Experiment #5 – Amplitude Modulation

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# EEE3352 Signal Analysis and Analog Communications

Section 0012

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# **Project Description**

The objective of this experiment is to introduce and explain AM modulation and different types of modulations to students. This laboratory also introduces the student to practical uses of the Fourier Transform.

# **2.0 About Laboratory Day and Equipment List**

# The laboratory session took place on the Tuesday section between 8:00am and 11:00am on October 17/24, 2023. My lab partners were Joahn. The equipment for the is experiment is listed below,

1. USB Flash Drive
2. Rohde & Schwarz RTM 3034 Oscilloscope
3. Tektronix AFG3022 Function Generator
4. TL084 Operational Amplifier & 2N2222 NPN BJT

# **3.0 Pre-Laboratory Preparation**

# 3.2 MATLAB Simulation

In the simulation section of the lab, we constructed a message signal with frequency of 100 Hz and a carrier signal of 1000 Hz. The following is the message signal,

A graph showing a message signal

Description automatically generated

The following is the FFT of the message signal,

A graph of a signal

Description automatically generated

The following is the FFT of the carrier signal,

A graph of a signal

Description automatically generated

The following is the modulated signal,

A blue and white signal

Description automatically generated

The following is the demodulated signal at the receiver end,

A graph of a signal

Description automatically generated

The following is the FFT of the demodulated signal,

A graph of a signal

Description automatically generated

The following is the carrier signal frequency domain at the receiver,

A graph of a signal

Description automatically generated

The following is the demodulated signal in frequency domain,

A graph of a signal

Description automatically generated

The following is the MATLAB code used to generate the figures in this section,

clear all;

clc;

close all;

Fs = 4000;            % Sampling frequency

T = 1/Fs;             % Sampling period

L = 1500;             % Length of signal

t = (0:L-1)\*T;        % Time vector

f = 100;              % Signal frequency

fc = 1000;            % carrier frequency

m = 0.5;              % Modulation Factor

%% Signals

X = sin (2\*pi\*f\*t);        % Message signal

% X = square(2\*f\*t\*pi);        % Message signal (square wave)

% X = sinc(2\*f\*(t-10));          % Message signal (sinc Function)

plot(X);

title("Message Signal")

A = abs(min(X))/m;          % Required dc offset from modulation index de?nition

car\_sig = sin(2\*pi\*fc\*t);   % Carrier Signal

x1 = (X+A).\*car\_sig;        % Modulated signal

figure;

plot(x1);

title("Modulated signal");

delta = 0;      % Frequency error

Phi = 0;        % Phase shift

carrier2=sin(2 \* pi \* (fc+delta) \* t + Phi);   % Carrier at the receiver end

x2 = x1.\*carrier2;                  % Demodulated signal

num\_harmonic = 1;               % Number of harmonic you want to see

cutoff = 4\* num\_harmonic\* f;    % Cutoff frequency of the lowpass filter

[b,a] = butter(5,cutoff/Fs);      % Low pass filter

x\_demod = filtfilt(b,a,x2);     % Get the message signal

figure;

plot(x\_demod);

title("Demodulated signal");

%% Plot the spectrum of signal, carrier and modulated signal

figure;

P = plot\_fft(X,L, Fs);

title("Message Signal (Transmitter) in Frequency Domain.");

xlabel("Frequency (Hz)");

ylabel("Magnitude of |FFT|");

figure;

p1 = plot\_fft(car\_sig, L, Fs);

title("Carrier Signal (Transmitter) in Frequency Domain.");

xlabel("Frequency (Hz)");

ylabel("Magnitude of |FFT|");

figure;

p3 = plot\_fft(x1, L,Fs);

title("Modulated Signal (Transmitter) in Frequency Domain.");

xlabel("Frequency (Hz)");

ylabel("Magnitude of |FFT|");

figure;

p4 = plot\_fft(carrier2, L, Fs);

title("Carrier Signal (Receiver) in Frequency Domain.");

xlabel("Frequency (Hz)");

ylabel("Magnitude of |FFT|");

figure;

p5 = plot\_fft(x\_demod, L,Fs);

title("Demodulated Signal (Receiver) in Frequency Domain.");

xlabel("Frequency (Hz)");

ylabel("Magnitude of |FFT|");

%% Function for FFT

function [P1] = plot\_fft(X, L, Fs)

Y = fft(X);

P2 = abs(Y/L);

P1 = P2(1:L/2+1);

P1(2:end-1) = 2\*P1(2:end-1);

f = Fs\*(0:(L/2))/L;

plot(f,P1)

end

# 3.4 Non sinusoidal carrier

We can use a periodic square wave carrier for AM modulation. We know that we can represent a square wave in the Fourier series by the following expansion,

And we can compute the coefficient for the periodic function using the following equations,

If we solve the Fourier series coefficient for the square wave we get the following result,

Given the Fourier series approximation, we can approximate the square wave. The following is a visual representation of the carrier signal.

A diagram of a carrier signal

Description automatically generated

Carrier Signal

The message signal for this AM modulation is , the following is the shape of the message signal,

A graph of a signal

Description automatically generated

Message Signal

To compute the modulated signal for DSB-SC AM, we simplify multiply the carrier and message signal to yield the following result,

A blue lines on a white background

Description automatically generated

Modulated Message Signal

Now that we have the modulated signal, the receiver must demodulate this signal. To modulate this signal, we can use a Butterworth low pass filter. To design the cut-off frequency for the filter we must determine the fundamental frequency of the carrier signal. Since we know the period of the carrier signal, we can determine the fundamental frequency by the following relationship,

The reason for the low frequency for the carrier signal is to simplify the example and to reduce computation time in computational software. Although, the frequency for the carrier signal is quite low, the message signal frequency is much lower () relative to the carrier. We can create a fourth-order Butterworth filter using the TL084 operational amplifier (like in the previous experiment) with a cut-off frequency of, which would have a roll-off of -40 dB/decade.

