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Electronics engineering virtual laboratory for COVID-19 pandemic

Laboratorio virtual de ingeniería electrónica para la pandemia de COVID-19

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Abstract

Due to the COVID 19 pandemic, many aspects of everyday life change how Higher Education Institutions work. The teaching of subjects containing laboratory practices had to adapt to remote working conditions. As a response, we adopted the software Proteus to develop laboratory practices in electronics engineering. We present Some conventional face-to-face practices adapted to be developed remotely in Proteus during this contingency by COVID-19. We present examples of laboratory activities applied to the Control area of the Electronic Engineering study program of the School of Chemical Sciences and Engineering of the Universidad Autónoma de Baja California (UABC) in 2020 and 2021. To develop these laboratory practices, the Collaborate tool of the Blackboard platform, which is the institutional virtual classroom of the UABC, was used as a virtual classroom. These combined tools provide the student with most of the competencies obtained in the laboratory but are now under pandemic conditions. They also serve as a basis to continue applying them in distance education.

Virtual laboratory, Electronics, Proteus

Resumen

Debido a la pandemia de COVID 19, muchos aspectos cotidianos cambiaron, entre ellos, la forma de trabajar de las Instituciones de Educación Superior. La enseñanza de materias que contenían prácticas de laboratorio tuvo que adaptarse a las condiciones de trabajo remoto. Como respuesta, adoptamos el uso de la herramienta de software Proteus para desarrollar prácticas de laboratorio en el área de ingeniería electrónica. Se muestran algunas prácticas convencionales presenciales, que fueron adaptadas para ser desarrolladas de forma remota en Proteus durante esta contingencia por COVID-19. Se presentan ejemplos de actividades de laboratorio aplicadas al área de Control del programa de estudios Ingeniería Electrónica de la Facultad de Ciencias Químicas e Ingeniería de la Universidad Autónoma de Baja California (UABC), durante 2020 y 2021. La implementación de estas prácticas de laboratorio se lleva a cabo mediante la herramienta Collaborate de la plataforma Blackboard, la cual es el aula virtual institucional de la UABC. El uso de estas herramientas combinadas permite proporcionar al alumno la mayoría de las competencias que se obtienen en el laboratorio, pero bajo condiciones de pandemia. Asimismo, sirven de base para continuar aplicándolas en educación a distancia.

Laboratorio virtual, Electrónica, Proteu

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Introduction

Due to the pandemic that we have experienced in recent months, different learning methods have been used, for example, virtual classes (Chang, 2020; Roatta & Tedini, 2021). Universities changed from traditional face-to-face learning to a virtual learning environment to continue working during the lockdown (Morales-Alarcón, 2021). Therefore, it was necessary to find alternative teaching methods, especially when dealing with practical subjects where it is necessary to use laboratory equipment and physical design prototypes (Gamage *et al.*, 2020). In this case, circuit simulators offer an adequate solution.

Due to the quarantine, it has not been possible to carry out physical practices in laboratories. Therefore, several simulation programs and strategies can help carry out these practices (Gomes da Silva *et al.*, 2021; Klein *et al.*, 2021).

The simulators allow an approximation of how a circuit would behave if built, considering physical factors, representing a helpful tool for the student to practice and experiment with electronic circuits virtually, quickly, and safely. In addition, a simulator represents an easy-to-use and learning tool since the user can create any circuit as desired.

In the subsequent sections, we present the Proteus software and examples of laboratory practices designed.

Platforms used by the Universidad Autónoma de Baja California during pandemic

The Universidad Autónoma de Baja California institutional platform is Blackboard Ultra (Blackboard Inc., 2021; Roatta & Tedini, 2021; Universidad Autónoma de Baja California & Centro de Educación Abierta y a Distancia, 2020b) and the virtual classroom tool is Blackboard Collaborate (Universidad Autónoma de Baja California & Centro de Educación Abierta y a Distancia, 2020a). Also, UABC uses Google Classroom and Google Meet as a secondary online institutional platform.

Use of the laboratory practice during COVID-19 pandemic

To develop these laboratory practices with the Proteus software, we use the Collaborate conferencing tool, so the instructor organized teams during the session, and every team worked together and attended the simulation.

What is Proteus software?

