Electronics for Langmuir Probe Measuring Plasma Density in the Ionosphere of Mars : MOM - 2

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ABSTRACT

Langmuir probes have been installed on satellites and sounding rockets to observe the general characteristics of thermal plasma in the ionosphere for more than five decades. Because of its simplicity and convenience, the Langmuir probe is one of the most frequently installed scientific instruments on spacecraft. A conducting sensor called probe is fixed to the medium under monitoring to collect the current using the probe is measured to examine various plasma parameters in the MARS ionosphere. As the current is proportional to the ambient plasma density; typically a sweep bias voltage is supplied to the sensor and the current-voltage characteristics are used to study plasma parameters. The automatic gain switching system is used to gain the current in desired voltage range. It works on basic principle of the Langmuir Probe. In this paper, we describe the design, implementation and laboratory test results. The Langmuir Probe experiment consists of gold coated cylindrical sensor as the input stage of the system. The sweep voltage is applied to the sensor for generating current. By keeping the sensor in plasma, it collects the current and its current-voltage characteristics analysis suggests the plasma parameters like electron density, ion density, electron temperature etc. The low pass filter are used to remove unwanted frequency of signal later. This paper describes the primary scientific objectives of the Langmuir Probe experiment and the technical capabilities of the instrument.

Keyword : - *Langmuir probe, Sweep voltage, Automatic gain switching system, Low pass filter*

1. Introduction

The development of Langmuir probe experiment is to understand electron density, ion density and electron temperature. Dr. Irving Langmuir, in the late 1920s was studying super-heated gases' unusual magnetic and electric characteristics. He introduced the term "plasma" to describe the ionized particles as their nature reminded him of carrying constituents by blood plasma. A useful definition of plasma is a quasi-neutral charged gas and particles that exhibits collective nature.

The sensor shown in the Fig. 1 is preferably a spherical probe with collection area such that ratio of collection area of sensor to that of spacecraft <<100 in order to insure that probe not be in wake of the spacecraft so that spacecraft voltage be stable over a sweep. Although LP does not give absolute value of electron density, it is undoubtedly the best instrument to study the fluctuations in electron density over various spatial scales, ranging between a few km and about 10 cm.

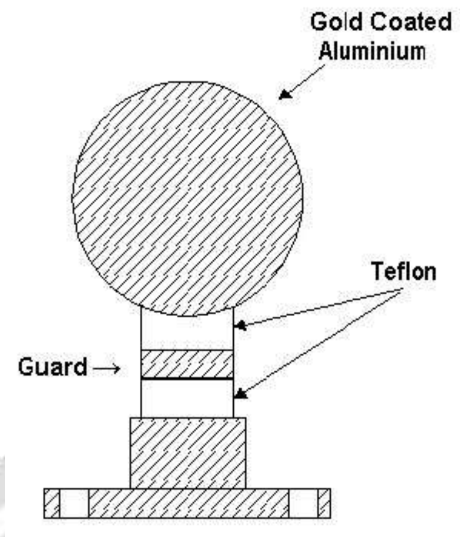

Fig -1 : Spherical Langmuir probe sensor with a guard electrode

1.1 Principle of Langmuir Probe

The basic plasma parameters can be finding out by placing a conducting probe kept into the plasma and collection the current to the probe as a function of the difference between the probe and plasma space potentials. The plasma space potential is just the potential difference of the plasma volume. When the probe potential (Vp) is above the plasma space potential (Vs) the gathered electron current attain a saturated level while in region just the opposite occurs. Finally evaluating the slope of the electron current-voltage (i-v) characteristic in region the measuring the ion or electron saturation current and using the electron and ion density find out.

When a positive voltage is applied to an electrical conductor or probe is kept in plasma, the negative charges attracted by it and probe is collect current. Langmuir probe measurement of ionospheric plasma density is based on this principle. The initial technique first used by Irving Langmuir consisted of exposing a small metallic probe to medium under study and measuring the current collected by collected by it as the probe voltage was slowly varied from a congenital negative voltage through zero to a convenient sweep voltage. The result current voltage characteristics were analyzed to obtain information about plasma parameters. Presently, the Langmuir probe system probe is connected to a amplifier which is grounded to through sweep voltage generator. The input impedance of the amplifier is small that potential difference between probe and plasma is determined by sweep voltage.

