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for Langmuir Probes**

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# A Dual-Cable Noise Reduction Method for Langmuir Probes

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## Abstract

To obtain fast time response plasma properties, electron density and electron temperature, with a Langmuir probe the applied probe voltage has to be swept at high frequency. Due to the RC characteristics of coaxial cables, an induced noise of square waveform will appear when a sawtooth voltage is applied to the probe. Such a noise is very annoying and difficult to remove, particularly when the probe signal is weak. This paper discusses a noise reduction method using a dual-cable circuit. One of the cables is active and the other is a dummy. Both of them are of equal length and are laid parallel to each other. The active cable carries the applied probe voltage and the probe current signal. The dummy one is not connected to the probe. After being carefully tuned, the induced noise from both cables are nearly identical and therefore can be effectively eliminated with the use of a differential amplifier. A clean I-V characteristic curve can thus be obtained. This greatly improves the accuracy and the time resolution of the values of  $n_e$  and  $T_e$ .

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## I. Introduction

Langmuir probe is a well-known and widely used basic plasma diagnostics for measuring the electron temperature and density<sup>1,2</sup>. In order to deduce these two plasma parameters an I-V characteristic curve has to be generated by sweeping the probe voltage. When a sawtooth waveform at a frequency of few hundred Hz is applied to the probe, one always sees a very annoying induced noise of nearly square waveform due to the RC characteristics of a coaxial cable. Particularly, this noise level increases with sweeping frequency and should not be ignored when the frequency is above 100 Hz. In a steady state or long pulsed plasma where the time resolution is not an issue (if the plasma is stable and there is very low fluctuation), the probe voltage can be swept slowly and usually a smooth I-V characteristic curve can be obtained. However, in many cases fast sweeping is necessary, such as: when the plasma is pulsed at a short time duration (in the order of ms), when there are fluctuations, and when the insertion of probe into the plasma needs to be reciprocated at high speeds to avoid burn-out in high temperature plasmas. In all these cases a fast time response of the measurement is required. The time response is dictated by the sweeping frequency of the applied probe voltage. When the sweeping frequency is higher than 100 Hz, the induced noise from the cable becomes significant. Many noise reduction methods have been tried, and the use of dummy cable was found to be the most effective and simplest. The dual-cable method and the experimental results are discussed in the following sections.

## II. Dual-Cable Method

The probe is platinum with a round tip, 1.35 mm in diameter. The probe wire is insulated by a ceramic tube and shielded by a stainless tube which is electrically connected to a stainless steel shaft. The vacuum feed through is at the far end of the shaft. The shaft is again electrically connected to the outer shield of a BNC coaxial cable but it is

isolated from the vacuum chamber with an insulating O-ring between the KF-40 flanges at the entry port. Therefore the outer shield is grounded at the instrumentation panel preventing the formation of a local loop.

The schematics of the Dual-Cable (DC) measuring circuit is shown in figure 1. A sawtooth probe voltage is generated by a functional generator (Wavetek 290) and amplified by a KEPCO (BOP 500M) bipolar power supply. The power supply and probe signals are isolated by a transformer which has two secondary windings. The output from the KEPCO power supply is fed to the primary winding. The voltage from the secondary winding number 1 is actively applied to the probe and a load resistor for current measurement. The secondary winding number 2 is connected to a dummy coaxial cable through a fixed step resistor and a variable wire resistor. Both the dummy and active cables are of same type, are equal in length and are tied together. Therefore their RC characteristics closely match each other. The waveform of the induced noises are nearly identical after being tuned.

In reality the characteristics of the two circuits (the active and dummy ones) are not exactly identical. First of all, the resistances for the secondary windings are different and affect the voltage amplitude as well as the RC characteristics of the circuit. The active cable number 1 is connected to the probe through a shaft which will also inadvertently change the RC characteristics. The difference in impedance of the two circuit has to be compensated. To the first order it was found sufficient to compensate the resistance. The course adjustment was done with stepping resistors and the variable wire resistor provided the fine tuning. Both the waveforms and amplitudes of the two noises are different before the compensation is made. After the two circuits are carefully tuned, the induced noise from both cable without plasma are nearly equal in both amplitude and shape as shown in Figure 2. Figure 2a is the sweeping voltage waveform. Figures 2b and 2c are the waveforms of the noises for the active and dummy probes respectively. The circuit is tuned until these

two signals coincide on the oscilloscope and their difference was almost zero to the first order. The uncompensated noise amplitude increases as a linear function of the sweeping frequency as is shown by the solid curve with dots in figure 3. The higher order noise was at a much higher frequency and was very small as is shown by the dashed curve with crosses in figure 3. The higher order noises are negligible when the sweeping frequency is below 1 kHz.

