Enhancing Students' Lab Experiences using Simulink-based Pre-Labs of Corresponding Hardware-based Labs

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Abstract:

This paper describes a novel instructional technique that enhances students' interests and lab experiences when Simulink-based pre-laboratory exercises are introduced to every corresponding hardware-based lab in analog and digital communication systems. Analog and digital communication systems course is always considered one of the most difficult course in the curriculum of electrical engineering due to rigorous mathematics and lack of signals' visualizations. This is a 4-credit course in our university and offered to junior/senior level students with 3 lecture hours and 3 lab hours per week. The communication systems laboratory consists of TIMS system from Emona Technologies which is based on modules. Students always find difficulty to visualize signals simultaneously at various stages in a communication system as well as feel fear to use hardware equipment, which eventually limits students' curiosity and creativity in the lab. Thus, we integrate Simulink-based pre-laboratory exercises of each corresponding hardware-based lab experiment. The feedback from students has confirmed that these pre-lab exercises successfully improved the effectiveness of lab experiments.

1. Introduction

Analog and digital communication systems is a required course for junior/senior electrical engineering students in most universities[1]. Computer engineering and computer science students also take this course as an elective. This course is a pre-requisite for almost all courses in the area of telecommunications such as wireless communications, advanced communications, detection and estimation, advanced digital communications, etc. This course includes a variety of topics ranging from analog communication systems to digital communication systems[2]. The main topics in this course include double sideband suppressed carrier (DSB-SC) modulation, conventional amplitude modulation (AM), single sideband suppressed carrier (SSB-SC) modulation, quadrature amplitude modulation (QAM), phase-locked loop (PLL), frequency modulation (FM), phase modulation (PM), pulse code modulation (PCM), delta modulation, binary pulse amplitude modulation (PAM), M-ary pulse amplitude modulation (M-PAM), phase shift keying (PSK), frequency shift keying (FSK), etc.

In lectures, students are taught analog and digital modulation techniques using block diagrams of the modulation systems which is heavily supported by mathematical derivations and models[2]. In communication systems laboratory, students perform experiments using lab equipment from National Instruments' Universal Software Radio Peripheral (NI USRP) or TIMS system from

Emona Technologies[3]. The later one, Emona TIMS, provides an excellent set of experiments which is modular based and perfectly aligned with analog and digital communication systems curriculum, thus it is widely used in communication systems laboratory in most universities[4].

In Emona TIMS based communication systems laboratory, a typical bench consists of all required modules from Emona Technologies as well as a spectrum analyzer and an oscilloscope. Spectrum analyzer and oscilloscope are used to visualize signals at various stages in a communication system. Due to the cost of these equipment (spectrum analyzer and oscilloscope) and space in a bench, only one spectrum analyzer and one oscilloscope are available at one bench, hence students can not view signals at various places simultaneously in a communication system which they have developed using Emona TIMS lab equipment. In addition, the high cost and delicate nature of Emona TIMS modules make them fear of damaging the modules. Therefore, students strictly follow instructions in the lab manual to complete their lab exercises which restricts them to use only one approach to achieve lab objectives. Consequently, these shortcomings, signals visualization and try only one approach, limit students' curiosity and creativity in the field of communication systems. Thus, we developed Simulink-based pre-laboratory examples and exercises to provide a practice environment to students before hardware experiment.

Although, TIMS Emona has web-based virtual laboratory for communication systems, which is quite expensive as well as limits students to only one kind of hardware and software. Moreover, MATLAB[5] or any other programming environment can be considered for communication systems exercises[6], however, it requires extensive programming skills which junior level students may not have. Thus, Simulink which uses model-based approach, provides an extensive set of pre-defined blocks[7,8]. It is easy to use by drag and drop a block on the work area and connecting these blocks to develop complete communication system. The display blocks include spectrum analyzer and scope to visualize frequency-domain and time-domain signals, respectively. Often, the communication system model developed in Simulink resembles to the system model given in any textbook. Simulink is integrated with MATLAB therefore university already has its license and most universities provide license to students. The use of Simulink does not cost any additional budget from the university. Because of all these advantages of Simulink, we decided to use Simulink for pre-laboratory exercises. We have also used Simulink for computer-based assignments in this course, however, we will limit our discussion on pre-laboratory exercises in this paper.

