

DESIGNING A HIGH RESOLUTION MICROCONTROLLER-BASED ELECTROSTATIC PROBE SYSTEM FOR PLASMA CHARACTERIZATION

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ABSTRACT

In this work, an automated system capable of biasing electrostatic probes in cold plasmas and acquiring the associated data is implemented. The step-by-step design, fabrication, and fine calibration of the entire system are presented. High resolution and accuracy, increased acquisition rate and high noise rejection, are the main claims for the system presented hereby. The device efficiency is eventually demonstrated through measurements in the negative ion H⁻ source "Prometheus I".

1. INTRODUCTION

The first fundamental technique for measuring the properties of plasmas, developed in 1924 by Irving Langmuir, refers to electrostatic probes. A probe, i.e. a small metallic electrode, is immersed in the plasma and biased in various voltages. The current collected provides unique information about the plasma parameters, difficult to obtain otherwise [1]. The application of this technique in a realistic manner (i.e. real time measurements, wide range of the applied voltage and produced current, acquisition of high amount of data and numerical treatment of them, extreme averaging for noisy environments etc.), has led to the development of both commercial and self-provided systems [2,3], with the former to be quite expensive usually.

Based on the above-mentioned and further requirements, the design and fabrication of such a custom system are herein shown and tested.

2. SYSTEM OVERVIEW

The conceptual diagram of the device is presented in Fig. 1.

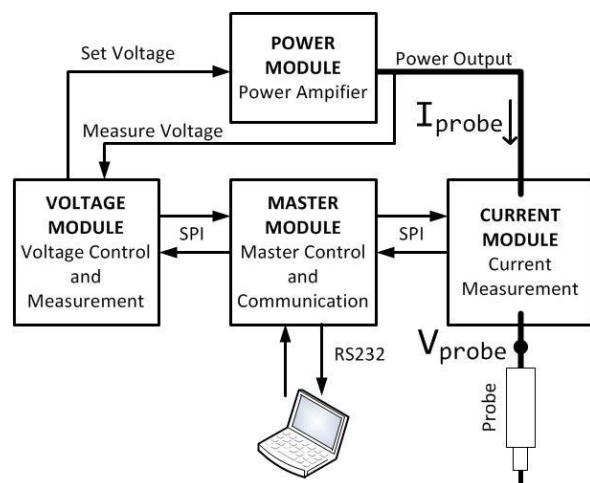


Fig. 1 Conceptual diagram of the device.

Briefly, the role of each module is as follows. The Power Module is responsible for biasing the probe according to the voltage reference on its input. The Voltage Module generates the voltage reference and measures accurately the output voltage of the Power Module. This voltage is slightly different from the one that finally biases the probe due to the Current Module drop-out. The Current Module measures the probe current, using the appropriate current scale. Finally, the Master Module schedules the operation, by controlling the voltage reference, acquires the sampled data, accumulates them, and transmits them to a personal computer through a RS-232 interface.

2A. POWER MODULE

The power module is essentially a linear power amplifier (Fig. 2). The DC power supply for the amplifier ($\pm 125\text{ V}$) is based on the TL783 linear voltage regulator.

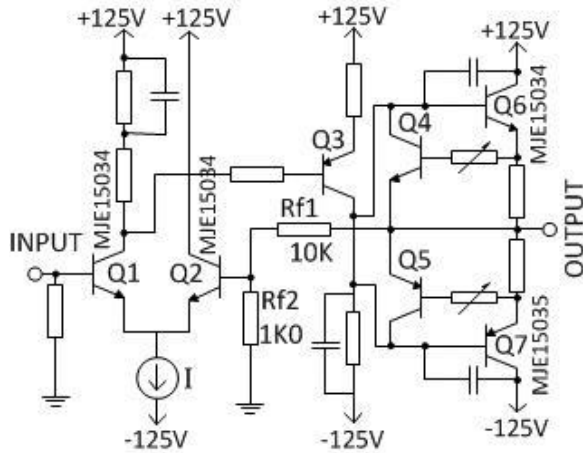


Fig. 2 Schematic diagram of the Power Module.

