Normal AM (Modulation and Demodulation)

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Abstract

Our project focuses on generating a dual sideband carrier waveform using a straightforward switching modulation circuit and demodulating the resulting AM wave via an envelope detector circuit. We utilized software simulations for analysis and validation. By linking theory with practical applications, we aim to deepen our understanding of analog communication systems and gain insights into creating and analyzing real-world AM signals.

1. Introduction

The Amplitude Modulated (AM) signal comprises both high and low-frequency components, with the low-frequency signal controlling the amplitude of the high-frequency carrier signal. This modulation creates the signal's envelope, and if the modulating signal is sinusoidal, the envelope of the resulting Radio Frequency (RF) signal will also exhibit sinusoidal characteristics. In typical AM radios, the low-frequency signal represents audio, while the high frequency corresponds to the transmitting frequency of the radio station. The depiction in Figure 1-1 illustrates an example of an AM signal in the time domain. [1]

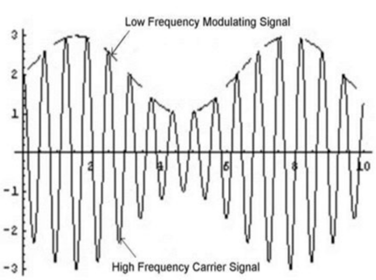

Figure 1 - 2: AM Modulated Signal

The mathematical representation for this waveform is as follows:

$$S_{AM}(t) = A[1 + \mu \cos(\omega_m t)] \cos(\omega_c t) \ldots(1)$$

Where, **A** → DC value of the waveform, **μ** → Modulation index. $\boldsymbol{\omega_m}$→ Modulation frequency (rad/s).$\boldsymbol{\omega_c}$→ Carrier frequency (rad/s).

After receiving an AM signal, it can be demodulated to recover the low-frequency signal using an envelope detector, which is one of the simplest AM demodulating circuits. For accurate recovery of the low-frequency signal, the envelope detector's time constant must be much longer than the high-frequency signal's period but much shorter than the low-frequency signal's period. Figure 1 - 2 shows the general concept of the envelope detection method to regain the low-frequency signal.[1]

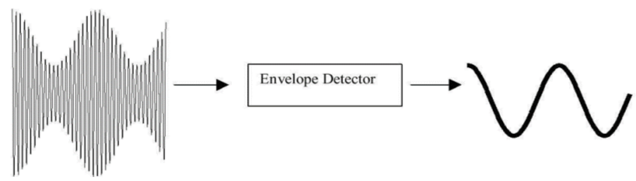

Figure 1 - 3: Demodulation of an AM Signal

Figure 1 - 3 illustrates the block diagram depicting the sequential process of Normal AM modulation, encompassing the modulation of the modulating signal m(t) with the carrier signal c(t), followed by the switching modulator, bandpass filtering, enveloping detection, amplification, and the final output stage.

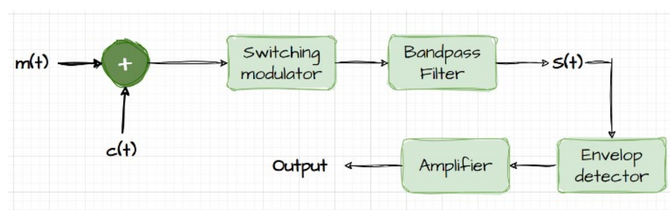

Figure 1 - 1: Normal AM Block diagram

2. Problem Specification

The project focuses on applying AM and demodulation techniques, aiming to create a standard AM waveform via a switching modulator and retrieve the original signal using an envelope detector circuit. Primary objectives involve accurate signal generation and recovery using fundamental circuits, facing challenges like dual sideband carrier waveform production, precise signal retrieval, modulation control, distortion reduction, and noise management in the demodulated signal.

3. Tools and Signal Analysis

In our project we used MATLAB, which is a numerical computing environment widely used for data analysis, signal processing, simulations, and system design. Its robust libraries, interactive interface, and user-friendly nature make it a preferred choice among engineers, scientists, and researchers for exploring signals and implementing diverse engineering concepts.

