Journal of Physics: Conference Series

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IOP Conf. Series: Journal of Physics: Conf. Series **792** (2017) 012084 doi:10.1088/1742-6596/792/1/012084

Design of an electronic system for acquisition of the tunneling current signal of a Scanning Tunneling Microscope STM

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Abstract. An electronic system was designed to acquire tunneling current of a Scanning Tunneling Microscope. A tunneling current originates from the interaction between a conductive tip and a conductive or semiconductor sample. Lower currents than 100 nA were generated and from them, voltages were obtained in the order of 1 volt. Using this mechanism, it is possible to construct images of the atoms positions on the surface of the sample, also other properties of the materials can be studied.

1. Introduction.

The scanning tunneling microscope STM is a device for imaging surfaces at scale atomic level [1]. The scanning tunneling microscope was developed in 1981 by researchers at IBM in Switzerland and winners of the Nobel Prize in physics Gerd Binnig and Heinrich Rohrer [2]. A scanning tunneling microscope is a useful tool for research in different fields such as nanoelectronics, nanomaterials, biotechnology, and nanorobotics, among others [3]. The specific results of the STM implementation and research include the following achievements: analysis of transistor surface oxide [4], identification through images of quantum dots in diodes [5], Atomic reduction of voltage bias on a controller [6], characterization of interface of MOS devices [7] and modulated hole with semiconductor [8].

2. Theory.

Tunnel effect refers to the phenomenon of quantum mechanics in which an electron has a probability of passing through a potential barrier with a height greater than the energy of the electron [9]. In the scanning tunneling microscope (STM), tunneling current, as well as the potential barrier height, also depends on the ratio of the electronic filling levels on each side of the barrier, the filling levels are referenced Fermi level, material work function ϕ, and polarization voltage V.
The value of tunneling current depends on the distance between the sample and the tip of the microscope, it can be expressed as

$$I_t = k\, e\, V\, exp(-2\frac{\sqrt{2m\phi}}{\hbar}d)\,, \tag{1}$$

where V is the applied voltage, $\hbar = \frac{h}{2\pi}$, m is the electron mass, e is the electron charge, ϕ is the effective potential barrier, d is the effective wide barrier and k is a constant of proportionality. A Scanning

Tunneling Microscope STM is composed of various mechanical and electronic devices. This instrument operates in two different modes: constant-height mode and constant-current mode. In constant-current mode, a feedback controller adjusts the height of the probe to keep the current constant [10]. In constant-height mode, the tip travels in a horizontal plane above sample while the current changes depending on the local topography of the sample [11].

3. Implementation.

The next elements were used for creating a current of the order of 10-100 nA, followed by the conditioning of this current to voltages of the order of 1 volt: current source, transimpedance amplifier TIA which converts the current signal to a voltage, logarithmic amplifier which linearizes the response of transducers with exponential response, conditioning amplifier which adjust gain and analog-digital which converter an analog signal to digital values. Figure 1 shows the elements used in this project and his connections. In the left part of the figure are observed the lumped elements that generate and transform the virtual current into a voltage signal, whereas in the right part are showed embedded systems which convert the analogous voltage signal to digital. Digital signal allows integrating to a software. In table 1, commercial references of the devices used in the different stages are given.

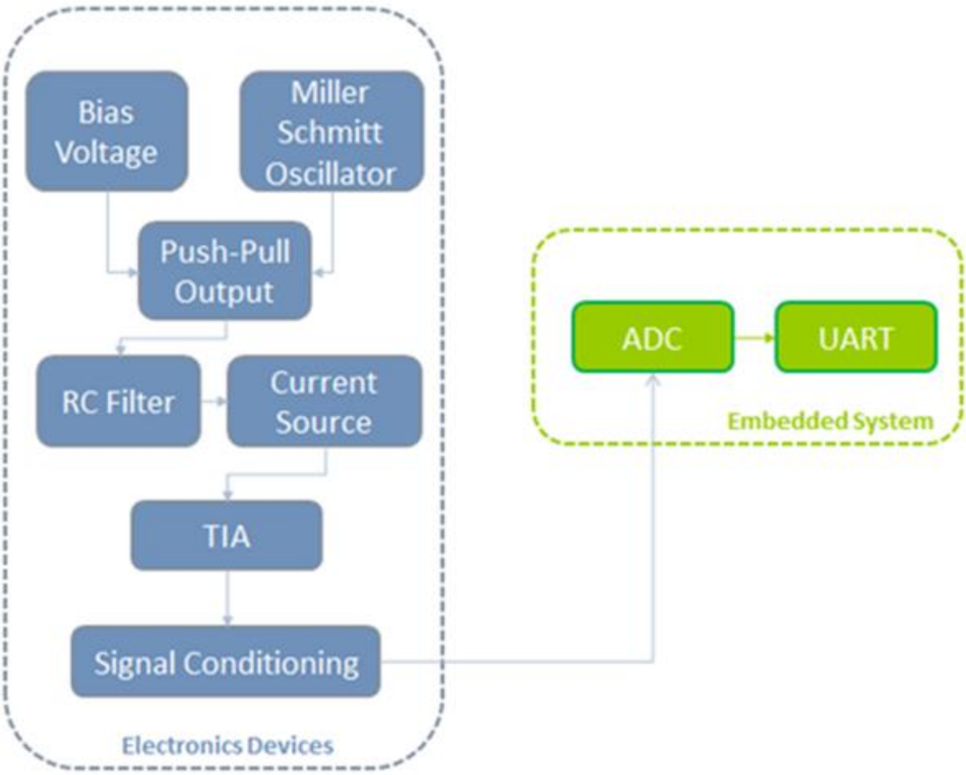

Figure 1. Electronic acquisition stage of the current tunnel signal and treatment [15].

