

Fpaa-Based Virtual Instrumentation Laboratory With Remote Access

José del Carmen Peña Fernández¹, José del Carmen Santiago Guevara², Rafael Chacon Rugeles³

¹Universidad de Pamplona – Colombia <https://orcid.org/0000-0001-8249-0071>

²Universidad de Pamplona – Colombia <https://orcid.org/0000-0002-4792-453X>

³Universidad Nacional Experimental del Táchira - Venezuela

Abstract

The virtual instrumentation laboratory based on FPAA with remote access, is a system that allows increasing the knowledge of configurable analog modules FPAA (Field Programmable Analog Array), in the function of conditioning the signal of a physical variable, which can offer a dynamic re-configuration, is an important electronic design tool in prototyping when developing an electronic system; and if it can also be accessed remotely for a more versatile performance.

Keywords: Configurable Analog, Prototyping, Signal Conditioning Modules.

1. Introduction

The “Virtual instrumentation laboratory based on FPAA with remote access” has great importance in developing knowledge in engineering, which focuses on the professional profiles of electronic engineers in training and seeks to improve the social relevance of each of the programs in electronic engineering of the different Colombo-Venezuelan higher education institutions, because these engineers require greater professional competence to make an impact on the regional society and on the academic development that is reflected in the high-quality accreditations of undergraduate and postgraduate; the research brings an added value in the high-quality evaluations of the Master's program in Electronic Engineering at the Universidad Experimental del Táchira (UNET).

1.1 Problem statement

Remote access virtual laboratories are a new concept in the teaching-learning processes, specifically in electronic engineering, where the use of electronic devices that are difficult to obtain and expensive is becoming widespread, although there are different works on remote

laboratories in basic areas. In some cases, there is no research in more specialized areas of the profiles and lines of deepening in electronic engineering.

Conditioning a signal from a transducer is a task that, in the case of sensors, requires more accurate systems. For this, using advanced analog electronics, it is possible to obtain values closer to physical variables in the work environment, before making any conversion to be presented to the human being.

Analog configurable modules are important because their treatment is analog (they receive and deliver an analog signal without conversions for processing), thus increasing the accuracy and speed of their treatment, but above all the design time.

Building a system that allows increases in the knowledge of analog configurable modules FPAA (Field Programmable Analog Array), in the function of conditioning the signal of a physical variable, which can offer a dynamic re-configuration, is an important electronic design tool in the prototyping when developing an electronic system, and if it can also be accessed remotely to analyze its performance, it will be more versatile.

1.2 Problem formulation

Currently, the design and implementation of electronic schemes in signal conditioning in sensors, based on operational amplifiers (OA), resistors and capacitors, generate unstable responses in the signals delivered by a transducer of a given physical variable. Therefore, it is necessary to use filters and signal amplifiers based on configurable analog modules (FPAA), ready to use several of their analog functions in the treatment of nonlinear responses.

The study proposes the development of a virtual instrumentation laboratory, focused on the signal conditioning of a sensor, with second-generation FPAA (AnadigmVortex) of dynamic reconfiguration, which is the maximum evolution in this area of electronics, thereby increasing the speed of response, accuracy and robustness to noise, and a data acquisition card to monitor their events once configured, through an intranet.

2. Objectives

2.1 General objective

Develop a virtual instrumentation laboratory, to compare the response obtained in the processing of the FPAA module in comparison with a module formed by operational amplifiers, which can be accessed remotely via web on an intranet.

2.2 Specific objectives

- Select the variable to be processed in the system, to be implemented in the virtual instrumentation laboratory.
- Obtain the mathematical model associated with the sensor signal conditioning system.

- Design a prototype of a virtual instrumentation laboratory in the area of electronic instrumentation, which can be accessed via web on an intranet.
- Validate the results using a statistical error package.

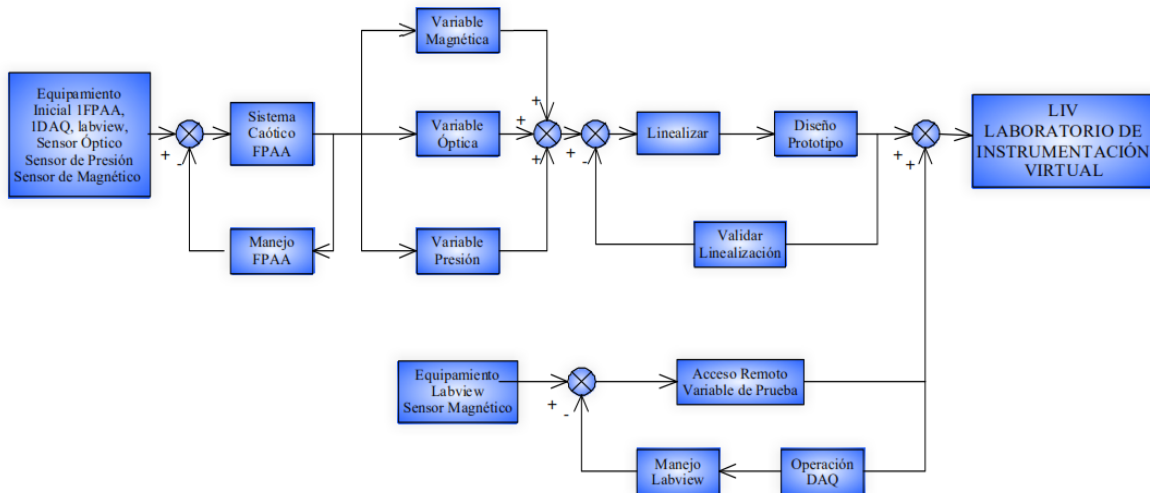


Figure 1. Methodology and Procedures. Made in UML. Diagrammer Trial Version.

3. Methodology and development

3.1 Research design

The methodology used to develop the virtual instrumentation laboratory based on FPAA with remote access is summarized in Figure 1. It starts with the procurement of three sensors of uncommon variables in the market, the importation of an FPAA development board from ANADIGM and Nacional Instrument products such as the Data Acquisition Board (DAQ) and the Labview and Workbench software. A methodology is implemented based on acquiring skills and good handling of these elements in sequential order, based on prototypes that serve the final objective. There are two parallel sequences in the proposed methodology, one is the handling of the FPAA until a selected variable is linearized according to the initial conditions, and in parallel, it offers the development of knowledge and skills in the control and monitoring of a variable through the DAQ and Labview software in server mode to achieve remote access.

3.2 Basic handling of the FPAA.

Two things are important in the basic handling of the FPAA, especially the AN221K04 development kit: knowing its connections and the software to program it. Therefore, it is advisable to follow the manual included in Annex 4.

When starting to use the board, it is important to use simple and very common applications such as a filter and an inverter.

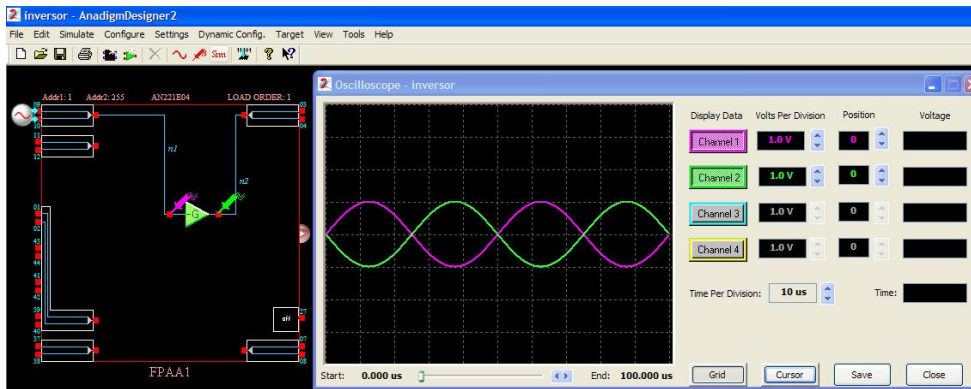


Figure 2. Inverter. Made in AnadigmDesigner 2 version 2006.

