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Abstract

An inexpensive, simple, and fast Langmuir probe sweeping circuit is presented. This sweeper completes a probe trace in 1.4 msec and has a maximum probe current capability of 5 A. It is suitable for pulse mode plasma operation with density greater than 10^{12} ions/cm^3.

Introduction

Langmuir probes have been used for measuring plasma parameters in gas discharges for almost half a century.[1] Today they still remain an important diagnostic tool in laboratory and in space plasma studies. A Langmuir probe is simply a small electrode in the form of a cylindrical wire, a plane disc, or a sphere. In the presence of a plasma, the probe collects current when a voltage V is applied. A continuous variation of the voltage will produce a characteristic I-V curve as shown in Fig. 1. From this Langmuir trace, the density, potential, and electron temperature of the plasma can be determined. In some experiments, the plasma is operated in a pulsed mode with density higher than 10^{12} ions/cm^3. Under this condition, a fast probe voltage sweep is required in order to sample the plasma at the desirable time period and also to prevent the probe from being destroyed by the high electron current. Some sophisticated pulsed electrostatic probe data acquistion systems have already been reported.[2,3] In this paper, the design of an inexpensive, simple and fast probe sweeping circuit with maximum current capability of 5 A is described.

Plasma Parameter Computation

Fig. 1 shows a typical Langmuir probe characteristic. The space or plasma potential V_p is determined from the "knee" of the trace. If A is the probe area, n is the plasma density, and m, e, and $\langle v_e \rangle$ are the mass, charge, and average velocity respectively, of the plasma electron, then the electron saturation current I_e^* measured at $V = V_p$ is given by

$$I_e^* = A\, n e \langle v_e \rangle \bullet 1/4 \quad . \tag{1}$$

If the plasma has a Maxwellian distribution function, then $\langle v_e \rangle = (8kT_e/\pi m)^{\frac{1}{2}}$ where kT_e is the electron temperature expressed in eV. The plasma density is given by

$$n = (I_e^*/eA)(2\pi m/kT_e)^{\frac{1}{2}} \quad . \tag{2}$$

When the probe-applied voltage V is less than V_p, the electron current decreases exponentially according to

$$I_e = I_e^* \exp\left[-e(V_p - V)/(kT_e)\right] \quad . \tag{3}$$

and kT_e is computed from the plot of ln I_e versus $(V_p - V)$.

If the mass of the ion and the electron temperature are known, the plasma density n can also be calculated from the ion saturation current of the Langmuir probe trace.[4] However, for a hydrogen or a deuterium plasma, the presence of three different ion species allows one to obtain the plasma density only from the electron saturation current.

Langmuir Probe Circuit

A schematic diagram of the Langmuir probe sweeper circuit is shown in Fig. 2. This circuit has the capability of generating a linear voltage ramp of 40 V within a time period of 1.4 msec as illustrated by the oscilloscope signal in Fig. 3. In addition, an adjustable offset DC voltage from 0 to ± 70 V is added to the sweeping voltage, so that either the anode or the cathode can be used as the reference potential. The quiescent or idling voltage applied to the probe is 20 V less than the offset voltage and the maximum voltage of the sweep is 20 V greater than the offset voltage. Since the probe current decays exponentially for $V < V_p$, the current collected at the quiescent voltage is small and the probe will not be over-heated.

The sweeper circuit contains five main components: a power amplifier, a comparitor, an optical isolator, and two DC power supplies. The power amplifier is a Torque System PA 223 power operational amplifier, which consists of a 741 operational amplifier and a bridge-type power amplifier output. The 741 amplifier operates as a voltage integrator with C_1 as the feedback capacitor. Diodes D_2 and D_3 are bridged across C_1 to keep the output power amplifier operating within its linear region. The diode and resistor network of D_4, R_1, and R_2, converts the output pulse of the sweeper from a triangular waveform to a sawtooth waveform.

