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COMPLEX ENGINEERING ACTIVITY

1) Problem Statement

Modulation of voice signal via AM-LC and AM-DSBSC

2) Introduction:

Throughout the world, communication is a key component. For common people, talking over phone, sending voice messages is just a touch of a button but for us telecommunication Engineers, the reality is very different. We know that how communication actually works. Here we introduce the concept of modulation. Modulation is the process of passing the information on another carrier signal. There are various types of modulation but in this task, we are going to use Amplitude Modulation. AM has its sub types out which we are using the following two:

i) Amplitude Modulation Double Side Band Large Carrier (also known as Full Carrier)
ii) Amplitude Modulation Double Side Band Suppressed Carrier (AM-DSBSC)

2.1) OBJECTIVES:

- To study the theory behind Amplitude Modulation
- To apply Amplitude Modulation Large Carrier and Amplitude Modulation Double Side Band Suppressed Carrier on a real time voice signal.
- To Demodulate the modulated signal using Envelope Detector and Coherent Detector
- To graph the signals in time and frequency domain.

2.2) Tools:

Software: MATLAB 2021.

3) Amplitude Modulation

3.1) INTRODUCTION:

3.1.1) Modulation:

Modulation is the process of putting information onto a high frequency carrier for transmission (frequency translation). Modulation occurs at the transmitting end of the system.

3.1.2) Amplitude Modulation Large Carrier (AM)

In Amplitude Modulation, the amplitude of the carrier waveform varies with the information signal.

In Amplitude Modulation, the baseband or the information signal is modulated to the carrier signal to produce the modulated sine wave.

Consider the carrier signal,

$$c(t) = A\,c\,cos\,(\omega ct), \qquad where\ \omega\,c\ = 2\pi f_c$$

The modulating signal (information signal),

$$m(t) = Am\,cos(\omega mt)$$

Then, the amplitude-modulated can be expressed as:

$$s(t) = [A\,c\ +\ m(t)]\,cos(\omega ct)$$

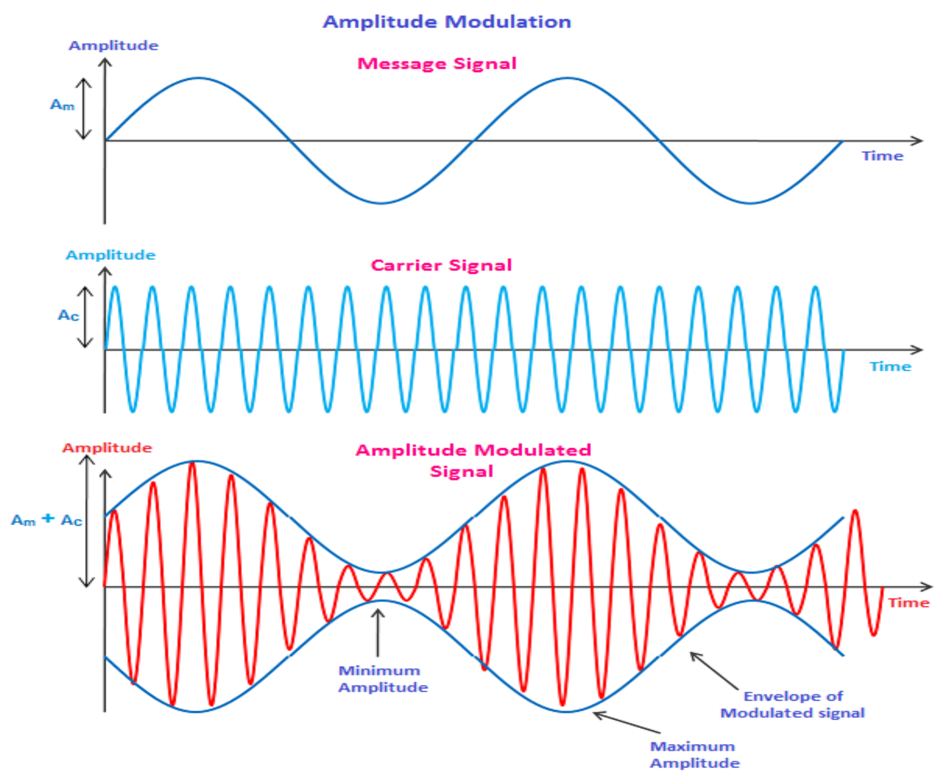
$$= [A\,c\ +\ A\,m\cos(\omega\,m\,t)]\cos(\omega\,c\,t)$$

$$= A\,c\,[1\ +\ m\,cos(\omega\,m\,t)]\,cos\,(\omega\,c\,t)$$

It can also be written as

$$s(t) = A_C cos(\omega ct) + \frac{m}{2} A_C cos\,((\omega c + \omega m\,)t) + (1/2)m\,A_m \cos\,((\omega c - \omega m)t)$$

Where notation m=A m /A c in expression above is termed as modulation index. Simply a measurement for the degree of modulation and bears the relationship of the ratio of A m to A c

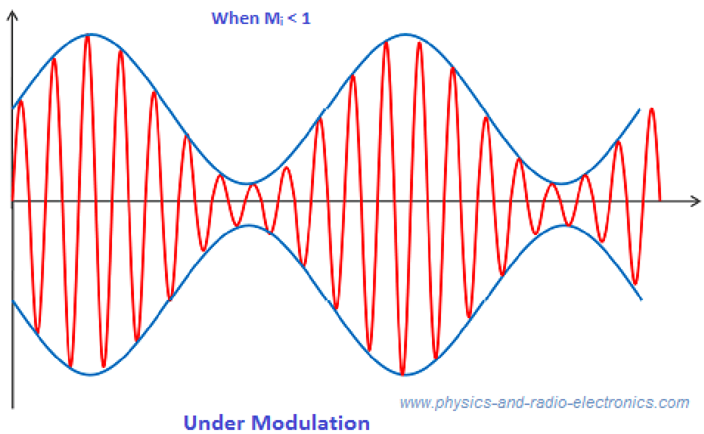


3.2) Modulation Index

The degree of modulation is an important parameter and is known as the modulation index. It is the ratio of the peak amplitude of the modulation signal, A m to the peak amplitude of the carrier signal, Ac. The modulation index, m is also referred as percent modulation, modulation factor and depth of modulation. It is a number lying between 0 and 1 and is typically expressed as a percentage. The modulation index can be determined by measuring the actual values of the modulation voltage and the carrier voltage and computing the ratio.

