In-Class Laboratory Exercises to Improve a Signals and Systems Course

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Laboratory Exercises for Signals and Systems

Abstract:

Signals and systems is a course that introduces students to mathematical concepts that are used to analyze systems or signals. In Wentworth Institute of Technology signals and systems was taught in the conventional way using lecture and readings to explain the theory and by assigning paper-based problem sets of theory and math. Conceptual understanding of the course content remained a challenge for many undergraduate students. A series of laboratory exercises was developed to help students visualize the complex mathematical concepts and gain a better appreciation for how the concepts are useful in real-world situations. Some of the exercises were hardware based hands-on activities and others were software based simulations.

Hardware based hands-on included amplitude modulation (AM), demodulation, and sampling by Telecommunication Instructional Modelling System (TIMS). Software-based simulation exercises included filter design and signal synthesis to strengthen understanding of the frequency response.

Evaluations were based on student performance of the new laboratory assignments, course grade, and student surveys (course evaluations). Recent offerings of this course taught in the traditional way by the same instructors resulted in only 53% of the students receiving a “B-” or higher grade for the course. In the first iteration of new laboratory exercises, the number of students who received a “B-” or better increased to 76%. Moreover, 87% of students “agree” or “strongly agree” that the laboratory exercises helped them to better learn the course content. 81% “of the students agree” or “strongly agree” that laboratory exercises increased their interest in the subject.

Introduction

Courses for undergraduate engineering students in signals and systems are usually the sophomore or junior level at many universities. Such courses provide an introduction to the concepts of signal operations, classifications of signals and systems, time-domain analysis of continuous-time systems, Laplace transform, Fourier analysis, sampling and discrete-time signal analysis. Courses in signals and systems are based on complex, abstract, theoretical, and mathematical concepts that are hard for many undergraduate engineering students to fully understand [1-4]. Typical pedagogy involves theory with lectures and readings, mathematical homework, and exercises with computer simulations. The concepts are difficult for the students to visualize. Most students have no conscious personal experience with these phenomena [1-4].

At our university, junior level electrical and computer engineering students with the required prerequisites of network theory, and multivariable calculus take signals and systems to acquire a strong foundation for advanced courses, such as digital signal processing and feedback controls. This course is a 4 hour lecture, 4 credit course. Problem sets related to these topics were assigned. However, our lecture based course did not have a hands-on laboratory component.

Inspired by an ASEE paper that reported on an analog-circuit platform [1] that was developed at Rose-Hulman Institute of Technology, eight labs were developed and used in the course. Three labs were hardware based and others were MATLAB based simulations. Another ASEE workshop was held at University of Rhode Island that focused on combining MATLAB simulation with Telecommunication Instructional Modelling System (TIMS) [2]. As an adaptation of these example practices, we developed three hardware based TIMS labs, which include amplitude modulation, amplitude demodulation, and sampling. This paper presents examples and effectiveness of the new laboratory exercises that were developed for and used within a junior-level signals and systems course, and compares the results with a prior, more traditional style offering of the course by the same instructors.

Design of New Labs

Five MATLAB computer simulation labs were developed to supplement the TIMS labs: system linearity, frequency response and Bode plots, filter design, Fourier series, and distortion analysis. The students did each lab with two students per group.

TIMS is a hardware training system, designed specifically for signal processing and telecommunications courses that requires only TIMS modules and an oscilloscope to use the system [5]. The TIMS system provides each hardware signal processing and telecommunication block as a “black box” to the students. This allows the students to combine several blocks in a short time, including generating input signals and analyzing the output signals. TIMS labs allow students to experiment with real world electrical signals in a way that is doable and understandable for more students compared to utilizing only theory and simulations [5].

As an example of the developed TIMS labs, the first TIMS lab investigated amplitude modulation. Figure 1(a) shows the block diagram for amplitude modulation, for which Figure 1(b) shows the module connections. In this system, the message was a 1 kHz sinusoid wave. This was added to a DC offset voltage, followed by multiplication with the carrier, a 100 kHz sinusoid wave. The students set up this system on TIMS and evaluated the function.