Those operational amplifiers are characterized by a high precision, very low bias current, low noise, low offset voltage (on the order of the μV) and high open-loop gain (on the order of the nA and pA).

Table 1. Precision operational amplifiers

Stage	Reference
Bias voltage	OPA129U
Miller-Schmitt oscillator	LF353
Howland current source	OPA2277U
Transimpedance amplifier TIA	LF353 or OPA129U
Voltage follower	OPA132
Inverter with DC level adjustment	LT1012S8

4. Results

Figure 2 shows the results obtained experimentally of direct current values, lower than 100 nA, that were transduced to voltages between 0 and 2 volts approximately with different two transimpedance amplifiers TIA: LF353 (blue dots) and OPA129U (red dots). A clear linear relation is observed between the current and the output voltage. Figure 3 shows the frequency response of the system with transimpedance amplifier TIA OPA129U, from which can be concluded that the system has a high-bandwidth.

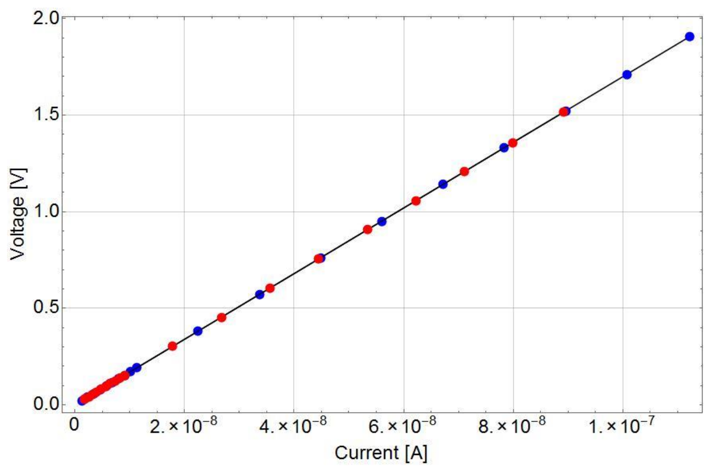

Figure 2. DC experimental analysis with transimpedance amplifier TIA LF353 (blue dots) and OPA129U (red dots).

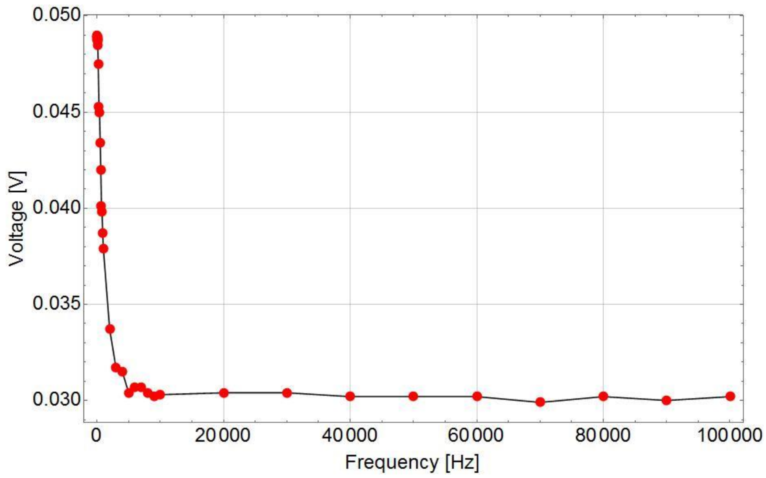

Figure 3. Frequency analysis with transimpedance amplifier TIA OPA129U.

Table 2. Mean values obtained for each stage

Stage	Mean Value
Bias voltage	10 mV
Miller-Schmitt oscillator	VOL=-13.5 V, VOH=14 V
Push-Pull output	60.812 mV
RC filter	10 mV
Howland current source	1 nA
Transimpedance amplifier TIA	20 mV
Inverter with DC level adjustment	20 mV8

5. Conclusions

Once it is designed an electronic system to transduce the tunneling current to suitable voltages, it is possible to continue the design of other elements of the microscope, such as the mechanical control device of the interaction of the tip with the sample and the software for generating images from digital signals.

6. Acknowledgements

This project is partially founded by Engineering Faculty of the Universidad Distrital Francisco José de Caldas de Bogotá, inside the Proyecto Curricular de Ingeniería Electrónica.

7. References

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