The push-pull output stage (Q3 to Q7) is driven by a differential amplifier (Q1 and Q2), which compares the input voltage with the output voltage reduced by the R_{f1}/R_{f2} voltage divider. This negative feedback configuration ensures a stable output voltage. This module has efficiently been tested in the voltage range $\pm 110\text{ V}$, supplying currents up to 0.5 A .

2B. VOLTAGE MODULE

The Voltage Module (Fig. 3) is separated into two parts. The first one (upper part) sets and the second (lower part) measures the voltage.

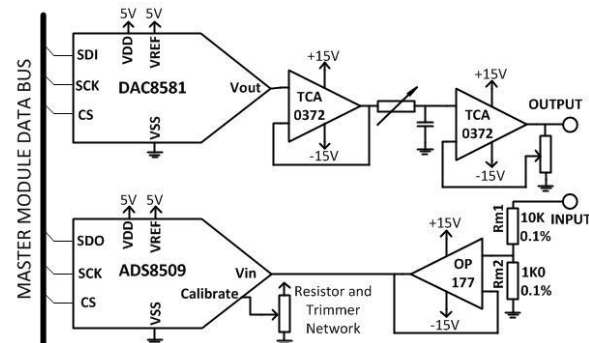


Fig. 3 Schematic diagram of the Voltage Module.

The setting part consists of a 16 bit digital-to-analog converter (DAC8581) followed by the amplifiers that drive the Power Module. The measuring part is based on a 16 bit analog-to-digital converter (ADS8509), which digitizes the

Power Module output fed to the analog front-end "R_{m1}/R_{m2} and OP177" (see INPUT in Fig. 3). The maximum error of the ADS8509 is ± 2 least significant bits and the maximum offset of the operational amplifier (OP177) is $40\ \mu\text{V}$ (cancellable with trimming). All the resistors have been selected with a tolerance of 0.1% and high temperature stability. The above features make the dynamic range of the Voltage Module close to that of the ADS8509, i.e. 96 dB. Data are transferred through a serial (SPI) data bus connected to the Master Module (section 2D).

2C. CURRENT MODULE

The Current Module (Fig. 4) is fully floating, in order to achieve high-side current sensing.

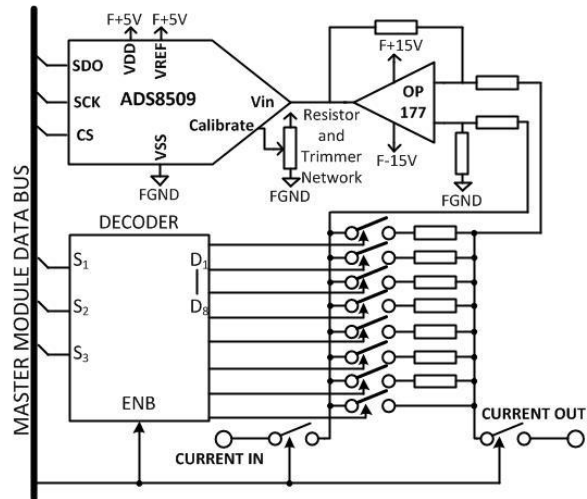


Fig. 4 Schematic diagram of the Current Module.

Seven current shunt resistors (thin film type) are employed for different current scales and a short-circuit option is installed for calibration. The selection among these eight states is done through the Master Module with the help of a 3-to-8 decoder. The maximum voltage drop along each resistor is maintained lower than 1 V by appropriately choosing the resistor value for each current scale, and it is differentially amplified in order to be measured. A second ADS8509 is used for this measurement and 96 dB dynamic range is again achieved for each scale. The accuracy is the same with the one mentioned earlier for the Voltage Module. Using different scales, currents from 1 A down to 30 pA can be measured. Finally, it is mentioned that the voltage drop across each resistor is numerically compensated from the probe V-I curve.