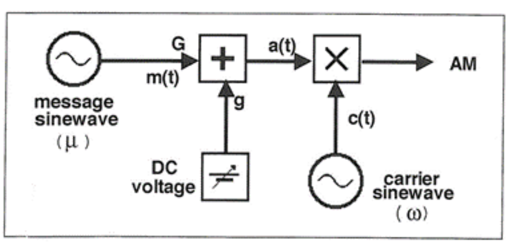

Figure 1(a) Generation of AM. A generated sinewave has a DC offset added. The resulting signal is multiplied by a carrier sinewave.

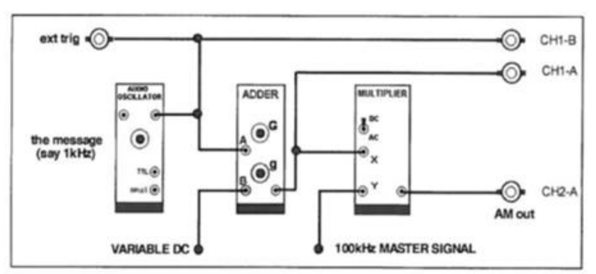

Figure 1(b) Module connections for schematic of Figure 1(a).

An image of the TIMS connected for this lab is shown in Figure 2. The TIMS rack system consisted of the following equipment: (a) Emona TIMS and (b) Agilent MSO-X 3102A oscilloscope. Three modules, Audio Oscillator, Adder, and Multiplier, were used for amplitude modulation. Students used TIMS modules to generate an amplitude-modulated signal with 100 kHz carrier. They varied the amplitude and frequency of the modulating signal and modulation indices to display the results on oscilloscope in both time and frequency domains. Then, the students modulated signals generated by function generator and observed them in time and frequency domains. Figure 2 shows an image of the TIMS modules and connections that implement modulation.

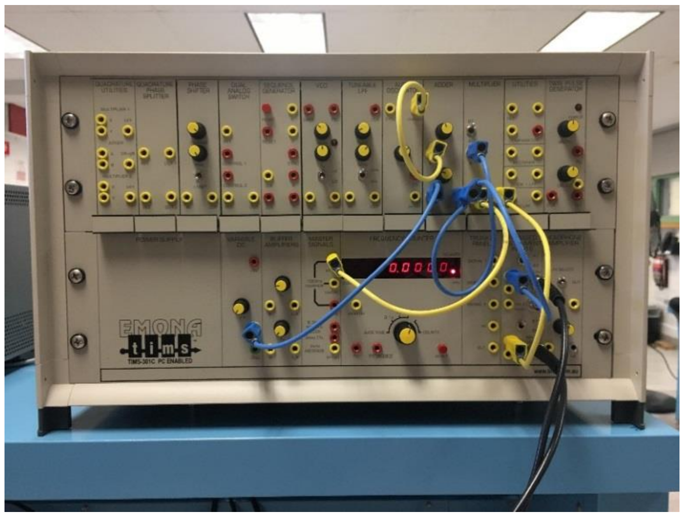

Figure 2 TIMS platform for amplitude modulation and demodulation.

Figure 3 shows the time and frequency domains of modulated signal. The upper trace in yellow is the message. The lower trace in green is the modulated signal and the middle trace in purple is the frequency domain representation of the modulated signal.

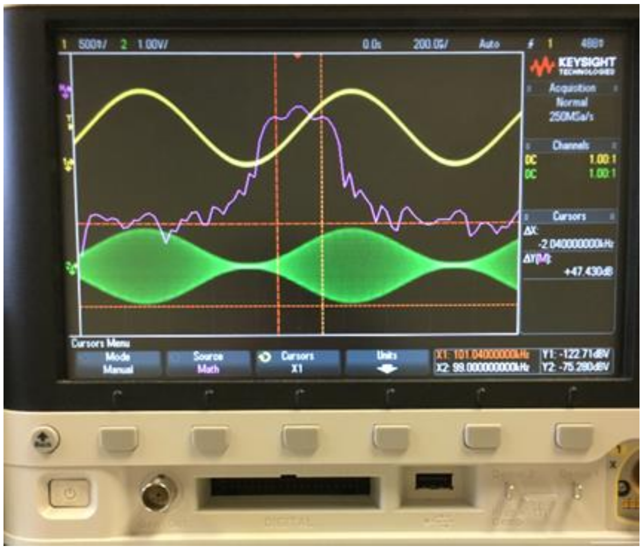

Figure 3 Amplitude modulated signal in time and frequency domains.