The second 741 operational amplifier, IC1, operates as a voltage comparitor to establish the thresholds for the sweep limit. As soon as a trigger from the optical isolator is received, the comparitor output voltage changes from high to low. This voltage is applied to the input of the PA 223 voltage integrator which in turn will generate a voltage ramp to the Langmuir probe at the "Probe-Out" terminal. When the maximum sweep voltage is reached, the comparitor output voltage changes from low to high and the probe voltage sweeps back to the quiescent voltage. The diode and resistor network, D_4 and R_2, connected across the integrator input, will make the return sweep much faster than the initial upward sweep (Fig. 3). The maximum probe current that can be drawn from the plasma is limited by the PA 223 power amplifier. This current can be reduced by decreasing the value of the resistor $R_3 = 30(I_L - 1)/(5.5 - I_L)$ where I_L is the maximum probe current. However, higher current limits could be attained with the availability of a larger power amplifier.

The Fairchild FCD 820 optical isolator is used to isolate the operational amplifiers from ground potential. There are two floating DC power supplies: one for driving the operational amplifiers and the other for generating the offset voltage. Since the voltage sweep occurs in a very short period of time (∿1.4 msec), the power for the sweep comes mainly from the filter capacitors, which are recharged in the interval between pulses.

After the I_{probe} and V_{probe} terminals of the sweeper are connected to the vertical and horizontal inputs, respectively, of an oscilloscope, the voltage sweep can be started at any time by applying a +10 V pulse at the "Trigger in" of the circuit. The ocsilloscope trace may be blanked off when a sweep is not being made by applying a voltage bias to the Z-input of the oscilloscope. A 1.4 msec pulse must then be applied to the Z-input to unblank the oscilloscope trace during the Langmuir probe sweep. The "DC offset" voltage is adjusted until the sweep ends approximately 5 V above the plasma potential.

The Langmuir probe trace shown in Fig. 1 was taken with this sweeper circuit from a Berkeley 24 cm x 24 cm multiline-cusp ion source[5] approximately 400 msec after the discharge voltage was switched on. This probe trace indicates that the deuterium plasma density was about 3×10^{12} ions/cm^3, and the electron temperature was 4 eV, and $V_p \approx 1.2$ V. The absence of oscillations in the part of the trace above V_p shows the quiescence feature of the multidipole plasma.

Acknowledgment

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References

1. C. Guy Suits, ed., <u>The Collected Works of Irving Langmuir</u>, (Pergamon, New York, 1961), Vol. 5, pp. 1-10.

2. J. C. Holmes and E. P. Szuszczewicz, Rev. Sci. Instr. <u>46</u>, 592 (1975).

3. Kurt F. Schoenberg, Rev. Sci. Instr. <u>49</u>, 1377 (1978).

4. M. A. Heald and C. B. Wharton, <u>Plasma Diagnostics with Microwaves</u> (Wiley, New York 1965).

5. K. W. Ehlers and K. N. Leung, Bull. Am. Phys. Soc. <u>23</u>, 805 (1978).

FIGURE CAPTIONS

Figure 1 The characteristic I-V curve of a 0.3 cm diameter disc Langmuir probe. The vertical line indicates the negative cathode potential.

Figure 2 Schematic drawing of the probe sweeper circuit.

Figure 3 The voltage vs time ramp generated by the probe sweeper circuit.