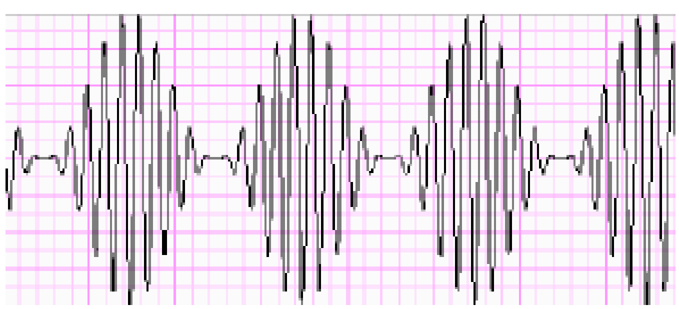
3.2.1) Under Modulation

When m <1, we call this as under modulation by ensuring the amplitude of s m (t) to be less than the carrier amplitude, message signal can comfortably be retrieved from the envelope waveform of s(t).



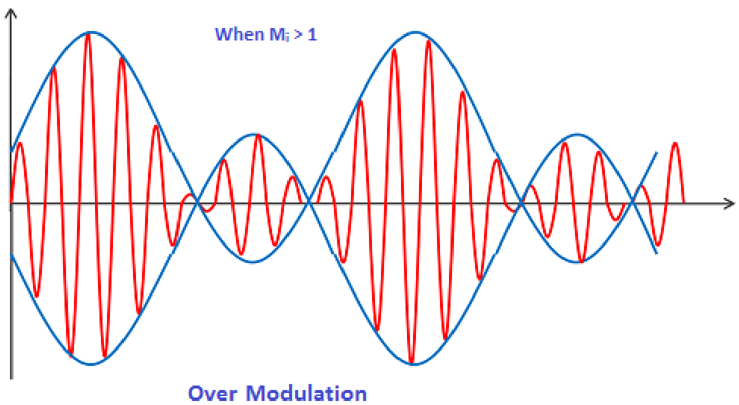
3.2.2) Ideal Modulation

When m = 1, this is the best modulation where to ensure successful retrieval of the original transmitted information at the receiver end. The ideal condition for amplitude modulation (AM) is when m = 1 also means A m = A c ; this will give rise to the generation of the maximum message signal outputs at the receiver without distortion.



3.2.3) Over Modulation

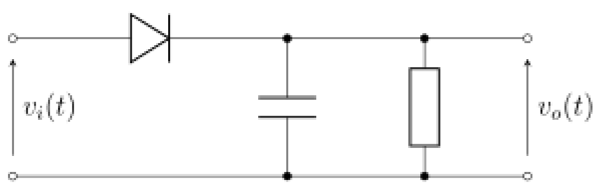
When m>1, we call this as over modulation. If the amplitude of the modulating signal is higher than the carrier amplitude, it will cause severe distortion to the modulated signal.



3.3) Demodulation:

Demodulation of an AM signal can be done by an envelope detector. An envelope detector is an electronic circuit that takes a (relatively) high-frequency amplitude modulated signal as input and provides an output, which is the demodulated envelope of the original signal.

An envelope detector is sometimes called as a peak detector.



with m(t) representing the original audio frequency message, C the carrier amplitude and R(t) equal to C + m(t). So, if the envelope of the AM signal can be extracted, the original message can be recovered.

An envelope detector can be used to demodulate a previously modulated signal by removing all high frequency components of the signal. The capacitor and resistor form a low-pass filter to filter out the carrier frequency. Such a device is often used to demodulate AM radio signals because the envelope of the modulated signal is equivalent to the baseband signal.

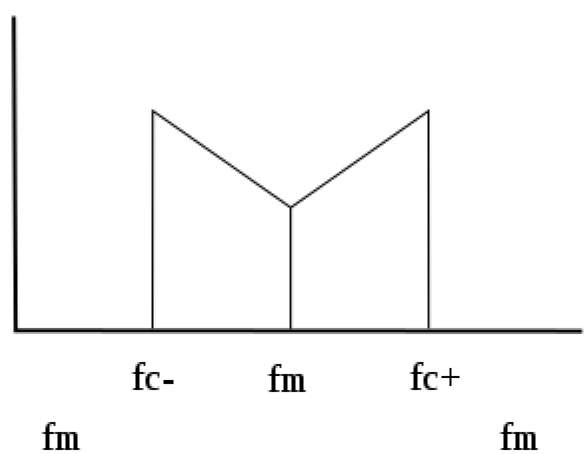
4) Double-sideband suppressed-carrier transmission (DSB-SC)

4.1) Introduction:

Double-sideband suppressed-carrier transmission (DSB-SC) is transmission in which frequencies produced by amplitude modulation (AM) are symmetrically spaced above and below the carrier frequency and the carrier level is reduced to the lowest practical level, ideally being completely suppressed.

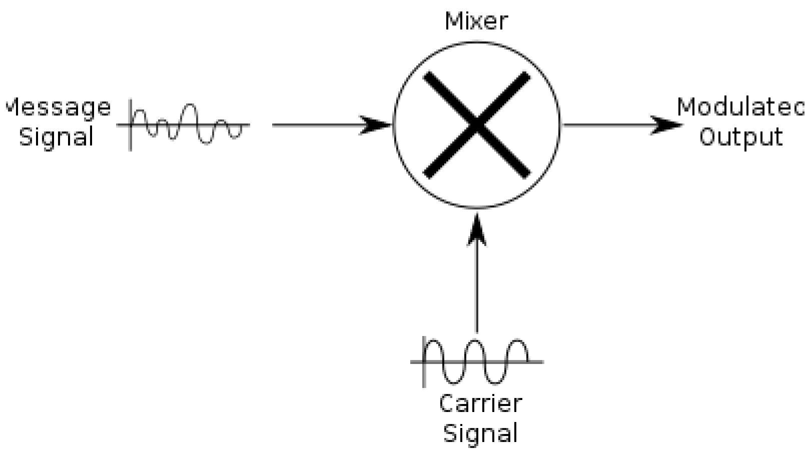
In the DSB-SC modulation, unlike in AM, the wave carrier is not transmitted; thus, much of the power is distributed between the side bands, which implies an increase of the cover in DSB-SC, compared to AM, for the same power use

DSB-SC transmission is a special case of double-sideband reduced carrier transmission. It is used for radio data systems. This mode is frequently used in Amateur radio voice communications, especially on High-Frequency bands.