By taking measurements from TIMS modules and comparing them to hand calculations using the abstract equations developed in the course, the students have been able to visualize the relation between the circuit function and the abstract equations. The visualization strengthens the relations between circuit, theory, and equations. Slowly the developing understanding leads to intuition.

As an example of the MATLAB based simulation labs, an exercise of filters design was done. The following signal x(t) includes a DC component, and two sinusoid waves with different frequencies. The students were asked to design corresponding low-pass, band-pass, and high-pass filter to extract the DC signal, $x_1(t)$, and $x_2(t)$ from x(t), respectively. 2nd-order RLC circuit was designed for each filter and students chose all the parameters.

$$x(t) = \underbrace{10}_{dc} + \underbrace{2\sin(100\ \ t)}_{x_1(t)} + \underbrace{4\sin(1000\ \ t)}_{x_2(t)}$$

Figure 4 and 5 show MATLAB simulation results. Figure 4 shows Bode plots of the designed low-pass filter, band-pass filter, and high-pass filter. Figure 5 shows DC signal and its filtered version, $x_1(t)$ and its filtered version, and $x_2(t)$ and its filtered version.

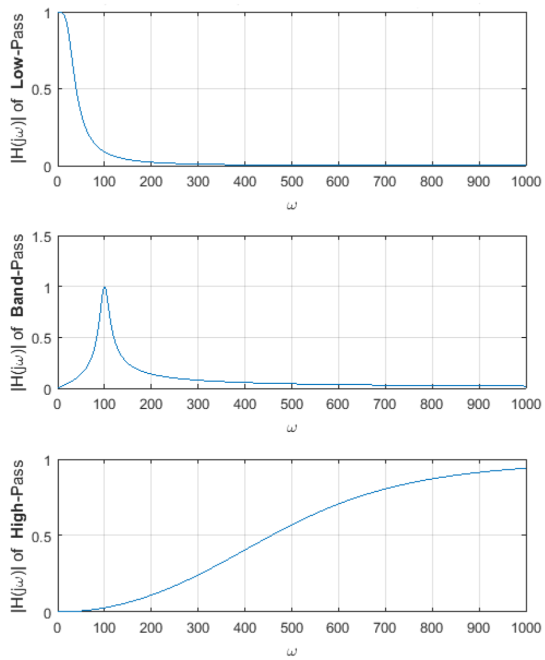

Figure 4 Magnitude response of the filter (Frequency-Domain)

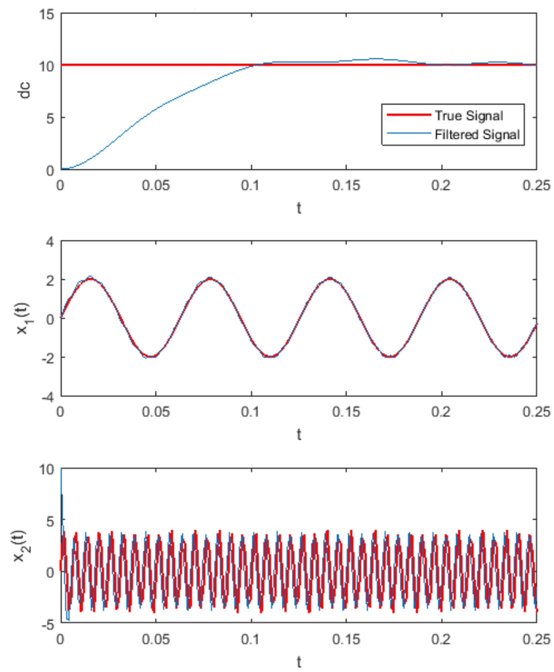

Figure 5 Signal and its filtered version (Time-Domain)

The exercise helps students visualize filtering of a signal from the original signal. As the students were designing the filters, they had visualized the effects of different parameters. This could help strengthen the conceptual coupling of frequency domain of filters and the time domain of the resulting signal.