The experiment was carried out on an axisymmetric tandem mirror device which was built at the MIT Plasma Fusion Center for space plasma propulsion study<sup>3-5</sup>. The simplified experimental setup is shown in Figure 4. The probe is located at the midplane of the device and is at a radial position of 5 cm, which is one half of the plasma radius. The plasma discharge was obtained by back filling the chamber to  $8 \times 10^{-5}$  torr of hydrogen which was broken down with a microwave power of 500 W at 2.45 GHz. It was further heated with an rf power of 10 kW at 3 MHz and at a pulse duration of 20 ms. Depending on the discharging conditions of the plasma, there are fluctuations and instabilities. In order to understand these properties as functions of magnetic field intensities, heating schemes and powers, and gas filling pressure, etc, a probe with sufficient time resolution is needed. To obtain a time resolution of ms the probe frequency has to be swept at about 1 kHz. The noise level at this frequency is very high as is shown in Figure 3.

The probe current signals before and after the compensation are shown in figure 5. Figure 5b is the noise signal from the dummy cable. It is seen that there are much larger high frequency pick-ups superimposed on the regular induced noise. The induced noise and pick-up cause very large distortion on the probe signal as is shown in Figure 5c. As is shown in Figure 5d the probe signal becomes very clean after these two signals are differentiated. Even the high frequency pick-ups are eliminated as they are also a common mode of the two cable. This shows that the DCM method can eliminate all common mode noise which is difficult to achieve with other methods. The effect of this noise on the I-V

characteristic curves can clearly be seen in Figure 6a and 6b which are expanded from the rising half of the fifth peak in Figures 5c and 5d respectively. From Figure 6a it is seen that the noise greatly distorts the I-V characteristic curves, making analyses extremely difficult. This noise almost renders the extracted values random. It was a very distressing problem. The I-V characteristic curve shown in Figure 6b are much smoother after the noises have been eliminated.

Here we would like to give a few comments on several other methods that have also been tried: One is to take a background shot which was subtracted from the probe signal numerically. The result is reasonable, but is not as good as the DCM method. The reasons are that there is a slight phase shift between the background shot and plasma shot and the noise level and waveforms were not well matched between the shots taken at different times. The high frequency pick-ups are different. The magnitude of the second order noise was also higher than that of the dual cable method. We have also tried to generate the noise with an equivalent RC circuit, the result was very poor because it is not possible to reproduce the waveform of the noise. However, these exercises lead to the present method which turns out to be the most natural solution.

The I-V characteristics were analyzed using the standard techniques<sup>1,2</sup>. Two  $T_e$  values but only one  $n_e$  value can be extracted from each peak of the probe current spectra in Figure 5d. The time scan of the measured  $T_e$  and  $n_e$  are shown in Figure 7. Large fluctuations can be seen. The time resolution is 0.5 ms in  $T_e$  and 1 ms in  $n_e$ .

### III. Concluding Discussion

It has been shown in this work that a satisfactorily clean I-V characteristic curve can be obtained for high frequency signals by minimizing the RC induced noise with the use of a split transformer and dual-cable system. The fluctuation time of the signal that can be measured with the present set-up is about 0.5 ms. The high order noise can not be ignored

when the sweeping time is faster than 0.5 ms. The linearity of the frequency response of the transformer is very important. If needed, the minimization of the high order noise can be facilitated by adding on a dummy probe and by compensating the capacitance as well as the resistance. A factor of 10 improvement in time resolution can be possible with further work.

