Enhancing an Electrical Engineering Communication Course with a FM Demodulator Project

Dr. Robert Barsanti and Dr. Jason Skinner, P.E,
The Citadel/The Citadel

Abstract

This paper describes a FM demodulation circuit simulation and implementation project for use in an undergraduate course in communications for electrical engineering students. The purpose is to provide a hands-on project to enhance undergraduate students understanding of the demodulation of FM signals. The project provides an alternative view point to the complicated mathematical descriptions using transform theory that are commonly provided in modern undergraduate communications texts. This low cost exercise provides an actual circuit implementation using both a hardware and software realization to allow for signal tracing. It is an ideal supplement to a three hour lecture course which does not have a companion laboratory. The circuit implementation includes a narrow band frequency modulated waveform which is demodulated using a simple slope detector circuit. The paper outlines the learning objectives, and how they align with the ABET program outcomes. It also provides an introduction to the FM modulation theory along with an overview of the necessary circuits and concepts.

Keywords

Communications circuits, simulation, FM demodulator

Background

Hands on activities provide a host of positive attributes including improving student motivation, retention, and understanding. Just as importantly is the ability to bring the theory to life and to provide an alternate means of understanding for the students. Often projects and simulations connect with students in ways that lectures and textbooks do not. [1, 2]

Furthermore, hands on projects provide a means to accomplish Accreditation Board for Engineering and Technology (ABET) program outcomes [3]. The proposed project addresses a number of these outcomes including;

1. An ability to apply knowledge of mathematics, science, and engineering (ABET outcome A).

2. An ability to design and conduct experiments, as well as interpret data (ABET outcome B).

3. An ability to identify, formulate and solve engineering problems (ABET outcome E).

4. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET outcome K).

Introduction

Completion of the BSEE degree requirements at The Citadel requires students to take five electrical engineering course electives in their senior year. The three credit hour course titled Communication Engineering is a popular choice. This three credit hour, lecture only class covers the topics of basic analog communications systems. It emphasizes the signals and systems spanning AM, FM, and pulse modulation systems. Simulations and projects have been developed on a variety of course topics. The purpose of this paper is to discuss a project to help students visualize FM demodulation.

This project has the student build the circuit and take measurements. It also requires them to simulate the circuit in time and frequency domain to aid in visualizing the signal conditioning as it passes through the circuit elements.

The learning objectives for the project are:

1. The student should be able to list the components in a FM demodulator.

2. The student should be able to explain the operation of the FM demodulator.

3. The student should be able to use software to simulate the circuit.

4. The student should be able to describe the effect of components on the signal.

5. Students should be able to discuss how changes to the circuit would affect the signal.

6. Students should be able to suggest modifications to the circuits.

Basic Frequency Modulation Theory

As a basis for later discussion, a basic overview of FM theory is provided. The below development follows that found in reference [4]. The reader is directed there for added information. Recall the general expression for a sinusoid,

$$a(t)\cos\theta(t) \qquad Eq. 1$$

In angle modulation the carrier amplitude *a(t)* remains constant and the angular argument *θ(t)* is a function of the message signal. The angular argument θ(t) is related to the instantaneous frequency f_i by

$$\theta(t) = 2\pi\int_0^t f_i(t)dt \qquad Eq. 2$$

In a frequency modulated signal the instantaneous frequency is the sum of a carrier frequency f_c and the modulating component related to the message signal *m(t).*

$$f_i(t) = f_c(t) + km(t) \qquad Eq. 3$$

Using Eq. 3 in Eq. 2 leads to the FM relationship between the angle and the message of a FM signal and the angle becomes

$$\theta(t) = 2\pi f_c t + 2\pi k \int_0^t m(t)dt \qquad Eq.4$$

So finally the FM signal is given by

$$s(t) = A_c Cos(2\pi f_c t + 2\pi k \int_0^t m(t)dt\,) \qquad Eq.5$$

For the simplicity of this project we will be using a single frequency message signal

$$m(t) = A_m \cos(2\pi f_m t) \qquad Eq.6$$

Using Eq. 6 in Eq. 5 produces the single tone FM signal

$$s(t) = \; A_c cos(2\pi f_c t + \beta \sin(2\pi f_m t)) \qquad Eq.7$$

The new symbol β is the modulation index given by kA_m/f_m . For small values of the modulation index β, the FM signal assumes a narrowband form, consisting of a carrier, and an upper and lower sideband, similar to that of AM. To say that β is small, means that $kA_m << f_m$.