Proteus, also known as Proteus Design Suite, is an electronic design automation software developed by Labcenter Electronics Ltd (Labcenter, 2021). This software is helpful to design, simulate and draw electronic circuits. Proteus is one of the most widely used engineering programs, especially electronics (Mandal, 2017).

Some of the advantages offered are:

- It allows instructors to perform virtual laboratories.
- It offers students a dynamic and fun learning tool.
- Electronic components are expensive, but in Proteus, we can use them for free, for example, the oscilloscope.

The main features of the Proteus software are:

- Virtual prototypes can be helpful to test the system before transferring it to the physical printed circuit board.
- Circuit design takes less time than practical construction of the circuit.
- There is no chance of any electronic components being burned or damaged in Proteus.

Proteus software

Proteus consists of two modules: ISIS (Intelligent Schematic Input System) and ARES (Advanced Routing & Editing Software).

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The ISIS application allows the user to create real circuits and test their operation on a PCB (printed circuit board). ISIS stands out for the quality of its schematics, total control over the appearance of drawings, templates to create custom schematics with its style, and easy creation of new components. Furthermore, with the help of the PAT tool (Property Assignment Tool), the user can program the option to perform repetitive tasks, e.g., assign, remove, rename, hide, show, or resize different objects.

The ARES application (Advanced Routing & Editing Software) is the component routing, placement, and editing tool. It is helpful for the manufacture of printed circuit boards.

Examples of laboratory practices of signals and systems on Proteus simulator

This section shows some examples of the laboratory practices adapted and developed during this pandemic.

Low-pass filter design and implementation

The function of this electronic circuit is to filter or eliminate various high-frequency signals, such as noise.

Virtual Materials:

- Three 1K resistors.
- One 560Ω resistor
- Two 10nF ceramic capacitors
- One TL081 op-amp
- Multimeter
- Function Generator
- Voltage Source
- Oscilloscope

The circuit implemented is the Sallen-Key voltage-controlled filter (Floyd, 2008), shown in figure 1.

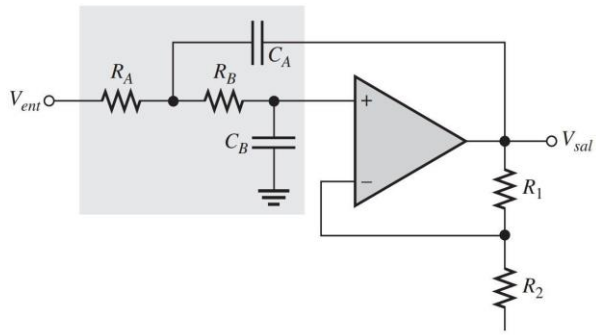

Figure 1 Sallen-Key filter
Source: (Floyd, 2008)

In order to create a fixed filter output, we need to obtain the relative damping factor (DF), which will establish the characteristics of the output signal from either a Butterworth, Chebyshev, or Bessel filter. The literature recommends using a Butterworth characteristic filter since it allows the frequencies within the bandpass to have the same gain, helping to visualize which signals will be inside easily and outside the filter.

To create a Butterworth characteristic, DF must be equal to 1.414. The formula for finding the damping factor is:

$$DF = 2 - \frac{R1}{R2} \quad (1)$$

Obtaining the damping factor, we proceed to calculate the critical frequency. The equation to find the critical frequency is:

$$fc \frac{1}{2\pi\sqrt(R_A R_B C_A C_B)} \quad (2)$$

The circuit needs a connection to a signal generator, starting from 3V to the TL081 operational amplifier. We use an oscilloscope to obtain the frequency and amplitude of the waveform. First, connect a probe to the generator output (v_i) and another to the TL081 output (v_o), as shown in figure 2. These measures allow the user to compare the input signal with the circuit output signal and helps the user visualize the difference between the two signals depending on the frequency used.

Simulate the circuit with the values mentioned above, as shown in figure 3.