### **Acknowledgement**

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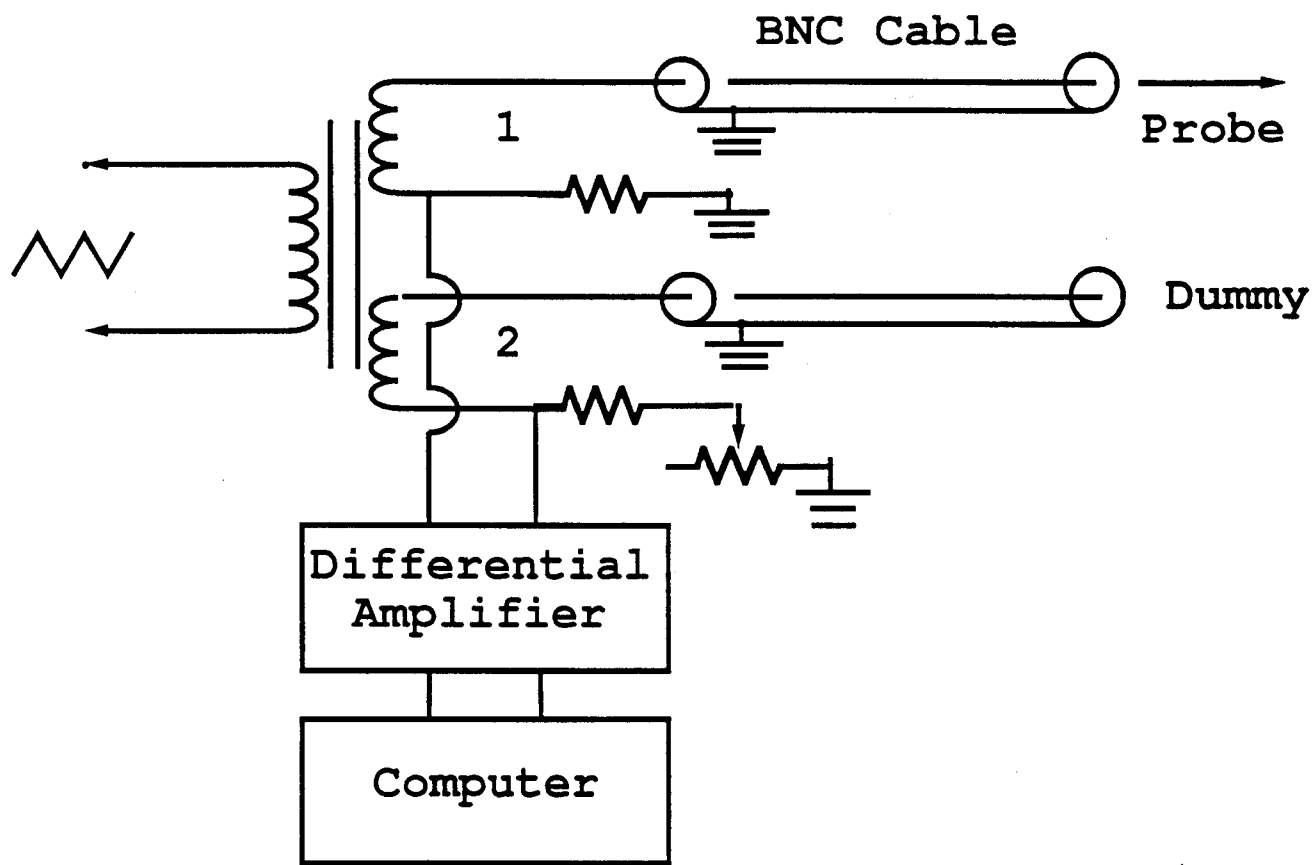


Figure 1. A Dual Cable Langmuir Probe circuit.