4. Procedure

Expressions of Signals

The modulating signal, $m(t) = A_m \cos(2\pi f_m t)$	$M(f) = \frac{A_m}{2}\,\delta(f - f_m) + \frac{A_m}{2}\,\delta(f + f_m)$
The carrier signal, $c(t) = A_c \cos(2\pi f_c t)$,	$C(f) = \frac{A_c}{2}\,\delta(f - f_c) + \frac{A_c}{2}\,\delta(f + f_c)$
The modulated signal, $S_{AM}(t) = A_c.[1 + \mu.\cos(2\pi f_m t)]\cos(2\pi f_c t)$	$S_{AM}(f) = \frac{A_c}{2}.[\delta(f - f_c) + \delta(f + f_c)]$ $+\frac{\mu A_c}{2}[M(f - f_c) + M(f + f_c)]$
The actual modulated signal: $S(t) = \frac{A_c}{2}\cos(2\pi f_c t)\left[1 + \frac{4}{\pi A_c}\, m(t)\right]$	$S(f) = \frac{A_c}{4}\,\delta(f - f_c) + \frac{A_c}{4}\,\delta(f + f_c) +$ $\frac{1}{\pi}[M(f - f_c) + M(f + f_c)]$

Table 1- 1: Expressions of Signals

Where, A_m is the amplitude, f_m is the frequency for m(t), A_c is the amplitude and f_c is the frequency for c(t). And μ is the modulation index.

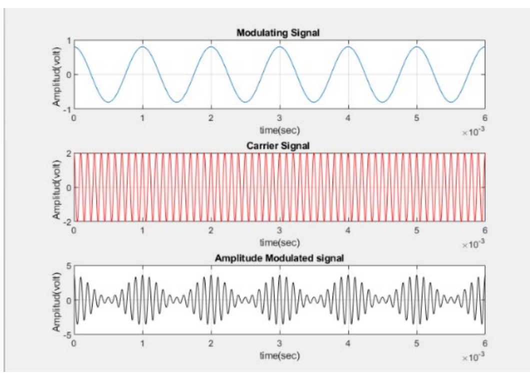

Figure 1 - 4: Plots of the Expressions of Signals (time domain)

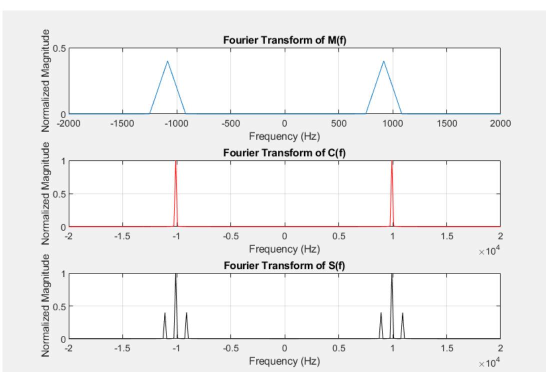

Figure 1 - 6: Plots of the Expressions of Signals (freq. domain)

Complex exponential Fourier series of the signal $p(t)$

$$\boldsymbol{p(t) = f(x) = \begin{cases} 1, & -\frac{T_c}{4} \le x \le \frac{T_c}{4} \\ 0, & -\frac{T_c}{2} \le x \le -\frac{T_c}{4} \\ 0, & \frac{T_c}{4} \le x \le \frac{T_c}{2} \end{cases}}$$

Where $\boldsymbol{T_c}$ is the fundamental period of carrier signal c(t) and equals $\frac{1}{f_c}$. So, Complex exponential Fourier:

$$p(t) = \sum_{n=-\infty}^{\infty} p_n e^{j2\pi n f_c t} \quad ; \; p_n = f_c p(f_c)$$

$$p_n = \frac{1}{T_c}\int_{T_c} p(t)\, e^{-j2\pi n f_c t}\, dt = \frac{1}{T_c}\int_{-\frac{T_c}{4}}^{\frac{T_c}{4}} (1).\, e^{-j2\pi n f_c t}\, dt$$

$$= \frac{1}{j2\pi n}\left[e^{\frac{j\pi n}{2}} - e^{-\frac{j\pi n}{2}}\right] = \frac{\sin\left(\frac{n\pi}{2}\right)}{n\pi}$$

- When n is even ; $p_n = 0$
- When n = 0 ; $p_0 = \frac{1}{T_c}\int_{-\frac{T_c}{4}}^{\frac{T_c}{4}} (1)\; dt = \frac{1}{2}$
- When n = $\{\pm 1, \pm 5, \pm 9, \ldots\}$; $p_n = \frac{1}{n\pi}$
- When n = $\{\pm 3, \pm 7, \pm 11, \ldots\}$; $p_n = -\frac{1}{n\pi}$

$$p(t) = \frac{1}{2} + \frac{1}{\pi}\sum_{n=-\infty}^{\infty} \frac{(-1)^{n-1}}{2n-1} e^{j2\pi(2n-1)f_c t}$$

5. A Bandpass filter Design

We designed an RLC parallel bandpass filter. We opted for an RLC filter due to the fact that it offers a narrow bandwidth which will help us filter out unwanted frequencies while minimizing the loss in the amplitude of the message signal, and a model strong enough to predict the output of the filter.

