

Temperature Effects on Pseudo-resistor Analysis

Beatriz Barsocchi Testa
Electrical Engineering
Centro Universitário FEI
São Bernardo do Campo, Brazil
beatriz.testa@hotmail.com

Cleiton Fidelix Pereira
Electrical Engineering
Centro Universitário FEI
São Bernardo do Campo, Brazil
cleitonfp@fei.edu.br

Renato Camargo Giacomini
Electrical Engineering
Centro Universitário FEI
São Bernardo do Campo, Brazil
renato@fei.edu.br

Abstract— The aim of this work is to present the results of experimental measures in the effective resistance of the pseudo-resistor at temperatures higher than the room temperature. This study was based on the RC constant in a testing circuit, through four different voltage levels (50 mV, 100 mV, 250 mV and 500 mV) along with eight temperature levels (from room temperature to a scale ranging from 30 to 60 degrees Celsius in 5-degree steps). The equivalent pseudo-resistance become lower as the temperature increases, reducing the RC time constant of the testing circuit.

Keywords—temperature, pseudo-resistor, RC constant.

I. INTRODUCTION

The pseudo-resistor was introduced by T. Delbruck [1] as an "adaptive element", used in a photoreceptor circuit with dynamic range input. Such an adaptive element is a resistor-like device, with its transistors biased in deeply sub-threshold region connected in an unusual way. It has a monotonic I-V relationship, and acts as a pair of diodes, in parallel, with opposite polarity [2]. As the transistor gates are not biased with fixed voltages, the effective resistance is huge for small signals and small for large signals.

A. Basic Operation of the Pseudo-resistor

The pseudo-resistor shown in this paper consists in an active resistor implemented in CMOS technology, characterized by transistors connected in an unusual way. As the transistor gates are not biased with fixed voltages, the effective resistance of the pseudo-resistor is huge for small signals and small for large signals, as can be seen in its characteristic curve demonstrated by Fig. 1.

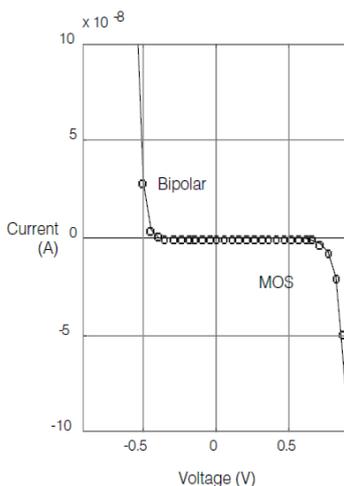


Fig. 1. Example of characteristic curve of the adaptive element.

At PMOS configuration, the transistors body is connected to the source and the gate to the drain, leading the circuit to act as a PMOS diode for positive VGS and a BJT diode for negative VGS. In order to achieve a symmetrical behavior for both positive and negative bias, two devices can be connected in a back-to-back configuration.

B. Performance

The pseudo-resistor (adaptive element) [1] has been widely used as a solution when very large time constants and a reduced active die area are required, as low pass filter, ac coupling, common mode feedback, ultrasonic transducers [3] and bioelectric signal acquisition [4]–[7].

However, pseudo-resistor behavior, besides been highly dependent of process and voltage, also suffers with distortions when subjected to temperature levels greater than room temperature (approximately 27 degrees Celsius). To do so, the characterization methodology proposed in [8] was used. The temperature dependency of the pseudo-resistor effective resistance will be shown experimentally, providing a relevant data so that the PVT compensation circuits (voltage, process and temperature variations) can be designed.

This paper is organized as follows: In section II, the methodology used to acquire and analyze the extracted data from the pseudo-resistor will be described. Section III shows experimental results and treated signals obtained in proposed study.

II. METHODOLOGY

To acquire data on the effective resistance of the pseudo-resistor, two main steps were required to ensure accuracy: the experimental acquisition of data and its treatment. Both will be described below.