The modules in Emona TIMS lab equipment are simple electronic circuits and function as building blocks of analog and digital communication systems. A block or a set of blocks in Simulink can be modeled corresponding to each module in Emona TIMS to perform the same function of building block in a communication system. In analog and digital communication systems' lab in our university, we developed pre-laboratory exercises with supporting examples in Simulink which exactly correspond to experiments using Emona TIMS lab equipment. We demonstrated the Simulink[5] examples and explained pre-lab exercises to students. Students were required to complete Simulink-based pre-lab exercise before lab experiment. These pre-lab exercises completely removed the limitations mentioned above and enhanced students' interests and creativity in the communication systems' lab. In the following sections, we will discuss the pre-lab exercises with their corresponding TIMS Emona hardware experiment. We will also demonstrate the effectiveness of these pre-lab exercises.

2. Double Sideband Suppressed Carrier (DSB-SC) Communication System

In double sideband suppressed carrier (DSB-SC) transmitter, the transmitted signal $g(t)$ is obtained by simply multiplying the information signal $m(t)$ with the carrier signal $c(t)$ as shown in Figure 1. At the receiver, the received signal $g(t)$ is multiplied by carrier signal $c(t)$ and then passed through a low pass filter to recover the information signal $m(t)$, as shown in Figure 2.

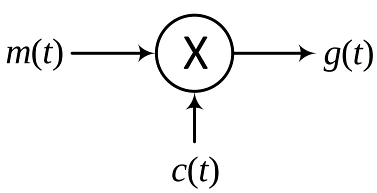

Figure 1: DSB-SC Transmitter

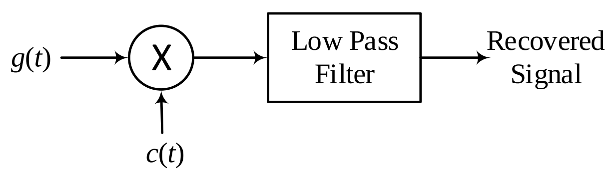

Figure 2: DSB-SC Receiver

To implement this DSB-SC communication system in the lab using TIMS Emona hardware, audio oscillator $m(t)$, voltage control oscillator $c(t)$, multiplier and low pass filter modules are required. The signals at different stages during the lab are displayed on oscilloscope and spectrum analyzer. The DSB-SC transmitter and receiver are developed as shown in Figure 3.