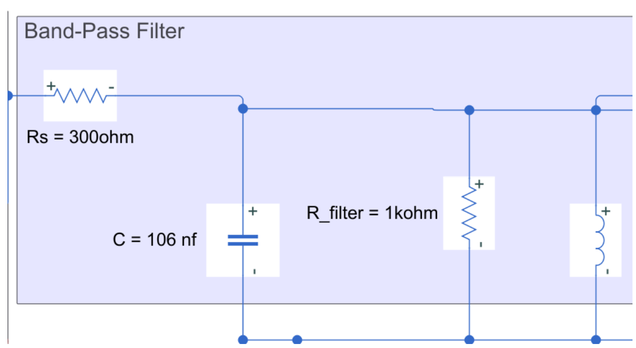

Figure 1 - 5: Band-pass filter circuit

Where, Rs = 300 Ω, Rf =1k Ω, C=106nf and L=2.4mH.

6. Components

Resistor: A two-terminal electrical component limits electronic flow in a circuit. Widely employed in electronics design and system modeling, measured in ohms (Ω).

Figure 1 - 7: Resistor symbol

Diode: A two-terminal component allowing current flow in one direction with low resistance and high resistance in the opposite direction. Varieties include Zener, light-emitting, and rectifier diodes.

Figure 1 - 8: Diode symbol

Capacitor: A capacitor stores energy as an electric charge between two conductors separated by a gap, measured by capacitance. [2]

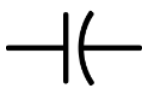

Figure 1 - 9: Capacitor symbol

Inductor: An inductor stores energy as magnetic energy when electrical current passes through it. Its significant property is impeding or resisting changes in the current flow. [3]

Figure 1 - 10: Inductor symbol

Operational Amplifier (Op-amp): is an integrated circuit that can amplify weak electric signals based on the difference between its two input pins and one output pin. [4]

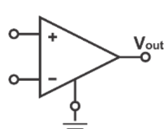

Figure 1 - 12: Op-amp symbol

7. Approach

Full circuit:

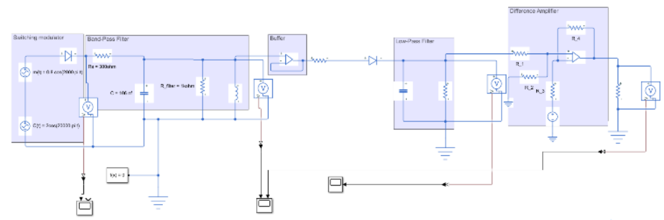

Figure 1 - 13: Normal AM Circuit

For Normal AM modulation, Switching modulator circuit:

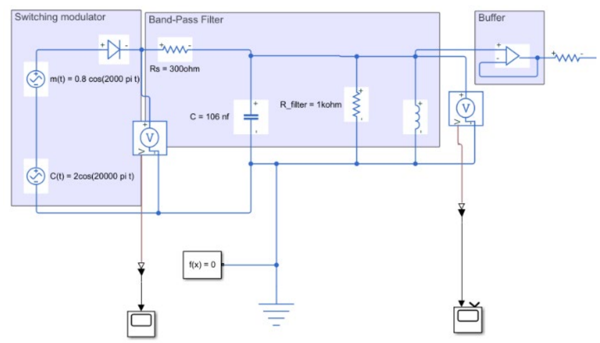

Figure 1 - 14: Switching modulator circuit

In our **switching modulator circuit**, we have used an ideal diode so the forward bias would not affect the output signal ... but in reality, we might use small DC to offset the effect of the diode.

For BPF: we opted to choose a parallel RLC filter since it is the most suitable passive filter for narrow frequencies. we first specified the resistor R = 300 ohm, the bandwidth B = 5000Hz, and center frequency Fc = 10000Hz. Then we calculated C and L from these values.

Buffer: we have used a buffer in the circuit to eliminate the loading effect on the output of the receiver so it would better simulate a real-life situation. If we plugged the receiver directly then the BPF will suffer from loading effect and therefore we inserted a buffer in between.