4.2) Generation:

DSB-SC is generated by a mixer. This consists of a message signal multiplied by a carrier signal is used.



The mathematical representation of this process is shown below, where the product-to-sum trigonometric identity

$$s(t) = C(t)\ x\ \ M(t)$$

4.3) Demodulation:

For DSBSC, Coherent Demodulation is done by multiplying the DSB-SC signal with the carrier signal (with the same phase as in the modulation process) just like the modulation process. This resultant signal is then passed through a low pass filter to produce a scaled version of the original message signal.

$$M`(t) = S(t) * C(t)$$

The equation above shows that by multiplying the modulated signal by the carrier signal, the result is a scaled version of the original message signal plus a second term. Since Wm << Wc this second term is much higher in frequency than the original message. Once this signal passes through a low pass filter, the higher frequency component is removed, leaving just the original message.

5) MATLAB Implementation:

i) User Inputs and specifications:

User Inputs:

```
clc;
close all;
clear;
A = input('Enter the Amplitude of the carrier Wave: ');
Fc = 30000;     % hertz
Fs = 100000;    % hertz
x = input('Enter the recording Time: ');   %SECONDS
Order = 2;
dt = 1/Fs;                                % seconds per sample
StopTime = x;
t = (0:dt:StopTime-dt)';
N=size(t,1);
```

In this code, we are taking the inputs such as the Carrier Frequency, Amplitude, Sampling Rate and order of circuits. We are also taking the time of audio signal as an input.

ii) Carrier Wave:

Carrier Wave

```
Carrier = (A*cos(2*pi*Fc*t)');
```

The equation of the carrier is given.

iii) Recording Sound (voice) signal:

Signal Wave = Recorded Voice signal

```
recObj = audiorecorder(Fs,16,1);
disp('Start speaking.')
```

```
Start speaking.
```

```
recordblocking(recObj, x);
disp('End of Recording.');
```

```
End of Recording.
```

```
Input_Signal=(getaudiodata(recObj))';
```

The built-in function of audio Recorder is used in which the following parameters are passed:

1) Sampling rate,
2) N-bits: The number of bits per sample. We are taking 16 bits per sample.
3) Input Option - we choose the mono speaker as the input option.

Next, we are storing the recording in a variable called RecObj. The recording is then being taken as the Input Signal.

iv) Input Signal Filtering

Filtering out the Input Signal to desired Frequency

```
beginFreq = 1000 / (Fs/2);
endFreq = 4000 / (Fs/2);
[b,a] = butter(Order, [beginFreq, endFreq], 'bandpass');
```

Bandpass filter design

```
Signal = filter(b, a, Input_Signal);
```

Here, we are passing the input signal through a bandpass filter to filter out the unwanted frequencies.

v) Modulation

Signal Modulation Large Carrier

```
Modulated_lc = (A + Signal).* (Carrier);
```

Signal Modulation Double Side Band Supressed Carrier

```
Modulated = Signal.*Carrier;
```

In this section of the code, we are applying the two required Amplitude modulation schemes as explained earlier in the report.

vi) Demodulation

Designing Of Bandpass filter for Demodulation

```
Freq1 = 20 / (Fs/2);
Freq2 = Fc / (Fs/2);
[num,den] = butter(Order,[Freq1,Freq2],'bandpass');
```

Demodulation of Signal (Double Side Band Supressed Carrier)

```
Demodulated = filter(num,den,Modulated);
Demodulated1 = Demodulated.*Carrier;
[e,f] = butter(Order*2,(Fc/2)/Fs,'low');
Demodulated2 = filter(e,f,Demodulated1);
```

Demodulation of Signal (Large Carrier)

```
en = lowpass(envelope(Modulated_lc), 0.2, dt);
```

Here, we first design a Bandpass filter for demodulation and then we apply the demodulation schemes i.e. Coherent and Envelope detector as explained in the theory part of the code.

vii) Graph Plot of Carrier

Plotting Of Carrier Wave

```
figure
subplot(221)
plot(t(1:100),Carrier(1:100));
title('Time Domain Representation of Carrier Wave');
xlabel('Time');
ylabel('Magnitude');
```

viii) Graph Plot of Message Signal:

Plotting Of Signal

```
subplot(222)
plot(t,Signal);
title('Time Domain Representation of Signal');
xlabel('Time');
ylabel('Magnitude');
```

ix) Graph Plot of Modulated Signal (Double Side Band Suppressed Carrier)

Plotting Of Modulated Signal

```
subplot(223)
plot(t,Modulated)
title('Modulated Signal');
xlabel('Time');
ylabel('Magnitude');
```

x) Graph Plot of Demodulated Signal (Double Side Band Suppressed Carrier)

Plotting Of Demodulated Signal

```
subplot(224)
plot(t,Demodulated2,'r')
title('Demodulated Signal');
xlabel('Time');
ylabel('Magnitude');
```

xi) Graph Plot of Full Carrier Modulation

Plotting Of Modulated Signal - LC

```
figure
subplot(211)
plot(t(1:100),Modulated_lc(1:100))
title('Modulated Signal Large Carrier');
xlabel('Time');
ylabel('Magnitude');
```

xii) Graph Plot of Full Carrier Demodulation

Plotting Of Demodulated Signal - Envelope

```
subplot(212)
plot(t,en,'r')
title('Demodulated Signal Envelope detection');
xlabel('Time');
ylabel('Magnitude');
```

xiii) Frequency Domain Analysis

Frequency Domain Analysis

```
fCarrier = (fftshift(fft(Carrier)));
fSignal = (fftshift(fft(Signal)));
fMod = (fftshift(fft(Modulated)));
fDemod = (fftshift(fft(Demodulated2)));
fMod_lc = (fftshift(fft(Modulated_lc)));
fDemod_lc = (fftshift(fft(en)));
freq = -Fs/2:(Fs/N):(Fs/2)-(Fs/N);
```

In this section of the code, we have shifted to frequency domain from time domain using the fast Fourier transform function of MATLAB and then we have also shifted the frequency signals towards the origin. From the sampling rate, we have defined our frequency range for plotting of graphs.

xiv) Graph Plotting in Frequency domain.

