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Solving the Capacitive Effect in the High-Frequency sweep for Langmuir Probe in SYMPLE

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Abstract. Langmuir Probe based measurements need to be routinely carried out to measure various plasma parameters such as the electron density (n_e), the electron temperature (T_e), the floating potential (V_f), and the plasma potential (V_p). For this, the diagnostic electronics along with the biasing power supplies is installed in standard industrial racks with a 2KV isolation transformer. The Signal Conditioning Electronics (SCE) system is populated inside the 4U-chassis based system with the front –end electronics, designed using high common mode differential amplifiers which can measure small differential signal in presence of high common mode dc- bias or ac ramp voltage used for biasing the probes. DC-biasing of the probe is most common method for getting its I-V characteristic but method of biasing the probe with a sweep at high frequency encounters the problem of corruption of signal due to capacitive effect specially when the sweep period and the discharge time is very fast and die down in the order of µs or lesser. This paper presents and summarises the method of removing such effects encountered while measuring the probe current.

1. Introduction

The “SYMPLE”(System for Microwave Plasma Experiment) is an experimental system conceived few years back in IPR to investigate the physics of interaction of extremely intense electromagnetic waves in an over dense plasma. Theoretically, such waves are predicted to be absorbed in the plasma unlike their low amplitude counterparts that do not propagate in over-dense plasma. The experimental setup of the SYMPLE is shown in figure 1.In order to identify the right parametric regime where the plasma meets with the required pre-requisites conditions for density in axial and radial distance etc. Langmuir Probe based measurements need to be routinely carried out to measure various plasma parameters such as the electron density (n_e), the electron temperature (T_e), the floating potential (V_f), and the plasma potential (V_p).

Figure 1.View of SYMPLE system

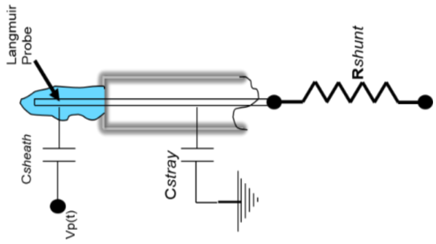

Figure 2. Langmuir Probe circuit immersed in plasma

The Langmuir probe in its simplest form is a small piece of metal inserted inside plasma as shown in figure 2. The I-V characteristic of the probe, as obtained by sweeping the probe potential from a negative to a positive value, contains information about the local parameters, namely, the electron temperature and the electron density. Thus, the Langmuir probes are known for their ability to provide the important measurements of local plasma at low cost with high speed and reliability.

Although a conventional Langmuir probe diagnostic method is very popular among plasma physicists for measuring various plasma parameters with constant density but it cannot be used to measure the plasma having transient characteristics. The current-to- voltage characteristic curve obtained in the latter case is present in every sweep period for which the probe is biased, thus giving variation in electron temperature with time by calculating every I-V curve acquired from every half sweep period [1]. The probe bias is swept at twice or higher frequency as compared to the plasma fluctuations from which we can derive the electron temperature by the equation (1) if the condition of $\ln(I_p) \sim V_p$ is met.

$$\text{Slope} = 1/ T_{ev} \tag{1}$$

where T_{ev} is the electron temperature.

2. Electronics

The signal conditioning electronics for the Langmuir probe diagnostic system consists of two parts viz: sweep biasing circuit and the current sensing circuit which is shown as one complete unit in the figure 3. The optical fiber based system is being used to safely transmit an extremely low jitter trigger for simultaneous triggering of ignitron and the function generator. It is also employed to provide the complete isolation between the diagnostic and the signal conditioning electronics in order to avoid any ground lifting. The sweep biasing involves the triggering of the function generator through the optical link for generating the required sweep pulse and amplifying it using the power amplifier PA-85. The current sensing involves the current measurement circuitry along with the signal conditioning electronics having programmable gain amplifiers and programmable filter module.

