMAP C6	11.4 1988 06.08 h	100872	2.5	36

*By float altitude we mean here the altitude at which the ascent rate becomes very small (less than 0.3 m/s).

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ties. But in the stratosphere, since no free electrons are present, the relevant factor is the difference in positive and negative ion mobilities. They are very close—within a factor of 2.[4] So the floating potential is small enough in our case to be safely neglected.

The second point refers to the work function of the probe surface material, which is of the order of 4.5 V.[5] We have coated the probe as well as the return electrode with the same material: aquadag (fine carbon coating). This will cause both the probe and the return electrode potentials to shift by an equal amount, i.e., the work function of aquadag. There will then be no net effect on the potential difference between the probe and the gondola.

The possibility of triboelectric charging of the probe cannot be neglected, and has to be carefully considered. Again, both the probe and the gondola will be affected. A simplified consideration of triboelectric charging on assumption that charging is proportional to the relative velocity of the body and air mass, and the surface area of contact, while discharging process has the characteristic time constant τ, give the steady-state voltage developed to be proportional to the scale size of the body. Since the probe diameter is 0.2 m while the gondola size is about 1.5 m, the triboelectric charging will be about 7 times more for the gondola than for the probe. We conducted an elementary wind tunnel experiment with the probe in winds of speed $\simeq 2$ m/s at atmospheric pressure. The observed voltages varied in different cases, but metallic bodies of the size of the probe developed voltages up to and of the order of 5 V. In the atmosphere, while the air density decreases with altitude, the air conductivity increases—both change exponentially with scale heights $\simeq 7$ km. Both these factors will reduce triboelectric charging potential of the probe. The net effect of triboelectric charging (due to air friction on probe or gondola) will be much reduced and is expected to be less than 0.2 V above 15 km. In comparison with the voltages of the order of 40 V, this is quite small.

Let us examine the fourth point now—that of the stray electric fields. Since the balloon is made of plastic film, which is highly charged at the time of launch, any small relative motion between the gondola-probe system and the balloon causes large stray fields to appear in the vicinity of the gondola-probe system. The balloon is highly charged at the time of launch, but it slowly discharges as the balloon ascends into regions of higher air conductivity. Due to this reason, the measured gondola-probe potential difference behaves quite erratically up to 20-km altitude during ascent, and should not be interpreted as the true gondola potential. At higher altitudes, these random or stray variations decrease, and one can assume that the measured potential is more representative of the gondola potential.

IV. MEASUREMENT OF GONDOLA POTENTIAL

Earlier estimates of the gondola potential done using telemetry record[2] shows that it is of the order of few tens of volts. To measure such large voltages with high impedance requires special techniques.

The instrument which we have used for making this measurement is similar to the one that was used for conductivity measurement.[1] There are, however, two differences. Firstly, during its operation the sensor is connected to the payload ground potential once every two min in order to provide a voltage reference. This 2-min period is large enough to take care of the transition to the steady-state condition (i.e., greater than 4τ at altitudes more than 20 km). Secondly, the operating voltage of the electronics is kept much higher: at -45 and $+7$ V. This is done in order to be able to measure higher voltages. During the IMAP-C6 flight which carried this instrument, the balloon ascent rate was

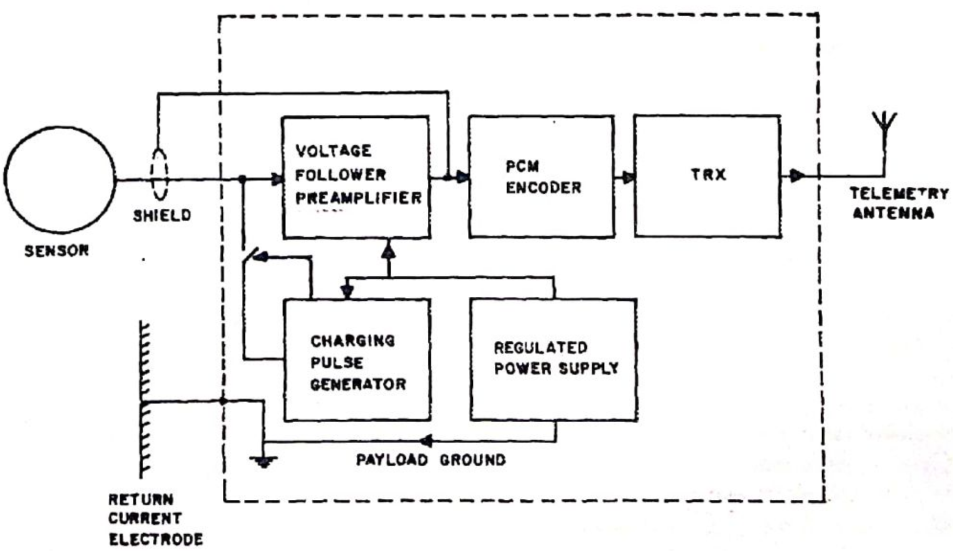

FIG. 2. Block diagram of conductivity payload.

arranged to be slow by filling less hydrogen gas in the balloon.