Ploting Of Frequencies of the Signal

```
figure
subplot(231)
plot(freq,abs(fCarrier)/N);
title('F-Domain Carrier Wave');
xlabel('Frequency');
ylabel('Magnitude');
subplot(232)
plot(freq,abs(fSignal)/N);
title('F-Domain Signal');
xlabel('Frequency');
ylabel('Magnitude');
subplot(233)
plot(freq,abs(fMod)/N)
title('F-Domain Modulated Signal');
xlabel('Frequency');
ylabel('Magnitude');
subplot(234)
plot(freq,abs(fDemod)/N);
title('F-Domain Demodulated Signal');
xlabel('Frequency');
ylabel('Magnitude');
subplot(235)
plot(freq,abs(fMod_lc)/N)
title('F-Domain Modulated Signal - large carrier');
xlabel('Frequency');
ylabel('Magnitude');
subplot(234)
plot(freq,abs(fDemod_lc)/N);
title('F-Domain Demodulated Signal- large carrier');
xlabel('Frequency');
ylabel('Magnitude');
```

In this section, we are plotting all the previously plotted graphs in frequency domain. This helps us in better analyzing and understanding of the signal.

xv) Verifying the Output

Verifying the output

```
disp('The original Signal.');
```

```
The original Signal.
```

```
sound(Signal,Fs,8);
pause(x);
disp('The Demodulated Signal.');
```

```
The Demodulated Signal.
```

```
sound(Demodulated2,Fs,8)
```

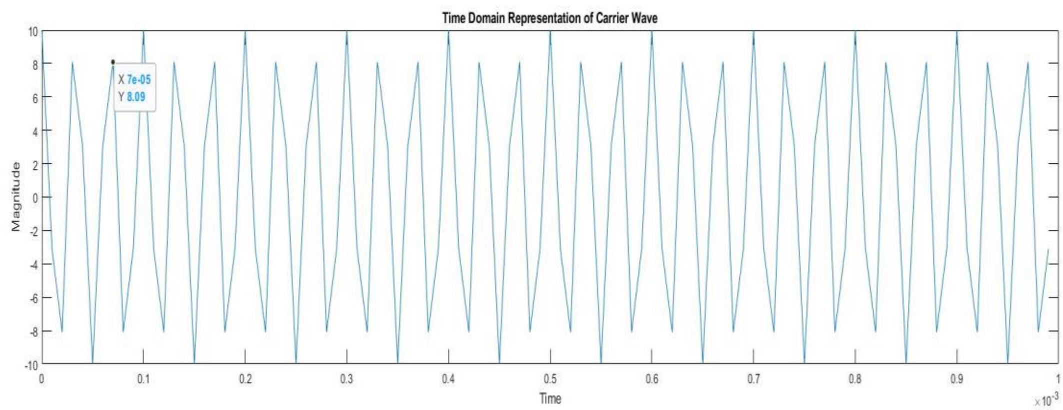
Over here, we are playing the original voice recording (our input signal) and then playing the demodulated signal to verify that our code works or not.

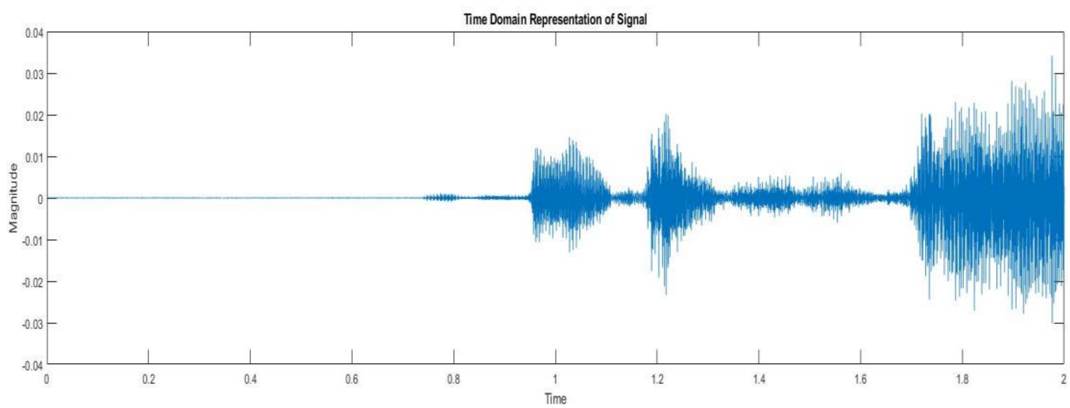
6) Results

i) Taking Input from the user:

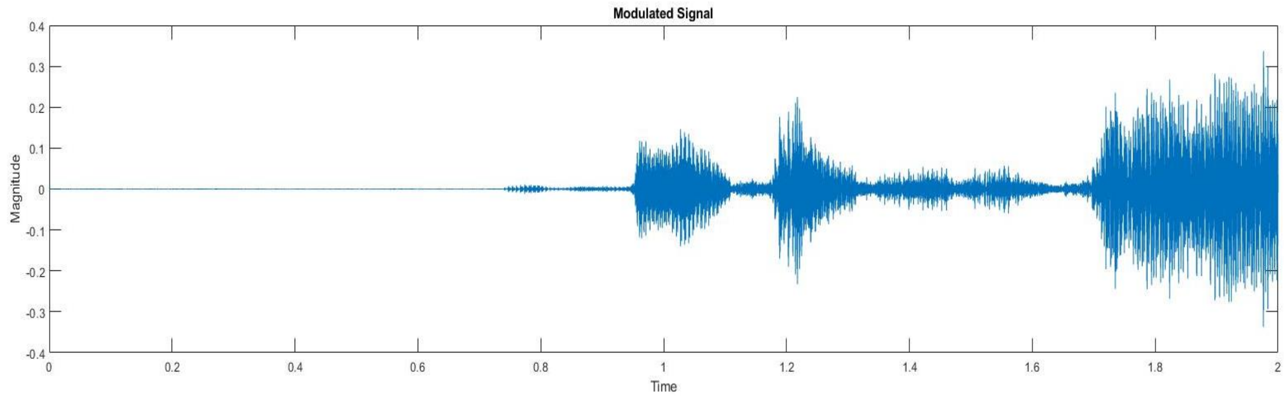
```
Enter the Amplitude of the carrier Wave: 10
Enter the recording Time: 2
```

