Ultra High Gain, Low Noise IVC Amplifier for Scientific Instrumentation Applications

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Abstract **– In this work, a very required measurement application in scientific instrumentation is presented, a current-voltage converter-IVC with ultra high gain and low noise. The circuit was designed based on transimpedance amplifier, in addition for providing special features, low power consumption and offset voltage cancellation. Due to the very high performance it has been incorporated at a characterization system for work function analysis. The proposed approach does not require additional expensive equipment's and it is very accurate and simple to use. Experimental results of its operation highlighting some performance characteristics are presented.**

Keywords— **Current-Voltage Converter, scientific instrumentation, low noise measurement, , ultra-high gain amplifier, sample characterization.**

I. INTRODUCTION

Instruments that need to determine the quantity of electrons expressed by currents of the order of picoamperes need a suitable infrastructure and equipment. With the emergence of new material analysis techniques, a better matching between setup and associated instrumentation performance to characterize such materials is required. In the study of materials with potential applications at electronics industry an important parameter is the work function (ϕ)[1,2]. It represents a great challenge and opportunity with application in micro and nanoelectronics, solar cells, sensors, energy storage and displays.

In view of that, this paper describes an application of an ultra high gain and low noise of current-voltage converter with performance to sense and measure events of ultra low scale. This instrumentation was incorporated into a new system for work function analysis as described in next sections.

II. IMPLEMENTATION

Targeting to solve the cost and complex measurement difficulties it is implemented a custom made transimpedance amplifier with a gain of 10^8[V/A], 160 dB, and estimated noise level of 0.5 pA/√Hz over a bandwidth from DC until about 500Hz. This performance is achieved using few components, and minimizing the parasitic and external influence on the proposed circuit. In the context in which this IVC amplifier was implemented, the current measurements were used to analysis the work function of materials in a system based on the Field Emission Retarding Potential Method - FERP [3] based in our experience obtained at an instrument dedicated to measure field emission behavior in thin films under vacuum[4].

A. Instrumentation Application

Fundamentally, the amplifier circuit is responsible for converting into voltage the current caused by the electrons which are emitted from the material under analysis as shown in the Fig. 1.

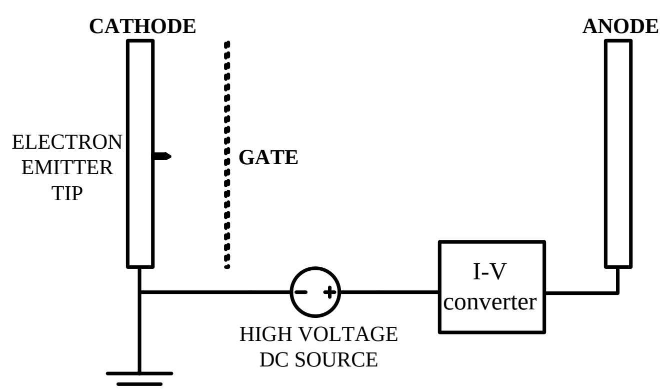

Fig. 1- The FERP setup. Electrons are emitted from the cathode via field emission through a DC voltage that provides large enough to generate electric field. The gate consists of a metallic grid that allows a fraction of the electrons to pass through. I-V converter is used to control the detectable current and as instrumentation equipment. All parts are inserted in a low vacuum environment.

Due to the conditions of the experiment, the measured current is in the order of picoamperes, requiring instrumentation that provides IVC under high gain and low noise. The circuitry is supply by batteries in order to avoid ground loops when incorporated to FERP system. Decoupling power supply from the rest of the system improves the precision of measuring. If the circuit for current measuring is connected to the same reference (ground level) of system, the error in the latter affects the determination of collected current. However, the drawback of decoupling power supply and current measured is that variations in the ground level in either circuits lead to fluctuations of the emission from the emitter and thus to variations of the collected current. These characteristics of the amplifier circuit are advantages comparing with picoammeter from Keithley 6514 that introduced 60 [Hz] and harmonics noises in the range of pA to nA in our systems.