The FM Modulator

The objective of the first part of the project is to simulate an FM waveform and investigate the spectral characteristics. The assignment has the students use PSpice software to simulate a single tone FM waveform given by

$$\mathrm{s}(t) = 2\cos[2\pi(10^4)t + \beta \sin(2\pi(10^3)t] \qquad Eq\ 8$$

The students are instructed to use Fig 1 as a guide, set $\beta = 0.2$, 1, 2 and 5 and for each case run a Time Domain Transient analysis showing 10 msec of time domain data for V1. Also, display a trace of the FFT of V1 using the FFT button in the output window. Then compare the measured signal bandwidth to what you would predict using Carson's rule [4].

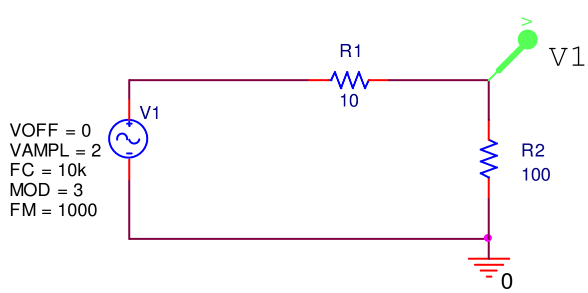

Fig. 1 FM Modulator Simulation

A typical result for the case β = 1.0 is shown in fig 2.

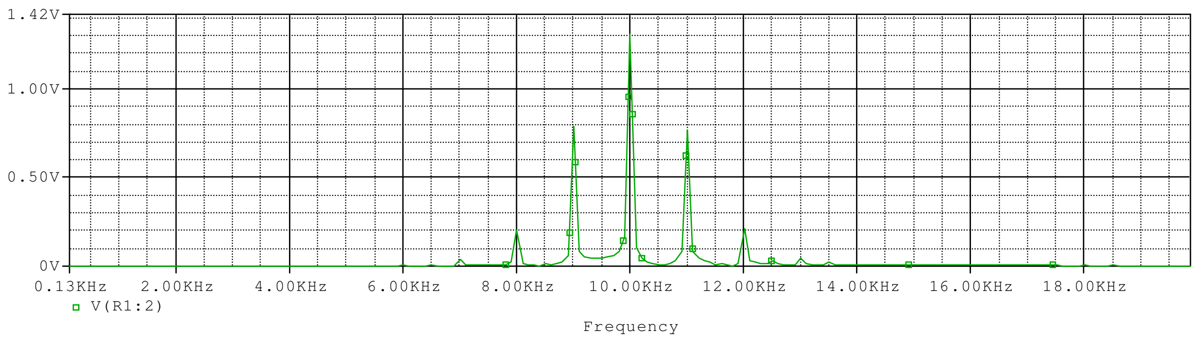

Fig. 2: FFT of s(t) from Eq.2 with β=1.0

The FM Demodulator

The objective of this portion of the assignment is to simulate a basic FM demodulator. Using Fig 3 as a guide, design a FM Demodulator to extract the single tone message.

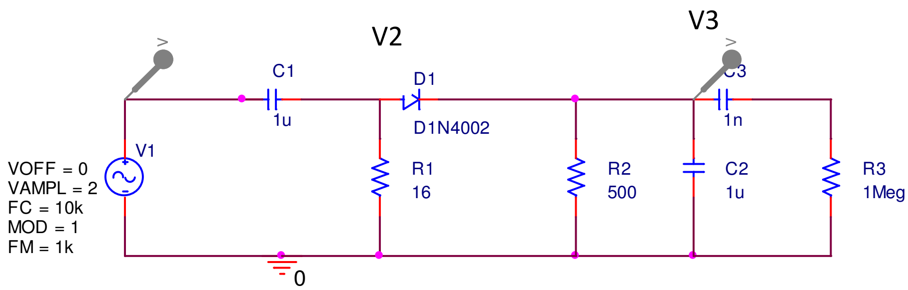

Fig. 3 FM Demodulator Simulation

Once constructed the students are to run an AC sweep from 1-20 kHz, to display the frequency response at V2 for the slope circuit, and retain this plot for the report. Next, they replace the Vac source with VSFFM source from step 1 (set $\beta = 1.0$), and run a time domain simulation to display the trace of the signal at V2 and V3 showing 10 ms of data. Finally, display a trace of the spectrum of V3 using the FFT button.