2D. MASTER MODULE

The core of the Master Module (Fig. 5) is a DSP Microcontroller (dsPIC33FJ128GP804) with the appropriate embedded code for managing the different modules.

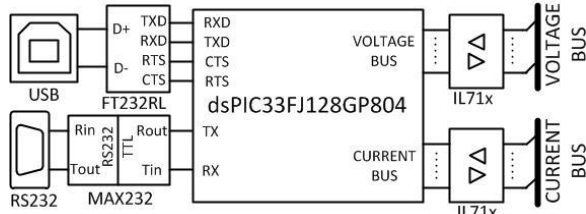


Fig. 5 Schematic diagram of the Master Module.

The DSP is electrically isolated by the floating Current Module and the Voltage Module by means of high speed magnetic de-couplers (IL71x). Although the actual interface with a personal computer is an RS-232 protocol (MAX232 Transceiver), the FT232RL USB-to-UART integrated circuit is installed as well for future extension of the system.

3. DEVICE CALIBRATION

Despite the fact that the intrinsic errors are kept low enough (see above mentioned features), fine calibration of the device leads to negligible offset and gain errors. Either trimmer networks connected to the two ADS8509 or correction factors in the software developed for user interface (MatLab™) can be used. In both cases, the calibration procedure has two stages. During the first stage, the Voltage Module is calibrated with the help of an Agilent 3458A ($8^{1/2}$ digits) multimeter. During the second stage, the Current Module is calibrated by terminating the output of the device to a low-tolerance resistor of known value.

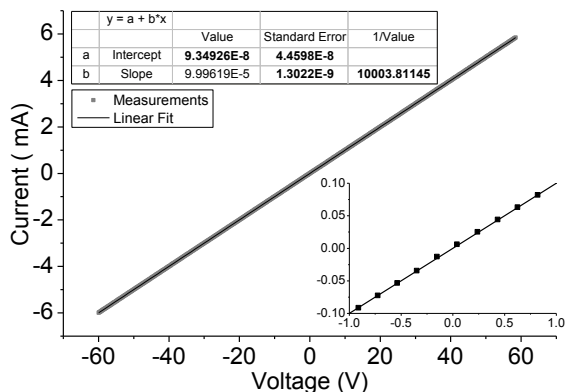


Fig. 6 Calibration verification on a 10 kΩ resistor.

The calibration may be verified as in Fig. 6, by biasing a known precise resistive load (here 10.00398 kΩ as measured with the Agilent 3458A) and plotting the V-I resultant curve (voltage step 195 mV and 8192 samples/point in Fig. 6). The linear fitting of the data unveils a current offset as low as 93.4 nA and resistance inaccuracy as low as 0.17 Ω.

4. DEVICE OPERATION

The output voltage of the device during an indicative operation cycle is presented in Fig. 7. This cycle is fully preset by the user. Namely:

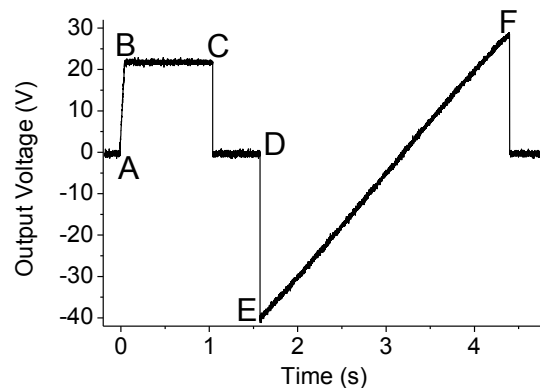


Fig. 7 Output voltage of the device during an indicative operation cycle.

- Cleaning of the probe surface for 1 s at 40 mW. In general, the user can set the cleaning voltage, current or power. "A" is the beginning point of the voltage which increases up to "B" where the preset power is reached.
- Cooling phase for 0.5 s (part C-D).
- Biasing of the probe between -40 V and +30 V (part E-F) with a reference-voltage resolution of 10 bits, i.e. output voltage step of about 195 mV. At every plotted point, 256 samples are averaged.