For Normal AM demodulation, Envelop detector circuit:

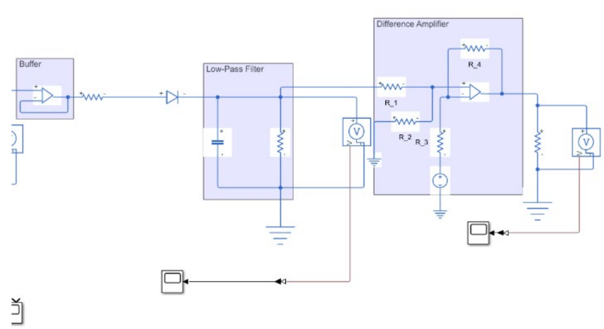

Figure 1 - 11: Envelop detector circuit

For Envelope Detector: An envelope detector is a circuit used in demodulating amplitude modulated (AM) signals. Its primary function is to extract the original modulating signal (such as an audio signal) from the modulated AM waveform received from the channel. We used Diode (rectifier), so the incoming modulated signal is fed into a diode, which rectifies the signal by allowing current flow in only one direction. This process removes the negative or positive half of the signal, effectively converting it into a unipolar waveform.

The Capacitor (filter): The rectified signal, which now represents the envelope of the modulated waveform, may still contain some ripple or remnants of the carrier frequency. A capacitor is used to smooth out this signal, filtering the high-frequency components while allowing the slower variations in the envelope signal to pass through. The capacitor is typically connected to a load resistor, and the output is taken across this resistor. This output provides the demodulated signal, which closely resembles the original modulating signal that was used to modulate the carrier.

Difference Amplifier: To receive the final message signal, we need to amplify it and offset the effect of the carrier. Therefore, we put it through a difference amplifier to offset the resulting signal and then amplify it so that it would have the same peak to peak as the sent message.

Results and Analysis

The modulating signal m(t):

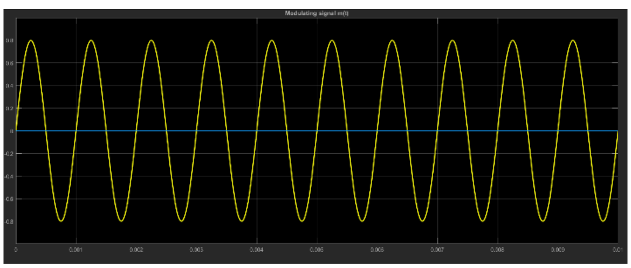

Figure 1 - 17: Plot of m(t) in time domain.

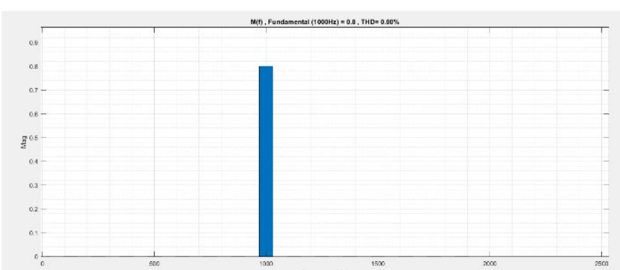

Figure 1 - 18: Plot of M(f) in freq. domain.

The carrier signal c(t):

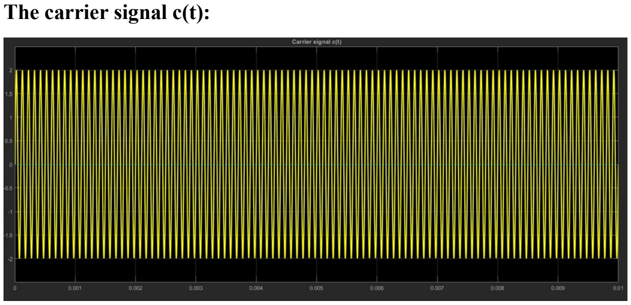

Figure 1 - 19: Plot of c(t) in time domain.

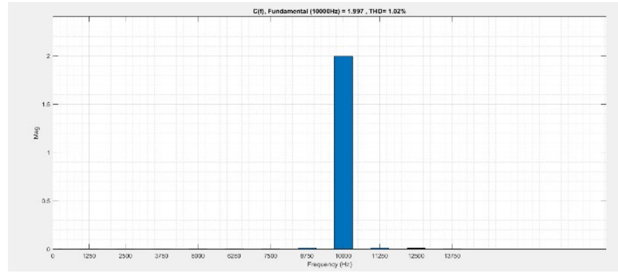

Figure 1 - 20: Plot of C(f) in freq. domain.