The following is the MATLAB source code used to generate the plots for this section,

%% Non sinusoidal carrier

syms n t

T = 0.1; % Period

a(n) = 2\*(sin(pi\*n/2)/(pi\*n) + (sin(pi\*n/2)/(pi\*n)));

n=1:2:50;

coeff = eval(a);

cos\_terms = cos((n\*2\*pi/T)\*t);

f = sum(coeff.\*cos\_terms);

t=(-pi):0.01:(pi);

figure

f = eval(f);

plot(t, f);

title("Carrier Signal (Square Wave, 25 terms)");

xlabel("time");

ylabel("c(t)");

% signal

figure

s = cos(t);

plot(t, s);

title("Message Signal (Cosine Wave)");

xlabel("time");

ylabel("s(t)");

figure

message = f.\*s;

plot(t, message);

title("Modulated Signal (Transmitted)");

xlabel("time");

ylabel("m(t)");

# **4.0 Experimental Procedure**

A diagram of a circuit

Description automatically generated

# 4.2 AM Modulation

To construct the modulated signal, we used the two circuits in Fig. 5.25 and Fig 5.26. The circuit in Fig. 5.26 uses an operational amplifier to generate the carrier signal and the circuit in Fig. 5.25 combines the carrier signal generated by the amplifier and the message signal generated by the function generator to produce the modulated signal. The following is the measurement of the modulated output signal,

A screenshot of a computer

Description automatically generated

Function Generator Input and Modulated Signal

A screenshot of a computer

Description automatically generated

Wider capture of Modulated Signal

A screen shot of a computer

Description automatically generated

DSB-LC Modulated Signal

A screenshot of a computer

Description automatically generated

DSB-LC Modulated Signal with Triangle Input Waveform

A screenshot of a computer

Description automatically generated

FFT Spectra for DSB-SC

# 4.4 Amplitude Demodulation

A diagram of an envelope detector

Description automatically generated

We built the circuit in Fig 5.28 to demodulate the modulated message signal.

A screenshot of a computer

Description automatically generated

Input Signal vs Demodulated Signal (DSB-LC)

This measurement shows that the demodulated signal is very close to the original signal, however, when we zoom into the demodulated signal, we can clearly see that their high frequency noise. We can see the same effect for the triangle wave input shown below,

A screenshot of a computer

Description automatically generated

Input Signal vs Demodulated Signal (DSB-LC) – Triangle Waveform

We perform the previous steps again but with a DSB-SC modulation,

A screenshot of a computer

Description automatically generated

Input Signal vs Demodulated Signal (DSB-SC)

A screenshot of a computer

Description automatically generated

Input Signal vs Demodulated Signal (DSB-SC) - Triangle Waveform

As the measurement shows, the envelope detector could not extract the message signal from the DSB-SC waveform.

# 4.6 Synchronous Detection

A diagram of a circuit

Description automatically generated

We built the circuit in Fig 5.29 to demodulate the modulated message signal.

Adjust for a DSB-LC signal. Compare Vin(t) with Vd(t). Sketch the waveforms. Has the message been recovered?

For the DSB-LC signal we were able to recover the message although with some high frequency noise.

A screenshot of a computer

Description automatically generated

DSB-LC Demodulated Signal vs Input Signal

A screenshot of a computer

Description automatically generated

DSB-SC Demodulated Signal vs Input Signal

Adjust for a DSB-SC signal. Again, compare Vin(t) with Vd(t). Sketch the waveforms. Is it possible to retrieve the original message? Explain.It is possible to demodulate both DSB-LC and DSB-SC signals using synchronous detection. For DSB-LC, you'll need to multiply the signal with a local carrier and then filter it to recover the message signal. For DSB-SC, you can directly multiply the signal with a local carrier and filter to obtain the message signal. Synchronous detection is effective for extracting the message signal from these types of amplitude-modulated signals.

# 4.8 Questions and Calculations

1. Why must m be less than 100% for envelope detection?

When m is higher than 100% then their must be a DC component to the signal which the capacitor would block.

2. Compare Envelope Detection to Synchronous Detection and list at least one advantage and one disadvantage of each

The envelope detection is much easier to build and requires cheaper and less components compared to the synchronous detection, but envelope detection cannot detect DSB-SC signals. Whereas the synchronous detection can detect both DSB-SC and DSB-LC signals at the cost of more complexity and cost.

# **5.0 Learned Objectives**

* AM Modulation
* Classes of AM Modulation
* Envelope Detection
* Synchronous Detection
* Usage of Operational Amplifiers

# **6.0 Conclusion**

In conclusion, Experiment #5 on amplitude modulation proved to be a pivotal learning experience in our study of signal analysis and analog communications. Through MATLAB simulations, we witnessed the modulation and demodulation processes, thereby enhancing our comprehension of how amplitude modulation operates in real-world applications.

Notably, this experiment extended our knowledge beyond the conventional sinusoidal carrier signals to include non-sinusoidal carriers like square waves. We also explored envelope detection and synchronous detection techniques, gaining insights into their advantages and disadvantages when applied to various types of modulated signals, such as DSB-LC and DSB-SC. Overall, this hands-on experience deepened our understanding of amplitude modulation, Fourier series, and the practical nuances of signal analysis in analog communications, setting a strong foundation for future endeavors in this field.