

Frequency Modulation and Demodulation

November 20, 2017

This lab is divided into two parts. In Part I you will learn how to design an FM modulator and in Part II you will be able to demodulate an FM signal. In the process you will also design an FIR differentiator.

1 Introduction

Modulation is the modification of some aspect of a carrier signal. Given a signal of the form

$$x_c(t) = A(t) \cos[\omega_c t + \phi(t)]$$

where ω_c is known as the carrier frequency. If $A(t)$ varies linearly with the modulating signal (your message to be transmitted), then we have *linear modulation*. If $\phi(t)$ varies with the modulating signal, then we have *angle modulation*. Figures 1, 2 and 3, show modulated signals using *amplitude modulation*, *phase modulation* and *frequency modulation*, respectively. As seen in Figure 1, the message signal is modifying the amplitude of the carrier signal, hence the name amplitude modulation. In Figure 2, the oscillation increased or decreased based on the slope of the modulating signal. In Figure 3, the amplitude of the signal is modifying the rate of oscillation of the carrier signal.

1.1 FM Modulation

In angle modulation, the amplitude of the signal is held constant and the phase is being varied with the message. An angle modulated signal is of the form:

$$x_c(t) = A_c \cos(\Omega_c t + \phi(t)). \quad (1)$$

The instantaneous phase of $x_c(t)$ is given by

$$\theta_i(t) = \Omega_c t + \phi(t), \quad (2)$$

and the instantaneous frequency is given by

$$\Omega_i(t) = \frac{d\theta_i(t)}{dt} = \Omega_c + \frac{d\phi(t)}{dt}. \quad (3)$$

Using this approach, if the message is proportional to $\phi(t)$, which is the *phase deviation*, then we have *phase modulation*. If the message is proportional to $\frac{d\phi(t)}{dt}$, which is the *frequency deviation*, then we have *frequency modulation*.