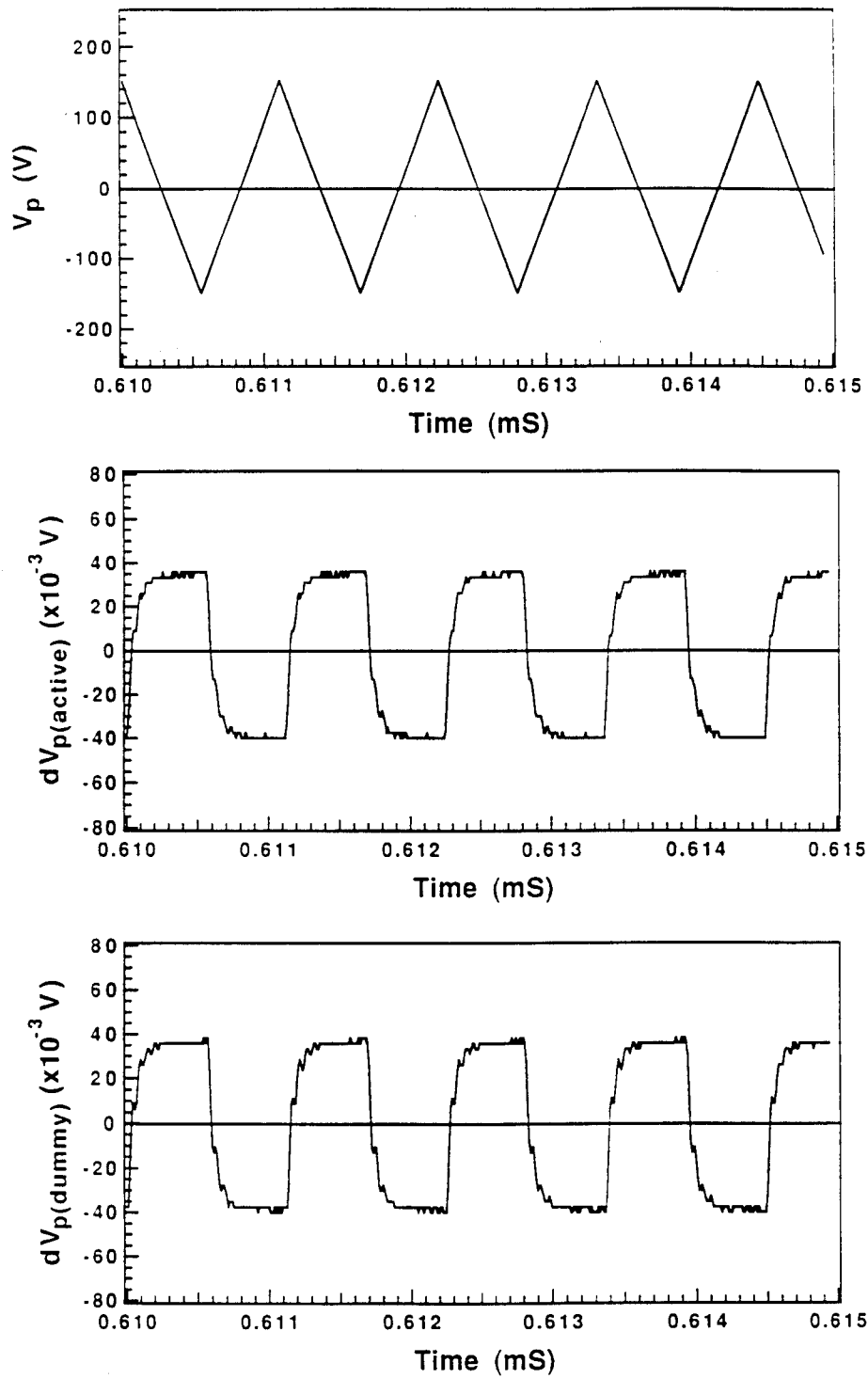


Figure 2. The noise signals without plasma from the probe with an applied sawtooth voltage at a frequency of 1000 Hz (a) after the circuit has been tuned: The induced noise waveform from the dummy cable (b) and from the active probe (c).

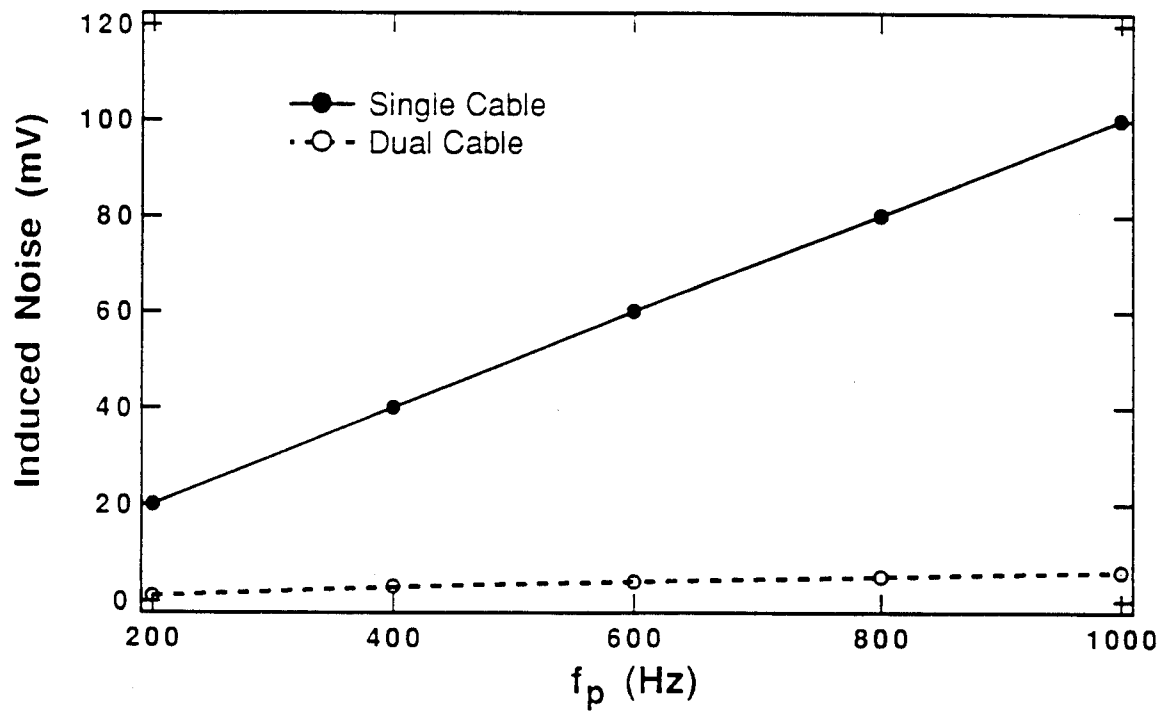


Figure 3. The amplitude of the induced noises as a function of the sweeping frequency of the applied sawtooth voltage.