B. IVC amplifier circuit

The Fig. 2 shows simplified diagram of implemented circuit for IVC amplifier.

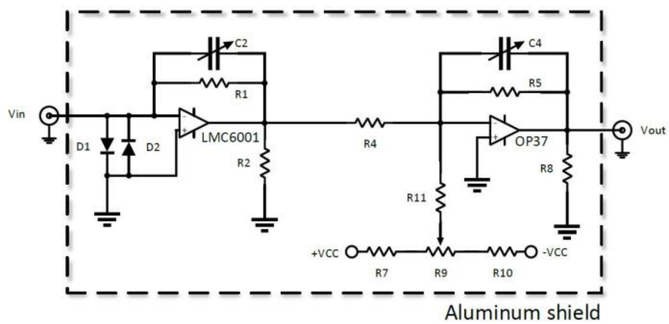

Fig. 2 - IVC amplifier circuit implemented in two stages.

The circuit is composed of two amp. op stages: a transimpedance amplifier with gain set at 10^8 V/A, or 160dB, and an additional output buffer circuit inserted also to null the offset voltage by an external knob adjust. To the buffer was used an OP37 and a LMC6001 like transimpedance due to its extremely low noise current of 22 nV/$\sqrt{}$Hz characteristic's that allows almost noiseless amplification when submitted to high gains.

The extremely high input resistance, and low power consumption, makes it ideal for applications that require decoupled power supply battery-powered instrumentation amplifiers as required for performing work function measurements as described in the previous section. As result of that the operational amplifier chosen is ideally suited for scientific instrumentations that require ultra-low input leakage such as: electrometers, leakage and ion detector, etc.

C. Special assembly

Although the LMC6001 is highly stable over a wide range of operating conditions, it is necessary to approach certain precautions to achieve the desired response when inserted to FERP systems. Large feedback resistors with even small values of input capacitance due to printed-circuit-board and connection parasitics can make the implementation of IVC amplifier is unfeasible.

It is generally recognized that any circuit which must operate with less than 1 nA of leakage current requires special layout of the PCB. As it is required to take advantage of the ultra-low bias current of the LMC6001, it is essential to have an excellent layout. In doing so, it was chosen to make the circuit connections without PCB, where all elements of the circuits are floating inside the box that places them. Another important point to consider is the existence of electromagnetic interference mostly due to the pumping system, to ensure a low vacuum environment and some instruments do setup operate at high voltage.

In face of that, the IVC amplifier was implemented in a grounded metal case as showed in Fig. 3 top, and it is plugged direct at top of the high vacuum chamber, close to the sample assembly and retarding potential circuit, as shown at Fig.3 botton. The pin 2 (inverting amp.op input) was solded directly at SMA input connector without contact with other parts of circuit. It neutralizes the parallel resistance from PCB at the feedback resistor of 100MΩ. The circuit is supplied by batteries with high stable voltage regulators and filters. An external offset null knob with resolution of 0,05mV is present at the amplifier box.