A. Signal acquisition

In order to acquire the data of the effective resistance of the pseudo-resistor, it was necessary to develop a prototype for temperature control that supports the interconnected encapsulated circuit in a protoboard, since the available equipments carries out temperature measurements only in integrated circuits (ICs) rather than in encapsulated components.

To do so, a wooden box, partly covered with a metal plate and a heating resistor, was built, and as a tool for temperature control, a Digital Thermostat was coupled to the box. Once the desired temperature is reached, a relay is triggered, causing the system temperature to drop back into the set range, and triggered again soon after, maintaining the temperature inside the box constant. The prototype described above can be seen as the box presented in the right side of Fig.2.

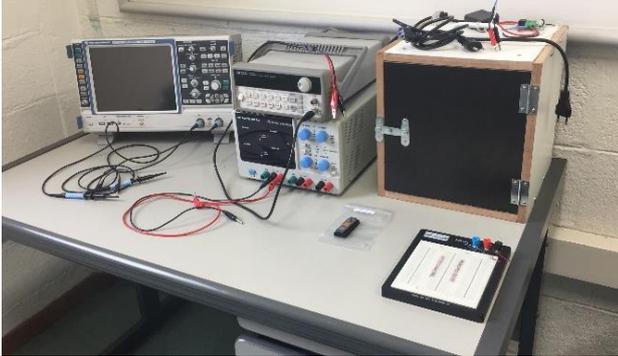


Fig. 2. Equipment used to perform pseudo-resistor measurements.

In addition, was also provided a function generator (upper middle), used to set the desired input frequency and voltage, a source (lower middle) for powering the circuit, and finally an oscilloscope (on the left) for measure acquirement. All described can be seen in Fig.2.

Having set all the necessary equipment, the connections were made according to the test circuit shown in Fig. 3.

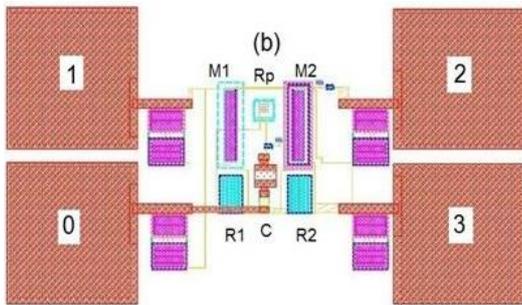
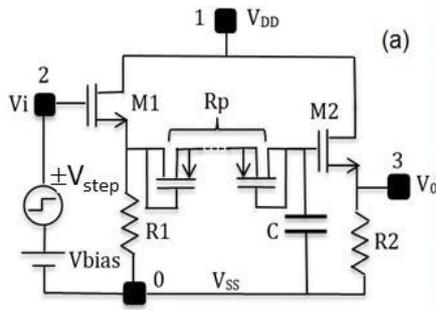


Fig. 3. (a) Pseudo-resistor evaluation circuit, (b) Implemented layout.

The circuit was powered by the source with 2.5V, while the pseudo-resistor with 1.4V. Such values were chosen due to the amplifier polarization, allowing the variation of the input signal (and consequently the output) for positive and negative voltages, from the polarization point.

First, the data were acquired at peak-to-peak voltages of 50 mV, 100 mV, 250 mV and 500 mV at room temperature (approximately 27 degrees Celsius). With the four waveforms saved separately in ASCII format (*.csv), the same procedure was repeated for each temperature, from 30 to 60 degrees Celsius, with 5-degree steps. Fig. 4 shows an example of screen generated by the oscilloscope in one of the measurements performed, showing both the input and output waveforms of the circuit.

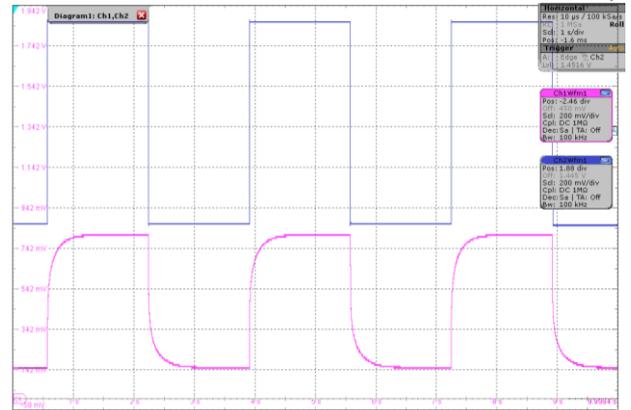


Fig. 4. Input and output pseudo-resistor waves comparison.