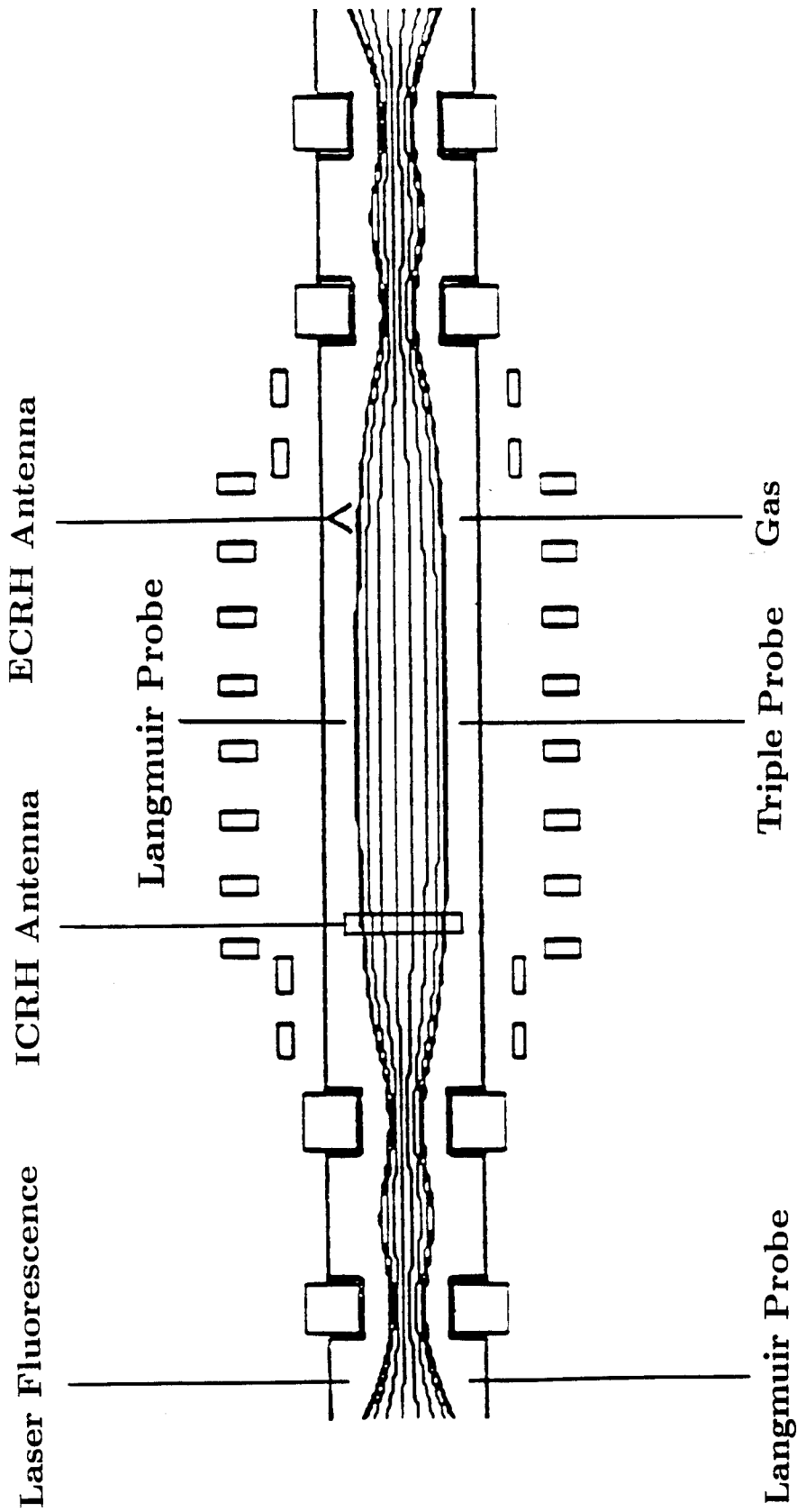


Figure 4. The simplified experimental setup of a Tandem Mirror Plasma Propulsion device.