Figure 3 shows the circuit diagram of the preamplifier used for measuring the gondola potential. It consists of an ultralow bias current and high-input impedance preamplifier (bias current ≈ 75 fA and input impedance $\approx 10^{14}\ \Omega$). The operational amplifier used was Burr Brown make OPA 104 CM. The maximum operating voltage for this device is 30 V. The effective operating voltage range of this operational amplifier is increased up to 60 V with the help of two transistors as shown in the circuit diagram. A network of resistors forms a voltage divider that splits the 60 V supply down to 30 V. For the two transistors used, each dropped this voltage by 0.7 V further. A constant 28.6-V power supply is thus provided for the operational amplifier. This circuit enables one to increase the operating voltage range without damaging the integrated circuit, while keeping the supply voltage constant across the op-amp under all signal conditions.

The present application requires measurement of voltages which are in general negative. Hence the circuit has been powered with -50 and $+10$ V. This circuit has been made to function like a voltage follower having a very high-input impedance ($10^{14}\ \Omega$) and can correctly follow input voltages between -45 and $+7$ V. The output of this preamplifier is divided using an inverting amplifier by a factor of 10 in order to keep it within telemetry range. The inverted voltage is taken care of in the final analysis.

Figure 4 depicts the measured values of the gondola potential. The gondola potential as measured by this instrument was almost zero before launch, and it fluctuated randomly after the balloon launch up to the time it reached 22-km altitude. At 22-km altitude, the value of the gondola potential was 45 V. As the balloon went higher, it decreased. After the balloon reached its ceiling altitude, the gondola potential came down very slowly towards the normal. After it attained the float period, the balloon was made to descend slowly. This operation was done using the apex valve. The gondola potential was found to increase during the apex valve operation. As the balloon descended, it was found that the gondola potential again increased at lower altitudes. It was observed that the potential acquired by the gondola at a particular altitude was higher during ascent as compared to the descent. This is shown in Fig. 4.

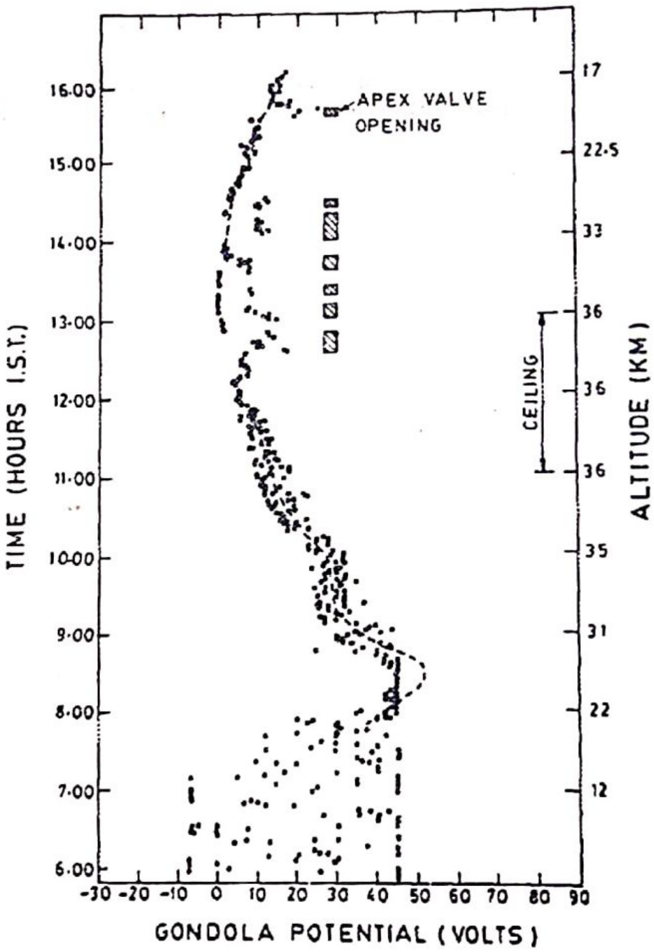

FIG. 4. Gondola potential obtained during IMAP C-06 flight by direct measurement.