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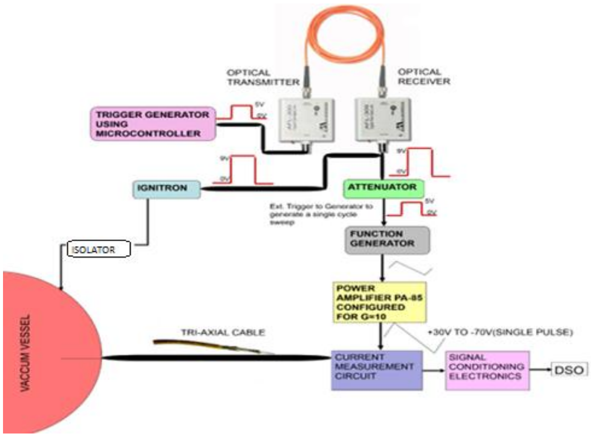

Figure 3. Complete system level diagram

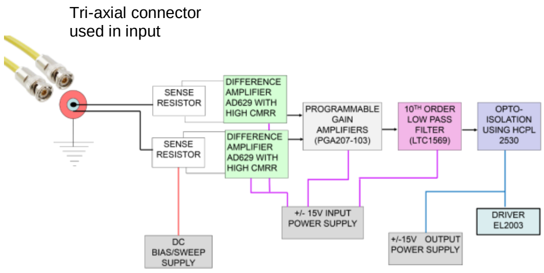

Figure 4. Current Sensing and Signal Conditioning Electronics

2.1. *Sweep biasing and the probe current sensing*

The electronics was well proven when the probe was dc-biased by looking at the probe characteristic received at the final output. But, when the probe is subjected with the sweep bias of high frequency of around 100 kHz with amplitude ranging between + 30 V to -70 V, the capacitive current becomes significant. Such high frequency presents severe limitation of differential operations for the front –end difference amplifier AD629 which possess poor ac CMRR of around 65 dB at these frequencies as shown in its datasheet in figure 5. Due to clear limitation of CMRR, the sweeping frequency is reduced to 10 kHz instead of the initial plan of 100 kHz by specially crafting the symmetry while retaining the same sweep duration of 10µs (duration of the discharge).

2.2. *Signal conditioning Electronics*

As the bias voltage is swept between the ion (~ - 70 V) and the electron (~ + 30 V) saturation regions , the probe collects the electrons of different energy which represents the electron energy distribution function determining the electron temperature. The probe current is pick-up by a sensing voltage over a small value shunt (200 Ω) resistor in the input of the difference amplifier AD629 followed by a signal conditioning electronics. The voltage signal corresponding to the current is fed to a programmable gain instrumentation amplifier PGA207 configured in a differential mode, which also receives the signal from another dummy difference amplifier AD629. This configuration not only remove any unwanted signal generated due to change in bias voltage or due to left-out ac-CMRR error of the difference amplifiers as shown in figure 8 ,but also imparts gain to the signal . The signal then passes through the filter-stage implemented using 8^{th} order Bessel filter MAX296 configured as low pass filter for filtering-out the high frequency noise generated by the plasma itself or other non-plasma sources like vacuum pumps, magnetic coils etc. [2]. The bandwidth of the filter module is set at 10 kHz .The optical isolation is implemented using opto-isolator HCPL2530 and associated circuitry before data acquisition. The opto-isolator is configured to be operated with a current source of 3 mA for each channel to maintain the linearity in the ± 5 V range which the expected signal will never cross.

Thus, the signal obtained after passing through the signal conditioning electronics as shown in the figure 4 is less noisy and data processing may be easier with lesser data points.

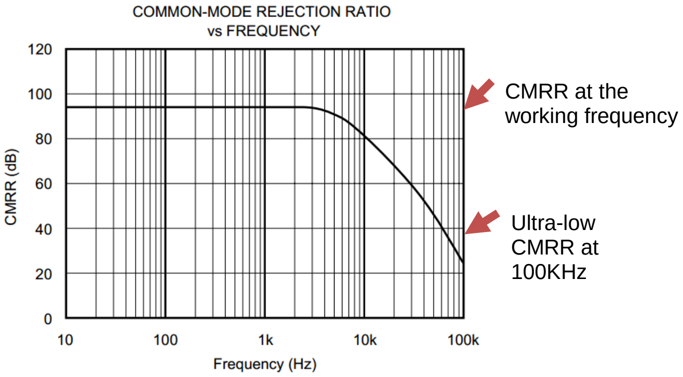

Figure 5. Plot showing CMRR of IC AD629 with frequency.

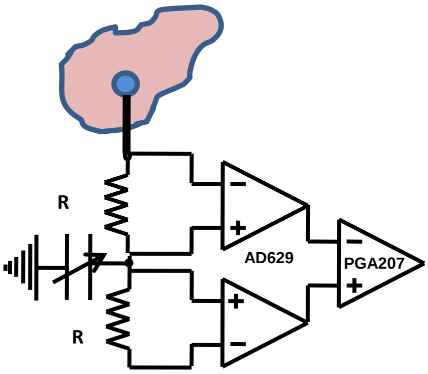

Figure 6. Front-end Electronics for Current Sensing.