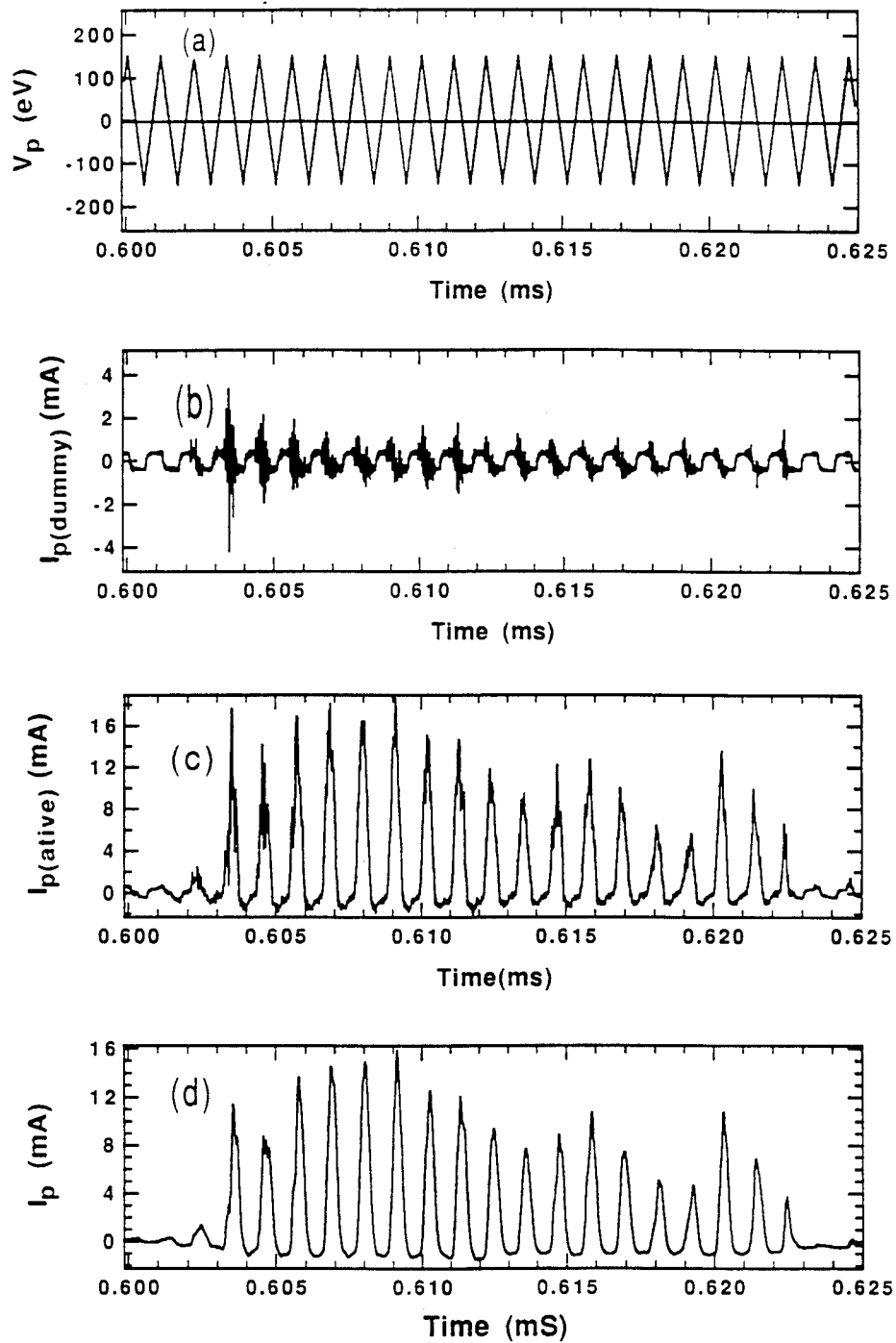


Figure 5. The probe signals during plasma discharge: The induced noise and high frequency pickups from the dummy cable (b), the total electron current from the active probe before differentiation (c), and the electron current after the noise and pickups have been eliminated by a differential amplifier (d).

