

## Block programming to develop interactive activities in the analysis of passive filters using an RC circuit for distance classes

### Programación a bloques para desarrollar actividades interactivas en el análisis de filtros pasivos usando un circuito RC para las clases a distancia

GONZÁLEZ-GALINDO, Edgar Alfredo†\*, CARRILLO-MORENO, Aldo Omar, DOMÍNGUEZ-ROMERO, Francisco Javier and PÉREZ-GARCÍA, Jorge

*Universidad Nacional Autónoma de México, Facultad de Estudios Superiores Aragón, Centro Tecnológico Aragón, Measurement and Instrumentation and Control Laboratory. Mexico.*

ID 1<sup>st</sup> Author: *Edgar Alfredo, González-Galindo* / ORC ID: 0000-0003-4654-9595, Researcher ID Thomson: G-7927-2018, CVU CONACYT ID: 351785

ID 1<sup>st</sup> Co-author: *Aldo Omar, Carrillo-Moreno* / ORC ID: 0000-0002-3201-1738, Researcher ID Thomson: GMX-3511-2022, CVU CONACYT ID: 1229120

ID 2<sup>nd</sup> Co-author: *Francisco Javier, Domínguez-Romero* / ORC ID: 0000-0003-0578-9322, Researcher ID Thomson: AFD-9764-2022, CVU CONACYT ID: 1037122

ID 3<sup>rd</sup> Co-author: *Jorge, Pérez-García* / ORC ID: 0000-0002-6085-6375, Researcher ID Thomson: ACR-3522-2022, CVU CONACYT ID: 1014606

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#### Abstract

Block programming was developed for interactive activities in the analysis of a passive low pass filter using a RC circuit for distance classes. On a breadboard, was integrated an Arduino development board, a potentiometer and a visual indicator (a light emitting diode LED). The development of the programming was carried out using the software LabVIEW to generate an interactive front panel that allows us to manipulate and visualize the calculations, the graphic expressions and at the same time vary at least one passive element. A graphical interface was obtained that allows iterations and immediate calculations for the missing parameters to see the behavior of the filter and also generates a display for the mathematical expression and its Bode plot, the resistance allows us vary the values and make a sweep to locate the angular frequency and activate the light emitting diode connected on the development board. In the programming a web camera was implemented to visualize the circuit in real time at the moment of manipulating a graphical interface.

#### Filter, Bode, Programming

#### Resumen

Se desarrolló la programación a bloques para actividades interactivas en el análisis de un filtro pasivo pasa bajas usando un circuito RC para las clases a distancia. En una placa de prueba (protoboard), se integró una tarjeta de desarrollo Arduino, un potenciómetro y un indicador visual (un diodo emisor de luz LED). El desarrollo de la programación se realizó usando el software LabVIEW para generar un panel frontal interactivo que permite manipular y visualizar los cálculos, las expresiones gráficas y al mismo tiempo variar al menos un elemento pasivo. Se obtuvo una interfaz gráfica que permite hacer iteraciones y calcular de forma inmediata los parámetros faltantes para ver el comportamiento del filtro y además se genera un visualizador para la expresión matemática y su diagrama de Bode, la resistencia nos permite variar los valores y hacer un barrido para localizar la frecuencia angular y activar el diodo emisor de luz conectado en la tarjeta de desarrollo. En la programación se implementó una cámara web para visualizar el circuito en tiempo real al momento de manipular la interfaz gráfica.

#### Filtros, Bode, Programación

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\* Author Correspondence (E-Mail: unam\_alf@comunidad.unam.mx)

† Researcher contributing as first Author.

## Introduction

Nowadays we can complement teaching and learning with simulators and with some programming programs that allow the way of transmitting the teaching to be more interactive and that the students can call their attention and many of these programs are available some for free due to the agreements of the universities with the companies and others allow you to have access for 30 days. While it is true that before the problem of the global confinement situation arose due to severe acute respiratory syndrome (SARS CoV2), and the disease it causes is called COVID-19(Hoffmann,2019). Nowadays, the way of learning and teaching is carried out by means of information and communication technologies (ICT), learning and knowledge technologies (LKT) and technologies of empowerment and participation (TEP) that are allies of teaching strategies and promoters of active learning processes.