The channel represented by the superior wave corresponds to the input wave, which is composed of a sum of the input voltage, generated by the source, in the pseudo-resistor with one of the four analysis voltages and the frequency, provided by the function generator, that best fits visually in the rise time of the capacitor. The channel represented by the inferior wave corresponds to the wave resulting from the output of the pseudo-resistor. Unlike the previous one, it does not have the characteristic shape of a square wave, demonstrating the charging and discharging time of the internal capacitor connected to the testing circuit. From there, the resistance value of the pseudo-resistor was extracted from the methodology presented in [8], that will be discussed in the next section.

B. Data Analysis

The characterization methodology [8] proposes the use of a test circuit, composed of a low pass RC filter, along with two source follow amplifiers, which can be seen in Fig. 3a. In addition, the low-frequency filter consists of two pairs of parallel-connected pseudo-resistors (R_p), a built-in capacitor (C) and the M_2 port capacitance, and the source followers provide functional isolation, that avoid direct contact of the high impedance circuit with the electrodes and the external environment. Fig. 3b shows the layout used for experimental implementation in the Global Foundries technology (0.13 μ m).

To obtain the equivalent resistance for a voltage variation, the R_p resistance can be considered as constant in a small-time interval, where the resistance dependency with the bias can be neglected. For each small range of time (Δt), the R_p can be calculated using (1). This range (Δt) is defined by $V_{ci}(t)$, output voltage at the beginning of the range, and $V_{ci+1}(t)$, voltage at the end, that extracted from waveform measured at output (V_o).

The used formula and its graphic are shown in Fig.5, generating the result that is shown in Fig. 6.

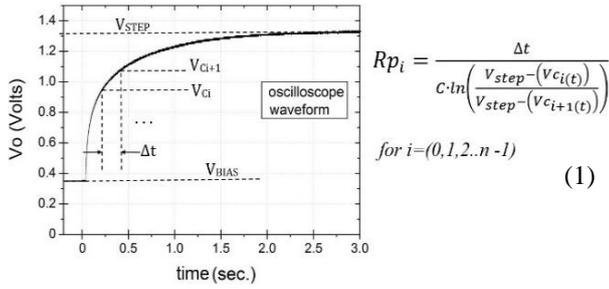


Fig. 5. Example of an experimental waveform used for equivalent resistance analysis.

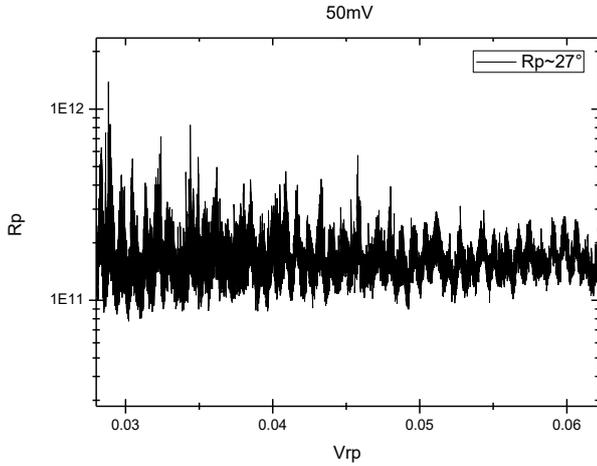


Fig. 6. Example of the average effective resistance graphic.