We consider the collection of electrons by a probe in plasma. The number of electrons which are incident perpendicular to a given plane per unit time due to thermal motion is given by

$$N = \int_0^\infty v_x dn_e(v_x)$$

where x is taken in the direction perpendicular to the plane and $dn_e(v_x)$ is the number of electrons whose density is between v_x and $v_x + dv_x$.

2. Langmuir Probe Electronics

Since the science focus of the LP electronics shown in the Fig. 2 is at low-altitudes (~ 300-350 km) and during deep dips, the master cycle length at low altitudes is configured to less time, the fastest operation. Between ∼300 km and ∼5000 km there are several important plasma boundaries, the plasma density is lower, so the master cycle is planned to be set higher at each voltage step. At higher altitudes, the master cycle is set to highest time stamp, primarily for solar wind monitoring. Data limitations play an important role in the LP operations.

The LP instrument is highly configurable so that it can operate in a variety of plasma conditions and can focus on specific scientific phenomenon. Equally as important, the LP instrument can be fine-tuned after orbital insertion to enhance scientific return. The initial configurations are based on predicted conditions along the MAVEN orbit. The LP sweep tables, sensor biasing (including waves bias current), and biasing tables for the guards and stubs are automatically changed based on the predicted orbital position to optimize the measurements. For example, the sweep tables have a narrow voltage range at low altitudes where dense plasma is expected (-5 V to 5 V). The voltage range is expanded when in the solar wind to -45 V to 45 V. The instrument also has a specific configuration designed for when the spacecraft is in Mars' umbra.

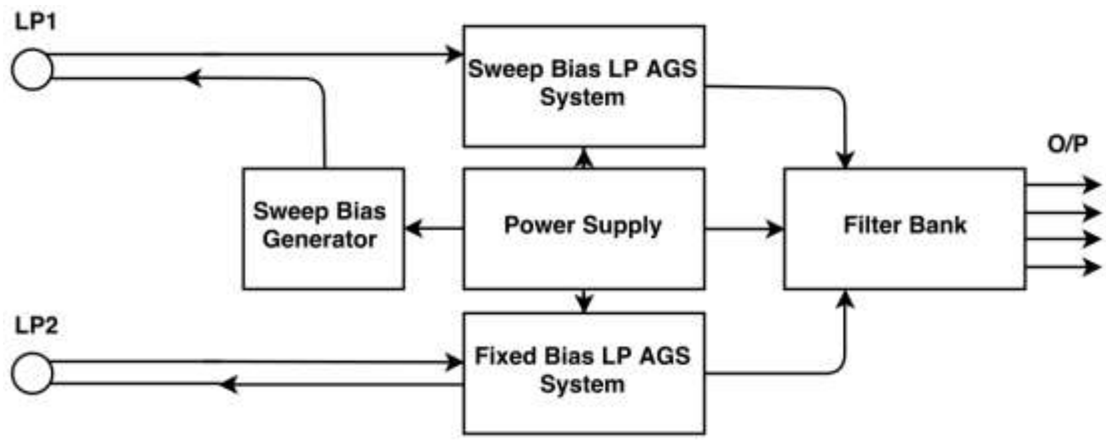

Fig -2 : LP Electronics Block Diagram

Raw power from space craft is applied to a switching regulator which supplies regulated power (±5V, ±12V & ±18V) to all the circuits.