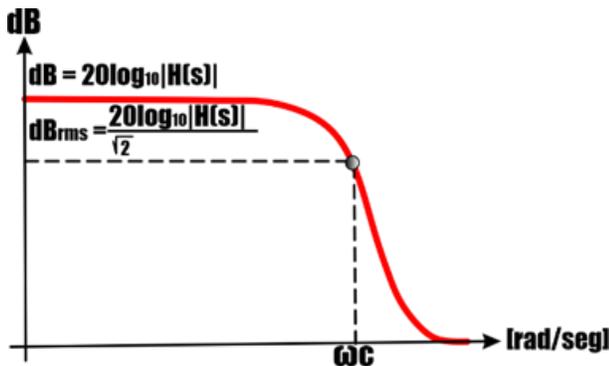
On the other hand, it is essential that their incorporation is mediated by pedagogical reflections, which implies, in turn, a set of decisions in relation to the teaching proposal, while the TAC is the set of reflections and decisions about teaching with the collaboration of digital tools and/or supports, i.e., learning and knowledge technologies. This necessary transition positions these resources as such, tools at the service of teaching and learning, stripped of ends in themselves. In this sense, ICTs imply a change in the position of the teacher and, therefore, in that of the student. It is a matter of working in a scenario where decisions are pedagogical. But it is not enough to master technology, content and didactics; it is necessary to strengthen the work with others. To provide information and communicate to develop skills to select our sources, analyze information, build new knowledge and promote participation. Hence, he calls technologies of empowerment and participation (TEP) those that promote active interventions through the use of ICT (Vidal, 2022).

In the Faculty of Higher Studies Aragon in the area of Physical Mathematical Sciences and Engineering in one of its careers of electrical and electronic engineering, the training of students has been complemented with the use of simulators in the basic subjects and in the specialization subjects, some simulators that have been used in the career of electrical and electronic engineering are: Proteus, Eagle, OrCAD & PSpice, multiSIM, LabVIEW, Mathematics, Matlab(DGTIC, 2019), Mathcad, Language C, Python, Visual Basic, and some simulators or software to develop schematic circuits, programming and simulation online are: Easyeda, DCACLab, MasterPLC, PC SIMU, PartSim, Falstad, Simulator.io, Schematics, Circuit Sims, DcAcLab, EveryCircuit, DoCircuits, PartSim, 123D Circuits, TinaCloud, Spicy Schematics, Gecko simulations, Fritzing, Simduino, TinkerCad, Yenka. In this time where a distance communication has been implemented having present that one way is visual, oral, and written using the tools provided by The University to be communicated with students at a distance.

### A. Passive Filter

The filters play an important role today in electronics, they have different applications within the area of health has become very important for the effects in which the COVID19 has driven the development of this type of electronic instruments to amplify the sound of the heart and breathing for diagnostic purposes using a stethoscope using band-pass filters (Birrenkott, 2021). In communications and image processing, as well as in instrumentation and automatic control. These can be classified into analog, digital and hybrid (switched-capacitor, which contains both analog and digital elements) filters. A filter is a two-port device capable of transmitting a limited frequency band. They can be passive or active (Huiracán, 2012). Passive filters are built based on resistors, coils and capacitors, Figure 1 shows the Bode diagram in magnitude of a low pass filter if it presents the condition when  $0 < \omega < \infty$  allows to pass the signal frequencies and as long as it does not exceed the amplitude of the input signal is maintained but when it crosses the angular frequency or frequency in Hertz begins to suppress and attenuate the amplitude of all higher signals and that region is called rejection frequency.

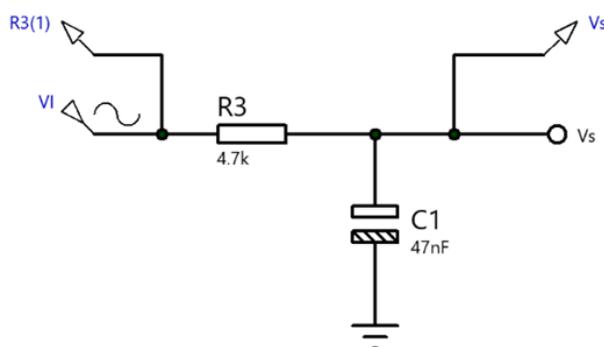
When we obtain  $\text{dB}=20\log_{10}[H(s)]$  we can obtain  $\text{dB}_{\text{rms}}$  if we divide by the  $\sqrt{2}$  and we obtain the point of intersection of the  $-3\text{dB}$  according to Figure 1.



**Figure 1** Magnitude Bode plot of a low-pass filter

Considering the system shown in Figure 2, an RC filter in low-pass configuration, the differential equation that governs its behavior can be determined by applying Kirchhoff's laws as well as the voltage drops produced in the resistors and capacitors (fundamental elements of any electronic circuit).