The other 4 MATLAB computer simulation labs and 2 TIMS labs are listed in Table 1. The first 4 labs are MATLAB labs and the last 2 labs are TIMS labs.

Table 1: Signals and Systems labs

Lab Title	Lab Description
System linearity	A linear system is one that satisfies the superposition principle. The principle of superposition requires that the response of the system to a weighted sum of signals be equal to the corresponding weighted sum of the response (outputs) of the system to each of the individual input signals. Students used MATLAB to graphically verify the linear/nonlinear property of each system.
Frequency response and Bode plots	Students were asked to determine the frequency response (both magnitude and phase responses) of each given system and

	plot the system frequency response by MATLAB.
Fourier series	Students were asked to calculate Fourier series equation of a given periodic signal. Then reconstruct the signal using different numbers of harmonics to see the effect.
Distortion analysis	Students observed signal distortion with oscilloscope and calculated the total harmonic distortion (THD) percentage with MATLAB.
Amplitude demodulation	Students used TIMS telecommunication systems modules to demodulate the modulated message signal and observed the signal in time and frequency domains.
Sampling	Students used TIMS telecommunication systems modules to sample analog signals and observed the signals.

Results

Course assessment of Signals and Systems labs:

Table 2 provides the students' final grades when the signals and systems course was taught either with lectures only or with lectures and the new laboratory exercises by the same instructors. 34 students enrolled in the lectures-only classes and 82 students took the course when the laboratory exercises were assigned during the recent two years. All students in the lecture-lab classes completed all of these laboratory assignments.

Table 2: Students final grade distribution

Final grade	**A and A-**	**B+, B, and B-**	**C+, C, and C-**	**D+ and D**	**F**
Lectures only	**14.7%**	**38.2%**	**20.6%**	**17.7%**	**8.8%**
New laboratory exercises	**22.0%**	**53.7%**	**14.6%**	**7.3%**	**2.4%**

When students studied the course with lectures only, 53% of the students received A/A- and B+/B/B-. In the first offering of the course using the new laboratory exercises, the number of students who received A/A- and B+/B/B- jumped to 76%. The number of students who failed the course declined from 8.8% to 2.4%.

Student feedback of the new laboratory exercises:

A survey was conducted the last week of the semester each year in the past two years to collect feedback to evaluate what the students thought about the new laboratory exercises labs. Based on the survey, 81% of students "agree" or "strongly agree" that the laboratory exercises increased their interest in the subject (Figure 6), 87% of students "agree" or "strongly agree" that the laboratory exercises helped them better to learn course content (Figure 7), and 88% of the students thought the laboratory exercises were excellent or very good (Figure 8).

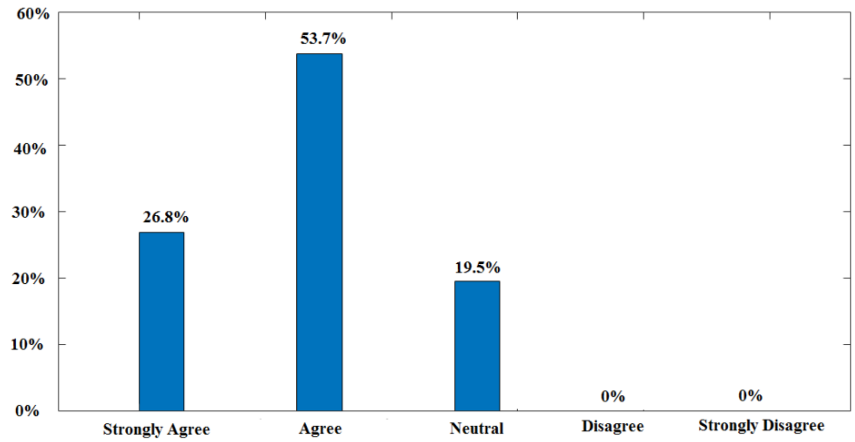

Figure 6: Results for question "The laboratory exercises increased my interest in the subject."