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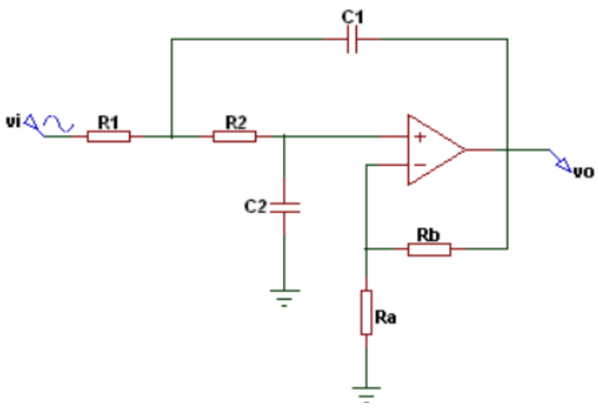

Figure 2 Introducing the signal to the circuit and input and output probe localization, made in Proteus
Source: Self-made

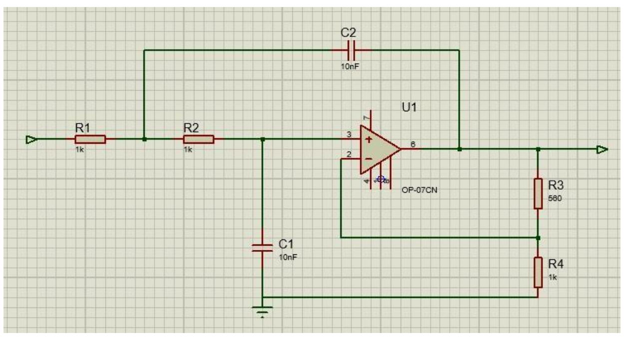

Figure 3 Circuit simulation in Proteus with the proposed values
Source: Self-made

By substituting different values for the circuit components, produce different amplitude output waveforms.

A common way to obtain the Bode Diagram is using the simulators from Matlab and Octave. The frequency response in the Bode Diagram is also available in Proteus. Figure 4 shows a Bode Diagram obtained in Proteus.

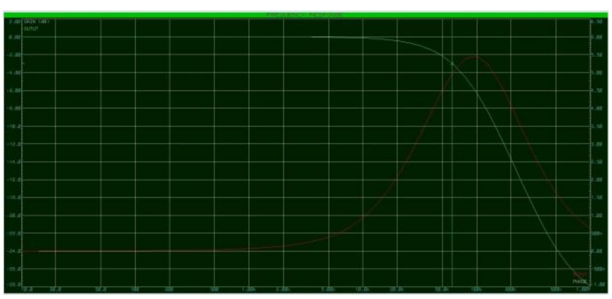

Figure 4 Bode Diagram answer in Proteus. Red: Magnitude and Green: Phase
Source: Self-made

Finally, obtain the amplitude and frequency using an oscilloscope.

Fourier analysis (spectrum)

Fourier analysis is helpful to analyze the frequency content of signals, and the harmonic behavior of a signal, converting a signal to the frequency domain. Fourier plots represent periodic functions, which are the infinite sum of harmonically related sinusoidal functions.

First, draw the electronic circuit to be analyzed to obtain a frequency analysis plot, as shown in Figure 5. Next, place a Fourier plot on the work area. Then, place the oscilloscope probes on the points of the circuit to be analyzed and pick up and drop them on the graph. Edit the chart properties to set the start time, end time, and resolution. Select the time interval and resolution that correspond to the signal to be analyzed. Figure 6 shows the Fourier plot or spectrum.

To obtain a Fourier plot, follow these steps:

- Draw the electronic circuit to be analyzed, as shown in figure 7.

- Place a Fourier plot on the work area.

- Place the oscilloscope probes on the points of the circuit to be analyzed and pick up and drop them on the graphic.

- Edit the chart properties to set the start time, end time, and resolution. Select the time interval and resolution that correspond to the signal to be analyzed. Figure 8 shows the Fourier plot or spectrum.

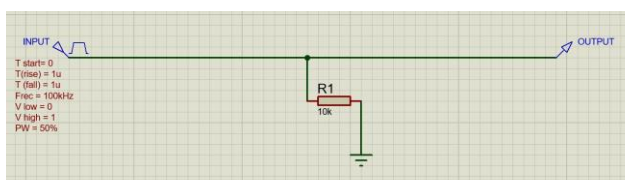

Figure 5 Fourier Analysis Example Circuit
Source: Self-made.