The Laplace transform has several applications. One of the most important is that it allows to solve differential equations in a simple way. Basically, it is a function that transforms a function of a variable  $t$  to a variable  $s$  (Guelbenzu, 2011). If the Laplace transform is applied to the differential equation that governs the input to output ratio, the filter is characterized by the transfer function of Equation 10. However, the analysis of the schematic circuit yields the equation that satisfies to obtain the Bode diagram in Figure 2 shows the first order passive low-pass filter that only lets through the signals that limits the angular frequency.



**Figure 2** Circuit with passive elements that make up a first order low pass filter, for this case

If we analyze the following circuit Kirchhoff's Voltage Law (KVL Kirchhoff's Voltage Law) we have two equations in the first mesh we have the following:

$$-V_i(s) + V_R + V_c = 0 \quad (1)$$

For the second mesh we have

$$V_s(s) = V_c = \frac{1}{sC} I_c \quad (2)$$

Substituting the variables in Equation 1 in each of the passive elements we have

$$-V_i(s) + RI_R + \frac{1}{sC} I_c = 0 \quad (3)$$

From Equation 3 we assume that the current  $I_c=I_R=I$  sby substituting it into Equation 3 and factoring the  $I$  we have the following expression:

$$-V_i(s) + I \left( R + \frac{1}{sC} \right) = 0 \quad (4)$$

If  $I_c=I$  in Equation 2 to obtain the current at the output of the circuit, the following is obtained:

$$I = sCV_s(s) \quad (5)$$

Substituting 5 in 4 we have

$$-V_i(s) + sCV_s(s) \left( R + \frac{1}{sC} \right) = 0 \quad (6)$$

Doing some algebraic operations, Equation 6 can be represented as follows

$$V_s(s)(sCR + 1) = V_i(s) \quad (7)$$

Now we can express the ratio of the output voltage with respect to the input voltage and finally we have the expression of the transfer function that will allow us to assign values to obtain the angular frequency  $\omega_c$  in units of radians/second and we can obtain the frequency in units of Hz if we clear it from the cut-off angular frequency  $\omega_c=2\pi f_c$ . The transfer function,  $H(s)$ , of a system or circuit is the ratio of the output,  $V_s(s)$ , to the input,  $V_i(s)$ , in the  $s$ -domain (frequency domain). The transfer function is very useful for characterizing the behavior, stability and responses of the circuit, The transfer function is a rational function of  $s$ , and the denominator of the transfer function is the characteristic equation of the system. The roots of this characteristic equation can be used to determine the stability of the system.

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The roots of the characteristic equation of the denominator are called poles. The roots of the numerator of the transfer function are called zeros. The poles are used to identify the frequencies at which the system will grow without stalling or becoming unstable (Schubert,2018). The transfer function is defined as:

$$H(s) = \frac{V_s(s)}{V_i(s)} = \frac{1}{1+sRC} \quad (8)$$

Another way of expressing the transfer function is as follows

$$H(s) = \frac{V_s(s)}{V_i(s)} = \frac{1}{\left(\frac{1}{RC}+s\right)} \quad (9)$$

If we relate Equation 9 to Equation 10 the angular frequency can be obtained.

$$H(s) = \frac{V_s(s)}{V_i(s)} = \frac{1}{(\omega_c+s)} \quad (10)$$

Then the cut-off frequency is obtained from the following relation

$$\omega_c = \frac{1}{RC} \left[ \frac{rad}{ses} \right] \quad (11)$$

To obtain the frequency in units of Hz, we only have to substitute  $\omega_c=2\pi f_c$  in Equation 11 and we have the following expression:

$$f_c = \frac{1}{2\pi RC} [Hz] \quad (11)$$

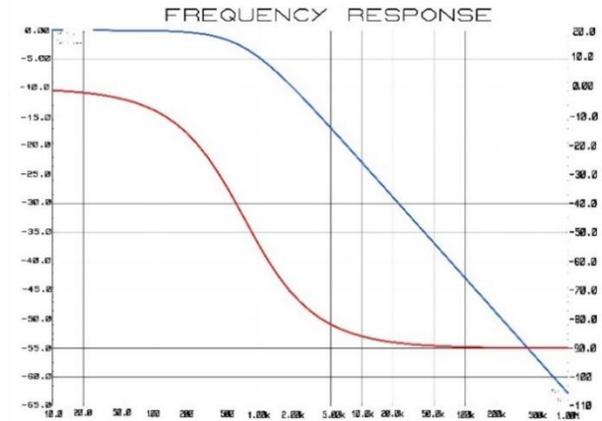
Substituting the values of Equation 10, Equation 11 and Equation 12 to obtain the value of angular frequency  $\omega_c$  and the frequency in Hz and the transfer function.