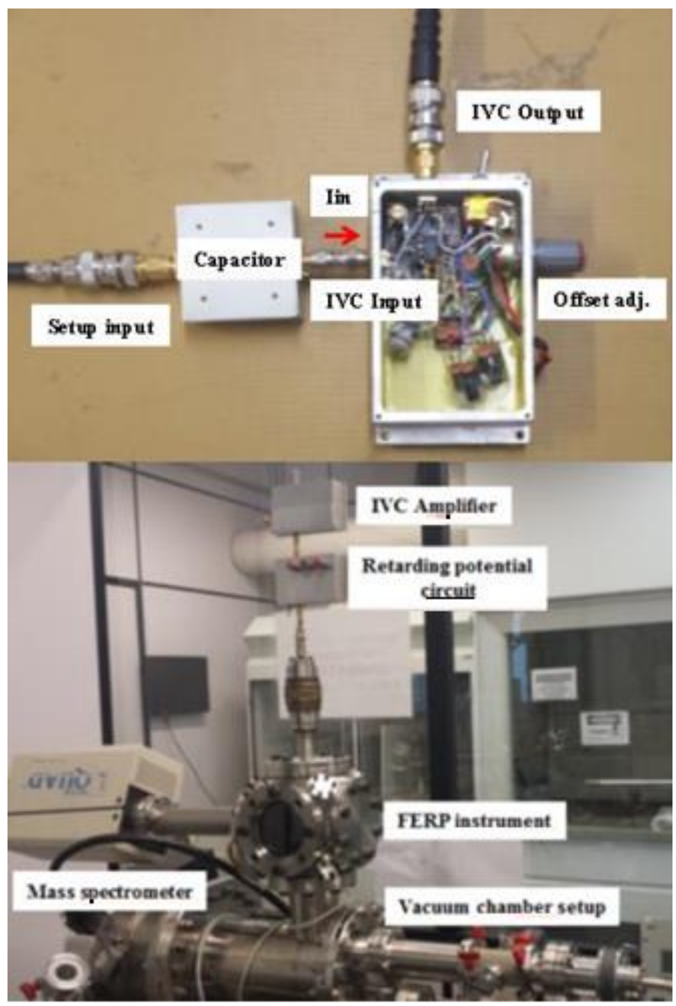

Fig. 3 - Picture of the IVC amplifier placed in to special case (top). The IVC amplifier is connected to FERP system to measure electrons emitted (botton).

III. RESULTS

The system proposed in this work was characterized as setup presented in the Fig. 4. The excitation source provides a frequency variable sinusoidal signal applied to a ceramic 1nF

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capacitor. The current is measured using the designed IVC amplifier or the Keithley 6514 Electrometer, or simply K6514, our commercial reference.

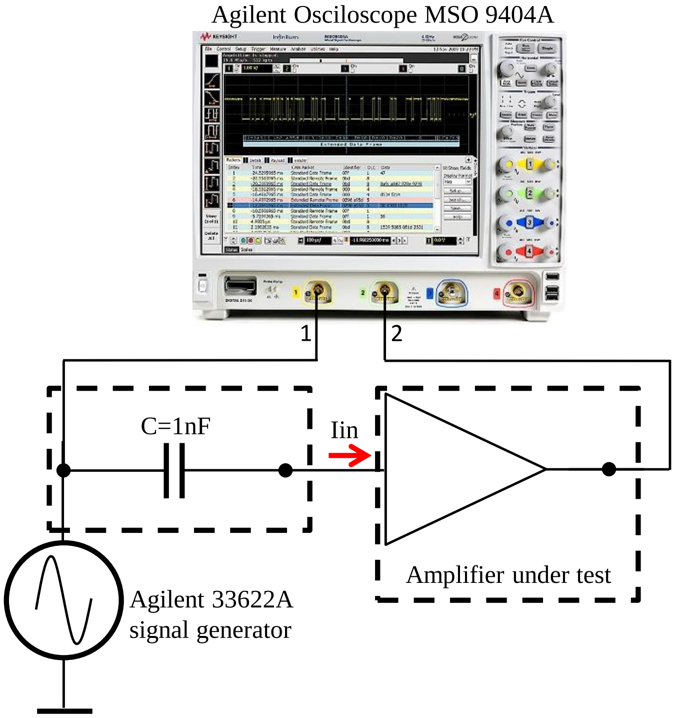

Fig. 4 - Set up used to characterization the amplifiers, IVC and the commercial Keithley 6514 electrometer at dashed box, amplifier under test.

The signals from Agilent 33622A signal generator and the amplifiers were collected with a Keysight Oscilloscope MSO9404A. The current response of the amplifiers was scanned from 10Hz to 100 kHz with amplitude of 1mV applied at the capacitor. The output voltage behavior of both amplifiers in function of frequency can be observed at Fig.5 where is clear the linear response of the IVC until close of 400Hz (the range of interest at FERP instrument). After this frequency the gain decrease of 3dBu and the IVC lose the linearity compared with theoretical model. The K6514 shown decrease of voltage since the beginning of range, losing 10dBu only the first decade.