For the connections on the board, the input and output cells and the cell pins on which the programming is done must be taken into account; for example, if input cell 1 (InputCell 1) and output cell 1 (OutputCell 1) are programmed, then the board will look like this:

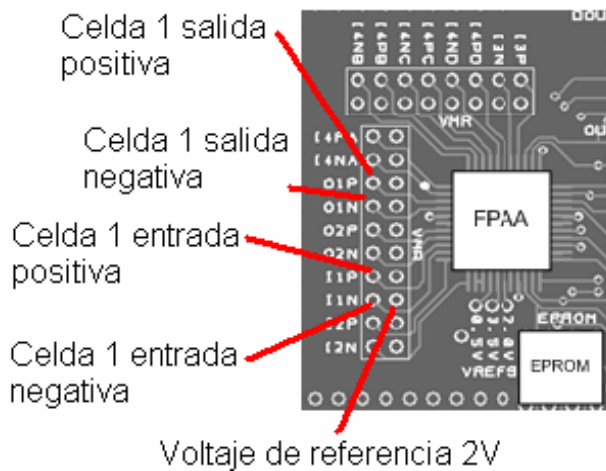


Figure 3. Connections on the board. Source: www.anadigm.com

AN221K04 AnadigmDesigner2 CARD
I1P InputCell1 contact 9
I1N InputCell1 contact 10
O1P OutputCell1 contact 3
O1N OutputCell1 contact 4

Table 1. The parallel between board pins and cells in AnadigmDesigner2.

As the outputs are differential, if the input is in common mode, the output after processing the input signal will be the same in OIP and OIN, only with reversed polarity.

3.3 Implementing a nonlinear system at the FPAA.

Understanding the difference between a linear and nonlinear system, in that it is not innovative to study linear electrical networks, as opposed to working with nonlinear elements (non-ideal) such as the resistor, capacitor and inductance and is currently studying a fourth element such as the memristor recently discovered (1971) by the electronic engineer Leon Chua, which has been taken as a basis for the study of chaos theory in engineering applications such as nano-electronics. For 37 years, it was a hypothetical device until April 2008 when a physical implementation was made.

It is important to demonstrate how FPAA can implement a nonlinear system and to understand that some of them can be linearized and others would have complex systems to understand them. This implementation would have an interesting effect in terms of interdisciplinarity and take sufficient skill in handling the FPAA with a view to the virtual instrumentation laboratory based on FPAA.

Since the early nineteenth century began to speak of nonlinear differential equations, but without the necessary tools to solve them, with the advent of computers in the seventies there are more approximations of nonlinear systems; in electronic engineering has been studying the Chua type circuit that is a model with nonlinear behavior.

Many applications relate chaos theory and electronics such as the case of switched converter control, chaos theory and the Gunn effect in p-type Ge, chaos theory in PWM control, chaos theory in microcontrollers, chaos theory in the search for unbreakable electronics, chaos theory and the hardware description language (VHDL), chaos theory in systems for hiding information, chaos theory in CDMA communications, etc.

Naturally, electronic engineering has been one of the disciplines that have done the most research in chaos theory. Virtually every electronic system uses oscillators. And self-oscillating systems have an essential nonlinearity, i.e., a linear approximation cannot be used to model them.

The implementation of the Chua type circuit in the FPAA is a challenge that in turn has as a complement to validate them with other tools such as Matlab.

The system of equations describing the Rossler system must be made known. Before bringing this system of differential equations to the AnadigmDesigner2 platform, the same system was developed in MATLAB-SIMULINK.

When talking about Rossler in chaos theory, what is emphasized is a type of attractor that represents a chaotic region, which is obtained or common at points outside the origin.

This type of attractor is common in Chua-type circuits, and the characteristic differential equations that describe it are the ones that are taken to the FPAA.

In the block diagram shown in Figure 3.4, it can be observed the process that was carried out for the characterization of the system in MATLAB - SIMULINK and in Anadigy - SIMULINK.

SIMULINK and AnadigmDesigner2.

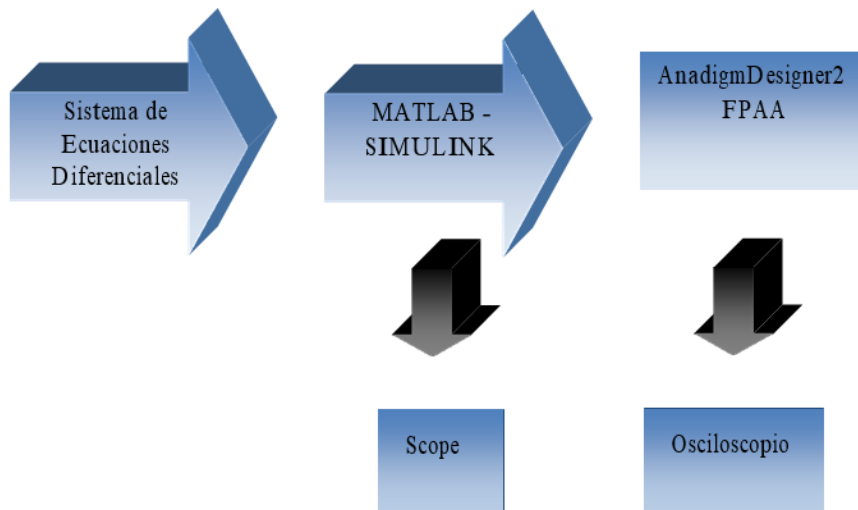


Figure 4. Block Diagram of the system characterization process Rossler in MATLAB - SIMULINK and AnadigmDesigner2.

3.4 Selecting a variable for laboratory development.

Three sensors will be studied and one of them will be instrumented in the laboratory according to its characteristics, starting with the magnetic sensor, then the pressure sensor and finally the optical sensor.

3.4.1 ZMX40M Sensor.

This device is a special tangential field difference tangential sensor with two AMR (anisotropic magneto-resistive) jumpers for ground motion or field measurements through comparative measurements.

The ZMX40M contains two extremely sensitive magnetic chips, mounted in parallel to each other in an SM8 package, which employ the magneto-resistive permalloy thin-film effect. It allows the measurement of fields or magnetism sensing parts. The sensors each consist of a chip covered with permalloy stripes, a chip covered with thin-film permalloy stripes forming a Wheatstone bridge, whose output voltage is proportional to the component of the magnetic field.

The chips are mounted in the package and are 3 mm apart. If a magnet travels horizontally over the sensor, each chip will give you an output that will reach its point as the magnet passes over it.