$$\omega_c = \frac{1}{(4.7 \times 10^3)(47 \times 10^{-9})} = 0.00021277 \left[ \frac{rad}{ses} \right]$$

$$f_c = \frac{1}{2\pi(4.7 \times 10^3)(47 \times 10^{-9})} = 748.01 [Hz]$$

$$H(s) = \frac{V_s}{V_i} = \frac{1}{\left[ \frac{1}{(4.7 \times 10^3)(47 \times 10^{-9})} + s \right]}$$

$$H(s) = \frac{1}{[0.00021277 + s]}$$



**Graphic 1** Magnitude and phase plot of the Bode diagram corresponding to a first order passive low-pass filter and it can be seen that at -3 dB it cuts at 45° with the data of the passive elements of  $4.7 \times 10^3 \Omega$  y  $47 \times 10^{-9} F$

### B. Hendrik Wade Bode

American engineer, researcher, inventor, author and scientist of Dutch descent, Hendrik Wade Bode (December 1905-June 1982) was born in Madison, Wisconsin. His father was a professor of education and a faculty member at the University of Illinois at Urbana-Champaign, he received his bachelor's degree in 1924, at the age of 19, and his master's degree in 1926, both in the field of mathematics, completed his doctorate in physics in 1935 at Columbia University, He is a pioneer of modern control theory and electronic telecommunications, revolutionized both the content and methodology of his chosen fields of research. In 1938 he made important contributions to the convergence of mathematics, information theory, telecommunications, control theory and electronic design, and was hired by Bell Laboratories in New York City, where he began his career as a designer of electronic filters and equalizers. In 1938 he made important contributions to the theory of control systems and mathematical tools for stability analysis of linear systems. He developed the asymptotic phase-magnitude diagram that bears his name, the Bode diagram, which clearly showed the frequency response of systems. Innovative methods for investigating system stability using the frequency domain. gain and phase margin concepts derived from his now famous diagrams.

The method is based on the observation that a logarithmic representation of magnitude (in dB) is additive in the elementary factor contributions of poles and zeros in the transfer function, and the observation that the instability of a feedback system is generated by positive feedback (i.e., a phase difference of 180 degrees or more at some critical frequencies), an estimate, which is obtained by comparing the magnitude plot with the corresponding phase plot. Although the method has good engineering properties and is very useful for the initial design of a (linear time invariant) system (such as an amplifier), it suffers from a lack of generality (Bode diagrams can only be derived fairly accurately for simple systems), allows quick and easy evaluation, and provides a sometimes surprisingly accurate estimate of stability. Bode had a good working relationship with Harry Nyquist, who was able to derive an accurate criterion for the stability of a system based on its frequency response. But perhaps he made his most important contributions at the beginning of World War II, with the development of a fully automatic anti-rocket defense system. It was a sophisticated example of Artificial Intelligence. The system successfully defended London from V-1 flying bombs during World War II. After the war, Bode along with his wartime rival, Werner von Braun, developer of the V-1 flying bomb and later the father of the U.S. space program, served as members of the National Advisory Committee for Aeronautics (NACA), the predecessor of NASA. During the Cold War, he contributed to the design and control of missiles and anti-ballistic missiles. When he retired in October 1967, he held a total of 25 patents in various areas of electrical and communications engineering, including signal amplifiers and ordnance control systems. Shortly after retirement, Bode was elected to the prestigious position of Gordon McKay Professor of Systems Engineering at Harvard University. During his tenure there, he conducted research on military decision-making algorithms and optimization techniques based on stochastic processes, which today play an essential role in modern control and estimation theory (Mitra, 2021).

The year 1960 is considered as the beginning of the modern era for nonlinear control. This is the same time when the first congress of the International Federation of Automatic Control (IFAC) was held in Moscow, which brought the theory of mechanics and Nyquist-Bode's feedback theory closer together to create the current control theory (Iqbal, 2017).