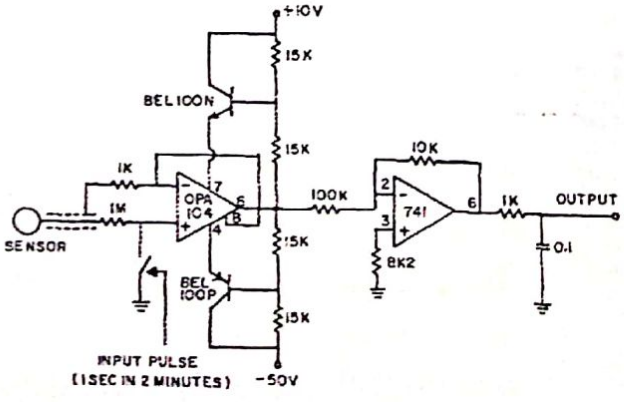

FIG. 3. Circuit diagram for direct measurement on gondola potential.

V. DISCUSSIONS

We have conducted measurement of gondola potential and have found it to be of the order of 40–45 V. Similar observations of rocket body potential had been made by Raja, Chandrashekhar, and Rao[6] and they had found that rockets develop potentials of the order of tens of kilovolts when they pass through the troposphere. In the ionosphere, rockets and satellites moving in space have been known to acquire a floating potential of the order of -1 V.[3]

As mentioned above, on the balloon-borne systems, we have observed electrical potentials of the order of 40–45 V. Following are some of the possible sources of this potential. It is possible that the gondola is getting charged by friction due to air passing around it. If it is frictional charging, then the gondola should acquire a negative potential.[7-12] But our measurements show that the gondola potential is positive which rules out gondola charging due to air friction.[13]

The other possible source is the balloon itself. The balloon is made from a polythene sheet, a dielectric material which can get quickly charged due to friction with air and can acquire voltages of the order of a few hundreds to thousands of volts. This voltage can affect the gondola via two possible mechanisms[14,15]: (1) The charge on the balloon can affect the gondola through a capacitative coupling mechanism. (2) The charge on the balloon can leak through the wires running between the balloon and the gondola. It is quite possible that the gondola potential that we have measured is the net effect of both of these processes, as well as of a number of other processes.

Since the balloon is made of a dielectric film, it acquires a large amount of charge during handling operations, before and during the hydrogen gas filling at the time of launch. Any subsequent relative motion between the balloon and the gondola-probe system will cause large induced voltages to appear between the gondola and the probe, which will appear to be randomly fluctuating. In fact, we do observe such fluctuations in our measurements during the balloon ascent up to about 22 km (Fig. 4).

We have mentioned that the apex valve and the cutoff device, which are situated very near to the balloon, are electrically connected to the gondola. During the balloon-launching process before the actual launching, the gondola is held to the launch truck so that it is in effect earthed. A large balloon carrying negative charge in appreciable quantity will cause polarization of charge inside the conductor. Positive charge will accumulate at the near end (to the balloon) and negative charge will accumulate at the far end towards the gondola. During the launch time, the gondola is held to the launch truck so that this negative charge will pass onto the ground through the truck. Thus, after the launch, the gondola is left with a net positive charge on it. This effect has been observed on the telemetry record. We also believe this mechanism to be the major contributor to the observed large gondola potential.

We should also consider the role of ambient atmospheric electric field. It is well known that the atmospheric vertical electric field is about 100 V/m at the ground level and decreases exponentially as one goes higher. It is about 0.5 V/m and 0.1 V/m at 25 and 35 km altitudes, respectively. This voltage is directed downward. In the present experiment a conducting wire about 160 m long is coming from the top side of the balloon to the bottom of load line where it is electrically connected to the gondola. A voltage of 16 000 V will develop across the wire at ground level. At 35 km this voltage will be about 16 V and is directed downward. This voltage will be positive with respect to the probe which is at lowest portion of the load line. It may also contribute to our measurements. The gondola potential is about 20 V at ceiling altitude. It take about 2 h to decay the entire voltage to zero value. It is difficult to explain this long-time delay if the entire voltage is due to the atmospheric electric field. The second point is that the ascent and the descent values of the gondola voltage curve in Fig. 4 are not symmetrical with respect to ceiling altitude. This explains that apart from atmospheric electric field, there is an additional source of gondola charging. The cause may be the balloon itself. However, the atmospheric electric field may also be contributing to our measurements to some extent.

Apart from this, there might be triboelectric charging of the gondola, as well as current leakage from the balloon and other mechanisms, all contributing to the net charging of the gondola which we have measured. Further study of this problem is in progress. Our main efforts towards minimizing the problem created by the gondola potential will be: (1) to electrically decouple the gondola from any unit which is higher up along the load line. This will involve, for example, having a separate telecommand unit for cutoff and apex valve operations; and (2) to increase the distance between the balloon and the gondola. This will help in reducing any capacitative coupling between the balloon and the gondola.

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