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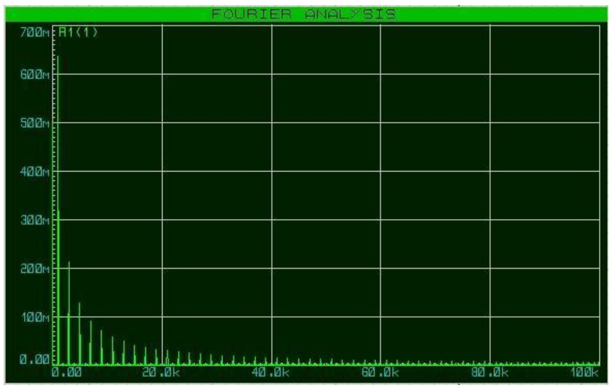

Figure 6 Fourier Analysis Graph or spectrum
Source: Self-made

Control laboratory

A mathematical model, expressed in time or frequency, can be represented, regardless of its order, as the integration of electrical circuits, which, in turn, forms a system that can respond to the input signal:

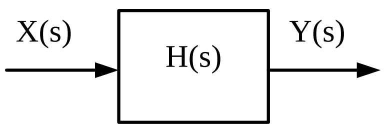

Figure 7 System representation
Source: Self-made

For the analysis of the transient response of a linear system, with a time-invariant input and output, it is convenient to have the representation through the transfer function (3), so that:

$$g(t) = \frac{y(t)}{x(t)} \qquad \mathbf{L} \qquad G(s) = \frac{Y(s)}{X(s)} \qquad (3)$$

It will also be helpful to use block diagram transformations to obtain the transfer function by part, for example, cascade systems, as is shown in figure 8.

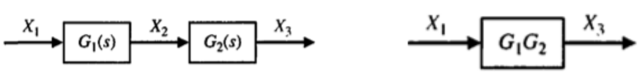

Figure 8 Transformations for obtaining transfer function
Source: Self-made

If we know the plant of the system, G(s), it will only require an input excitation to know the output.

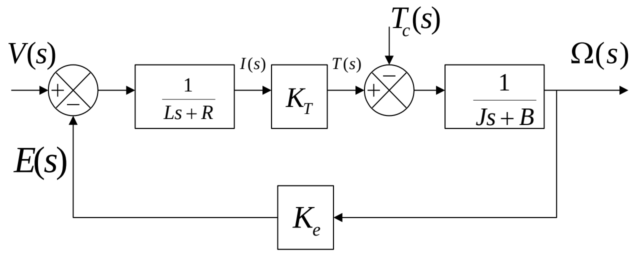

Figure 9 The transfer function for CD motor blocks

$$\frac{\Omega(s)}{V(s)} = \frac{K_T}{JL\,s^2 + (JR + BL)s + RB + K_T K_e}.$$

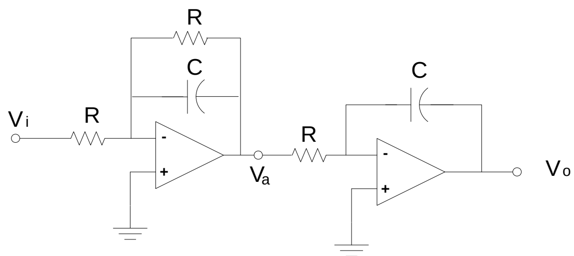

Figure 10 Circuit simulation for plant or process G(s)
Source: Self-made

Table 1 presents the DC motor parameter values used for the simulation.

R	Armor resistance (Ohms)	1.1648
L	Armor Inductance (Henrys)	0.0068
J	Equivalent moment of inertia ($Kg\ m^2$)	1.0271
J_m	Motor inertia moment ($Kg\ m^2$)	0.0271
J_c	Load inertia moment ($Kg\ m^2$)	1
B	Equivalent coefficient of viscous friction ($N\ m/(rad/seg)$)	0,23646
B_m	Motor's coefficient of viscous friction ($N\ m/(rad/seg)$)	0.00776
B_c	Load's coefficient of viscous friction $N\ m/(rad/seg.)$.	0.2287
K_T	Constant drive torque ($N\ m/Ampere$)	0.55
K_e	Constant counter-electromotive force $(V/(rad/seg.))$.	0.82
i	Current in the armor (Amperes)	I(s)
V	Voltage applied to the armor (Volts)	V(s)
ω	Angular speed motor (radians/seg)	$\Omega(s)$
T	Torque developed by the motor (Newton-meter)	T(s)
T_C	Perturbation or Disturbance (Newton-meter)	Tc(s)

Table 1 DC motor parameter values

Remember that it is possible to create a system G(s) from its transfer function, with the configurations presented in figures 11 and 12.