The switching signal:

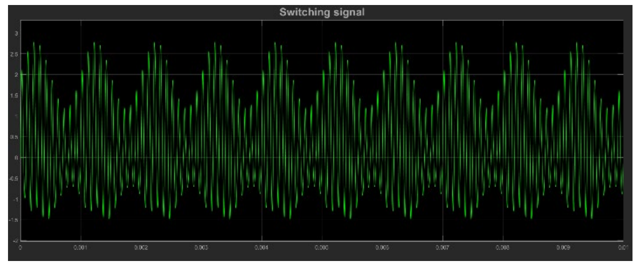

Figure 1 - 21: Plot of switching signal.

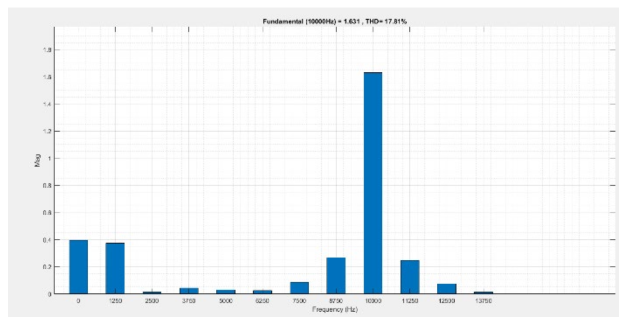

Figure 1 - 15: Plot of switching signal in freq.

The modulated signal s(t):

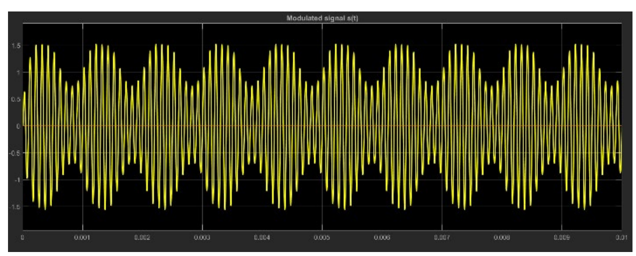

Figure 1 - 22: Plot of s(t) in time domain.

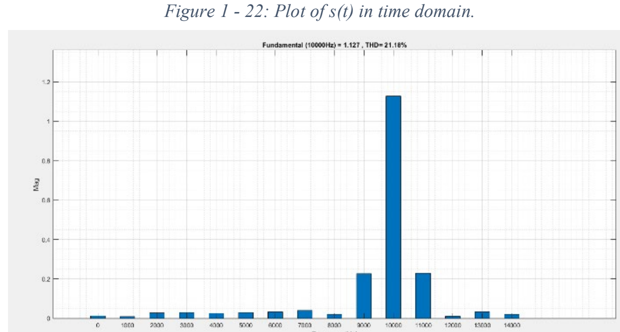

Figure 1 - 23: Plot of S(f) in freq. domain.

The recovered signal after envelop detector:

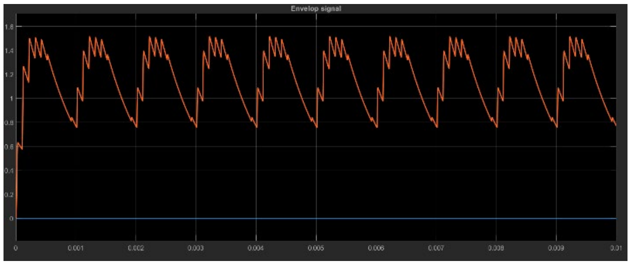

Figure 1 - 24: plot of Recovered signal in time domain.

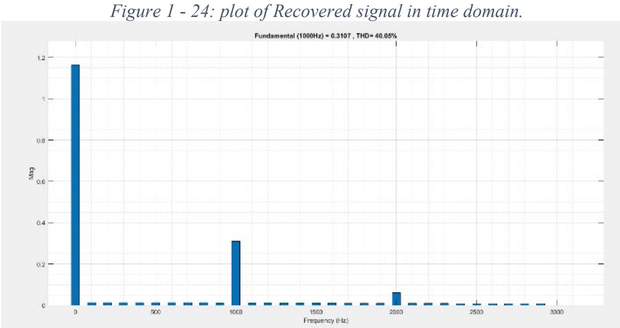

Figure 1 - 25: plot of Recovered signal in freq. domain.

