

Admittance Probe Method of Measuring Time Resolved Plasma Electron Temperatures*

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It is shown that the plasma electron temperature in electron volts is given by the product of the ion saturation current and the probe-to-plasma resistance at the floating potential. An ac capacitance bridge circuit is described which will measure this resistance with a response time that approaches the ion transit time across the sheath. The method is demonstrated by a measurement of electron temperature in the Wisconsin toroidal octupole.

THE current to a plane Langmuir probe at potential $V < V_p$ is given by¹

$$I = I_{0i} - I_{0e} \exp[e(V - V_p)/kT_e]$$

where V_p is the plasma potential, I_{0i} and I_{0e} are the ion and electron saturation currents respectively, and T_e is the plasma electron temperature. The slope of the I - V characteristic at the floating potential V_f has the dimension of an inverse resistance and is given by

$$Y = \frac{1}{R} = - \left. \frac{dI}{dV} \right|_{V_f} = \frac{eI_{0i}}{kT_e}$$

The admittance probe method consists of measuring the ion saturation current with a single Langmuir probe and then measuring the admittance Y by use of a balanced capacitance bridge. Alternately, two identical probes, spaced many Debye lengths apart, can be used to measure the two quantities simultaneously. The electron temperature is then found from

$$kT_e/e = I_{0i}R.$$

A capacitance bridge is required to ensure that the probe remains at the floating potential. It can be shown that the amplitude of the output signal from an initially balanced capacitance bridge is proportional to the value of the admittance Y added across one leg provided $|Y|$ is much less than the capacitive susceptance of each leg of the bridge.

The admittance probe circuit is shown in Fig. 1. Switch S_1 allows the same probe to measure admittance or ion saturation current. The probe cable should be kept short to reduce the input capacitance. The unterminated cable should be the same type and length as used with the probe. A sine wave source of frequency f and amplitude δV drives the bridge through a Pulse Engineering PE-5158 pulse transformer. C_1 is adjusted to resonate with L_1 at frequency f . The bridge is balanced to give zero output in the absence of plasma.

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¹ F. F. Chen, *Plasma Diagnostic Techniques* R. H. Huddleston and S. L. Leonard, Eds. (Academic Press Inc., New York, 1965), Chap. 4.

In choosing component values, δV should be as large as possible, but well below kT_e/e . For best frequency response, f should be large, but well below the ion plasma frequency

$$f_{pi} = (ne^2/\pi M)^{1/2}$$

where n is the ion density per cubic centimeter and M is the ion mass in grams. This frequency limitation results from the fact that the capacitive reactance of the sheath becomes comparable to R at $f = f_{pi}$.² Since $1/f_{pi}$ is the order of the time required for an ion to travel a Debye length, the admittance probe response is limited by the ion transit time across the sheath.

The response time of the circuit is given by

$$\tau = Q/2\pi f = R_1 C_{out}$$

where C_{out} includes C_1 and the capacitance of the scope and connecting cable. R_1 is added to reduce the Q and to improve the response time. If the probe is used in a fluctuating plasma, noise from the plasma may override the signal if R_1 is too small. A further frequency limitation results from the fact that the probe can only follow floating potential fluctuations with period greater than RC_{in} where C_{in} includes the bridge capacitance and the capacitance of the probe cable. Floating potential fluctuations much less than kT_e/e should not affect the admittance measurement.

Ion saturation current is measured by a standard Langmuir probe circuit. V_B should be several times kT_e/e and R_2 should be chosen to satisfy $I_{0i}R_2 \ll V_B$.

The admittance probe circuit may be calibrated by placing various resistors between the probe tip and ground to establish over what range the output signal is proportional to $1/R$. A probe should be used which has a collecting area of the proper size to give resistances in the linear range when placed in the plasma. It should be verified that the output signal goes to zero when $\delta V = 0$. The response time can be tested by touching the probe tip to ground and observing the risetime of the signal.

The admittance probe method closely resembles the double probe method³ of measuring T_e in that it involves a

² F. W. Crawford and R. Grard, *J. Appl. Phys.* **37**, 180 (1966).

³ E. O. Johnson and L. Malter, *Phys. Rev.* **80**, 58 (1950).

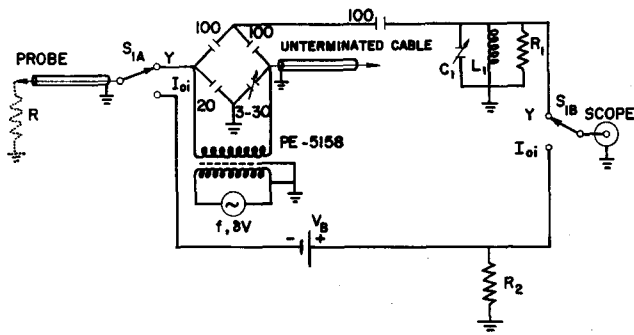


FIG. 1. Admittance probe circuit. Switch S_1 allows the same probe to measure ion saturation current or sheath admittance ($Y=1/R=eI_{oi}/kT_e$). The ratio of the two outputs gives a measure of the electron temperature.

measurement of both ion saturation current and the slope of the $I-V$ curve at the floating potential. Like the double probe, the admittance probe suffers from the disadvantage that only the most energetic electrons are sampled, and hence, for a non-Maxwellian distribution, the temperature inferred from these probes may not be representative of the bulk of the electrons. The admittance probe has the advantage that probe construction is simpler since only one electrode is required.

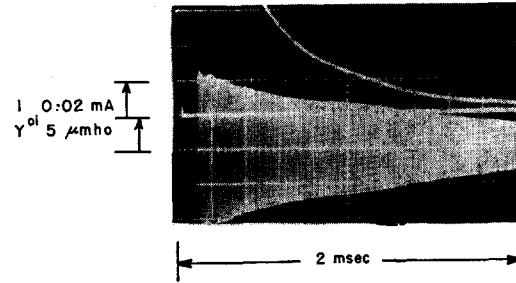


FIG. 2. Decay of ion saturation current and probe admittance for gun injected plasma in the Wisconsin toroidal octupole. The electron temperature ($kT_e/e=I_{oi}/Y$) decays exponentially from an initial value of ~ 10 V with a decay time of ~ 1 msec.

The admittance probe has been used to measure the decay of electron temperature during the quiescent confinement period in the Wisconsin toroidal octupole.⁴ This plasma has $n\sim 10^9$ cm^{-3} and $kT_i\sim 40$ eV. With $f=250$ kHz and $\delta V=0.1$ V, the traces shown in Fig. 2 were obtained. The electron temperature apparently decays exponentially from an initial value of ~ 10 eV with a decay time of ~ 1 msec, in good agreement with results obtained from a swept single Langmuir probe.

⁴ R. A. Dory, D. W. Kerst, D. M. Meade, W. E. Wilson, and C. W. Erickson, Phys. Fluids 9, 997 (1966).