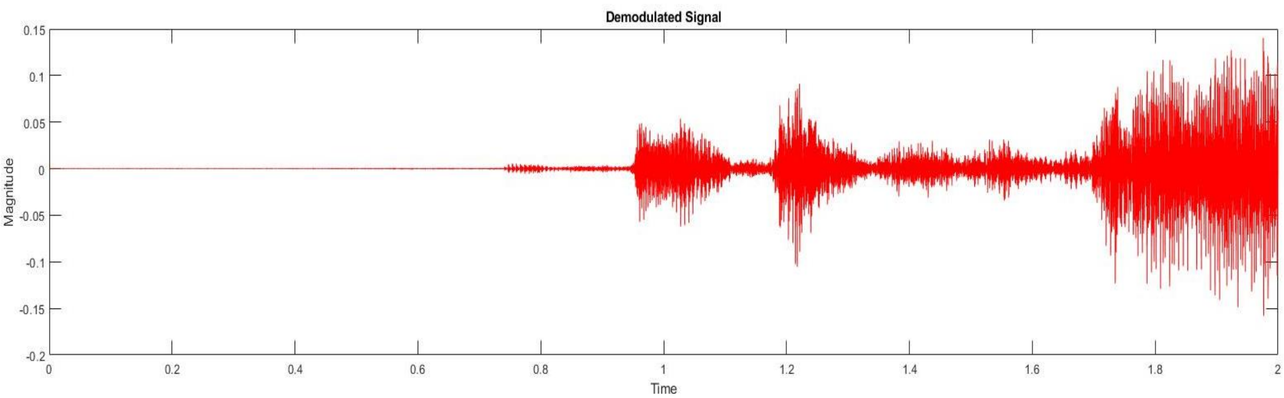
ii) Graph Plot of Carrier and Message signal



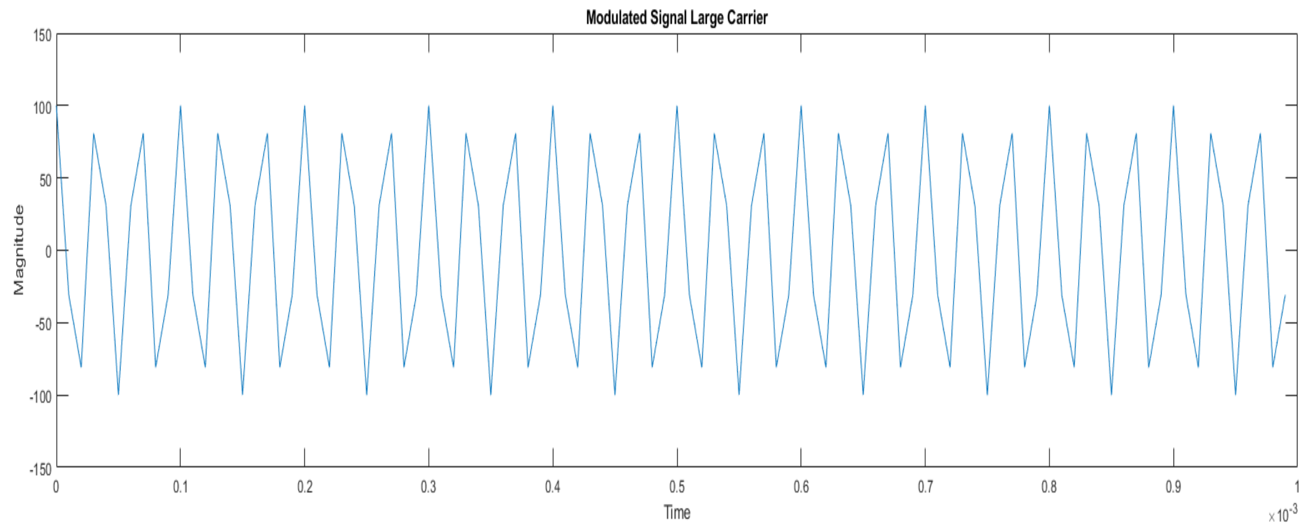


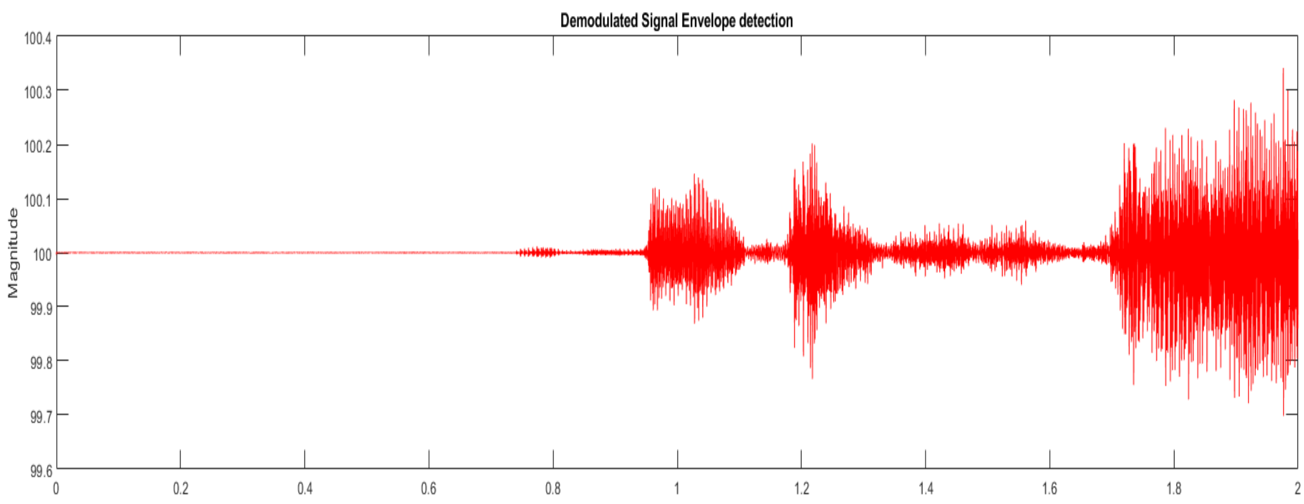
iii) Graph Plot of Modulated and Demodulated Signal (DSBSC)