The output (amplified) signal:

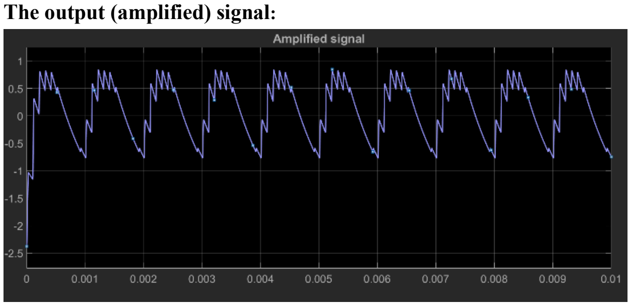

Figure 1 - 26: plot of the output (amplified) signal in time domain.

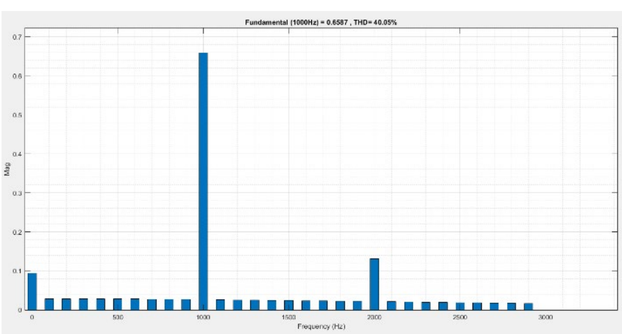

Figure 1 - 27: plot of output (amplified) signal in freq. domain.

As shown in figure above, we noticed that the major frequency component is at 1000Hz,which is the same frequency as that of our m(t) signal. Also, the amplitude is very close to the one in m(t).

The results could be improved by smoothening the curves at the receiver.

The plotting for s(t) and recover signal:

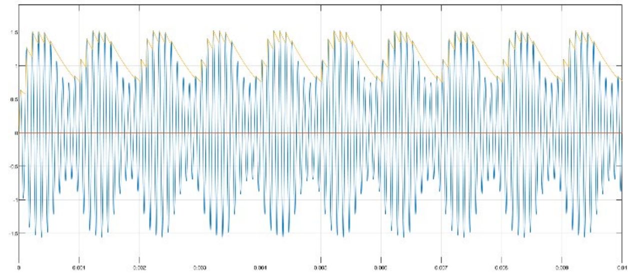

Figure 1 - 28: plotting for s(t) and recovered signal

As shown in figure above, the results match each other, and recovered signal follows the peak of the AM waveform.

The m(t) with the final signal after amplification:

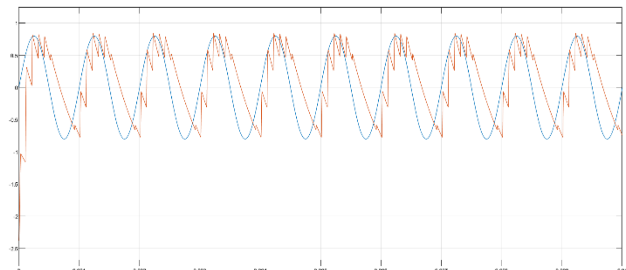

Figure 1 - 29: plotting for m(t) and amplified signal.

As notable above, the results closely match, and have consistent post-amplification amplitude and frequency, indicating the accuracy and reliability of our results.

Theoretical results:

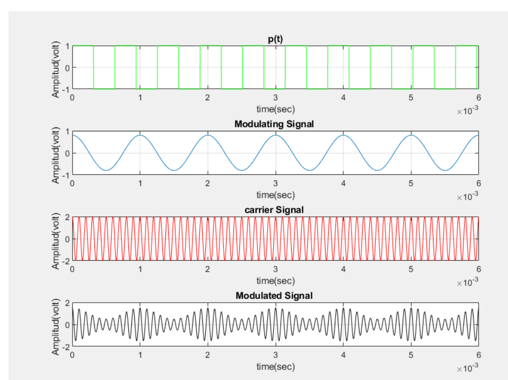

Figure 1 - 30: Actual Signals plots in time domain

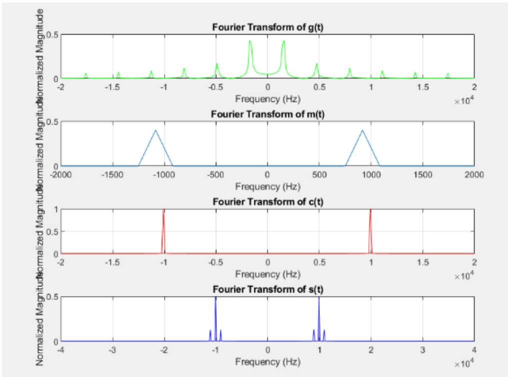

Figure 1 - 31: Actual Signals plots in freq. domain

The plots above, show the expected results from our simulation, specifically on the modulator sides. The first figure is in time domain and the second is in frequency domain. And the results from simulation closely match the results above.