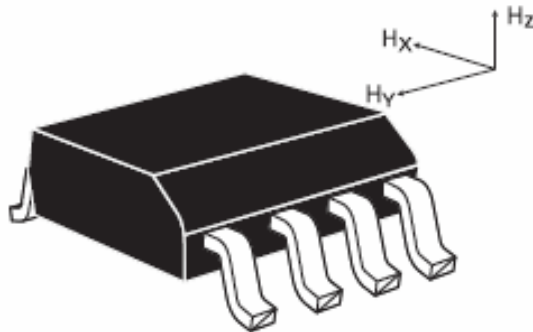


Figure 5 ZMX40M Sensor. Source:

http://www.nxp.com/acrobat_download/applicationnotes/AN00022_COMPASS.pdf

Characteristics

- H_y output voltage is proportional to the magnetic field across each chip.
- Both chips are in the same orientation and separated from the center 3 mm apart in the Y direction.
- The fields in H_x allow up to 30 kA/m.
- Extremely small chip distance from the top of the package for accurate measurement.
- Internal magnet of each chip for the creation of auxiliaries in the H_x field.

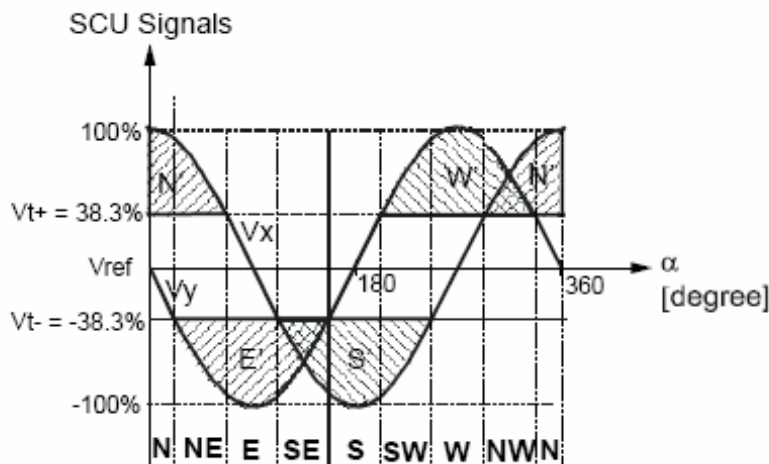


Figure 6. Outputs out of phase magnetic sensor arrangement. Source:

http://www.nxp.com/acrobat_download/applicationnotes/AN00022_COMPASS.pdf

AMR chip 1: supply voltage between +Vb1 and -Vb1, bridging output voltage between +Vout1 and -Vout1.

AMR 2 chip: supply voltage between +Vb2 and -Vb2, bridging output voltage between +Vout2 and -Vout2.

By implementing its linearization we obtain the following design.



Figure 7. Linearization of a magnetic field sensor.

The implementation, in this case, was limited because the development of the application can only be simulated, requiring three FPAA cards for assembly and testing.

3.4.2 Pressure sensor

It is a very versatile and accurate sensor with the characteristic of application as an altimeter, or barometer, its linearity in the operability values makes it unnecessary to perform conditioning in amplification, filtering, or linearization, as it would be impractical when using the FPAA.

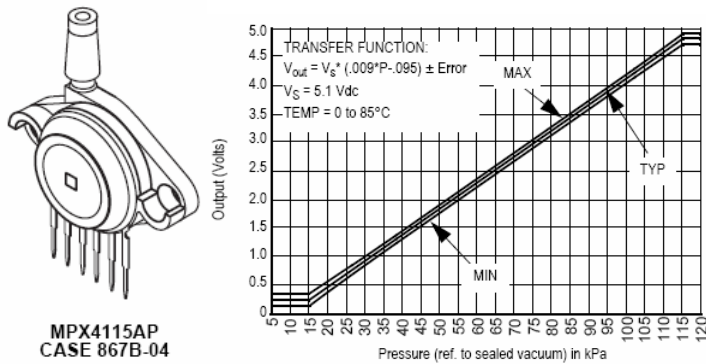


Figure 8. Pressure sensor MPX4115AP Motorola. Source:

http://www.freescale.com/files/sensors/doc/data_sheet/MPX4115A.pdf

3.4.3 Optical sensor.

Silicon photodiode 4 series pin

The device obtained for the implementation is a Silicon 4 series device, as shown in Figure 9.



Figure 9. Series 4 PIN silicon optical sensor.

3.5 Implement an instrumentation prototype with operational amplifiers and the FPAA.

3.5.1 prototype based on operational amplifiers.

The prototype of the optical power meter based on operational amplifiers is made in two stages, in the first one the coupling of the photodetector is made, because the function of the diode is to convert light into current, the diode is inversely polarized working in photovoltaic mode, the positive pin of the diode is connected to the non-inverting input of the operational amplifier, which affects a voltage, by the direct relation of current to voltage.

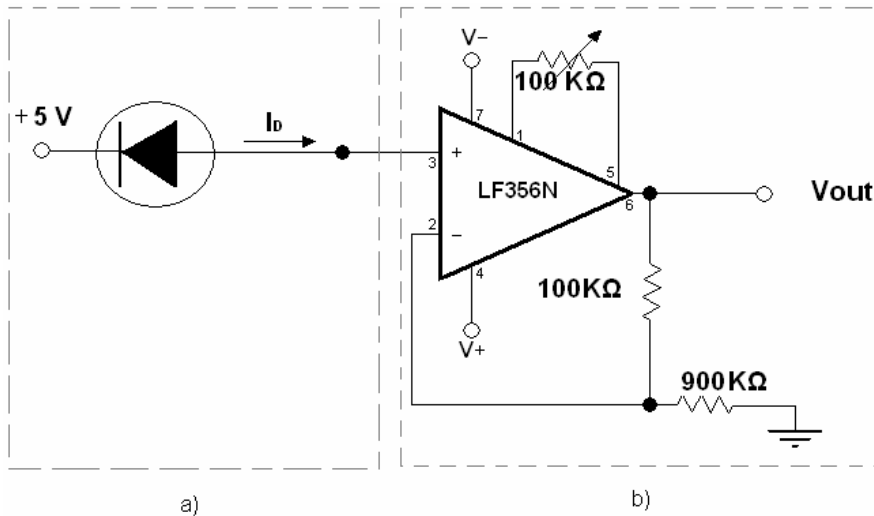


Figure 10. Optical power meter using the LF356N a) First stage, b) the Second stage.

Since the currents generated by the diode are on very small scales, the second stage is in charge of assigning a specific gain to the signal for further processing. For this gain, an amplification stage is used through the LF356N integrated, which has an operational amplifier and has the aforementioned characteristics. It uses a simple topology such as a non-inverter, which collects the input voltage, and enters the positive pin; it is known that the gain of the operational amplifier is very large, and the voltage on the positive pin is equal to the voltage on the negative pin, and the voltage on the negative pin can be calculated. The relationship between the output voltage and the input voltage is due to a small voltage divider.

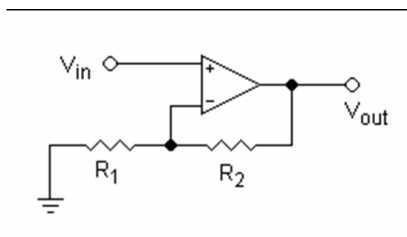


Figure 11. Non-inverting topology for operational amplifiers.

$$V_{out} = V_{in} (1 + R_2/R_1)$$

$$Z_{in} = \infty$$

3.5.1.1 Procedure

The topology used for the operational amplifier is NON-INVERTER, as explained in Figure 11.

$$V_{out} = V_{in} (1+900K\Omega/100K\Omega)$$

$$V_{out} = V_{in} (10);$$

$$V_{in} = V_{out}/10$$

Due to the amplification stage, the signal V_{out} can be measured with a multimeter and is obtained at V_{in} .