Bode also studied the asymptotic representation of frequency response (Nuñez, 2021). The Bode magnitude diagram plots the modulus of the transfer function (gain) in decibels as a function of frequency (or angular frequency) in logarithmic scale. It is often used in signal processing to show the frequency response of a linear and time invariant system (Sanchez, 2022). We can find nowadays several applications with RC and RL filters in areas ranging from electronics to mechanical engineering, but also as a modeling approach for these same areas. The unit of measurement known as decibel, or dB, is often adopted to characterize the properties of liters. Its name means one tenth of a belio, which is itself a tribute to Alexander Graham Bell. Basically, the decibel is used to express the logarithmic ratio or gain between two quantities of power (DA, 2021). Filters have been applied in different areas such as biology by developing functionalized molecular layer neuro-electronic interfaces for electronic components and biological objects plays a crucial role for the success of bioelectronic devices (Wolf, 2021).

### C. Data acquisition

DAQ data acquisition is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure or sound. A DAQ system consists of sensors, DAQ measurement hardware, and a PC with programmable software. For more than 30 years, NI PC-based DAQ devices have set the standard for accuracy and performance. Measurement accuracy is arguably one of the most important considerations when designing any data acquisition application (NI, 2021). There are various data acquisition boards which are inaccessible and expensive in the market to develop research projects, that is why development boards have been used which have enabled to carry out academic works for teaching-learning and research in various areas, these boards are economical so that students, academics and researchers can be within their reach, but also particular cards have been developed as an example, we can observe the work of Skulski, Ruben and BenZvi in the creation of a device, called Femto DAQ for the acquisition and processing of signals by SiPM for the HAWC ('High-Altitude Water Cherenkov') Observatory (Duarte, 2019).

Another example of applications where a development board has been implemented is in the measurement of parameters that are necessary to evaluate the performance of solar panels, ambient temperature and sunlight intensity can also affect the performance and efficiency of the panels to know certain parameters are implemented sensors an Arduino connected to the PLX-DAQ can be a solution to obtain measurement data and acquire output data from the solar panel performance (Supriyono, 2022). Many academic and research projects are being carried out with a software Parallax Data Acquisition Tool (PLX-DAQ) linked to Microsoft Excel to acquire up to 26 channels of data from any microcontroller Parallax provides easy spreadsheet analysis of data collected in the field, laboratory analysis of sensors and real-time monitoring of equipment (Parallax, 2022).

Implementing a form of virtual and interactive teaching-learning is much better because the teacher has the freedom of teaching that allows them to develop and use available tools without depending on a platform that allows them to access or use programming languages, although it is true that it was a challenge to use new distance learning platforms using programs that some academics did not know, if we implement already known tools together with what was learned during the confinement and if we add that the academic uses programming language tools and pay the subscription to a server, it becomes more chaotic as mentioned by Ortega (2022), nowadays the implementation of a virtual laboratory is an important factor in the understanding of analogue system simulations in online education and helps to achieve the teaching objective for which it was implemented. The integration of a website developed in the languages of HTML, CSS and PHP, according to the author it is observed that 90% of the respondents believe that the implementation of the virtual laboratory is useful for learning analogue systems, 85% state that the interface of the laboratory website is user-friendly and intuitive, and 80% consider that the operation of the virtual laboratory with the execution of the simulators is efficient (p. 79, 81).

Sometimes the surveys do not allow to observe a real result, the students must visualise in real time the simulation, the physical connection, the acquisition of data and the measurements of the physical variables in that way it is motivating for the student to observe the behaviour of the experimental arrangement that is being tested in that instant and at a distance, as are the electronic instruments that are developed in the case of the career of electronic electrical engineering. There are didactic programmes that are excellent for implementation in subjects where only the theoretical part is taught, so that students can understand some concepts or definitions that allow them to develop the reasoning that leads to problem solving, but in some careers the theoretical-practical complement becomes fundamental as students use creativity and innovation in the development of technologies in the area of Physical Sciences - Mathematics and Engineering. There are some points of view as Sotomayor (2022) mentions that one of the possible weak points that I find in my innovation is its fundamentally practical character, since it is too big a break in relation to the way philosophy is commonly taught. Based on this, I consider it necessary to observe rigorously how it is given in practice, since it is possible that on many occasions the activities deviate from the central theme and to a certain extent the teaching of properly philosophical content is lost (p. 72).

In this work, a block programming software called LabVIEW was used to generate an interactive graphical interface using an Arduino development board and a webcam to visualise in real time the manipulation of a passive element and generate iterations to calculate the parameters and generate the Bode diagram, during the online class modality to complement the theoretical-practical knowledge in teaching-learning, in the Electrical and Electronic Engineering Degree.

