An Undergraduate Engineering Ethics and Leadership Education Program

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Amplitude Modulation Circuit Implementation for use in an Undergraduate Communication Course for Electrical Engineering Students

Abstract – Modern descriptions of analog communication schemes are mathematics based using transform theory and block diagrams. This presentation style leaves undergraduate students with the challenge of relating these theories to real world circuit implementations. This is particularly true if the lecture class does not have a complementary laboratory component. This paper attempts to bridge this gap by presenting a basic yet comprehensive project that can be used to demonstrate amplitude modulation and demodulation theory. It is specifically designed to stir the interest of junior or senior level electronics minded electrical engineering students. In this project, a double sideband large carrier waveform is produced using a simple switching modulator circuit. The resulting amplitude modulation (AM) waveform is then demodulated using an envelope detector circuit. The proposed project requests that students perform a circuit simulation as well as an actual circuit implementation. The circuit behavior is studied via both analysis using software tools and measurement using hardware components. The project further requires that the electrical signals are visualized in both the time and frequency domain to enhance concept understanding. The paper outlines an introduction to the modulation theory along with an overview of the necessary circuits and concepts. Additionally, suggested student activities, project assignment alternatives, along with detailed mathematical solutions are provided.

Keywords: Engineering communications, Circuit Projects, PSpice software.

BACKGROUND

Course projects are one of the seven high impact practices discussed by Koh in [1]. Additionally, hands on activities are noted to improve learning motivation and retention. For example, it is noted by Zhan in [2] that the use of real world examples in the classroom improves student involvement and enhances the learning experience. In that regard, the electrical engineering curriculum has used simulations to assist student learning for more than two decades. A strong argument for the use of circuit simulators in the classroom can be found in [3], where the authors argue the superiority of the “learn by doing” approach to teaching circuit analysis. A more recent example of this teaching paradigm can be found in [4] where circuit simulation software is combined with Mathcad to permit student interactive experimentation.

Incorporation of projects into lecture classes provides an added mechanism to align the curriculum with the Accreditation Board for Engineering and Technology (ABET) program outcomes. Four of the relevant program outcomes are listed below.

- **Outcome a:** "an ability to apply knowledge of mathematics, science, and engineering"

  The proposed project requires the student to apply communications theory to a practical circuit implementation.
• **Outcome b:** "an ability to design and conduct experiments, as well as to analyze and interpret data"

The proposed project provides the opportunity for the student to experiment with the circuit parameters and evaluate the circuit response.

• **Outcome e:** "an ability to identify, formulate, and solve engineering problems"

The proposed project gives the student a chance to solve for a number of circuit components and signal parameters associated with the assignment.

• **Outcome k:** "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice"

The proposed project uses modern simulation software and basic circuit measurement techniques to produce the requested results.

**INTRODUCTION**

Senior level undergraduate electrical engineering students at The Citadel may elect to take a one semester course in Communications Engineering as part of their degree requirements. This three credit hour course presents the basic principles of analog communications systems including signal flow and processing in amplitude, frequency and pulse modulation systems. This course is typically taught using one of the popular Communication Engineering textbooks such as ref [5]. Unfortunately, these texts can be overly mathematical, leaving the student mystified by the modulation and demodulation process. The purpose of this paper is to describe a simple circuit simulation project that demonstrates the relevant concepts in an intuitive manner.

This project covers amplitude modulation and demodulation. A double sideband large carrier waveform is produced using a simple switching modulator circuit. The resulting AM waveform is then demodulated using an envelope detector circuit. It requires the students to simulate the circuit and then construct the circuit and monitor signal in both the time and frequency domain. Plots and discussion are required at each stage to show understanding of the relevant modulation concepts.

The learning objectives for the proposed project covering six levels of Bloom’s taxonomy are:
1. The student should be able to list the necessary components of the AM switching modulator and the associated demodulator circuit.
2. The student should be able to explain the operation of the switching modulator and demodulator.
3. The student should be able to use simulation software to describe the signal flow thorough the circuit.
4. The student should be able to compute required values for various circuit components.
5. The student should be able to anticipate how changes in the signal or circuit will affect the results.
6. The student should be able to be able to suggest improvements to the circuit.
**Basic Amplitude Modulation Theory**

Amplitude modulation is the process of transferring information signals to the amplitude of a high-frequency continuous-wave carrier. The modulated AM waveform can be described by

\[ s(t) = [A_c + m(t)] \cos(2\pi f_c t), \]  

where \( A_c \) is the carrier amplitude, \( m(t) \) is the arbitrary message signal, and \( f_c \) is the carrier frequency. As a result of the modulation property of the Fourier transform, the signal spectrum is given by

\[ S(f) = \frac{A_c}{2} [\delta(f - f_c) + \delta(f + f_c)] + M(f - f_c) + M(f + f_c), \]

where the carrier spectrum is composed of two Dirac delta functions at \( \pm f_c \) and the message signal spectrum is translated to \( \pm f_c \).

Creation of the AM waveform of Equation (1) can be realized in a three-step process depicted in figure 1.

**Figure 1: Amplitude modulation block diagram**

**The Project Assignment**

**The Modulator**

As discussed in ref [5], page 79, a switching modulator circuit can be constructed as shown in figure 2. The large signal carrier \( V1 \) and single tone message \( V2 \) are placed in series. The carrier signal causes the diode \( D1 \) to turn on and off periodically at the carrier frequency resulting in the modulation of the message signal \( m(t) \) onto the carrier \( c(t) \). The frequencies and amplitudes were chosen for illustration purposes, not to simulate any particular AM system.