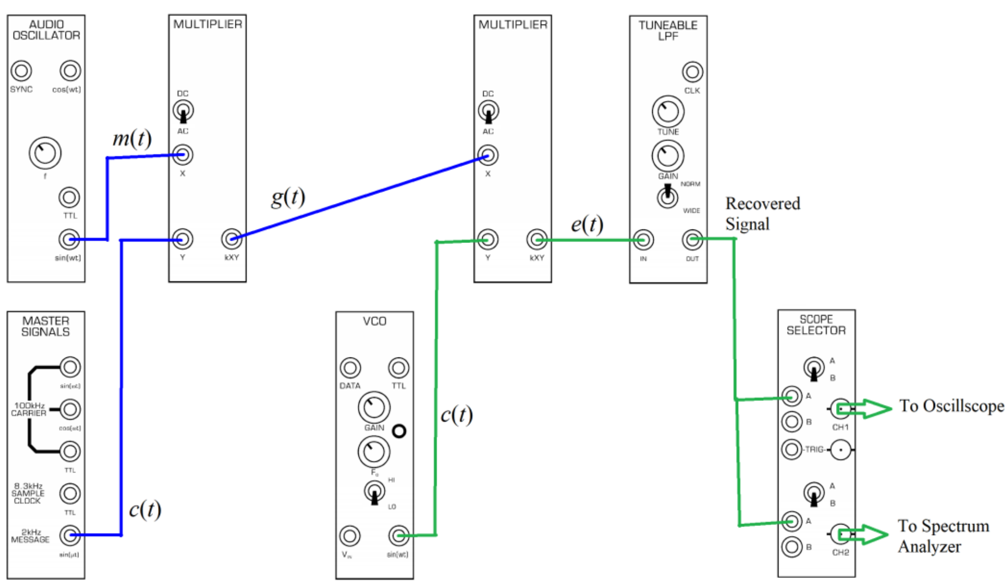

Figure 3: DSB-SC Transmitter and Receiver using TIMS Hardware Modules

In this hardware setup, students can not visualize more than two signals simultaneously in oscilloscope or spectrum analyzer which impedes their learning. Moreover, most students feel hesitant to use the hardware confidently. Furthermore, most students use the given values of the parameters and do not try something new. All these shortcomings can be resolved, if students perform a pre-laboratory exercise using Simulink.

In pre-lab exercise, students develop a DSB-SC transmitter and receiver using Simulink, as shown in Figure 4. First, sine wave block is used to generate information signal (message signal) $m(t)$ as well as to generate carrier signal $c(t)$ with given carrier frequency. If required, cosine signal can be generated using sine wave block by adding a phase of $pi/2$ in the block properties. Both signal blocks $m(t)$ and $c(t)$ are connected to the multiplier block to take product of the two to generate DSB-SC modulated signal. At receiver side, a sine wave block is used to generate carrier signal with given carrier frequency, and then multiplied with the received signal using multiplier block. Finally, the output of multiplier is fed into a low pass filter using analog filter design block to obtain the recovered signal. Scope and spectrum analyzer blocks are used to visualize the signals in time-domain and frequency-domain, respectively.

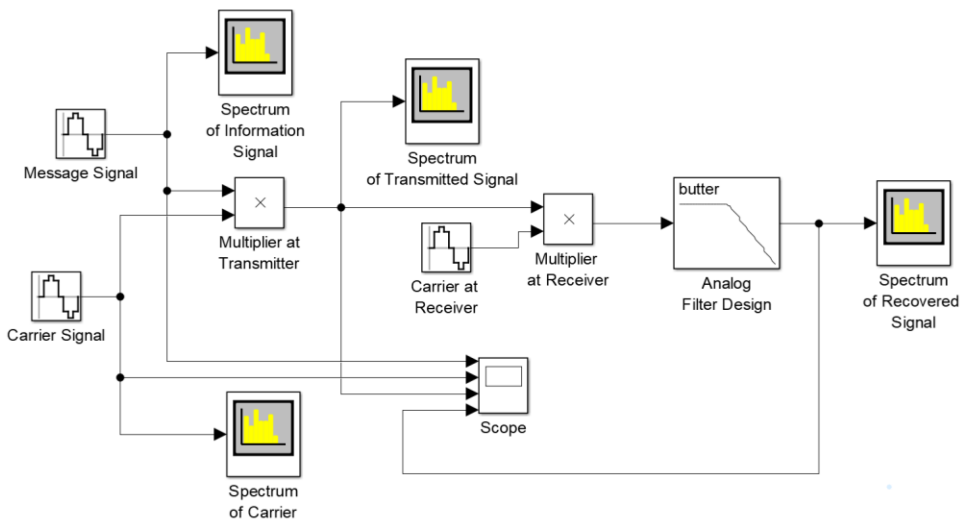

Figure 4: DSB-SC Transmitter and Receiver in Simulink

Conventional Amplitude Modulation (AM) Communication System

In conventional amplitude modulation (AM), the transmitted signal $g(t)$ is obtained by first adding a constant to the information signal $m(t)$ and then multiplying the sum with the carrier signal $c(t)$ as shown in Figure 5. At the receiver, the received signal $g(t)$ is passed through a diode rectifier then through a low pass filter to recover the information signal $m(t)$, as shown in Figure 6.