III. EXPERIMENTAL RESULTS

To evaluate the RC constant behavior with the temperature variation, the experimental responses of the circuit characterization shown in Fig. 4 were analyzed and smoothed by a percentage filter in Origin8 software. They are shown, divided by voltages steps 50 mV (Fig. 7), 100 mV (Fig. 8), 250 mV (Fig. 9) and 500 mV (Fig. 10), so that it becomes possible to perform the analysis of both the linear and non-linear behavior of the pseudo-resistor, and characterized by temperature. With the results showed, it is possible to observe that as the temperature gets higher, the equivalent resistance of the pseudo-resistor become lower.

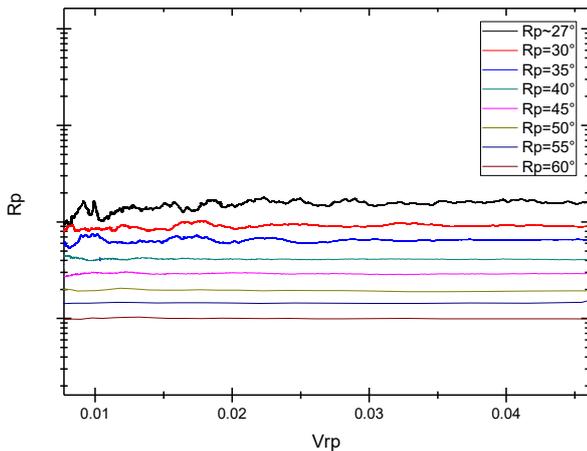


Fig. 7. Pseudo-resistor equivalent resistance curves for 50mV.

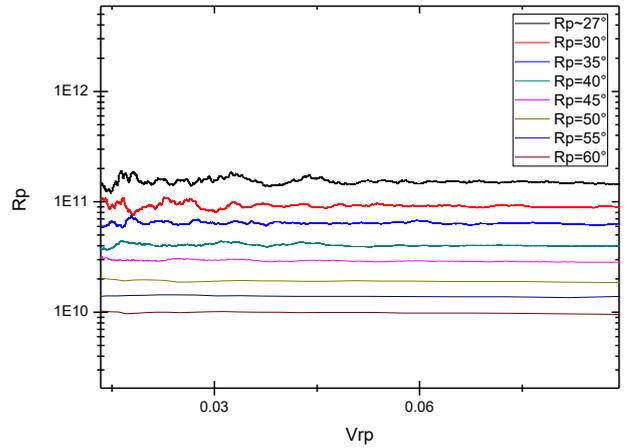


Fig. 8. Pseudo-resistor equivalent resistance curves for 100mV.

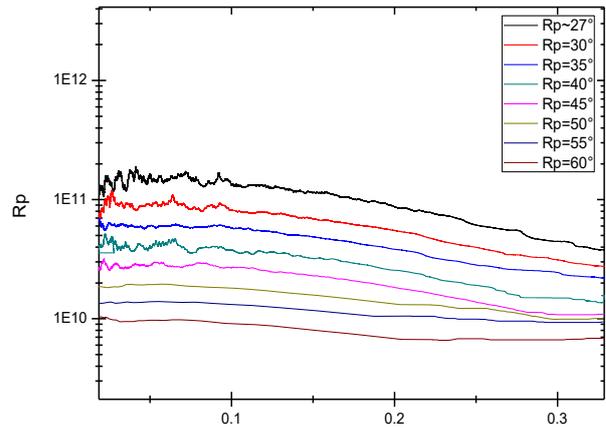


Fig. 9. Pseudo-resistor equivalent resistance curves for 250mV.

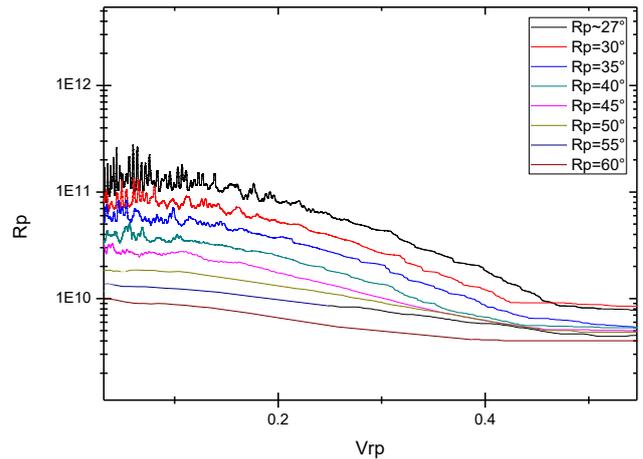


Fig. 10. Pseudo-resistor equivalent resistance curves for 500mV.