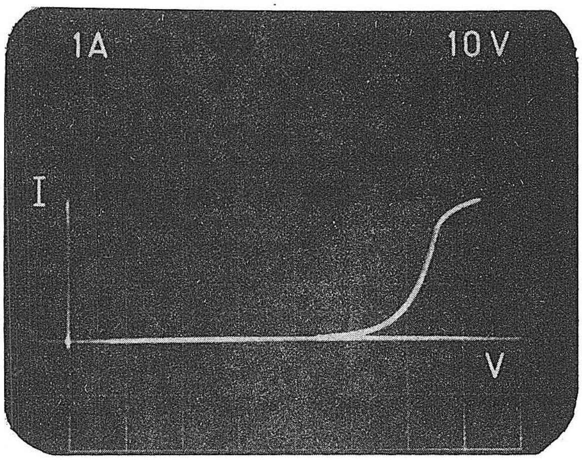

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Fig. 1
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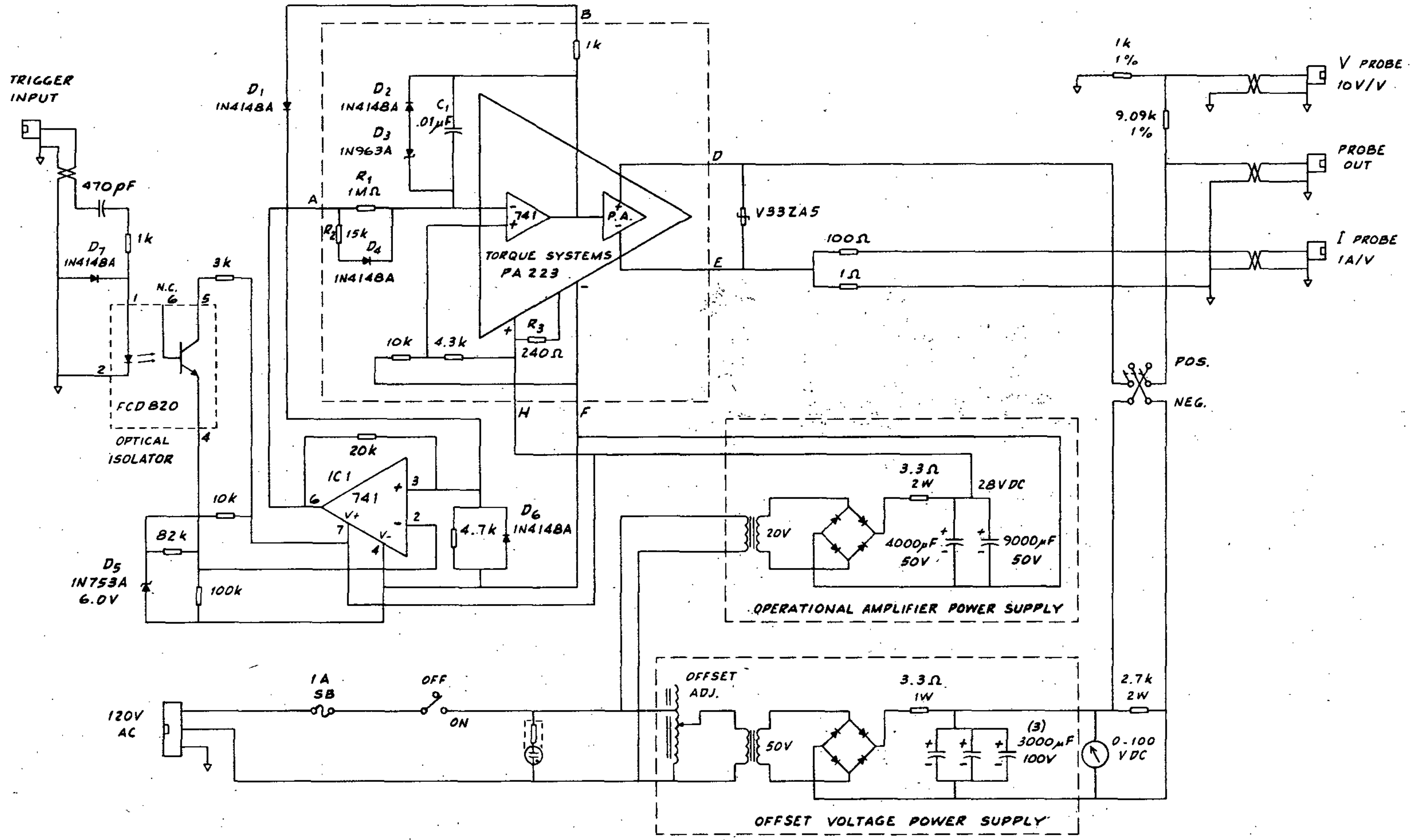

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Fig. 2

XBL 7812-14002

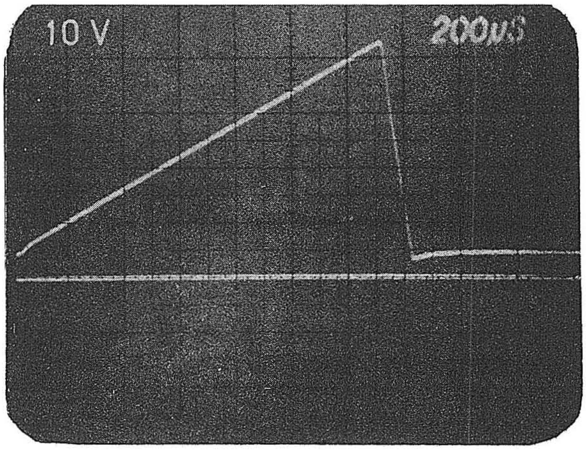

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Fig. 3
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