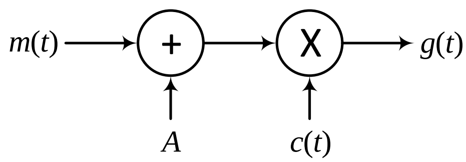

Figure 5: AM Transmitter

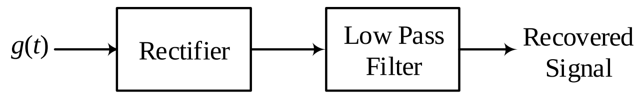

Figure 6: AM Receiver

Several TIMS Emona hardware modules are required for the conventional AM communication system in the lab, as shown in Figure 7. First, audio oscillator $m(t)$ and variable DC voltage modules are connected to adder module in order to add them. Second, both output of adder module and master signal $c(t)$ are connected to the multiplier module to generate conventional modulated signal $g(t)$. Then, the modulated signal is fed into rectifier (utilities module). Finally, the output signal from rectifier is passed through tuneable LPF module to get the recovered signal. This recovered signal can be connected to scope selector module to visualize the signal in the oscilloscope and spectrum analyzer.

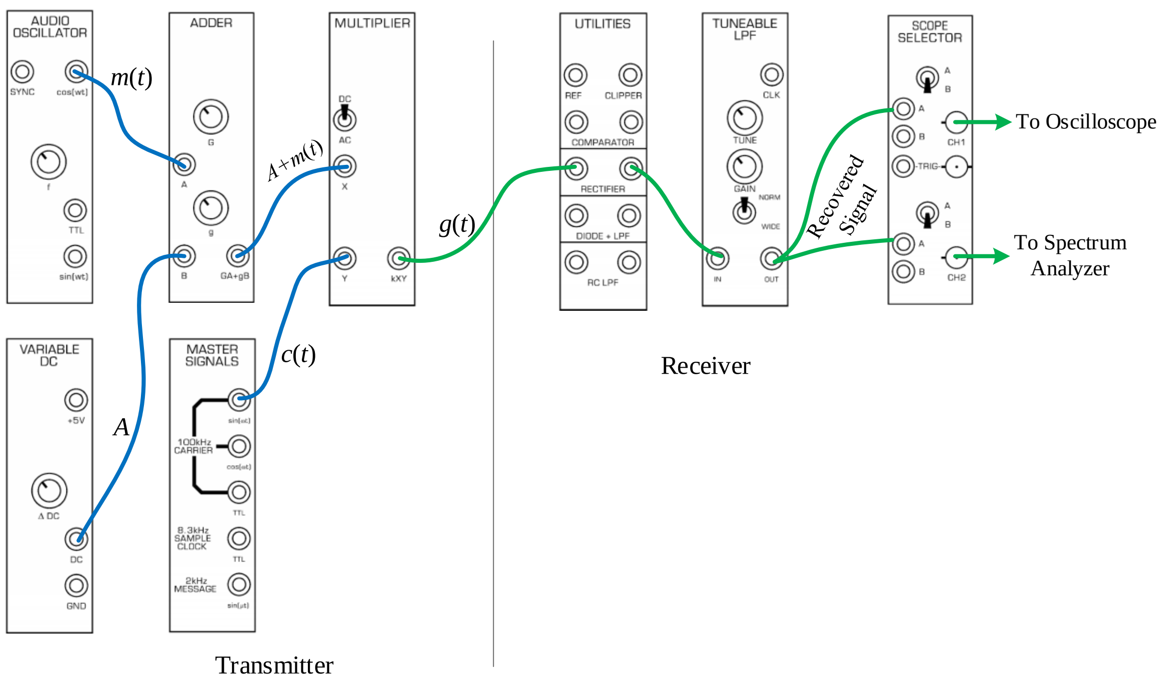

Figure 7: Conventional AM Transmitter and Receiver using TIMS Hardware Modules

In conventional AM pre-lab, students develop the communication system in Simulink as shown in Figure 8. First, sine wave block is used to generate information signal $m(t)$ and constant block is used to generate a constant DC voltage ‘A’. Both blocks are then fed into the add block to add signals together. Second, carrier signal $c(t)$ is generated using sine wave block with a given carrier frequency and then fed into multiplier block to generate AM modulated signal $g(t)$. Next, square law modulator is used to mimic TIMS rectifier module, where the signal is squared using math function block and then passed through an amplifier using gain block. Finally, the signal is passed through a low pass filter using analog filter design block to obtain the recovered signal.