Comments on The Plots

The plots shown above prove that our system works within the expected specifications. **Figure 27** shows the result of the modulator with the envelope detector wave above it, we can see clearly that the modulated signal resembles very closely the one calculated from our model. In our model, we have plotted s(t) and we found that it has maximum amplitude of 1.5V and the minimum of 0.5V, this is very closed to the simulation result which shows that the maximum amplitude is **indeed** 1.5V and the minimum is 0.65V.

The recovered signal from the envelop detector, is smaller in amplitude and offset by the carrier signal, and this is excepted. Therefore, we have put it through a difference amplifier, which offsets the envelop signal and amplifies it by a factor of 2.1, which gives us a signal whose average value is around zero, Vp-p 1.58V, and has a frequency of 1kHz which is almost identical to the specification to the message signal.

Conclusion

This project delves into practical applications of amplitude modulation (AM) and demodulation, offering hands-on experience in implementing theoretical knowledge. We had to build a modulator circuit which generated a signal that we demodulated with an envelope detector circuit. we simulate and construct the circuit, analyzed signals in time and frequency domains, and presented their findings. Phase One covers AM modulation theory, complex Fourier series, filter design, and MATLAB signal visualization. Phase Two focuses on AM demodulation, involving envelope detector design and analyzing demodulated output in time and frequency domains. We have learned many valuable lessons during this project; we had a closer look over the inner workings of AM modulator, design, and analysis. We have also had fun implementing filters and amplifiers correctly and seeing how they function in real life.

References

[1] NormalAM. (n.d.). *Laboratory, Electronic Devices*. Retrieved Dec 30, 2023, from https://ece.charlotte.edu/wp-content/uploads/sites/301/2023/05/ecgr3156-experiment-8-amplitude-modulation-and-demodulation.pdf

[2] Capacitor. (2024, Jan 1). *byjus*. Retrieved from https://byjus.com/physics/capacitor-and-capacitance/#:~:text=A%20capacitor%20is%20a%20two,material%20known%20as%20a%20dielectric

[3] Inductor. (2024, Jan 2). *byjus*. Retrieved from https://byjus.com/jee/inductor/#:~:text=An%20inductor%20is%20a%20passive,of%20current%20flowing%20through%20it

[4] OpAmp. (2024, Jan 2). *ablic*. Retrieved from https://www.ablic.com/en/semicon/products/analog/opamp/intro/#:~:text=An%20operational%20amplifier%20is%20an,between%20the%20two%20input%20pins

Appendix

Design a Bandpass filter

Let Rs = 300ohm, BW= 5000Hz and fc = 10000Hz.

Now let, $\beta = \frac{1}{RC} \rightarrow C = \frac{1}{R\beta} = \frac{1}{300.(2\pi).(5000)} = 106\ \mu F$

To calculate L:

$$\omega_L = \frac{1}{\sqrt{LC}} \rightarrow {\omega_L}^2 = \frac{1}{LC}$$

$$L = \frac{1}{{\omega_L}^2 C} = \frac{1}{(2\pi.10000)^2 x106x10^{-9}} = 2.39mH \approx 2.4mH.$$