2.3. Capacitive Effect

The swift variations of the sweep potential in large voltage range (+ 30 V to - 70 V) within short time-scale (~ 10 µs) leads to the milli-amperes of the unavoidable capacitive currents of the order of the ion saturation current thus, distorting the I-V characteristic. For a Langmuir probe, there are many capacitive sources but the one which is most important for us in high frequency sweep is the parasitic capacitance or stray capacitance, formed between a co-axial conductor's core and its shield or environment [3] in case of unshielded cables. Various types of cablings were tried out like shielded twisted pair, co-axial cable etc. but the double-shielded cables called as tri-axial cables are employed for the rapid sweep biasing of the probe. In tri-axial cable configuration, the inner shield and the central conductor are simultaneously biased with the same signal, while a shunt resistor placed in line with the central conductor measures the current. The outer shield is at the potential of the plasma chamber. Most of the capacitive effect was removed using the tri-axial cable connected in the configuration as depicted in the figure 7.Some left-out error as shown in figure 8 was removed

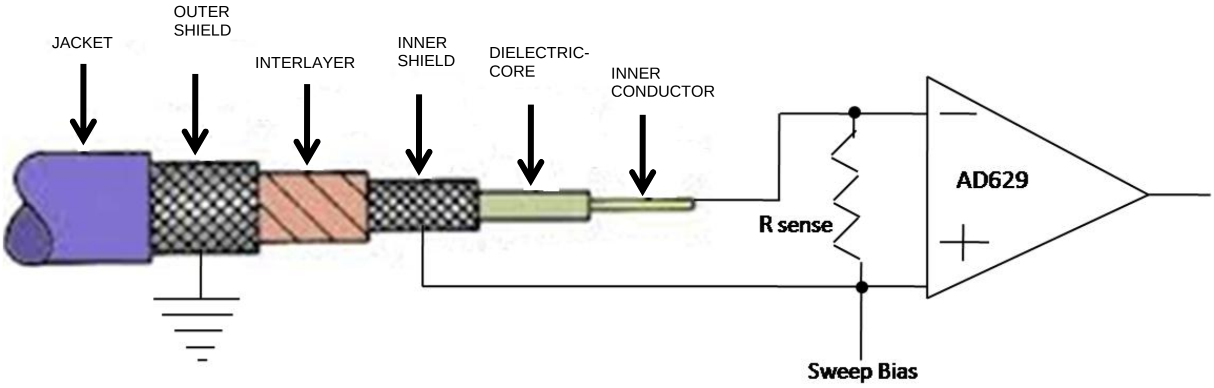

Figure 7. Configuration of the tri-axial connector with Front-end electronics.

using the differential configuration of instrumentation amplifier PGA207 after the current-sensing stage as shown in the figure 6. Figure 8 shows the mV noise that is still present after the tri-axial cable configuration while figure 9 shows the complete elimination of noise after the differential configuration implemented in PGA207.

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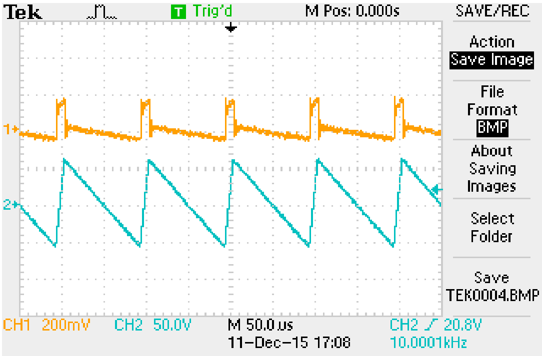

Figure 8. Reduced Capacitive effect implementation of tri-axial cable configuration.

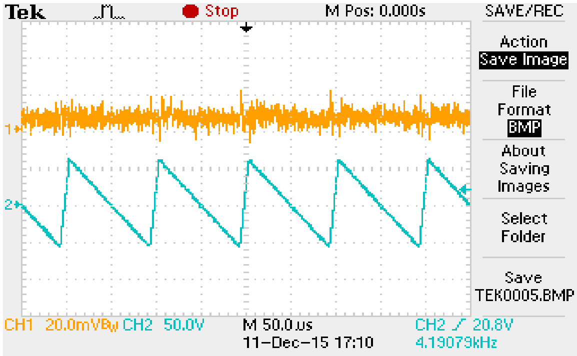

Figure 9. Complete noise elimination after differential configuration of INA.

The signal is now completely clean from the capacitive effect which is then further conditioned in the consecutive signal conditioning stages.