The project directions have the student use PSpice software (Orcad PSpice™) to generate the circuit of figure 2 to implement the signal

\[ s(t) = 2[1 + 0.8 \cos(2\pi(10^3)t)] \cos(2\pi(10^4)t). \]  

The assignment directs them to reproduce and explain the time-domain and frequency-domain plots and to relate them to the circuit implementation. The explanation should include the reason for the spectral replication and why the replicas are reduced in amplitude. Extra credit is provided to those who take the effort to compute the Fourier series coefficients as
From Fourier theory, we know that periodic sampling of a continuous message signal will produce a periodic repetition of the message signal spectrum. These replica spectra will occur at the sampling frequency and will be scaled by the Fourier series coefficients of the sampling pulses. Therefore in order to capture the double-sideband large-carrier (DSB-LC) signal at frequency $f_c$, and reject all others, a bandpass filter is required to be centered at $f_c$.

The students are directed to compute a bandpass filter centered at the carrier frequency $f_c$. They should have the requisite knowledge to know that

$$LC = (2\pi f_c)^2.$$  \hspace{1cm} (5)

And, if they are given that

$$Q = 2\pi f_c RC = 2\pi,$$  \hspace{1cm} (6)

The students should be able to compute one choice of solution to be $R = 1\, \text{k}\Omega$, $L = 2.5\, \text{mH}$, $C = 100\, \text{nF}$. Added credit could be given for computing the 3 dB down bandwidth using the filter theory equation

$$2\alpha = \frac{1}{RL} = \frac{w_c}{Q}.$$  \hspace{1cm} (7)

After selecting the $R$, $L$, and $C$ values, the plot of the DSB-LC waveform of figure 4 should be produced.
The Envelope Detector

Recovery of the message signal $m(t)$ from the modulated waveform $s(t)$ is accomplished for large signal AM via an envelope detector, or peak-following circuit. Since the information of the message will reside in the amplitude variations of the AM wave, by tracing the amplitude variations of the high-frequency carrier, the message signal is recovered. Not coincidentally, the simplicity of the demodulation is the reason for the popularity of broadcast AM. Figure 5 shows the addition of a diode and RC circuit to accomplish the demodulation and recovery of the message signal.

Proper selection of the RC time constant will permit fast charging and slow discharge of the output capacitor. This results in an output voltage that will follow the peak of the AM waveform, thereby recovering the message signal. This results in an output voltage that will follow the peak of the AM waveform, thereby recovering the message signal. Typically, the value of the RC time
constant is chosen to be near the period of the carrier waveform to allow proper peak detection. Extra credit is awarded to students that show the mathematical relationship between the RC time constant and the resulting output ripple voltage as

\[ V_{\text{ripple}} = V_{\text{peak}} \left( \frac{T}{RC} \right), \]  

(3)

where \( T \) is the period of the carrier. The recovered signal can be seen below in figure 6.

Figure 6: Modulated (top) and recovered (bottom) signal in time domain
Breadboard Circuit Implementation

The hands-on portion of the assignment can be accomplished using standard components and measuring equipment found in a typical electronics lab. Figure 8 depicts one breadboard implementation. As an alternative to using a function generator source and oscilloscope measuring device, the necessary signals can be created and measured using the Analog Discovery instrument and Waveforms SDK manufactured by Digilent Inc. [8, 9, 10]. As an example, figure 9 displays a DSBSC spectrum produced by the Waveforms software.

Figure 7: Modulated (top) and recovered (bottom) signal in frequency domain

Figure 8: Amplitude Modulator and Demodulator breadboard circuit
Student Comments and Additional Activities

The simulation part of this project was assigned for the first time in 2014, and again in 2015, and 2016. The circuit implementation was added in 2016, based on student course feedback. In 2014, the class was taught to 33 students spread over two class sections. In 2015, it was taught to 37 students in two class sections.

Student course feedback comments about the project assignment were positive and showed an appreciation for the simulations. Below are listed a sampling of the applicable student responses to the question- What did you like most about this course?

“The projects that integrated the course material into the completion of basic circuit design were a nice component of the class that helped tie concepts and procedures which were learned in other classes into the material that we were covering”

“I enjoyed learning and using the PSpice simulations that we were required to do for lab assignments.”

“Having projects in PSpice gave me a better understanding for the concepts of how AM and FM signals are manipulated.”

Both verbal and written student course feedback indicated that the students enjoyed this project. They particularly appreciated being able to trace the signal path at each step of the modulation and demodulation process. In the second and third class attempts a number of student innovations were submitted. These included: using transistors instead of diodes to improve the
switching response, using active filters to improve the filtering response, and adding a dc blocking capacitor to the demodulator output to remove the dc bias.

Since our students have significant PSpice experience from previous course work, they were able to focus on the project and not on how to get the software to cooperate. For this project, the students were given specific values for the frequencies since a standard result was desired for grading purposes. However, the project could easily be made more “open ended” by not specifying the signal or circuit particulars. This would add difficulty, but would allow the students to experiment with alternative designs. For example, different carrier frequencies could be used and extra credit could be awarded for computing the necessary BPF filter parameters. Another idea is to have the students try other message signals, such as square, triangle, or voice waveforms.

Future projects will incorporate the Analog Discovery Kit as a relatively inexpensive means to conduct the breadboard part of the project. The associated Waveform SD Kit allows for the generation and measurement of all the necessary signals.

**Summary**

This paper discussed a student project to create an amplitude modulator and demodulator using simple passive circuit elements. The theory of the circuits was discussed along with the anticipated results. The learning objectives for the project were presented, as were the ABET outcomes that would be satisfied. Post lesson student comments and ideas for additional student activities, and alternate assignments were also provided.

**References**