To find the power you must clear P de $R=I_D/P$ where I_D is the current produced by the photodiode.

$$P = I_D / R$$

For this design, a silicon photodiode type PIN series 4, from Silicon Sensor International AG, was used as a light sensing device. It has a spectral response of 400- 1100 nm and its Responsivity (R) is 0.38 A/W at 660 nm.

3.5.1.2 Results

With this design, the operation of the photodetector and the amplification stage is tested by measuring a signal and noting its sensitivity to light, which is the basis of the power meter. The problem of the design is not obtaining I_D , despite obtaining the voltage at the input of the amplifier, the necessary tools to find the current produced by the photodiode are not available.

For this design was used as a light sensor device, a silicon photodiode type PIN series 4, from Silicon Sensor International AG. It has a spectral response of 400-1100 nm and its Responsivity (R) is 0.38 A/W at 660 nm.

3.6 Prototypes based on FPAA

For the prototypes, the ANADIGM FPAA card with the AN221E04 chip is used. This card will be very useful for the implementation of the optical power meter. The design will require the same stages that were used in the previous prototypes; first, the conversion of current to voltage and then giving a gain to the signal to make it manageable.

The difference with the FPAA is to reduce these two stages, by designing the necessary inside a CAB and programming the card. In addition, the signal can be treated with functional blocks such as filters, peak detectors and other devices to improve the signal characteristics.

3.6.1 First prototype

The coupling stage between the photodetector and the FPAA is done directly, the photodetector is worked in photoconductive mode, as it is not polarized and is connected to the input pins inputcell1 of the FPAA.

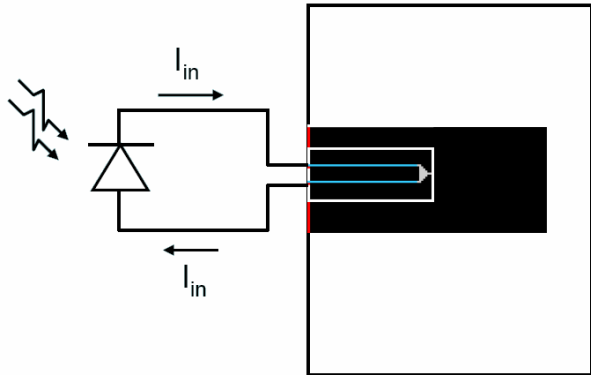


Figure 12. Coupling between the photodetector and the input cell number 1 of the FPAA

In the photoconductive mode, the diode is operated in the open circuit as seen in Figure 12. The generated electron-hole pairs separate and drift to opposite sides of the depletion layer. Since electrons are attracted to the n-side and holes to the p-side, an ifot photoinduced reverse current flows through the diode from the n-side to the p-side. the effect of this behavior is that the energy barrier is reduced for its equilibrium value. Now, more majority carriers can cross the junction, that is, holes cross from p to n and electrons cross from n to p, creating a direct current through the diode.

The input cell is configured in differential mode and no device is applied, this is so as not to alter the input signal and make the required changes.

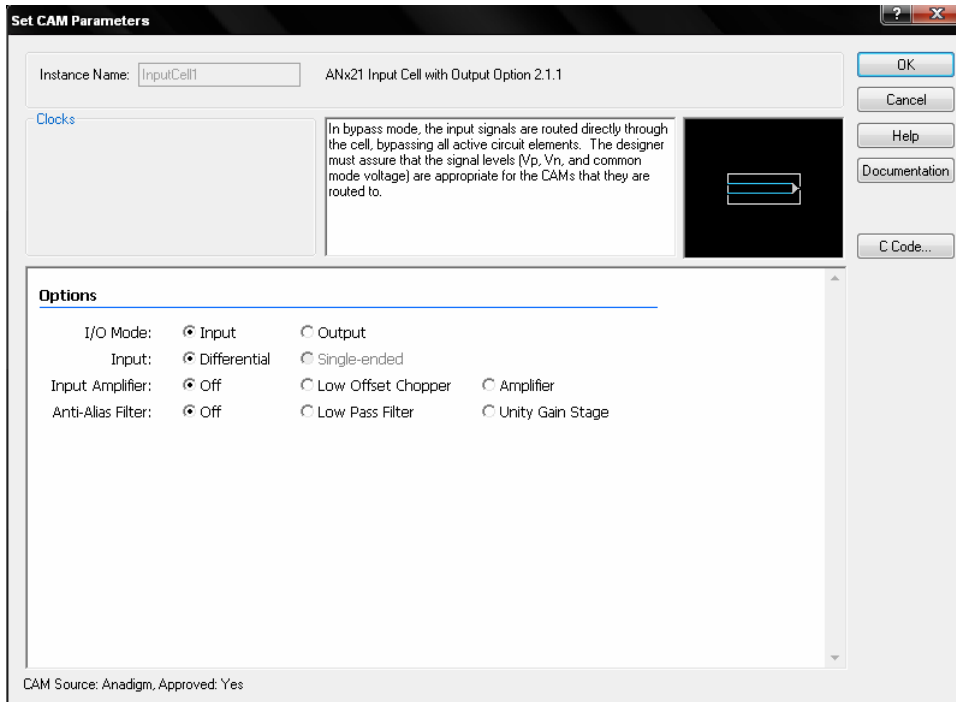


Figure 13. Configuration of input cell 1 (inputCell1) of the FPAA

PARAMETER	SYMBOL	MIN.	PROM.	MAX.	UNID.	COMMENT
Input range	V_{ina}	Ver entradas análogas anteriores			V	
Offset Input equivalent	V_{os}	N/A	N/A	N/A	mV	See CAM of The operation
Coeficiente de temperatura de voltaje Offset	V_{of}	N/A	N/A	N/A	$\mu V/^{\circ}C$	See CAM of the operational amplifier used
Input frequency	F_{in}	-	-	8	MHz	Depends on the CAM
Rejection ratio for power supply	PSRR	N/A	N/A	N/A	dB	See CAM of the operation
Input resistance		-	-	-	Mohm	
Input capacitance	C_{in}	-	-	-	pF	

Table 2. Voltage input in differential mode, Amplifier OFF, filters OFF and unity gain phase OFF.

This stage is integrated by the CAM Transimpedance Amplifier, which is a transimpedance amplifier, whose characteristics allow the current received from the photodetector to be detected and measured with greater precision

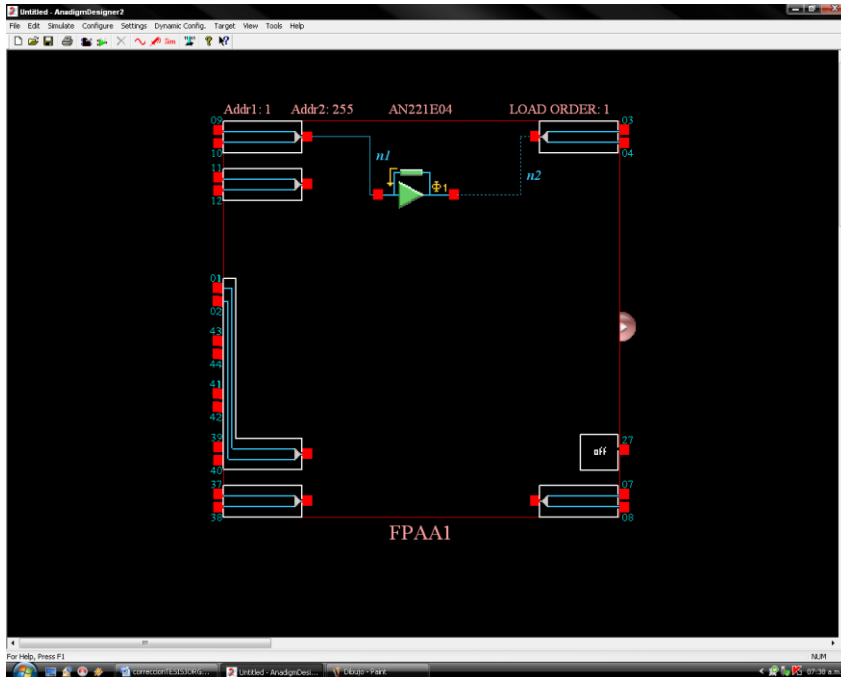


Figure 14. Connection of the transimpedance amplifier between input 1 and output 1 of the FPAA.