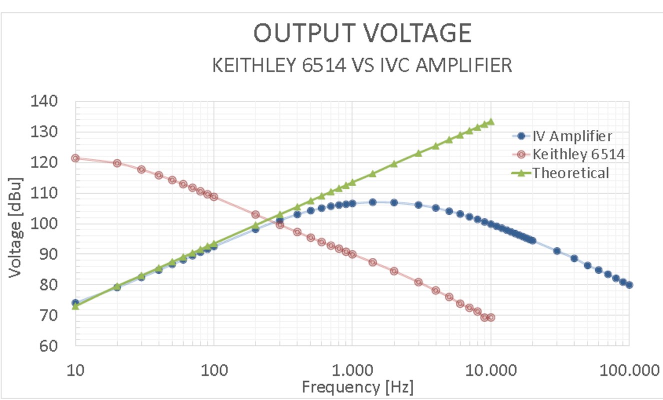

Fig. 5 - Comparison of Voltage output linearity response between the commercial instrument K6514 and IVC amplifier system proposed.

Other aspect is related with the gain linearity. The comparison between theorical expected current at the capacitor and the experimental from IVC amplifier response is shown in the Fig. 6.

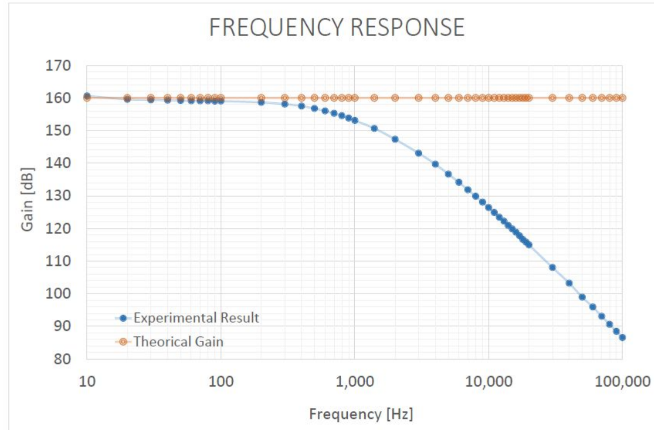

Fig. 6 - Comparison between theorical and experimental performance for the IVC amplifier circuit

The IVC amplifier gain behavior is stable at 160dB until 400Hz, cut-off frequency. A good agreement was observed between theoretical and experimental performance due to careful assembly eliminating big part of parasitic influence and external interference to the circuitry.

In order to characterize the noise performance, was used the same set up of the Fig.4, but removed the signal generator and connect the SMA capacitor input to the ground. The noise level was measured with the oscilloscope during 10 seconds where the average of amplitude level is about 50µVrms, it means 0.5pArms background noise current and the minimum value that can be measured is about 1 pA.

About K6514, in the operation manual, the noise level is about 0.750fA peak-peak measured with “capped” triaxial connector. The K6514 used has a 1 meter triaxial cable input with 3 crocodile clips. It introduces a high noise level (mainly 60 Hz and harmonic frequencies from environment) with 0.9 Vrms from the preamp analog output through oscilloscope and spectrum software. To performance this noise measurements an additional external aluminum shielding was prepared. After it, the level of 60 Hz noise drop to 16 mVrms. It is about 300 times (up to 50dB), noisier than the IVC amplifier, in other words, it means 150pA of background noise due the use of triaxial cable at K6514, at pA scale.

IV. CONCLUSION

It was demonstrated an IVC amplifier circuit applied to scientific instrumentation that provides ultra-high gain, about 160dB and low noise, about 0.5pA. This circuit has proven suitable for instrumentation applications that operate under critical conditions of ultra-low input leakage and EMI.

The IVC performance exceeded the expectations and can be used to measure currents from 1pA until 50nA with a bandwidth about 400Hz, enough to the FERP experiments. Also, the hardware assembly the IVC amplifier connected directly at the application, without a coaxial input cable, avoid introduction of noise signal at the measurements. This is the right strategy to sub nA measurements.

Finally, the construction cost is about of \$30.00 including the SMA connectors and aluminum metallic case, is extremely affordable especially when many amplifiers is necessary at to monitoring the experiments.

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VI. Acknowledgement

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