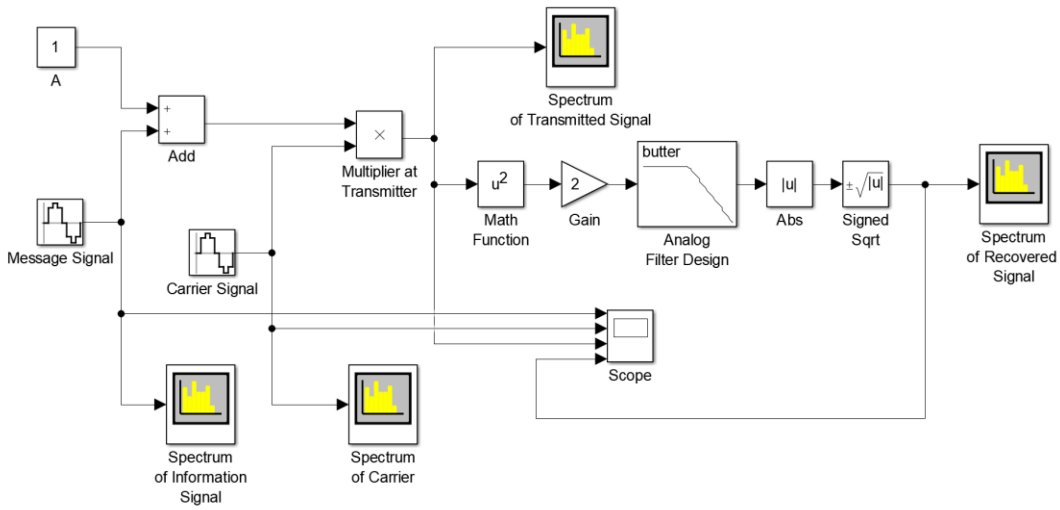

Figure 8: Conventional AM Transmitter and Receiver in Simulink

Single Sideband Suppressed Carrier (SSB-SC) Communication System

In single sideband suppressed carrier (SSB-SC), the transmitted signal $g(t)$ is obtained by adding the product of information signal $m(t)$ and the carrier signal $c(t)$, and the product of $pi/2$ shifted version of information signal and $pi/2$ shifted version of carrier signal, as shown in Figure 9. At the receiver, the received signal $g(t)$ is multiplied with the locally generated carrier signal and then passed through a low pass filter to recover the information signal $m(t)$ as shown in Figure 10.