AnadigmDesigner does not simulate current generators, so the output voltage and the transimpedance ratio are taken into account to know the input current.

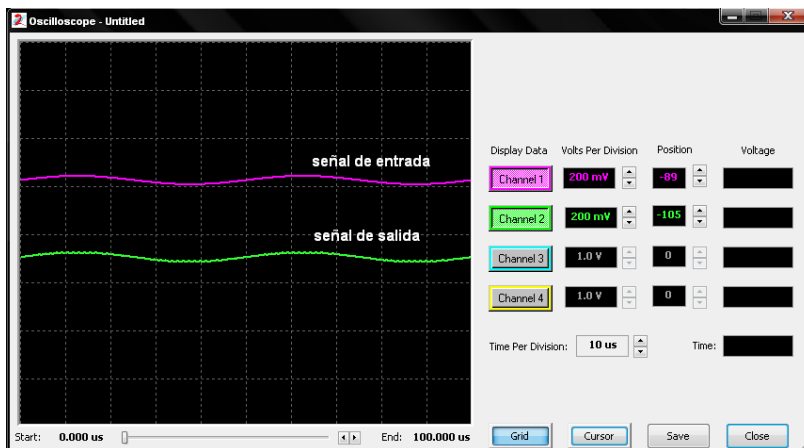


Figure 15. Input and output signal to the AnadigmDesigner2 oscilloscope.

A transimpedance amplifier CAM is created. Its function is to convert any current input to voltage. The transimpedance parameter is programmable, it gives the ratio of voltage to incoming current.

CAM PARAMETERS			
Transimpedance	0.0102-1.30 V/ μ A	@ Fc = 4MHz	The value of the limiting transimpedance value is dependent on the cut-off frequency.
	0.163-20.8 V/ μ A	@ Fc = 250KHz	
	0.817-104 V/ μ A	@ Fc = 50KHz	

Table 3. Characteristics of the transimpedance amplifier.

Equations

La función de transferencia del circuito es:

$$V_{out} = -z \cdot I_{in}$$

Where z is the assigned transimpedance value e I_{in} is the input current, in this case, the one delivered by the photodetector.

The values of the internal capacitors are chosen to take into account the best performance so that they satisfy the following relation:

$$Z = 1 / (f_c (C_{out1} + C_{out1a} + C_{out1b})) \quad (3.8)$$

The CAM is designed to work with current input. Most CAMs are designed to work with voltage inputs. This CAM can be used by connecting a photodiode to the pins of an input cell. Note that the transimpedance parameter is designed with a transfer function for current input from devices such as photodiodes.

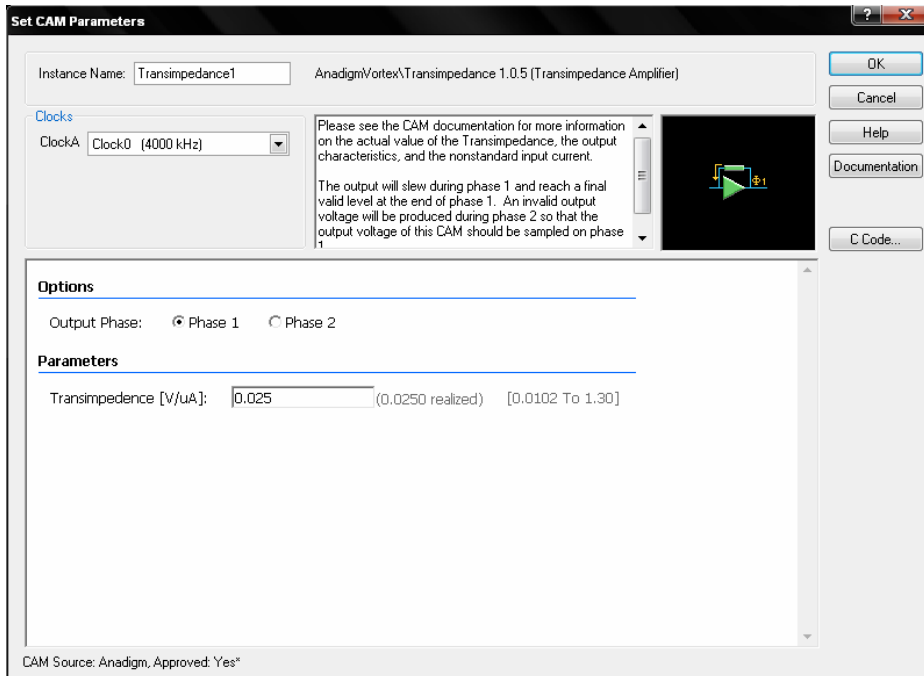


Figure 16. Parameters of the CAM transimpedance amplifier with a value of: $0.025 \text{ V}/\mu\text{A}$

As can be seen in the figure, the transimpedance value is $0.025 \text{ V}/\mu\text{A}$, which is equivalent to an internal impedance of $25 \text{ K}\Omega$.

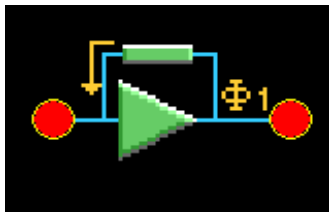


Figure 17. Transimpedance amplifier.

In this stage, a gain is given to the signal delivered by the transimpedance amplifier, as it is delivered as a voltage in very small values.

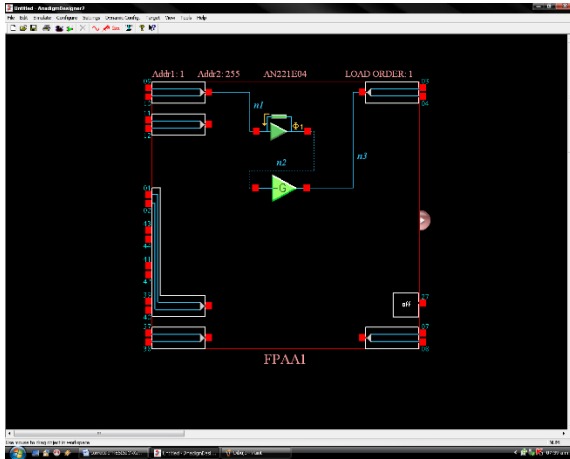


Figure 18. Connection of the transimpedance amplifier to the inverting gain amplifier.

This stage is also realized through the FPAAI, using the CAM GainInv, as its name indicates, it is an amplifier with inverted gain.