MATLAB codes

Code1:

```
clc;
close all;
clear all;

disp(' example: m=1 means 100% modulation');


m=1; % for 100% modulation

%modulating signal m(t)
A_m=0.8; % Amplitude of modulating signal
f_m=1000; % Frequency of modulating signal
Ta=1/f_m; % Time period of modulating signal
t=0:Ta/999:6*Ta; % Total time for simulation

m_t=A_m.*cos(2.*pi.*f_m.*t); % Eqation of modulating signal

%carrier signal
A_c = 2;
f_c = f_m.*10;
T_c = 1/f_c;
c_t = A_c.*cos(2.*pi.*f_c.*t);



g_t = square(t.*f_m.*10);
```

```
s_t = (c_t/2).*(1+(4/(pi.*A_c)*m_t));

%plot g(t)
figure(1);
subplot(4,1,1);
plot(t,g_t,'g'), grid on;% Graphical representation of
Modulating signal
title ( 'p(t)');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');

%plot m(t)
%figure(2)
subplot(4,1,2);
plot(t,m_t), grid on;% Graphical representation of Modulating
signal
title ( '  Modulating Signal   ');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');

%plot c(t)
%figure(3)
subplot(4,1,3);
plot(t,c_t,'r'), grid on;% Graphical representation of
Modulating signal
title ( '  carrier Signal   ');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');

%plot s(t)

subplot(4,1,4);
plot(t,s_t,'k'), grid on;% Graphical representation of
Modulating signal
title ( '  Modulated Signal   ');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');


% Fourier Transform of g(t)
G_f = fftshift(fft(g_t)) / length(g_t);
L = length(g_t);
f = (-L/2:L/2-1)*(1/(L*Ta))*1000;

% Fourier Transform of m(t)
M_f = fftshift(fft(m_t)) / length(m_t);

% Fourier Transform of c(t)
C_f = fftshift(fft(c_t)) / length(c_t);

% Fourier Transform of s(t)
S_f = fftshift(fft(s_t)) / length(s_t);

% Plotting the Fourier Transforms
figure;

subplot(4,1,1);
plot(f, abs(G_f),'g'), grid on;
title('Fourier Transform of g(t)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-20000 20000])

subplot(4,1,2);
plot(f, abs(M_f)), grid on;
title('Fourier Transform of m(t)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-2000 2000])

subplot(4,1,3);
plot(f, abs(C_f),'r'), grid on;
title('Fourier Transform of c(t)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-20000 20000])

subplot(4,1,4);
plot(f, abs(S_f),'b'), grid on;
title('Fourier Transform of s(t)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-40000 40000])
```

Code2:

```
clc;
close all;
clear all;
%XXXXXXXXXXX Define AM modulation Index XXrXXXXXXXXX
disp(' example: m=1 means 100% modulation');

m=1; % for 100% modulation
Am=0.8; % Amplitude of modulating signal
fa=1000; % Frequency of modulating signal
Ta=1/fa; % Time period of modulating signal
t=0:Ta/999:6*Ta; % Total time for simulation

ym=Am*cos(2*pi*fa*t); % Eqation of modulating signal

figure(1)
subplot(3,1,1);
plot(t,ym), grid on;% Graphical representation of Modulating
signal
title ( '  Modulating Signal   ');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');
%XXXXXXXX carrier signal generation XXXXXXXXXXXXX
Ac=2;% Amplitude of carrier signal [ where, modulation Index
(m)=Am/Ac ]
fc=fa*10;% Frequency of carrier signal
Tc=1/fc;% Time period of carrier signal
yc=Ac*cos(2*pi*fc*t);% Eqation of carrier signal
subplot(3,1,2);
plot(t,yc,'r'), grid on;% Graphical representation of carrier
signal
title ( '  Carrier Signal   ');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');
%XXXXXXXXXXXX AM Modulation XXXXXXXXXXXXXX
y=Ac*(1+Am*cos(2*pi*fa*t)).*cos(2*pi*fc*t); % Equation of
Amplitude
%modulated signal
subplot(3,1,3);
plot(t,y,'k');% Graphical representation of AM signal
title ( '  Amplitude Modulated signal  ');
xlabel ( ' time(sec) ');
ylabel (' Amplitud(volt)   ');
grid on;


%>>>>>>>>>>>>>>>>>Fourier Transform<<<<<<<<<<<<<<<<%

% Fourier Transform of g(t)
YM_F = fftshift(fft(ym)) / length(ym);
L = length(ym);
f = (-L/2:L/2-1)*(1/(L*Ta))*1000;

% % Fourier Transform of m(t)
% M_f = fftshift(fft(ym)) / length(ym);

% Fourier Transform of c(t)
YC_F = fftshift(fft(yc)) / length(yc);

% Fourier Transform of s(t)
S_f = fftshift(fft(y)) / length(y);

% Plotting the Fourier Transforms
figure;

subplot(4,1,1);
plot(f, abs(YM_F)), grid on;
title('Fourier Transform of M(f)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-2000 2000])

subplot(4,1,2);
plot(f, abs(YC_F),'r'), grid on;
title('Fourier Transform of C(f)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-20000 20000])

subplot(4,1,3);
plot(f, abs(S_f),'k'), grid on;
title('Fourier Transform of S(f)');
xlabel('Frequency (Hz)');
ylabel('Normalized Magnitude');
xlim([-20000 20000])
```