2.1 Implementation

There are typically four blocks that works together and built the whole development model as describe before to measure electron density. These four blocks are :

- Sweep Bias Generator
- Sweep Bias LP AGS (Automatic Gain Switching) System
- Fixed Bias LP AGS (Automatic Gain Switching) System
- Filter Bank

2.2 Sweep Bias Generator

The spherical sensors can be operated as current-collecting Langmuir probes to provide information on the plasma density and electron temperature. For this mode, the pre-amplifier in the probe is switched to low impedance input and the probe is given a bias voltage rather than a bias current as for the electric field mode. The bias voltage is referred to satellite ground. Ideally, a positively biased probe collects an electron current that is proportional to the plasma density, provided the electron temperature is constant. Thus, variations in density will result in corresponding variations in the probe current. Also in this mode it is important to control the photo-electrons in order to minimize the errors that they cause. The electronics for a Langmuir probe measurement include an electro-meter and circuitry that controls the rate and amplitude of a triangular sweep and the current gain. The power supply has set as +12V to -12V and the sweep signal will be of about 5V. The circuit and its output is shown in the Fig. 3.

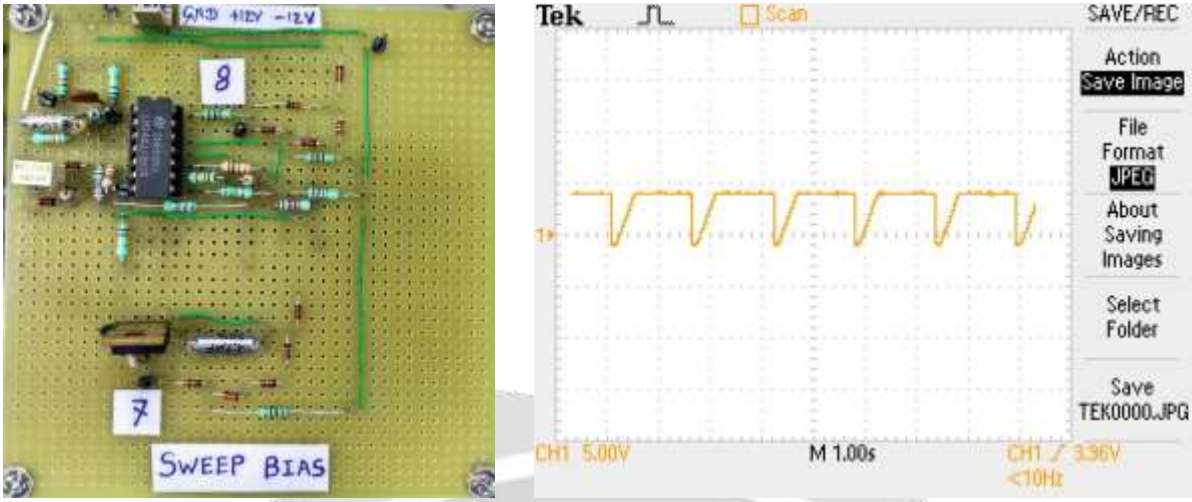

Fig -3 : Sweep Bias Generator Circuit and its Output

2.3 Sweep Bias LP AGS System

The electron density may change in the order of $10^3\ cm^{-3}$ to $10^5\ cm^{-3}$ according to various dynamical and photo-chemical processes occurring in the ionosphere. When an electro-meter is designed to cover the maximum electron density with one telemetry channel, a 12-bit analog to digital converter (ADC) may not have enough resolution in the current measurement. In this case, it is recommended to prepare two or three different current gains for the measurement so that it can measure with sufficient accuracy for large changes in the current. Here, Two pre-amplifier has gain 3000 and 3. Variant gain will be from 30,000 to 3. The circuit and its output is shown in the Fig. 4.