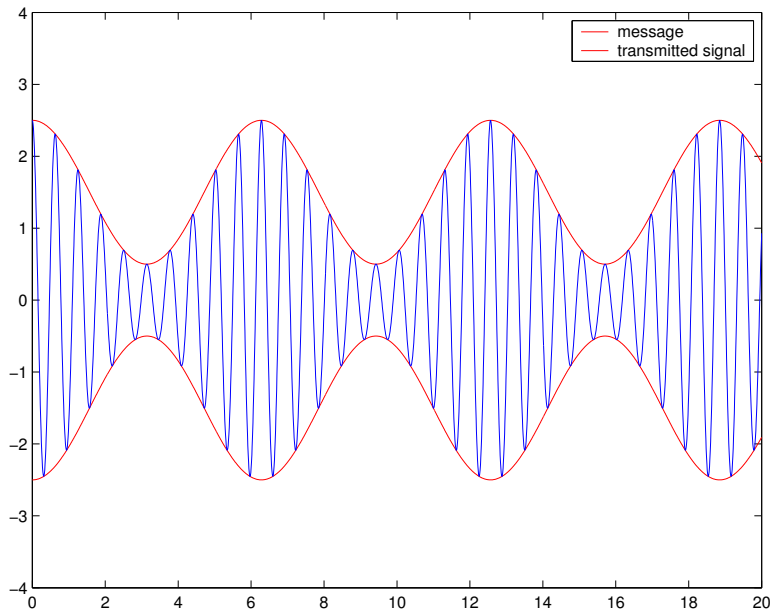


Figure 1: Amplitude modulation

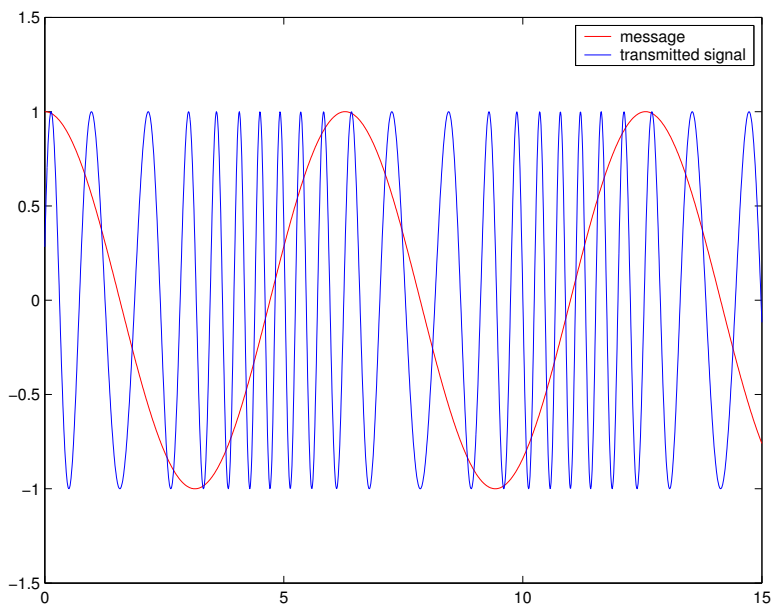


Figure 2: Phase modulation

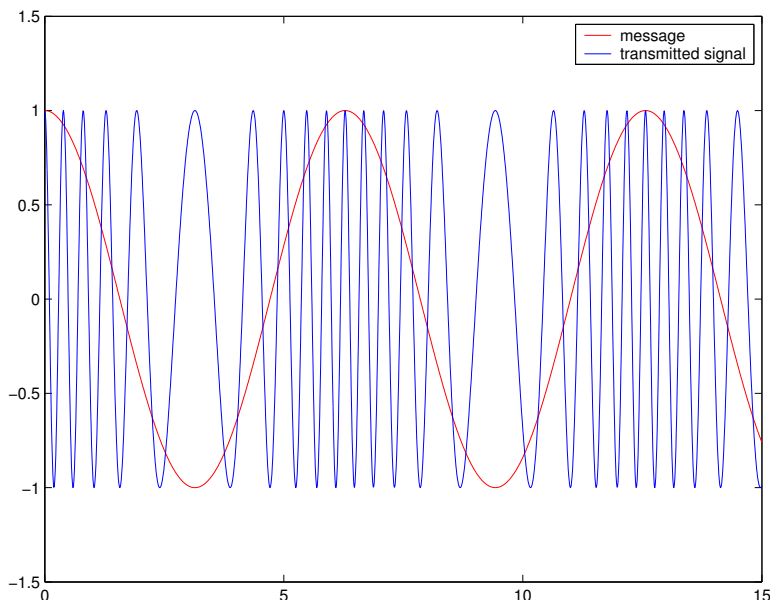


Figure 3: Frequency modulation

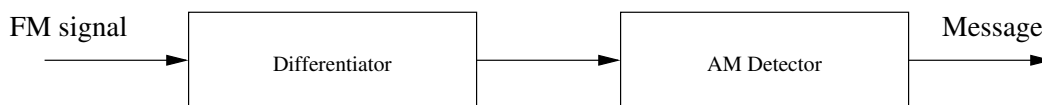


Figure 4: Frequency discriminator

In order to have phase modulation,

$$\phi(t) = k_p m(t), \quad (4)$$

where k_p is known as the *deviation constant*. For frequency modulation,

$$\frac{d\phi(t)}{dt} = k_f m(t), \quad (5)$$

where k_f is known as the *frequency deviation constant*. Consequently, an FM modulated signal is of the form

$$x_c(t) = A_c \cos(\Omega_c t + k_f \int_t m(\alpha) d\alpha). \quad (6)$$

An FM signal is shown in Figure 3

1.2 FM Demodulation

There are several ways to demodulate an FM signal. In this lab you will use a differentiator followed by an AM detector to demodulate an FM signal as shown in Figure 4

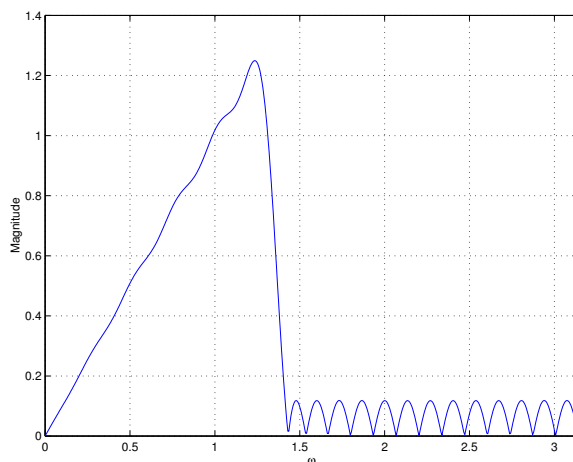


Figure 5: Magnitude response of FIR equiripple differentiator for $\omega = 0$ to 0.4π

In order to implement the above the frequency discriminator, we need to design a differentiator. One way to implement a differentiator is using an optimal equiripple linear-phase FIR filter. This filter is optimal because the weighted approximation error between the desired frequency response and the actual frequency response is spread evenly across the passband and evenly across the stopband. This results in minimizing the maximum error. *Remez* algorithm may be used to generate this filter. Below are samples of the output generated using the `firpm` function.

2 Lab Part I: FM Modulation

1. Write a new code to generate an FM signal.
2. Use 100Hz for your message and 500Hz for the carrier frequency.
3. Observe the output of the codec as you vary the frequency of the message.

3 Lab Part II: FM Demodulation

1. Show that the system given in Figure 4 will extract the message from an FM signal.
2. What is the desired frequency response of an ideal digital differentiator.
3. Write a MATLAB code to generate your FIR differentiator using the `firpm` function.
4. Design the IIR filter needed for the AM detector.
5. Start a new project.
6. Implement an FM demodulator.
7. Run your FM modulator code on one board.

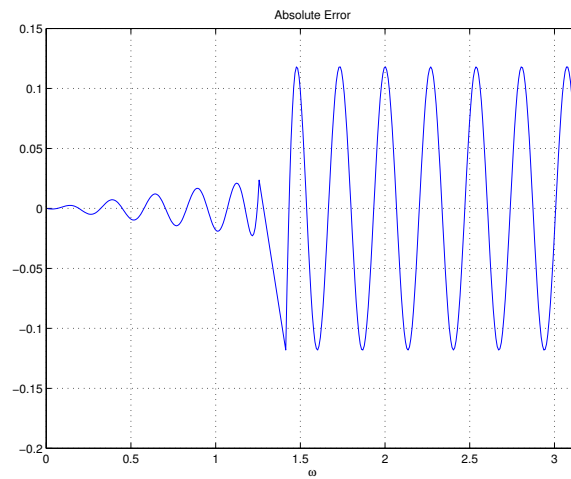


Figure 6: Absolute error of an FIR equiripple differentiator for $\omega = 0$ to 0.4π

8. Connect your first board with the FM modulator with the second that has the FM demodulator.
9. Run your FM demodulator code and verify that it works.