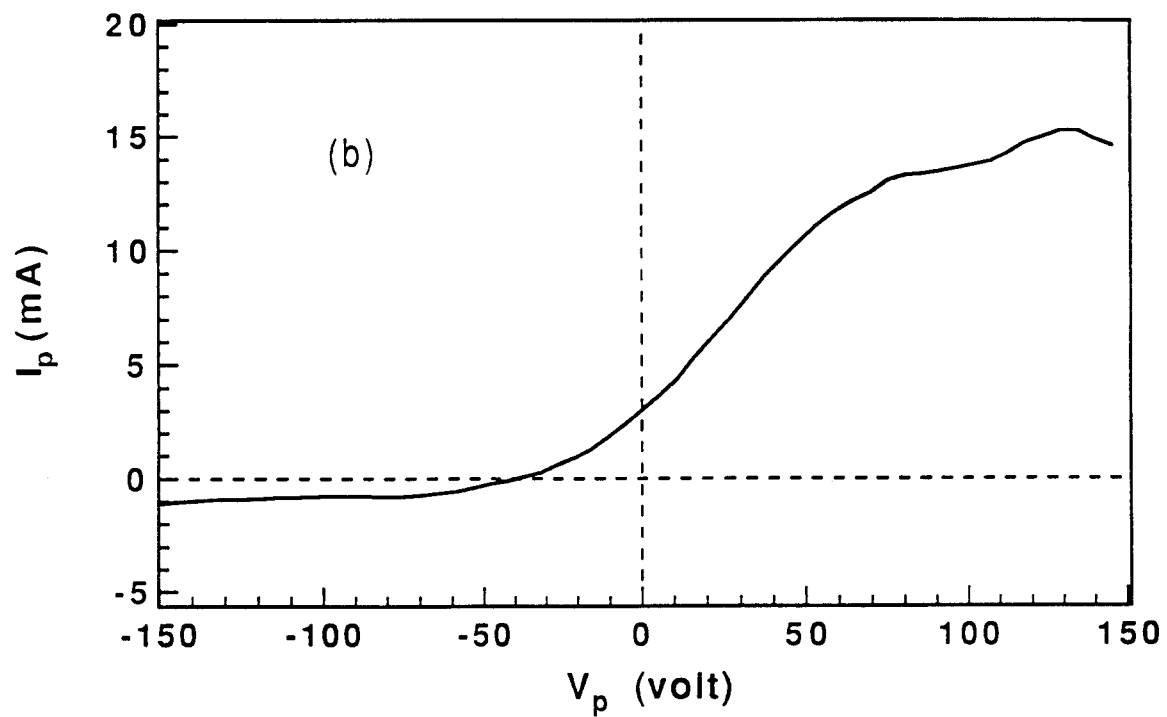
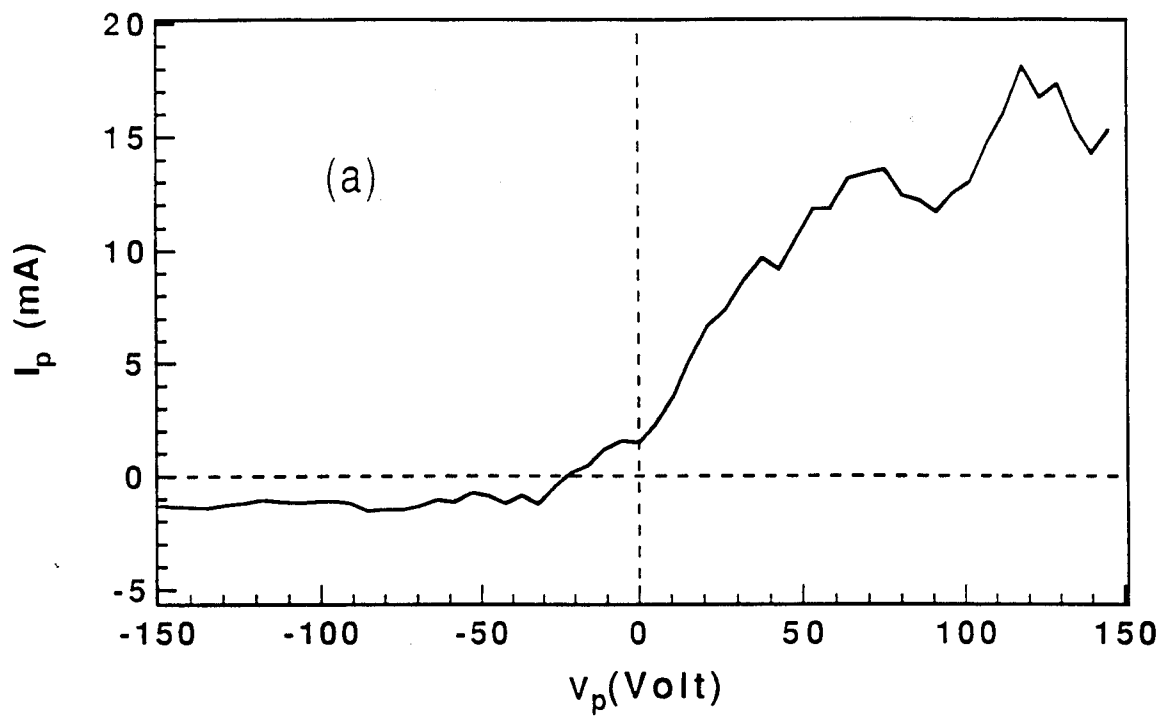


Figure 6. The expanded plots of the I-V characteristics on the rising side of the peak number 5 in Figure 4c (a), and Figure 4d (b).