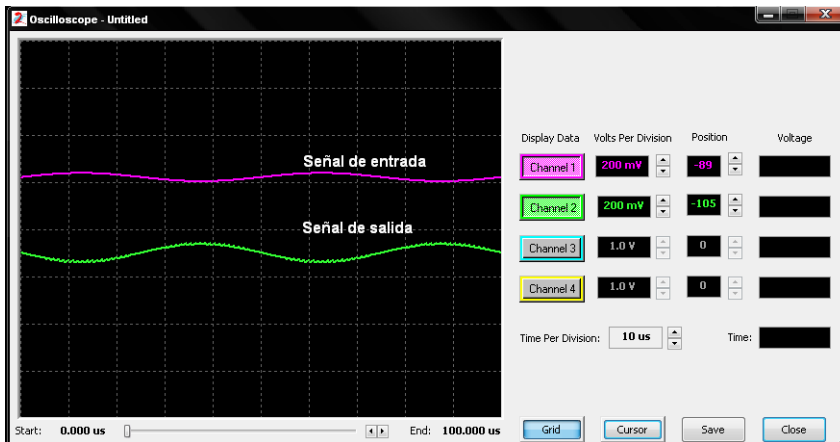


Figure 19. Input and output signal with inverted gain on AnadigmDesigner2 oscilloscope.

As can be seen in Figure 19, the output signal has obtained a certain gain, but due to the characteristics of the amplifier that generates this gain, its phase has been inverted.

A CAM is created in a complete cycle that not only assigns a gain to the input signal but also inverts its phase. The input voltage is multiplied by the programmed gain value. The phase of the output voltage signal will always be opposite to the phase of the input voltage signal.

Equations

The transfer function of the circuit is:

$$V_{out}(s)/V_{in}(s) = -G$$

The values of the internal capacitors are chosen to take into account the best performance so that they satisfy the following relationship:

$$G = C_{in}/C_{out}$$

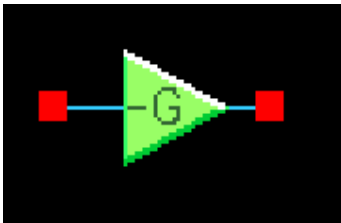


Figure 20. Inverted gain amplifier.

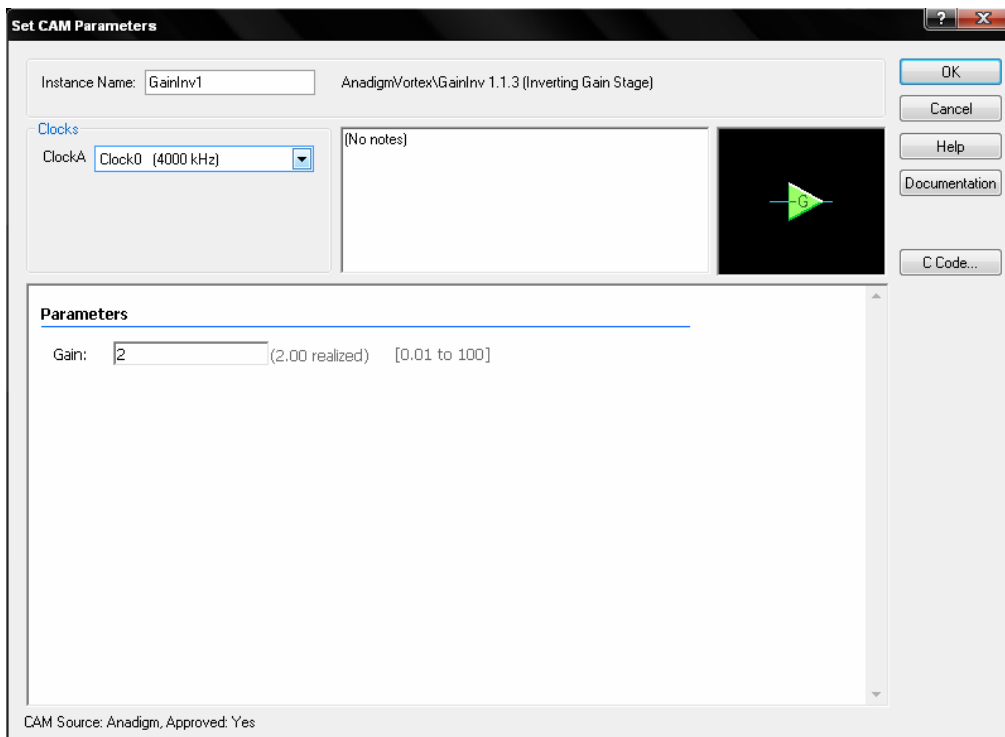


Figure 21. CAM parameters inverted gain amplifier $G = 2$.

As shown in Figures 20 and 21, the gain value is 2. Then another inverted gain amplifier is adapted, with unity gain as shown in Figure 22, which only changes the phase of the signal so that it is equal to the input signal.

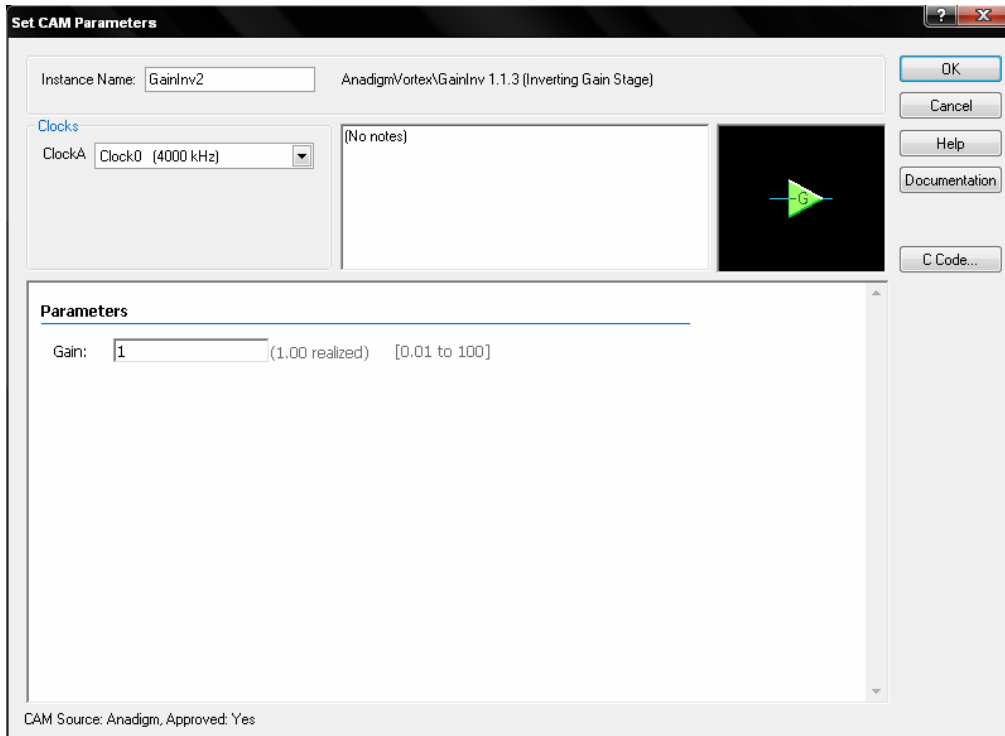


Figure 22. CAM parameters inverted gain amplifier $G = 1$.

The AnadigmDesigner2 design is shown in Figure 23.