5. TEST IN PLASMA ENVIRONMENT

The final stage of the present work is the probe test in a real plasma environment. The experimental setup used is the multi-dipolar ECR negative ion H⁻ source "Prometheus I" [4].

A home-made single cylindrical (Γ -shaped tungsten 0.25 mm in diameter) electrostatic probe is housed in a telescopic configuration of alumina/quartz [5]. 15 mm of the tungsten wire

is exposed to the bulk plasma at the center of the source (here 20 mTorr and 600 W at 2.45 GHz).

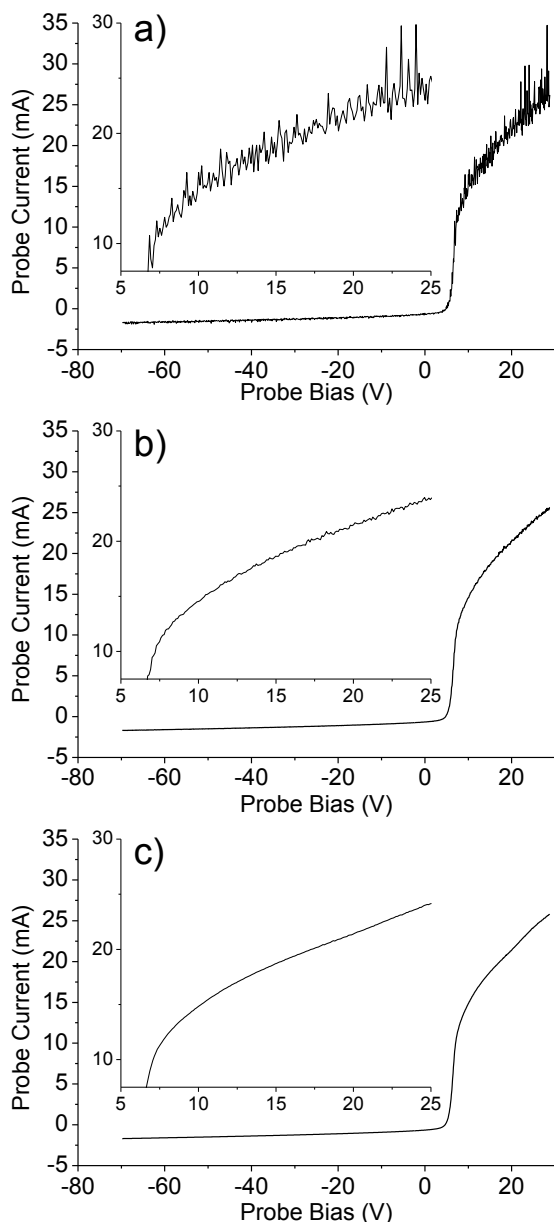


Fig. 9 Langmuir curves obtained in "Prometheus I" with different averaging: a) 1 sample/point, b) 256 samples/point, and c) 4096 samples/point. Selected bias step 97.5 mV. The insets focus on the electronic-current part of the curves.

Indicative V-I curves obtained with the present system in "Prometheus I" are depicted in Fig. 9a to 9c, where the high rejection of the "plasma noise" by means of embedded averaging in the microcontroller is clearly demonstrated. The corresponding elapsed time for tracing each curve is 1.45 s, 8.04 s, and 120.06 s, respectively.

6. CONCLUSIONS

In this work, an automated electrostatic probe system was designed and fabricated. The basic modules were presented and their operation was explained. Finally, the system was calibrated and used in a real plasma environment, proving its functionality. This effort produced a low-cost solution with a system which is also versatile, highly customizable, and accurate for electrostatic probe measurements. The full design details of the present system are available by the High Voltage Laboratory of the University of Patras, Greece, through provision services to whom it may concern.

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