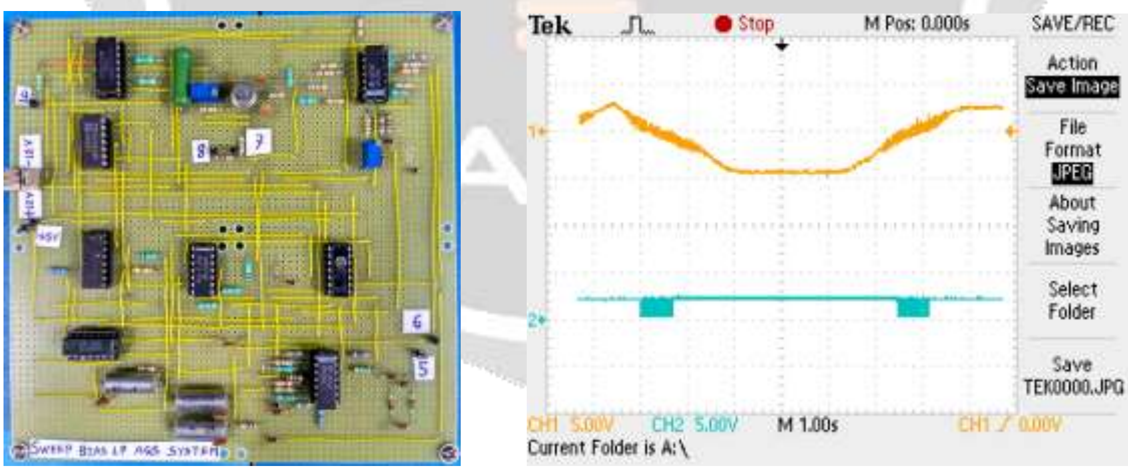

Fig -4 : Sweep Bias LP AGS System Circuit and its Output

2.4 Fixed Bias LP AGS System

The electronics to measure the electric field consist of pre-amplifier and main electronics. The sensor is connected to the pre-amplifier. The electric potential difference induced between the probe and the common ground of the rocket is picked up by the pre-amplifier which has unity gain amplifier and high input impedance. The resistance between the sensor and the plasma is of the order 10 MΩ or smaller in the dense ionospheric plasma. Therefore it is necessary that the input impedance of pre-amplifier is more than 10 MΩ. The circuit and its output is shown in the Fig. 5.

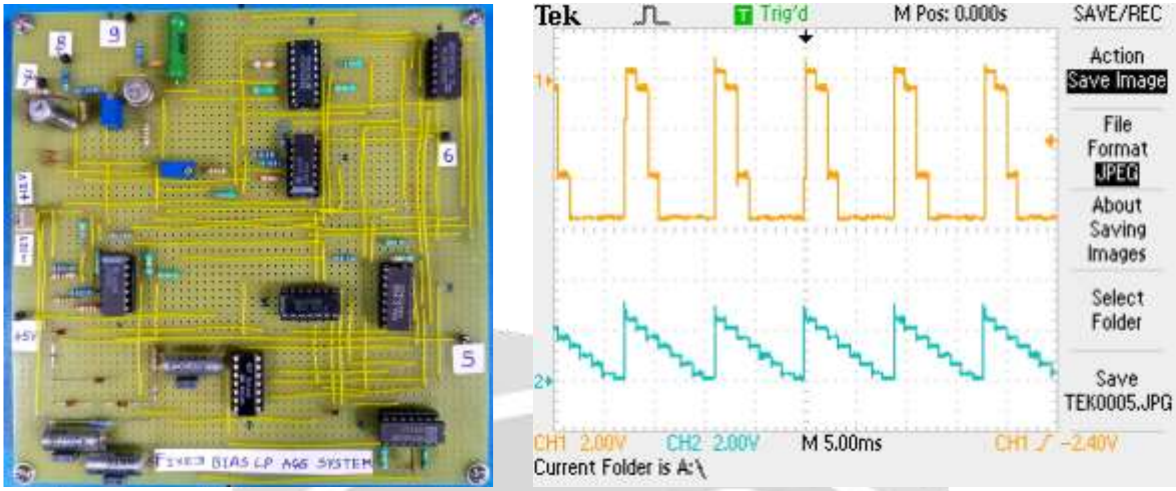

Fig - 5 : Fixed Bias LP AGS System Circuit and its Output

2.5 Filter Bank

The high frequency signal is passed through the high pass filter which consists of a capacitance and resistance. The single probe signal and the double probe signal are low pass filtered in order to reject the high frequency components. The cut-off frequency of low pass filter for the single probe signal is 20 Hz (the 3rd order filter). The circuit is shown in the Fig. 6.