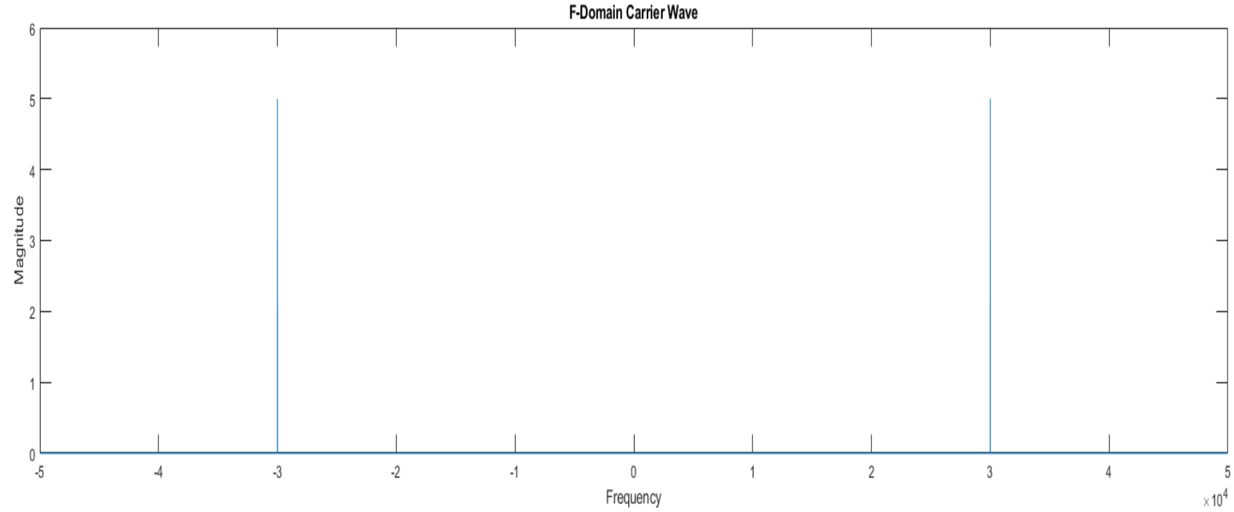


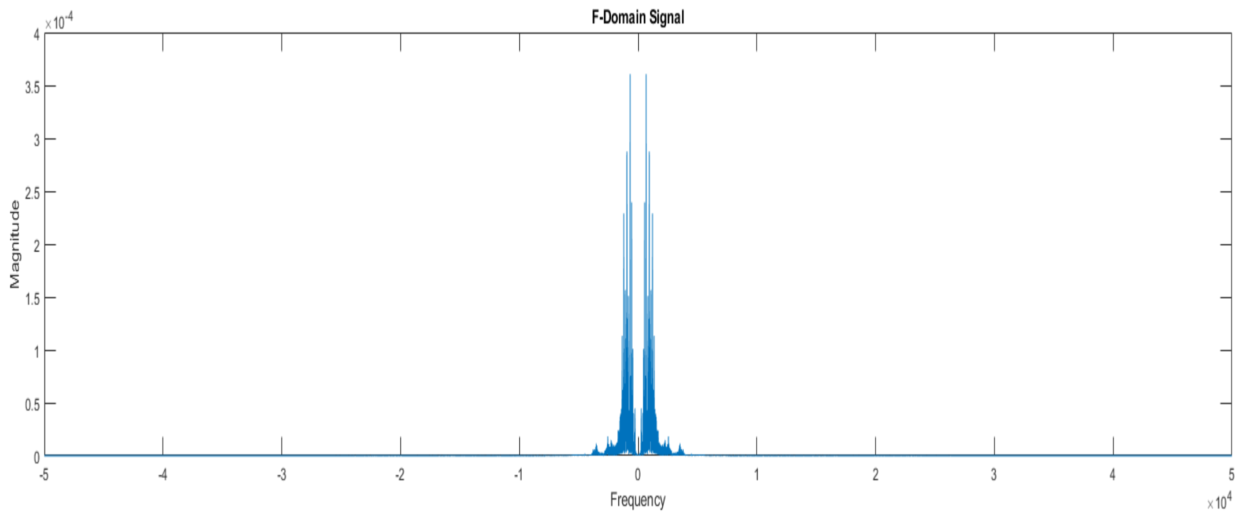
iv) Graph Plot of Modulated and Demodulated Signal (Large Carrier)