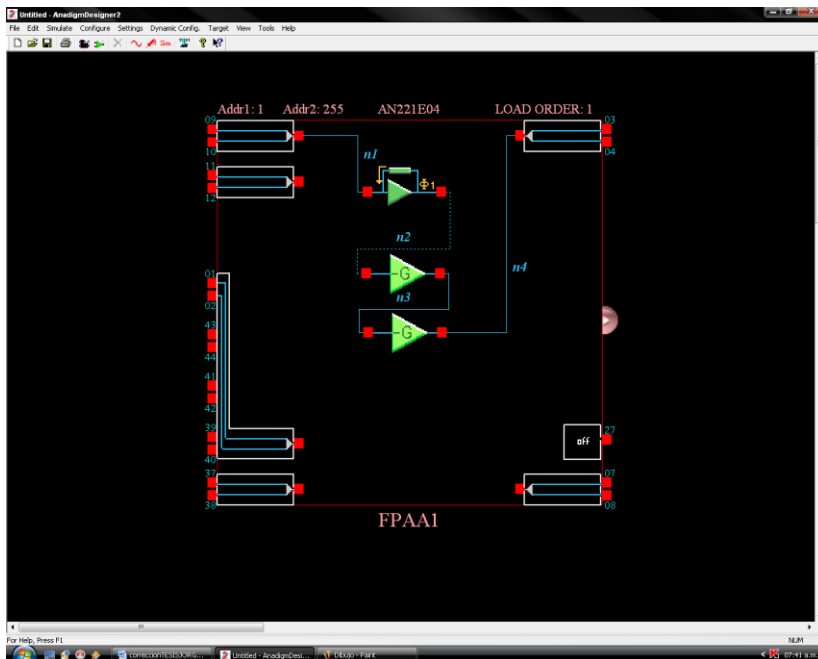


Figure 23. Connection of transimpedance stage with gain and phase correction.

In this simulation, the output signal in addition to obtaining a gain has the same phase as the input signal.

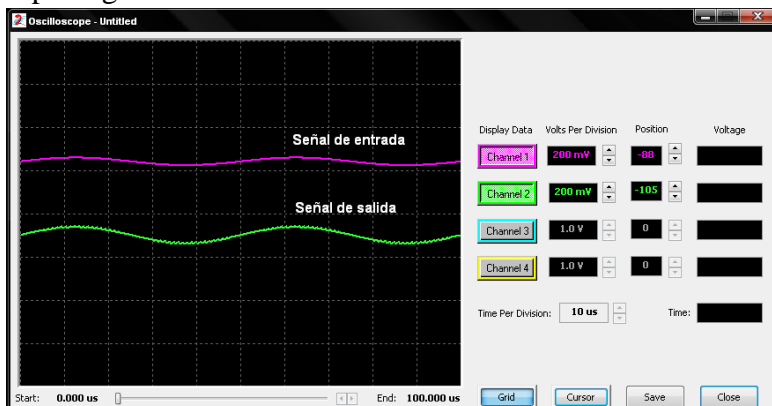


Figure 24. Input signal and output signal with gain on the oscilloscope of the AnadigmDesigner2.

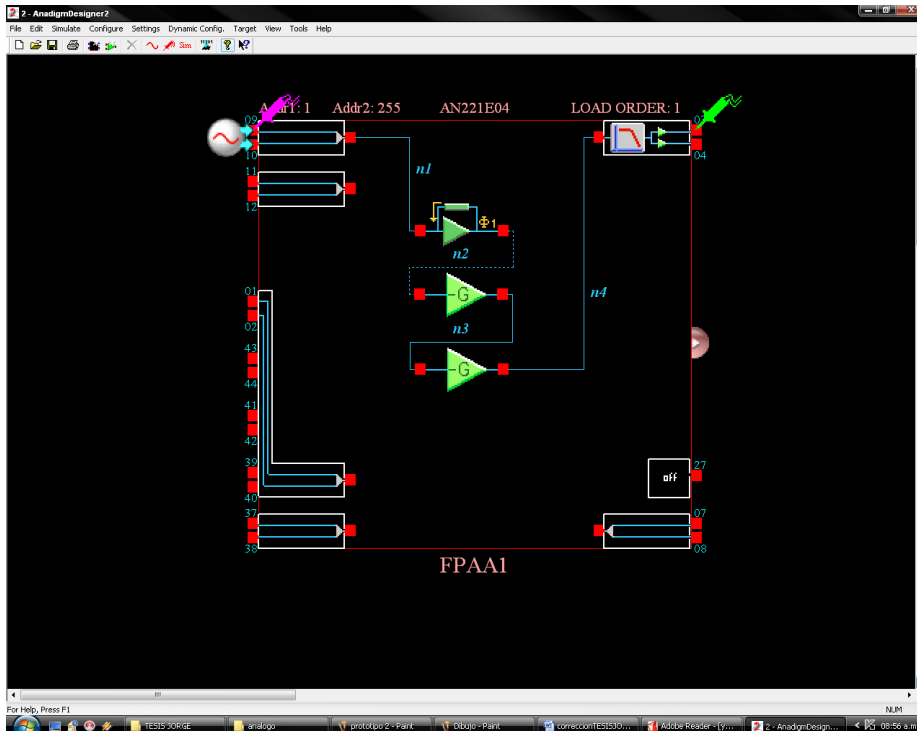


Figure 25. Prototype with output configuration.

The output signal is measured between the configured positive output pin O1P and the analog reference of the FPAA, this signal is measured in volts and takes into account the formula of the transimpedance amplifier $V_{out} = z * I_{in}$.

$$I_{in} = V_{out}/z \quad I_{in} = V_{out}/25 \text{ K}\Omega$$

The gain applied to the output of the transimpedance amplifier must be taken into account and replaced with

$$\begin{aligned} V_{out} &= V_{out}/G \\ I_{in} &= V_{out}/z * G \\ I_{in} &= V_{out}/25 \text{ K}\Omega * 2 \end{aligned}$$

Having these factors, are replaced in (3.6) and the power is found, which is the objective of this design.

$$P = I_D / R$$

For this design, a PIN series 4 silicon photodiode from Silicon Sensor International AG was

used as a light sensing device. It has a spectral response of 400-1100 nm and its responsivity (R) is 0.38 A/W at 660 nm.

A 660nm emitting diode with an emission power of 10 μ W to 194 μ W was used. With these values and taking into account the responsivity factor for the wavelength, i.e. 0.38 W/A for 660nm.

The currents to be handled by the photodetector are between 3.8 μ A and 74 μ A. To convert the output voltages to current and then to power, the formulas mentioned above were taken into account.

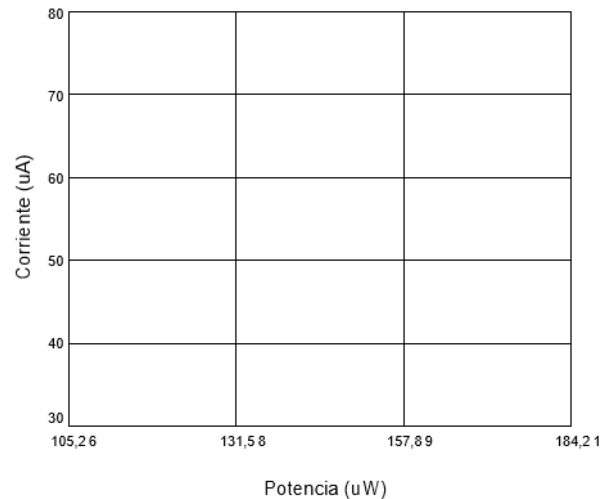


Figure 26. Photodiode current $\lambda = 660$ nm

The drawback of this design despite having the necessary features to find the optical power, is the internal configuration of the FPAA card, as indicated by its electrical characteristics, the output voltage has reference values of +/-2 V. Therefore, the range of power values available is only part of the range that needs to be measured.