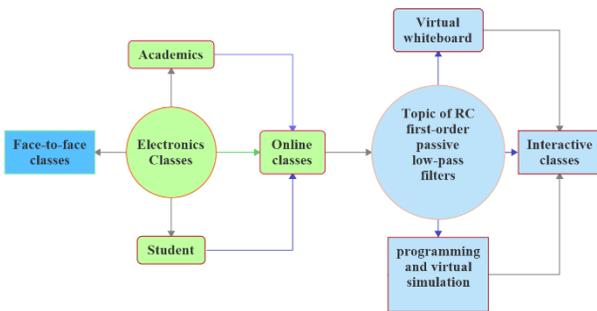
### **Objectives**

A block programming will be developed for interactive activities doing passive filter analysis using an RC circuit, applied to distance learning classes with a development board that allows the generation of the Bode diagram and visualisation of the mathematical model.

**Hypothesis**

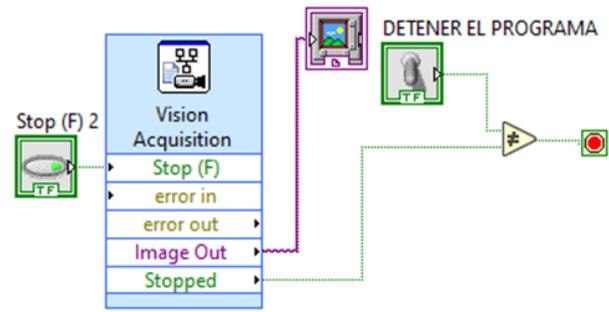
The challenges and challenges in recent years for university academics of the Electrical and Electronic Engineering course at the Faculty of Higher Education Aragon at the National Autonomous University of Mexico, to transmit the knowledge of teaching-learning during this health contingency of SARS CoV2 severe acute respiratory syndrome. If interactive programming is developed that can capture the attention of the students at the end of the theoretical analysis, then they will be able to understand how the passive filters behave with the RC circuit, and the option to vary at least one passive element using a development board, to generate a sweep and modify the cut-off frequency in the Bode diagram is displayed on a front panel.

**Methodology and development**



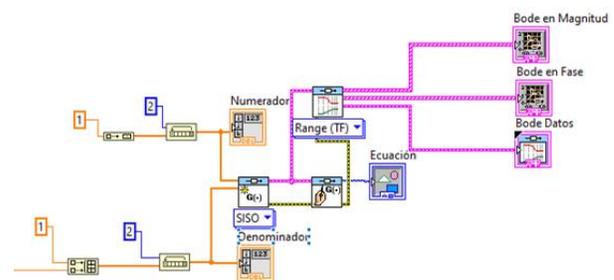
**Figure 3** Procedure to generate interactive classes using the tools to generate teaching-learning for the students of the Electronic Electrical Engineering course at FES Aragón

Figure 4 shows how to enable the webcam, for this you need to be in the work area of the block diagram, and the following path is required to locate it Vision and Motion and then select Vision Express and select Vision Acquisition, and in the image output option all you do is select an indicator that will allow me to see in real time the image generated by the webcam in the front panel area and this arrangement is placed within a While Loop.



**Figure 4** Wiring diagram to enable the camera to make a classroom interactive so that students can see how the theory is physically displayed and see how the electronic components can be manipulated

To generate the Bode diagram in magnitude and phase, it is necessary to obtain an arrangement that allows to introduce the coefficients that are going to generate the polynomial of n order, both in the numerator and in the denominator that conforms the transfer function, to generate these connections, as shown in Figure 5, before introducing these values of the coefficients, an arrangement must be generated, These blocks are found in the option of the block diagram area in Control and simulation in the option Model construction and we select the blocks to generate the programming, so that this arrangement can show the graphical interpretation, you must go to the frequency response folder and select the CD Body block. Vi



**Figure 5** Connection diagram to generate the Bode in magnitude and phase of the low-pass filter and express it graphically on the front panel

In the formula diagram it is possible to introduce the mathematical equations to calculate the angular frequency of cut-off and its respective frequency in units of Hz. It can be helped with a coefficient with the name of the variable A that multiplies the part of the denominator of the polynomial function to introduce it in the arrangement to generate the transfer function and using the blocks of condition operations the value will be placed to generate the sweep and locate the angular frequency that is being sought, as can be seen in Figure 6.