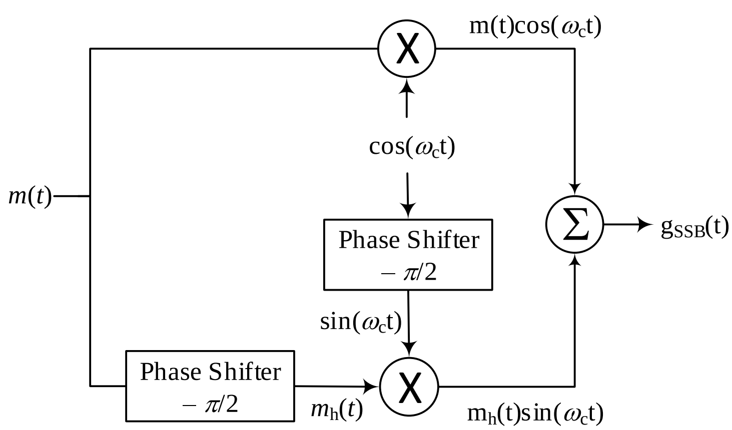

Figure 9: SSB-SC Transmitter

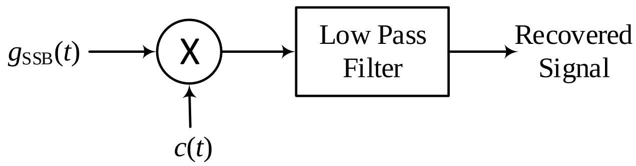

Figure 10: SSB-SC Receiver

To implement SSB-SC communication system, various TIMS modules are required in the lab and are connected according to Figure 11.

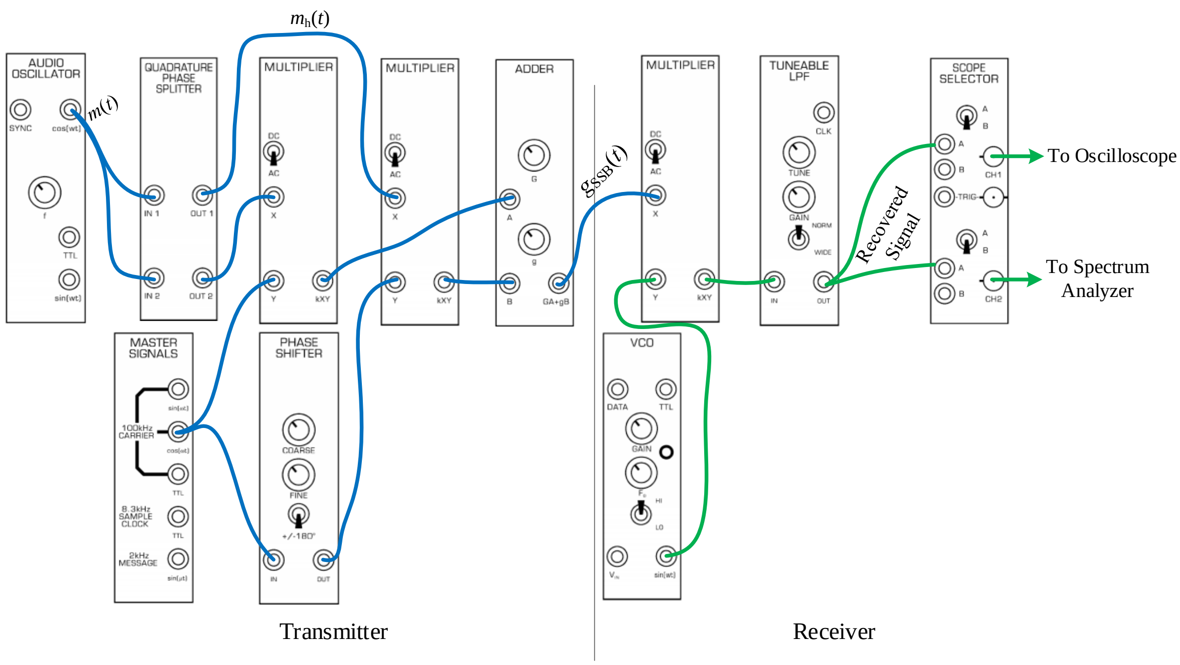

Figure 11: SSB Transmitter and Receiver using TIMS Hardware Modules

In the corresponding pre-lab exercise, students develop the Simulink model according to Figure 12. Note that there is no Hilbert transform or signal phase shift block in Simulink's communication system toolbox or digital signal processing (DSP) system toolbox. Phase shift to the signal is implemented using magnitude-angle to complex and complex to real-imaginary blocks. First, a constant block with 90 value is configured and fed into the angle input of the magnitude-angle block. The signal needed for phase shift is fed into the magnitude input of the magnitude-angle block. The output of the magnitude-angle block is connected to the complex to real-imaginary block. Finally, the output from the real part of the complex to real-imaginary block is used, as it provides the pi/2 shifted version of the signal. This set of blocks for phase shifting is used for carrier signal as well as message signal to obtain their phase shifted (Hilbert transform) versions.