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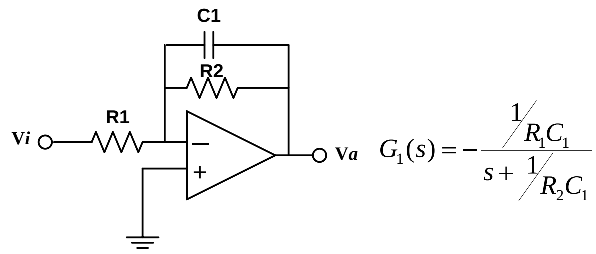

Figure 11 Circuit simulation for plant or process G(s)
Source: Self-made

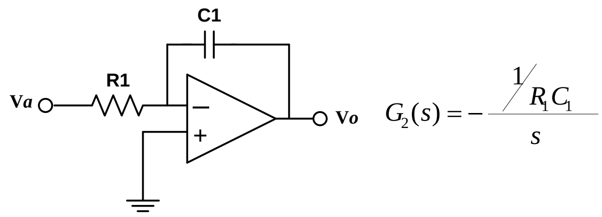

Figure 12 Circuit simulation for plant or process G(s)
Source: Self-made

For the next step, we have to obtain the closed-loop system to watch its behavior without compensation to notice what parameters need to be adequate to the requirements, as shown in figure 13.

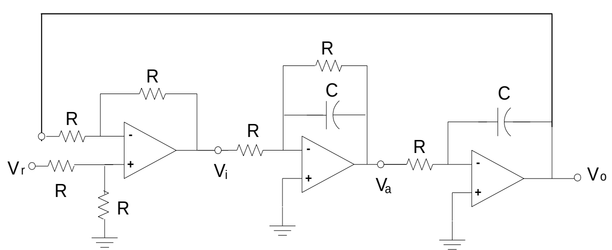

Figure 13 Plant G(s) in a closed-loop
Source: Self-made.

Compensators are added to the original system, either in direct path or in feedback, to improve its performance characteristics to meet the design specifications both in transient and steady-state.

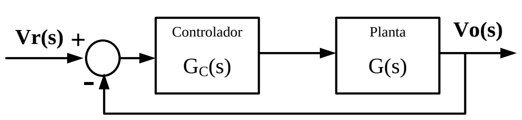

Figure 14 Closed-loop system with controller Gc(s)
Source: Self-made

The controllers will add zeros, poles, or a combination of both to the system, creating a leading or lagging or leading-trailing offset, as appropriate. Table 2 presents the formulas for calculating the elements of the lead-lag compensator.

Type	Compensator transfer function and conditions	Formulas for calculating resistances and capacitors:
Advance	$G_C(s) = K_C \frac{s + 1/T}{s + 1/\alpha T}$ $0.07 < \alpha < 1$	where: $T = R_1C_1$, $\alpha T = R_2C_2$, $K_c = \frac{R_4C_1}{R_3C_2}$

Table 2 Elements of the overrun compensator

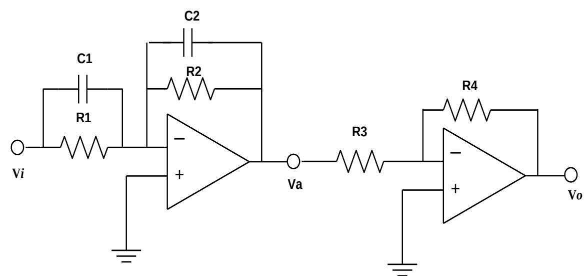

Figure 15 Compensator Gc(s)
Source: Self-made

Once the student finishes with all the connections, he can make measurements by connecting the function generator to the Vr input of the control loop, with a square signal from the generator with an amplitude from zero to one volt, and choosing an appropriate frequency until the transient response, and its steady-state are visible. At this point, we need measurements of the input and output signal of the control loop in each oscilloscope channel so that the student measures the transient, overshoot, and steady-state times.