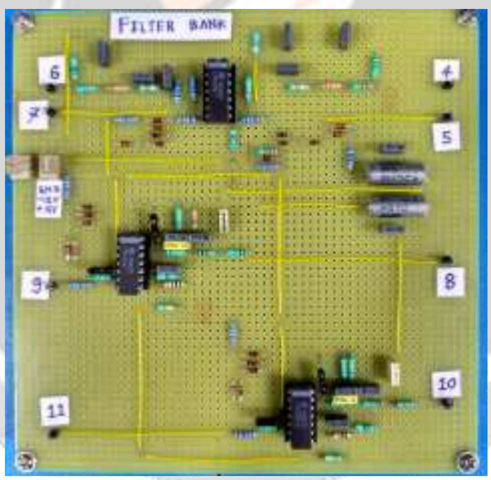

Fig - 6 : Filter Bank Circuit

2.6 Test Results

In general, the raw data in Langmuir probe measurements contain noise that may be intrinsically generated from the data acquisition system and/or interactions between the probe and plasma. The plasma potential is determined by finding the inflection point of the electron current data, which indicates the peak of the first-order differentiation. Since current noise tends to increase when it is differentiated, it becomes more difficult to find the plasma potential in the differentiated current. In this case, a pre-amplifier may be used between the electrode and main electronics. A numerical algorithm may also be applied to reduce the noise level of the probe current. The Fig. 7 shows the results.

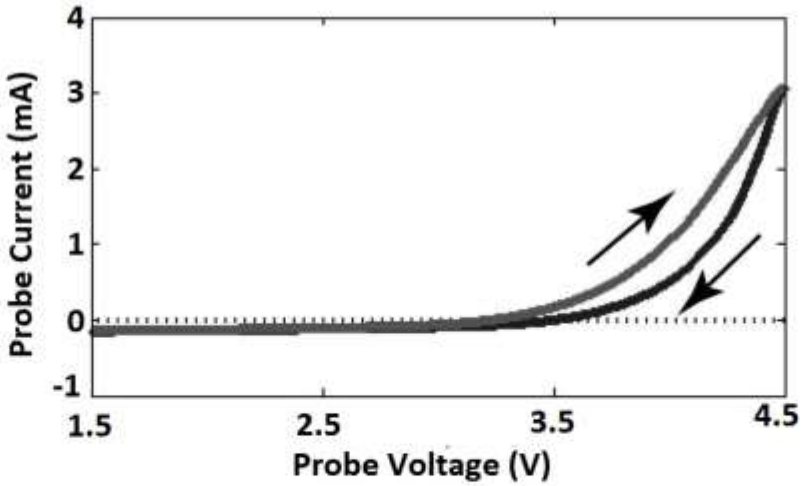

Fig - 6 : I-V Output

4. CONCLUSIONS

Of all the techniques to measure plasma, the Langmuir probe is the simplest as consisting of sticking a wire into the plasma to measure the current at different applied voltages. Although, it is not the remote technique; as the “wire” should be designed carefully as not to interact to the plasma nor be destroyed. The interpreting the current-voltage (I/V) curves is merely difficult to use a large literature of theoretical papers. In this literature review report, little portion of this can be discussed in detail. Specialized topics and related electrostatic diagnostics, such as double probes, emissive probes, oscillation probes and probes in a magnetic field capacitive probes in flowing or high pressure plasma can be summarized only.

On the other hand, the most widespread use of Langmuir probes on now a days is in the semiconductor industry, which focuses on radio frequency (rf) sources used in producing plasma for deposition and etching. The partially ionized plasma requires the understanding of Mars' ionosphere characteristics and special techniques in probe constructing theory. Emphasis can be given to this new approach of diagnostics research.

5. ACKNOWLEDGEMENT

I would like to express a deep sense of gratitude and whole hearted thank to my project mentor Prof. S. A. Haider in order to guide me throughout the way. It was his keen interest, encouragement and full cooperation that have made it possible for me to move ahead with the work. I would also like to thank my academic guide Mr. Gardas Naresh Kumar whose guidance had inspired me for this literature review work. I am grateful to Dr. Durga Prasad and Chandan Kumar for helping me doing this experiment. Finally, I am very much grateful to my wife who always gave me constant support and encouragement.

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