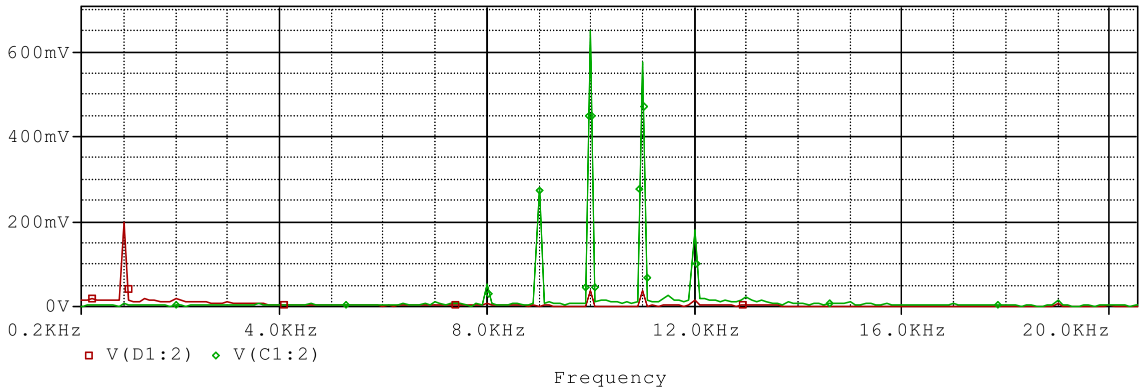

Fig. 4: FFT measured at V3 in demodulator circuit for β = 0.1. The 1 KHz demodulated output is shown in red.

Deliverables

The students are required to produce both circuit schematics and each of the plots and graphs generated. They are instructed to use a table to compare the BW from the FFT plot to that predicted using Carson's rule for each value of β . The students are prompted to explain the role this frequency response plays in the demodulation process, and to discuss the effectiveness of the demodulator overall.

Breadboard Circuit Implementation

The demodulator circuit of figure 2 was constructed on a breadboard and is depicted in Fig. 5. Both the FM input signal shown in figure 6, and the measured output signals shown in figures 7 and 8 were obtained using the Analog Discovery kit [7, 8].

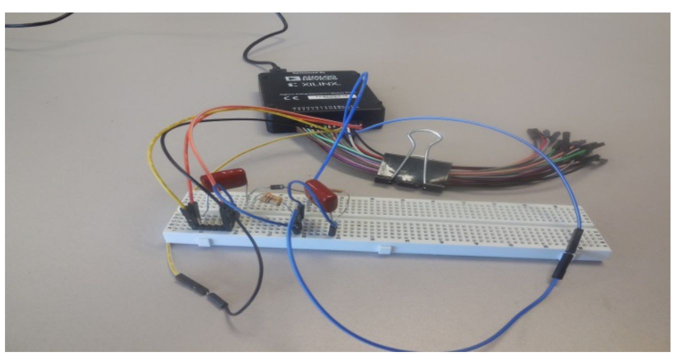

Fig. 5: FM Demodulator breadboard

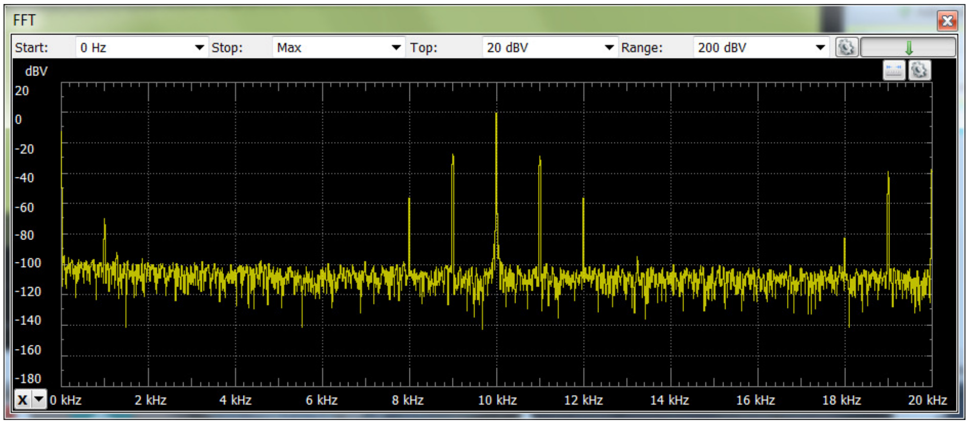

Fig. 6: FFT of the FM input signal generated using the Analog Discovery system.