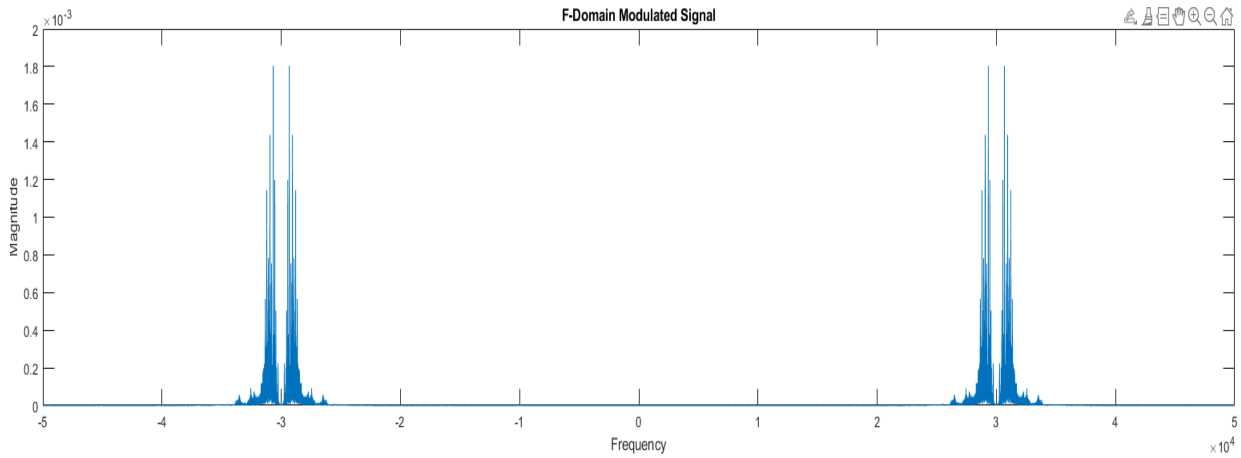


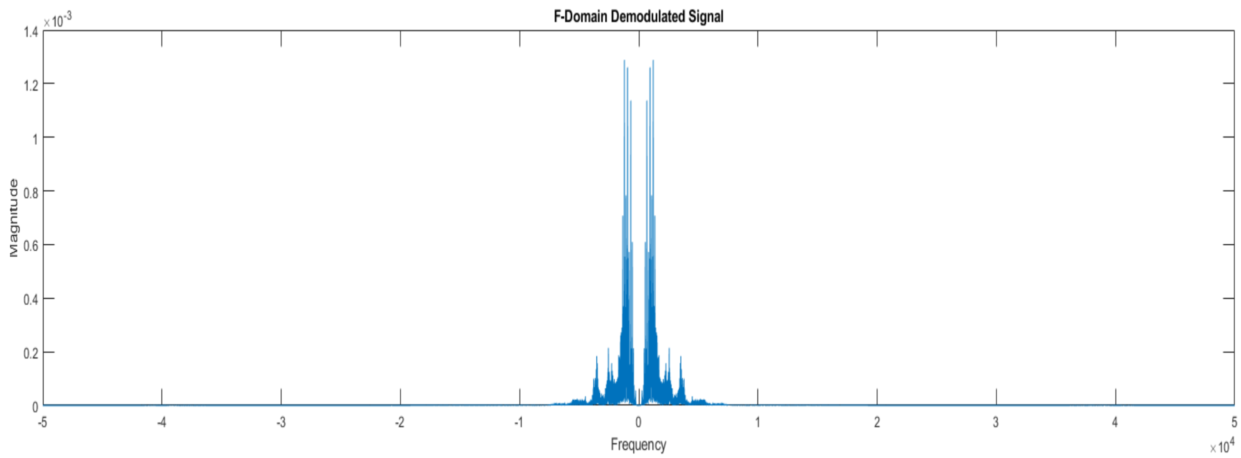
v) Graph Plot of F-Domain Message and Carrier Signal



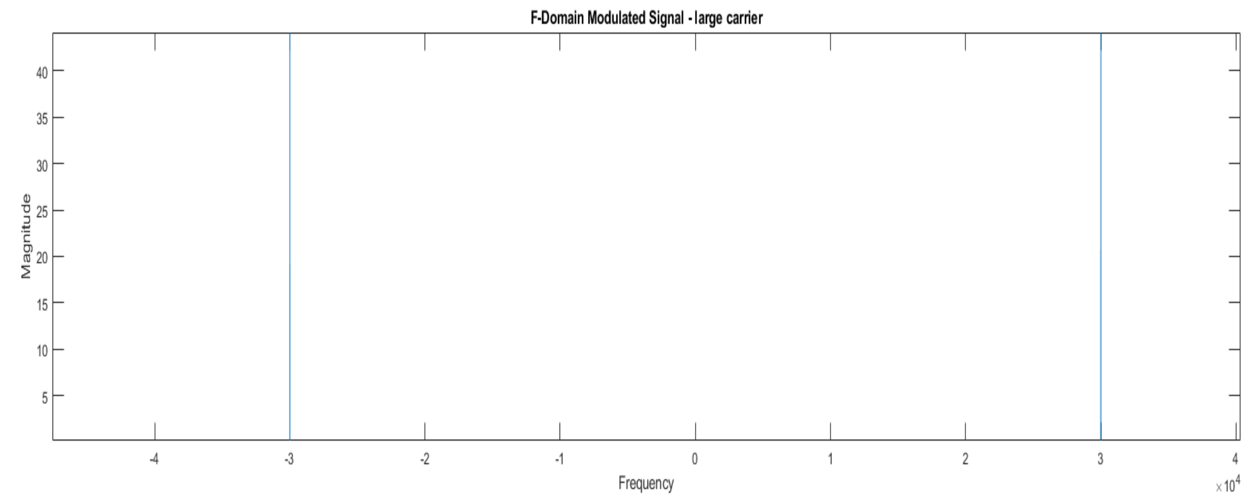


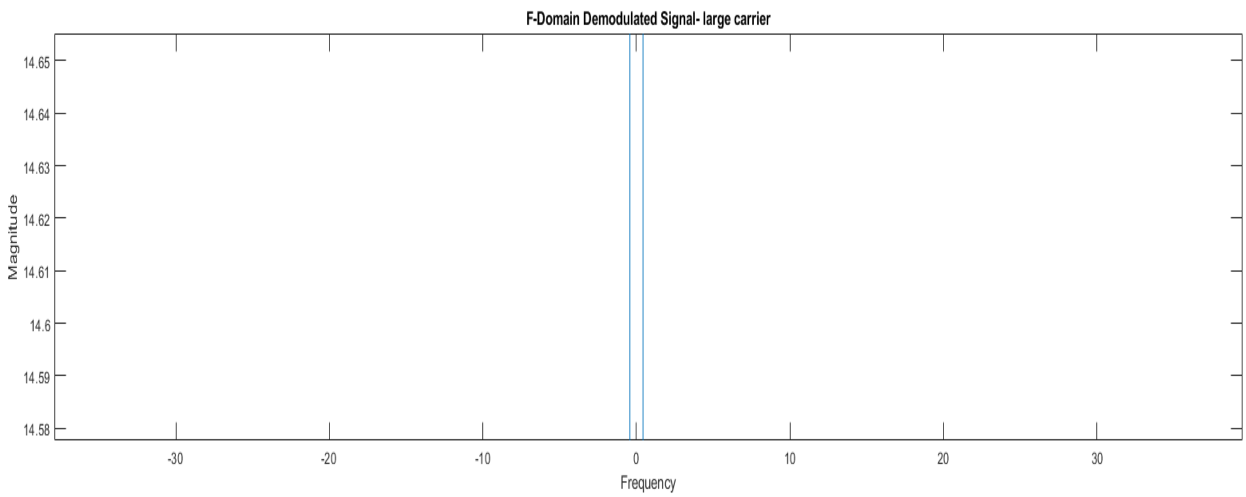
vi) Graph Plot of F-Domain Modulation and Demodulation (AM-DSBSC)





vii) Graph Plot of F-Domain Modulation and Demodulation (AM-LC)





7) Steps:

i) Take the input from users.
ii) Record a voice signal
iii) Filter the Voice signal to remove unwanted Frequencies.
iv) Apply Modulation (AM-DSBSC)
v) Design filter for Demodulation.
vi) Pass signal through Filter.
vii) Demodulation process (AM-DSBSC).
viii) Apply Low Pass Filter.
ix) Apply Modulation (AM-LC)
x) Make envelope detector for Demodulation.
xi) Demodulation process (AM-LC).
xii) Apply Low Pass Filter.
xiii) Plot Graphs in time domain.
xiv) Fourier Transformation of signals for Frequency Analysis.
xv) Shift Frequency signals to origin.
xvi) Plot Graphs in Frequency Domain.