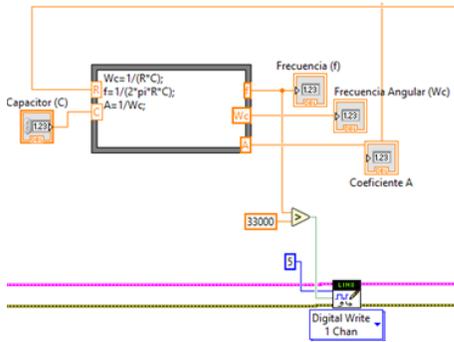


Figure 6 Wiring diagram for the calculations of Hz frequency and angular frequency and transfer function coefficient

The simulation of the variation in the increase of the resistance value was done using the mathematical operation blocks to multiply the data logarithmically as shown in Figure 7, these will be obtained from the development board by introducing a variable resistor in the pin of the analogue port A0 where a variable resistor will be connected.

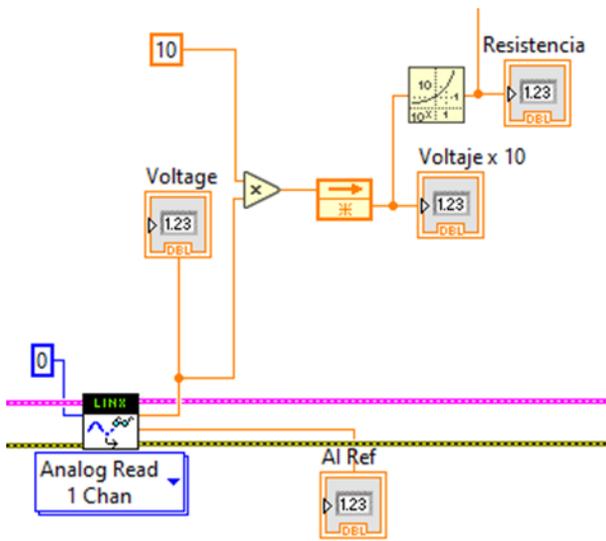


Figure 7 Wiring diagram to obtain the change of the resistor value to sweep the angular frequency to the left or right side, by setting the capacitor value constant

To interact with the Arduino development board within the block programming in LabVIEW is used the tool called Digilent LINX is the successor of LabVIEW Interface for Arduino. Both packages are from the same software author who recommends migrating to LINX. LINX is designed to be a more generic hardware abstraction layer for embedded devices, rather than being designed for a single specific microcontroller platform (NI Engineer, 2021).

It is required to download to integrate it to the tool of the block diagram that allows to configure the programming, as well as the Firmware and the development board works as an interface or as a data acquisition board as shown in Figure 8, to generate the arrangement is important that when selecting the Open option is required to generate a control that allows to select the port where it is linked to the development board in case of omitting this option when running the program will not be sent the instructions required by the user will send the card for operation.

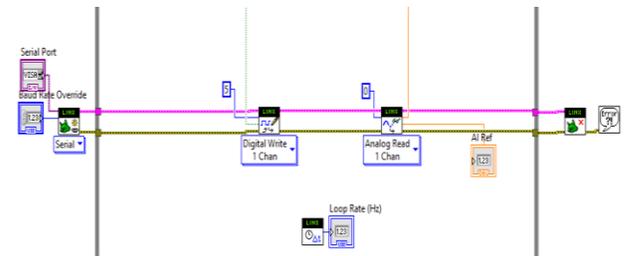
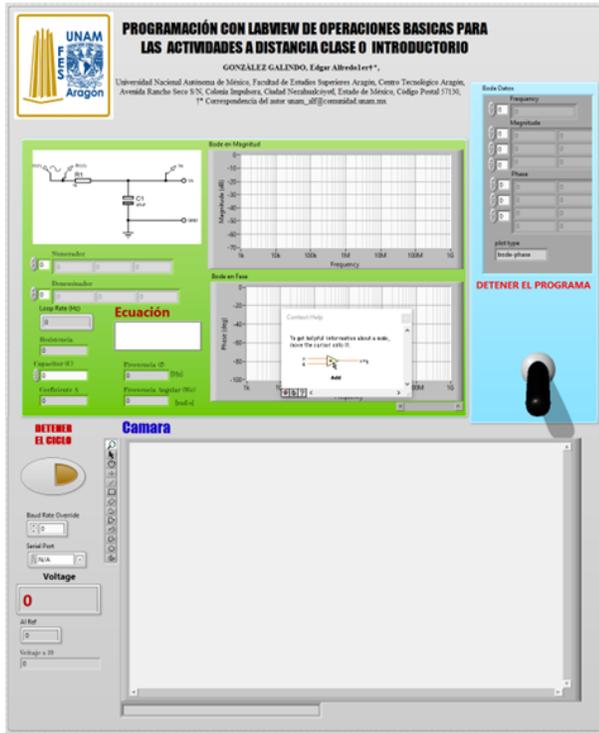