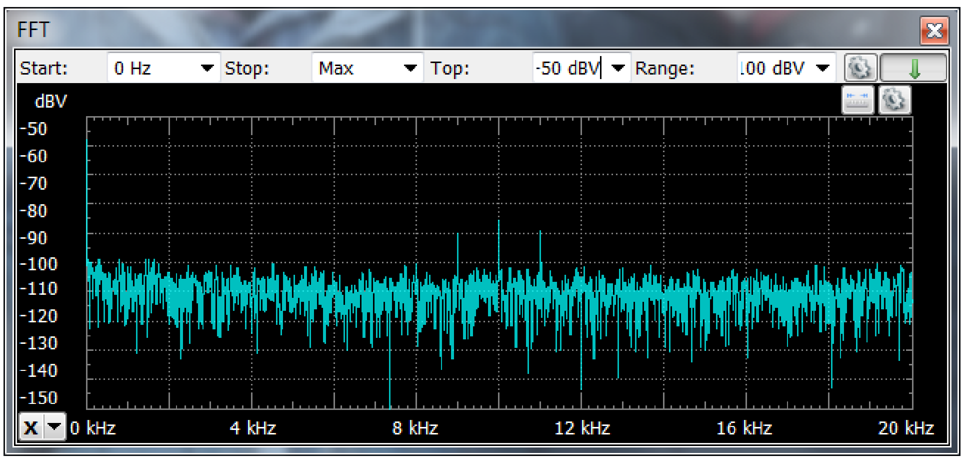

Fig.7: FM demodulator signal measured at the diode input using the Analog Discovery system.

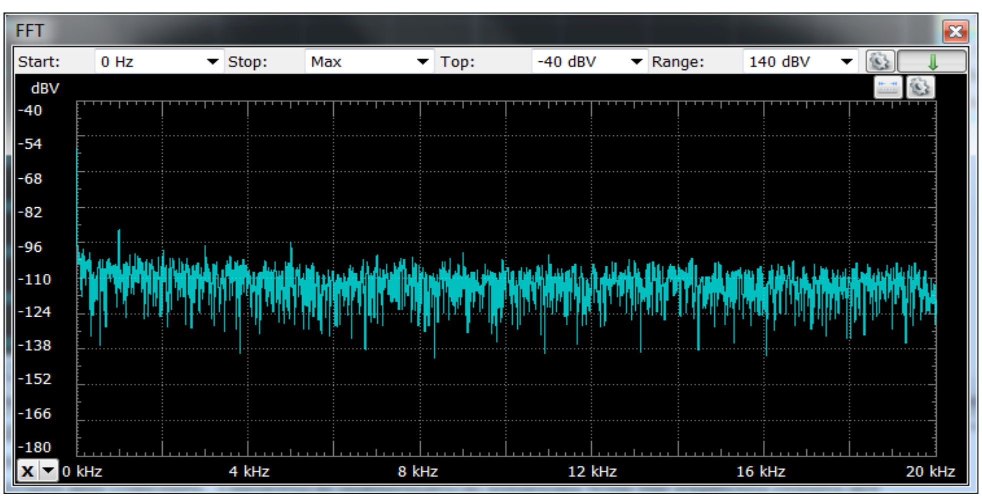

Fig.8: FM Demodulator output signal measured using the Analog Discovery system.

The analog discovery kits [7] provided an inexpensive means for producing and recording the necessary signals.

Student Comments

Based on student feedback, many students enjoyed the both the software and hardware portion of the project. In particular they appreciated being able to trace the signal in both the time and frequency domain both in PSpice and using the analog discovery instrument using the FFT functionality. Many students enjoyed the hardware portion of the project, and the simplicity of using the analog discovery instrument system.

Summary

The paper was dedicated to providing a low cost, hands-on project that can be added to an undergraduate communications lecture class to enhance both student interest and understanding of modulation concepts. The paper provided project objectives, circuit simulations, and hardware implementation details.

References

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Dr. Robert J Barsanti Jr., The Citadel

Robert Barsanti is a Professor in the Department of Electrical and Computer Engineering at The Citadel where he teaches and does research in the area of target tracking and signal processing. Since 2015, Dr. Barsanti has served as the William States Lee Professor and Department Head. Before joining The Citadel in 2002, he served on the faculty and as a member of the mission analysis design team at the Naval Postgraduate School in Monterey, CA. Dr. Barsanti is a retired United States Naval Officer. His memberships include the Eta Kappa Nu, and Tau Beta Pi honor societies.

Dr. Jason S. Skinner, The Citadel

Jason Skinner is an Associate Professor in the Department of Electrical and Computer Engineering at The Citadel, where he teaches and conducts research in the areas of mobile wireless communication systems and networks, spread-spectrum communications, adaptive protocols for packet radio networks, and applications of error-control coding. Dr. Skinner is a member of AFCEA, ASEE, IEEE, IEEE Communications Society, IEEE Information Theory Society, IEEE Signal Processing Society, Tau Beta Pi, and Phi Kappa Phi.