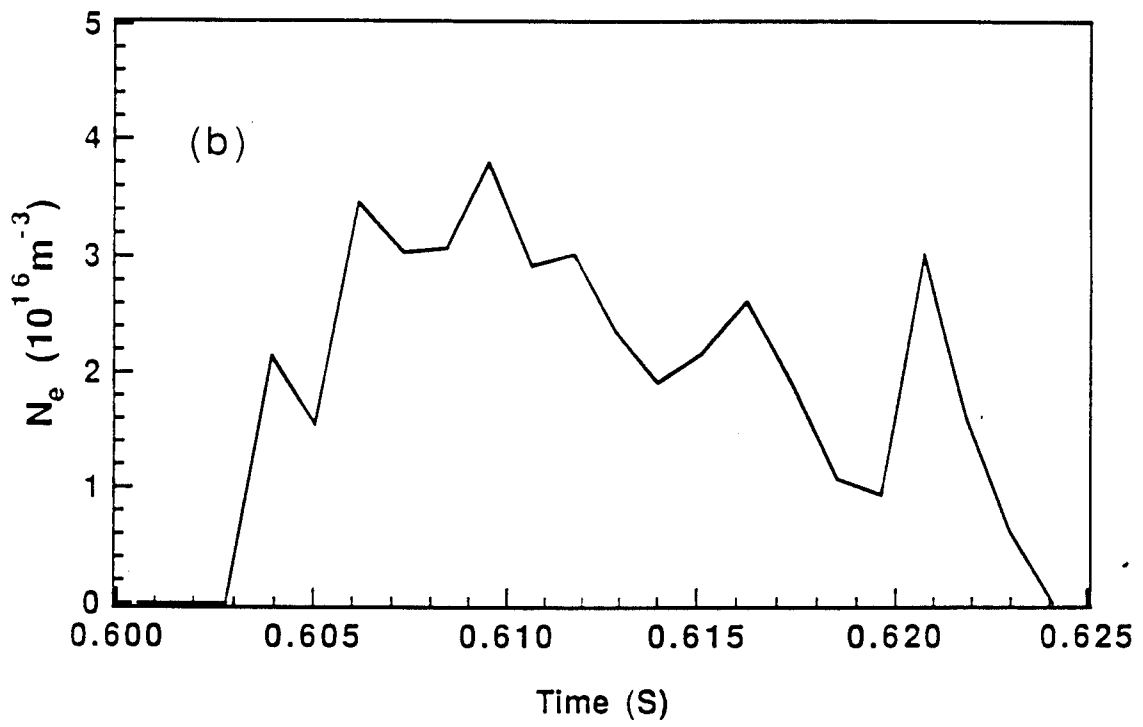
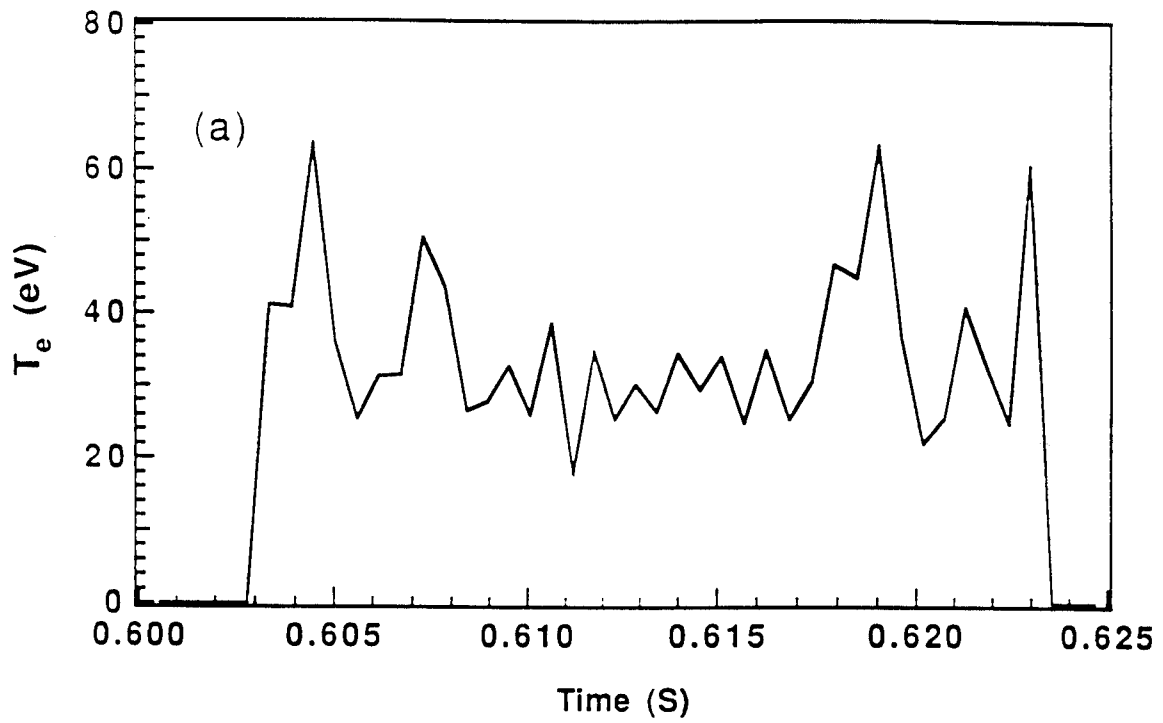


Figure 7. The time scan of  $T_e$  and  $N_e$ .