3. Experimental Setup and Testing

A total of 8-channels of the signal conditioning electronics mounted in a 4U- chassis will be used using the tri-axial cable configuration for sensing the current from the probe biased with the sweep. The whole of the electronics system is kept in the corridor, away and outside the exposure of the experimental setup. A microcontroller based circuit is used for generating a 5 V TTL pulse for triggering the optical fiber transmitter link which transmits a 9V pulse for simultaneous triggering of the ignitron as well as function generator(via an attenuator). The function generator then generates the desired sweep pulse of the required rise time for biasing the probe.

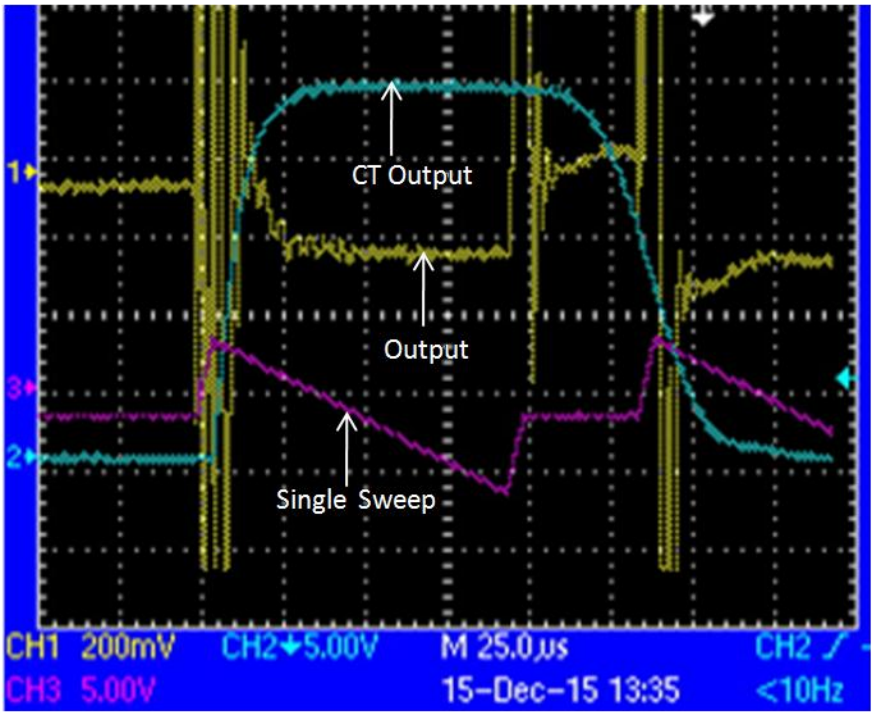

Figure 10. Testing results from the electronics system.

The probe current is sensed by a shunt resistor connected across the dedicated difference amplifier IC AD629 which works in the presence of high common mode voltage. The capacitive effect left-out from the tri-axial cable correction also could not be removed fully by the difference amplifier IC AD629 due to its low ac CMRR of about 80 dB at 10 kHz (figure 5), leaving some residual capacitive effect of amplitude of around 100 mV in its output. This inability to sufficiently suppress the common mode signal leads to a noise signal generated as a result of common mode signal which was comparable to the useful signal. A dummy combination of the same configuration using AD629 is used for feeding at one of the differential terminals of the programmable gain instrumentation amplifier IC PGA207. The residual capacitive effect is finally removed when seen at the output of the instrumentation amplifier as shown in figure 6. The final current-voltage characteristic curves as result of the testing is displayed in figure 10.

This figure has three plots containing the single sweep pulse, CT output and the final output. This depicts the temporal profile obtained for a discharge of 100 μs with an average voltage of 200 mV measured across a shunt of 200 **Ω**. The captured data (200 mV) in the Langmuir probe corresponds to the ion saturation currents (I_s) across a 200 Ω shunt resistance. Using the formula $I_s = n_e A v$, for a given probe area and the ion saturation current of 1 mA, the density of the plasma for this particular discharge is $2 \times 10^{17}/m^3$.

4. Conclusion

With the use of the tri-axial cable and connector configuration, the capacitive effect reduces drastically for the high –frequency sweep which is further removed by using one dummy difference amplifier in the electronics system. Thus, the effect of the change in the bias voltage and the capacitive effect are completely nullified at the output of the INA. The time dependent current-voltage characteristic is obtained using the Langmuir probe by sweeping the probe at a frequency of 10 kHz with 10 μs rise time.

Acknowledgement

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References

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