Figure 8 Connection diagram for using the Arduino development board using LINX to operate as a data acquisition board, enabling digital port 5 and analogue input A0, setting the USB port selector and the baud rate for digital transmission of the communication

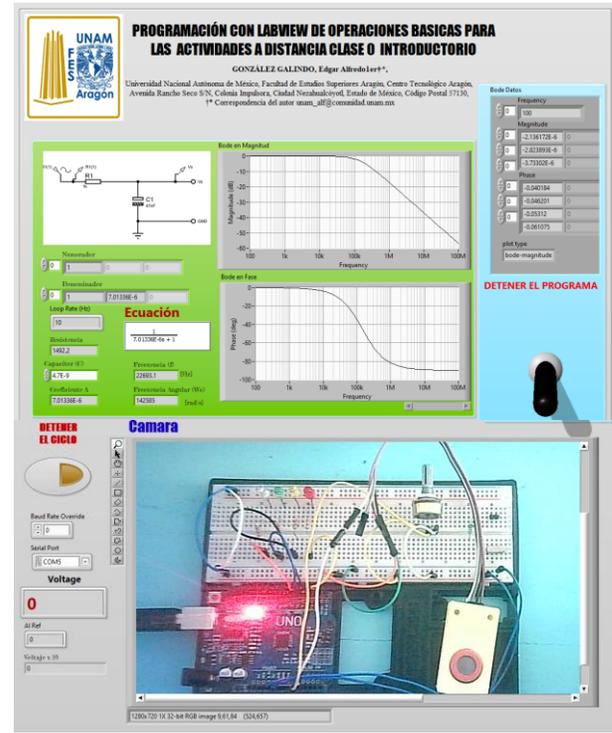
Results

The importance for the student to observe both the calculations and the mathematical model, the graphical interpretation of an electronic circuit and to see a schematic circuit of a first order passive low pass filter RC. By programming all the variables in the block diagram and displaying on the front panel as shown in Figure 9, the transfer function is recorded on this panel, The values entered for the passive element, in this case the capacitor, are proposed and the value of the resistance will be entered externally with the potentiometer to be able to sweep the frequency and activate a light emitting diode which will indicate that the previously programmed cut-off angular frequency has been located and it will be seen how the bode diagram varies in magnitude and phase and the data when the signal is introduced into the analogue port of the Arduino development board.



**Figure 9** Front panel to develop interactive teaching and learning where we can show the mathematical analysis and graphic expression, as well as the display for the connection of the electronic circuit through a webcam

On the front panel of Figure 10 when running the program, the value of the capacitor is introduced using the scientific notation expression and the resistance is a data that is entered externally as seen when the webcam is activated. On the test board (protoboard) is placed a variable resistor (potentiometer) and on one side are also placed an array of light emitting diodes (LED'S) will indicate at the exact moment that has been obtained the angular frequency of cut-off of this particular filter. In this way the students not only observe a schematic circuit figure but also see how it interacts and how more information can be obtained when it is simulated through virtual programming. This way of complementing teaching-learning motivates students to develop their imagination and creativity applied to electronic circuits.



**Figure 10** Final development front panel for visualisation for interactive knowledge sharing for online teaching-learning of the Electrical and Electronic Engineering course at the Facultad de Estudios Superiores Aragón

Implement an interactive way of teaching to show the knowledge in a visual way and that through a card of economic development and easy access for all students, allows to develop block programming once, to manipulate and calculate through iterations and locate the angular frequency or frequency in Hz making a sweep and get the data and to express it graphically so that students can alter the data and obtain an infinite number of values of a passive element that can be purchased commercially. This type of programming is more interactive and the student can easily change the data and enter it from his monitor as if he had an electronic instrument to generate and calculate passive filters.

## Conclusions

90% of the students who took the class in a virtual and dynamic way managed to understand the subject in a theoretical-practical way. This way of carrying out the teaching-learning the student can develop in real time the activity both virtual and physical. We were able to develop block programming and link it with the Arduino development board to send and receive instructions by configuring the analogue-digital input.

A webcam was programmed so that the students can see the interaction between the front panel and the Arduino development board in real time. The mathematical expression and the graphic expression of the Bode diagram of the RC passive low-pass filter and the calculations developed through block programming to generate a sweep and locate the previously programmed frequency and visualise it with a light-emitting diode were obtained.

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