As can be seen in Fig. 10, for a temperature increase of approximately 30 degrees Celsius the equivalent pseudo-resistance falls almost one order in its value. The resistance decrease showed can be harmful for the performance of any circuit that use pseudo-resistors. Therefore, the resistance variation must be predicted during the project design and balanced by a compensation circuit, so that any project which uses pseudo-resistor technology is not harmed by temperature at the environment it lies.

CONCLUSION

The aim of this work was to present the results of experimental measures in the effective resistance of the pseudo-resistor from room temperature to a scale ranging from 30 to 60 degrees Celsius in 5-degree steps, along with four different voltage levels: 50 mV, 100 mV, 250 mV and 500 mV. After an analysis based on the RC constant in a testing circuit, it was shown that the equivalent pseudo-resistance become lower as the temperature increases, reducing the RC time constant of the testing circuit. Therefore, during the project design of any circuit, the resistance variation must be predicted and corrected by a compensation circuit, avoiding that circuits with this technology present different characteristics.

ACKNOWLEDGMENT

The authors would like to thank to MOSIS Educational Program (MEP) and the financial support provided by Brazilian research agencies CAPES and CNPq. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

REFERENCES

- [1] T. Delbrück and C. A. Mead, "Analog VLSI adaptive, logarithmic wide-dynamic-range photoreceptor" in Proc. IEEE Int. Symp. Circuits and Systems, vol. 4, 1994, pp. 339–342.
- [2] R. R. Harrison and C. Charles, "A Low-Power, Low-Noise CMOS Amplifier for Neural Recording Applications", IEEE Journal of Solid State Circuits, Vol. 38, No. 6, pp. 958-965, Jun. 2003. I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
- [3] S. Y. Peng, M. S. Qureshi, P. E. Hasler, A. Basu, e F. L. Degertekin, "A charge-based low-power high-SNR capacitive sensing interface circuit", IEEE Trans. Circuits Syst. I Regul. Pap., vol. 55, n° 7, p. 1863–1872, 2008.
- [4] C. F. Pereira, P. L. Benko, J. C. Lucchi, e R. C. Giacomini, "Teraohm pseudo-resistor experimental characterization aiming at implementation of bio-amplifiers", in 2016 31st Symposium on Microelectronics Technology and Devices (SBMicro), 2016, p. 1–4.
- [5] C. F. Pereira, P. L. Benko, M. Galeti, J. C. Lucchi, e R. C. Giacomini, "Experimental study and modeling of pseudo-resistor's non-linearity", in 2017 32nd Symposium on Microelectronics Technology and Devices (SBMicro), 2017, p. 1–4.
- [6] P. L. Benko, M. Galeti, C. F. Pereira, J. C. Lucchi, e R. C. Giacomini, "Bio-amplifier based on MOS bipolar pseudo-resistors: A new approach using its non-linear characteristic", J. Integr. Circuits Syst., vol. 11, n° 2, p. 132–139, 2016.
- [7] C. F. Pereira, P. L. Benko, J. C. Lucchi, e R. C. Giacomini, "Transitory recovery time of bio-potential amplifiers that include CMOS pseudo-resistors", 2014 Int. Caribb. Conf. Devices, Circuits Syst. ICCDCS 2014 - Conf. Proc., p. 5–9, 2014.
- [8] P. L. Benko, M. Galeti, C. F. Pereira, J. C. Lucchi, e R. Giacomini, "Innovative approach for electrical characterisation of pseudo-resistors", Electron. Lett., vol. 52, n° 25, p. 2031–2032, 2016.