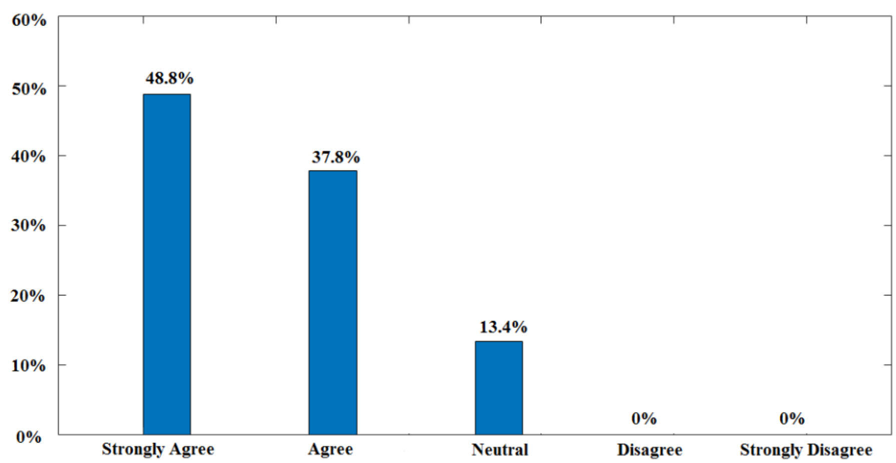

Figure 7: Results for question "The laboratory exercises helped me better to learn course content."

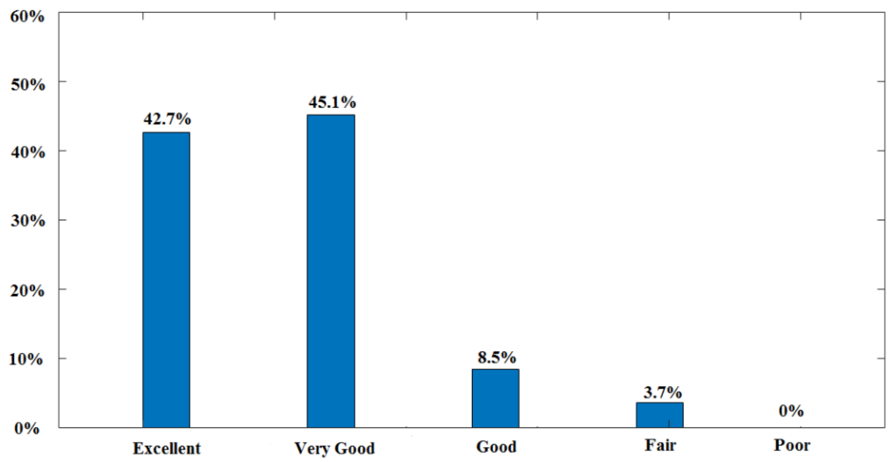

Figure 8: Results for question “What overall rating would you give the laboratory exercises.”

Discussion and Conclusions

Signals and systems is an abstract mathematical course, in which many students have difficulty relating to their experience or gaining intuition. At many institutions, the signal and system course is lecture only without any formal laboratory. In this paper laboratory type of exercises were designed to be added to the course. These activities were utilized and all students completed all of the new laboratory assignments. Based on improvement in student grades and positive feedback from students in a survey, the laboratory activities seem to enhance engagement and learning. The laboratory exercises helped the students develop a practical understanding of the abstract concepts of signals and systems, including time domain, frequency domain, and S domain.

To help students develop a way to relate the abstract equations of signals and systems to concepts they have already learned, some of these activities should be based on phenomena they already are familiar with, such as electrical circuits. By having the students make measurements, tables, and graphs, they can start to visualize the relations between familiar phenomena, and new theory and equations.

In addition, the laboratory exercises usually involved group work. Engineers are now, more than ever, are expected to collaborate and cooperate with others [10]. Thus, the activities provided another experience collaborating with their peers, especially for complex math related activities.

Having a combination of MATLAB simulations and TIMS hardware labs seemed to be a good combination to enhance student engagement and learning. One idea for even more improvement would be to add more TIMS based hardware lab [5]. Another future direction would be to assess whether the students who have benefited from the new laboratory exercises will continue to be more successful in their future study.

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