+/-2 V. Therefore, the range of power values available is only a part of the range that needs to be measured.

Conclusions

The virtual instrumentation laboratories are a tool that allows better use of the equipment of the electronic laboratories of the universities since it increases the availability and also prolongs its useful life.

The conditioning of a physical variable can have three possible conditions, the one that does not require the instrumentation because it has an almost linear output, that can be performed in a linearization on a FPAA chip or that requires more than one FPAA for its conditioning.

The handling of programmable analog devices requires skill, which should start from practical experience with conventional passive and active devices, to apply a more engineered design and compare design time, accuracy and robustness to noise.

Characterization models from a statistical package are important to compare and determine the specific model required from the data obtained, and error estimation is important for system validation.

When a researcher decides to use an analog configurable device such as the FPAA, for a given application it is important to know the technological limits that affect the device in the implementation, because if this parameter is known in advance, it could predict with some degree of accuracy the performance of the device within the application itself.

Designing an instrumentation laboratory in sections is a mistake that, when implementing the prototype, implies practically starting from scratch since it is essential to know the capabilities of the computer, its communication ports, operating currents, coupling impedances, grounds, and operating points,

The remote access has two options, one via the intranet to do it with a Windows application in conjunction with Web support and blocking certain applications guarantees the perfect operation of the server, and two through the Internet that, although it is not a planned objective works perfectly through tools such as Logmein to access remotely without problems and public IP addresses.

Although it was not a planned development to work together several FPAA the Virtual Instrumentation laboratory is implemented with three, which leads to taking into account that the AnadigmDesigner2 software must be included in a specific order, the power supply voltages must be independent, the configurations or interconnections applied compatible.

The servers to be implemented must have special capabilities and work with portable equipment is limited, communication converters such as USB-serial creates conflicts when they are excessive.

REFERENCES

- [1] Anadigm. (2003). AN221E04 Datasheet (DS030100-u006a) dynamically Reconfigurable FPAA with enhanced I/O [base de datos en línea] consultada: 17 de septiembre de 2007 en: http://www.anadigm.com/sup_litlibrary.asp
- [2] Anadigm. (2003). AN221E04 Datasheet (PR030900-0038) Anadigmvortex consultada: 21 de septiembre de 2007 en: http://www.anadigm.com/sup_litlibrary.asp
- [3] Anadigm. (2002). AN221E04 Field Programmable Analog Arrays – User Manual (UM021200-U007g) consultada: 24 de octubre de 2007 en: http://www.anadigm.com/sup_litlibrary.asp

- [4] Anadigm. (2006). AN221E04-v3 AnadigmVortex Development Board (UM022100-K003a) consultada: 21 de septiembre de 2007 en: http://www.anadigm.com/sup_litlibrary.asp
- [5] Anadigm. (2003). Interfacing analog signal to the anadigmvortex FPAA device (AP030500-U205) consultada: 22 de septiembre de 2007 en: http://www.anadigm.com/sup_litlibrary.asp
- [6] Anadigm. (2003). FPAA Customer Applications (VX020700-0001d) consultada: 12 de Febrero de 2008 en: http://www.anadigm.com/sup_litlibrary.asp
- [7] Anadigm. (2003). AN221E04 overview (GF30100-0010A) consultada: 12 de Febrero de 2008 en: http://www.anadigm.com/sup_litlibrary.asp
- [8] Anadigm. (2003). Anadigm Corporate Overview (PR080200-0007B) consultada: 15 de Marzo de 2009 en: http://www.anadigm.com/sup_litlibrary.asp
- [9] Obregon. (2007). Sistemas Complejos, geofísica e ingeniería. [Base de datos en línea] consultada: 4 de Noviembre de 2009 en:

<http://www.udistrital.edu.co/comunidad/grupos/trabajo/complexidad/memorias/prim%20encuentro/DIA%203/02.%20NELSON%20OBREGON%20-%20SISTEMAS%20COMPLEJOS,%20GEOFISICA%20E%20INGENIERIA.pdf>
- [10] Cornejo. (2004). Complejidad y Caos [Base de datos en línea] consultada: 5 de Noviembre de 2009 en:
<http://www.eumed.net/cursecon/libreria/2004/aca/4.pdf>
- [11] Mayné, J. (2003) **Sensores Acondicionadores y procesadores de señal** [Libro en línea]. Consultado 15 de marzo de 2009 en: www.librodescarga.blogspot.com
- [12] Creus, S, A. (2008). **Instrumentación Industrial**. (7^a ed.). Barcelona, España: Marcombo S.A.
- [13] Roca, A. (1999). **Control de Procesos**. México: Alfaomega grupo editor. S.A.
- [14] Doebelin, E. (2005). **Sistemas de Medición e Instrumentación**. (5^a ed.). México: McGRAW-HILL.

- [15] Contreras, F. (2007). **Estadística Descriptiva y Análisis Descriptivo con SPSS**. San Cristóbal, Venezuela: FEUNET.
- [16] Pérez, J., Hilario, A., Castro, M. , Mur, F., Yeves, F., Piere, J (2000). **Simulación y Electrónica Analógica**. Santafé de Bogotá, D. C, Colombia: Alfaomega Grupo Editor. S.A.
- [17] Balbo, J. (2005). **Guía Práctica para, La Investigación sin Traumas**. San Cristóbal, Venezuela: FEUNET.

BIBLIOGRAFÍA COMPLEMENTARIA

- [18] Estrategias docentes colaborativas basadas en la utilización de laboratorios remotos vía internet

http://156.35.172.16/CDITI/congresos/web_cuiet14/comunicaciones/comunicaciones/Comunicacion136.pdf
- [19] laboratorio de acceso remoto.
[http://digital.ni.com/worldwide/latam.nsf/87e62f4c89ea9df9862564250075e6e4/f54369a0ec8c0b4486256b5f006565a9/\\$FILE/LabRemoto.PDF](http://digital.ni.com/worldwide/latam.nsf/87e62f4c89ea9df9862564250075e6e4/f54369a0ec8c0b4486256b5f006565a9/$FILE/LabRemoto.PDF)
- [20] Servicio de laboratorio virtual e instrumentación remota vía Internet.
http://www.uma.es/ieducat/II_jornadas/PIE06_093.pdf
- [21] Diseño de un experimento interactivo controlado vía Web

[http://digital.ni.com/worldwide/latam.nsf/87e62f4c89ea9df9862564250075e6e4/62dae7a411992f7986256b5f0064fae0/\\$FILE/Experimento%20Interactivo.pdf](http://digital.ni.com/worldwide/latam.nsf/87e62f4c89ea9df9862564250075e6e4/62dae7a411992f7986256b5f0064fae0/$FILE/Experimento%20Interactivo.pdf)
- [22] Desarrollo básico de un laboratorio virtual de control de procesos basado en Internet
<http://www.saber.ula.ve/bitstream/123456789/17233/2/articulo6.pdf>
- [23] Instrumentación virtual en la enseñanza de la ingeniería electrónica
<http://www.comunidadandina.org/bda/docs/VE-EDU-0004.pdf>
- [24] Universidad Experimental del Táchira, Dpto. de Cs Física Núcleo de Electricidad. (1997). **Mediciones** (Semestre IV de Ingeniería Eléctrica) San Cristóbal, Venezuela: Gallego, G.