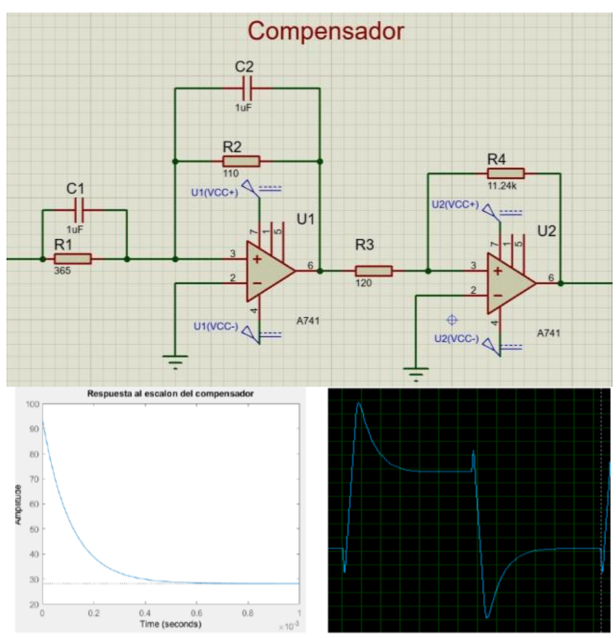

Figure 16 Compensator Gc(s) step response in open loop, obtained in Matlab (left) and Proteus (right)
Source: Self-made

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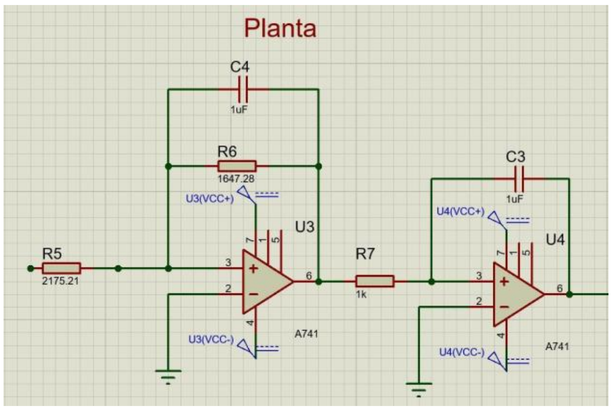

Figure 17 Proteus circuit representing the system G(s)
Source: Self-made

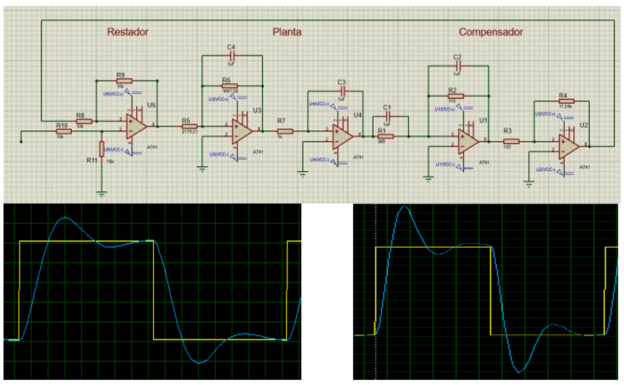

Figure 18 Closed-loop circuit with compensator and the step responses of the uncompensated (left) and compensated (right) feedback system, respectively
Source: Self-made

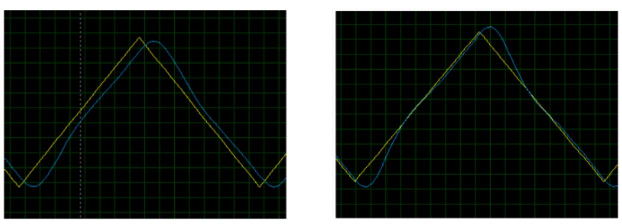

Figure 19 Uncompensated (left) and compensated (right) feedback system ramp response, respectively (Proteus)
Source: Self-made

In addition, this configuration appears in another practice where the input to the control loop is a sine wave, and the frequency compensator design methodology is applied; some of the requested readings are gain, phase relationship at specific frequencies, and the gain and phase margins.

Conclusions

As it is known, traditional students prefer face-to-face learning, but with the COVID-19 pandemic, everything changed, and the way students and instructors work is one of them.

The use of software simulators simplified the transition to online education. The use of Proteus lets the students obtain part of the knowledge they get in traditional learning. The students experiment the different stages of design, simulation and implementation using operational amplifiers that represent a position control loop by means of compensation for a DC motor model.

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