8) Conclusion:

From this Complex engineering problem, we learnt how to:

1) Record Voice signals in MATLAB
2) Design Filter in MATLAB as per required Specification.
3) Modulation and Demodulation Techniques of Amplitude

After making the logic, designing the algorithm and writing the code, we were able to not only plot the results in Time and Frequency domain, we were also able to verify our results by playing the original and demodulated message signal.

Appendix A: MATLAB CODE:

User Inputs:

```
clc;
close all;
clear;
A = input('Enter the Amplitude of the carrier Wave: ');
Fc = 30000;     % hertz
Fs = 100000;    % hertz
x = input('Enter the recording Time: ');   %SECONDS
Order = 2;
dt = 1/Fs;                               % seconds per sample
StopTime = x;
t = (0:dt:StopTime-dt)';
N=size(t,1);
```

Carrier Wave

```
Carrier = (A*cos(2*pi*Fc*t)');
```

Signal Wave = Recorded Voice signal

```
recObj = audiorecorder(Fs,16,1);
disp('Start speaking.')
recordblocking(recObj, x);
disp('End of Recording.');
Input_Signal=(getaudiodata(recObj))';
```

Filtering out the Input Signal to desired Frequency

```
beginFreq = 1000 / (Fs/2);
endFreq = 4000 / (Fs/2);
[b,a] = butter(Order, [beginFreq, endFreq], 'bandpass');
```

Bandpass filter design

```
Signal = filter(b, a, Input_Signal);
```

Signal Modulation Large Carrier

```
Modulated_lc = (A + Signal).* (Carrier);
```

Signal Modulation Double Side Band Supressed Carrier

```
Modulated = Signal.*Carrier;
```

Designing Of Bandpass filter for Demodulation

```
Freq1 = 20 / (Fs/2);
Freq2 = Fc / (Fs/2);
[num,den] = butter(Order,[Freq1,Freq2],'bandpass');
```

Demodulation of Signal (Double Side Band Supressed Carrier)

```
Demodulated = filter(num,den,Modulated);
Demodulated1 = 2* Demodulated.*Carrier;
[e,f] = butter(Order*2,(Fc/2)/Fs,'low');
Demodulated2 = filter(e,f,Demodulated1);
```

Demodulation of Signal (Large Carrier)

```
en = lowpass(envelope(Modulated_lc), 0.2, dt);
```

Plotting Of Carrier Wave

```
figure ('Name',' Graph Plot of Carrier and Message signal')
subplot(211)
plot(t(1:100),Carrier(1:100));
title('Time Domain Representation of Carrier Wave');
xlabel('Time');
ylabel('Magnitude');
```

Plotting Of Signal

```
subplot(212)
plot(t,Signal);
title('Time Domain Representation of Signal');
xlabel('Time');
ylabel('Magnitude');
```

Plotting Of Modulated Signal

```
figure ('Name',' Graph Plot of Modulated and Demodulated Signal (AM-DSBSC)')
subplot(211)
plot(t,Modulated)
title('Modulated Signal');
xlabel('Time');
ylabel('Magnitude');
```

Plotting Of Demodulated Signal

```
subplot(212)
plot(t,Demodulated2,'r')
title('Demodulated Signal');
xlabel('Time');
ylabel('Magnitude');
```

Plotting Of Modulated Signal - LC

```
figure ('Name','Graph Plot of Modulated and Demodulated Signal (AM-LC)')
subplot(211)
plot(t(1:100),Modulated_lc(1:100))
title('Modulated Signal Large Carrier');
xlabel('Time');
ylabel('Magnitude');
```

Plotting Of Demodulated Signal - Envelope

```
subplot(212)
plot(t,en,'r')
title('Demodulated Signal Envelope detection');
xlabel('Time');
ylabel('Magnitude');
```

Frequency Domain Analysis

```
fCarrier = (fftshift(fft(Carrier)));
fSignal = (fftshift(fft(Signal)));
fMod = (fftshift(fft(Modulated)));
fDemod = (fftshift(fft(Demodulated2)));
fMod_lc = (fftshift(fft(Modulated_lc)));
fDemod_lc = (fftshift(fft(en)));
freq = -Fs/2:(Fs/N):(Fs/2)-(Fs/N);
```

Ploting Of Frequencies of the Carrier and Message Signal

```
figure ('Name','Graph Plot of Frequency Domain Carrier and Message Signal')
subplot(211)
plot(freq,abs(fCarrier)/N);
title('F-Domain Carrier Wave');
xlabel('Frequency');
ylabel('Magnitude');
subplot(212)
plot(freq,abs(fSignal)/N);
title('F-Domain Signal');
xlabel('Frequency');
ylabel('Magnitude');
```

Ploting Of Frequencies of the Double SIde Band Supressed Carrier Modulation and Demodulation

```
figure ('Name','Graph Plot of Frequency Domain Modulation and Demodulation (AM-DSBSC)')
subplot(211)
plot(freq,abs(fMod)/N)
title('F-Domain Modulated Signal');
xlabel('Frequency');
ylabel('Magnitude');
subplot(212)
plot(freq,abs(fDemod)/N);
title('F-Domain Demodulated Signal');
xlabel('Frequency');
ylabel('Magnitude');
```

Ploting Of Frequencies of the Large Carrier Modulation and Demodulation

```
figure ('Name','Graph Plot of Frequency Domain Modulation and Demodulation (AM-LC)')
subplot(211)
plot(freq,abs(fMod_lc)/N)
title('F-Domain Modulated Signal - large carrier');
xlabel('Frequency');
ylabel('Magnitude');
subplot(212)
plot(freq,abs(fDemod_lc)/N);
title('F-Domain Demodulated Signal- large carrier');
xlabel('Frequency');
ylabel('Magnitude');
```

Verifying the output

```
disp('The original Signal.');
sound(Signal,Fs,8);
pause(x);
disp('The Demodulated Signal.');
sound(Demodulated2,Fs,8)
```