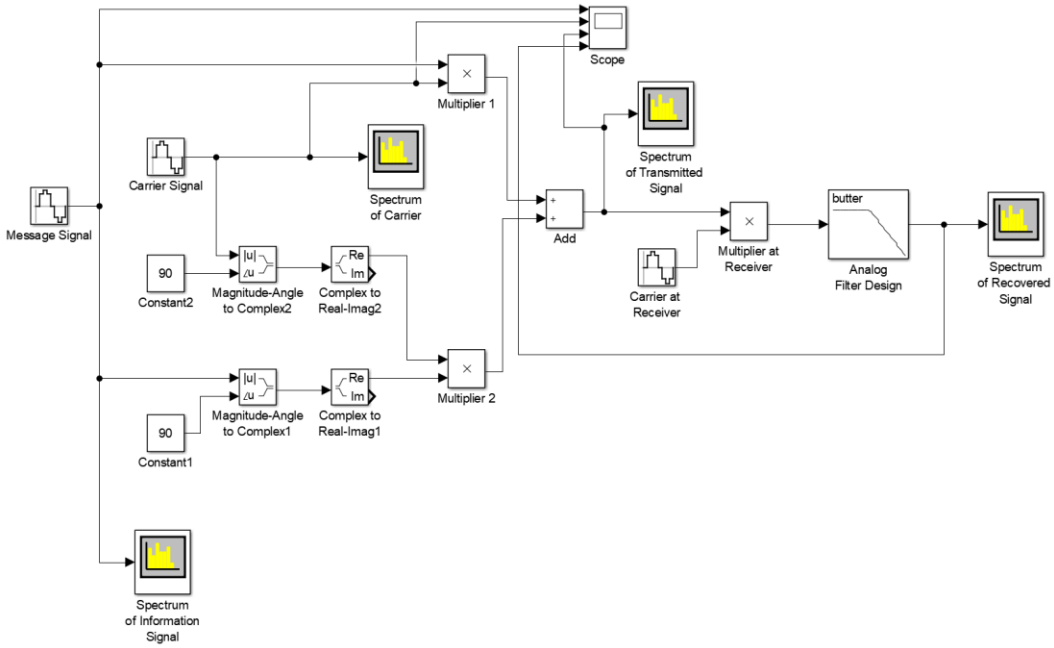

Figure 12: SSB Transmitter and Receiver in Simulink

Discussion

Developing the communication system strengthens students' concepts learned in the lecture. Simulink blocks are similar to TIMS Emona modules, such as Simulink multiplier block is similar to TIMS multiplier module, message signal generator is similar to audio oscillator, and so on. Therefore, working on pre-lab using Simulink prepares students for the hardware lab. When students perform lab experiment using hardware, they are already aware of different blocks/modules and their functions, so they remain confident throughout the lab work. If students find any error in the resulted signals, they quickly find its solution. If students would like to try different frequencies and parameters, they first check with Simulink and then they try it in hardware. Students are also able to visualize signals at any stage and compare them using scope and spectrum analyzer blocks in Simulink, which also helpful for them to troubleshoot their designed communication system.

We also collected feedback from students, which confirms that integration of Simulink-based pre-lab exercise corresponding to each hardware-based lab experiment improved students' learning and experience in the communication systems' laboratory.

Conclusion

In this paper, we introduced an effective instructional technique to enhance students' understanding and experiences in the laboratory. This instructional technique when incorporated in pre-laboratory exercises also filled the gap between lecture and laboratory experiments.

Students were assigned pre-lab exercises of the corresponding lab to design the system using Simulink. Simulink was selected as its blocks look like TIMS modules. Performing pre-lab exercises not only improved students' confidence in the lab but also removed the fear of damaging equipment. Moreover, it increased students' curiosity to try different parameters and signal types in Simulink to grasp the topic completely. When, we asked students, they provided positive feedback that the pre-labs improved their lab experiences.

References

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