19AIE204 Introduction to Communication Systems

PROJECT REPORT

Square Law Modulation and Demodulation Scheme for AM

Bachelor of Technology
in
Artificial Intelligence & Engineering

Submitted by **Team 3** (B batch)

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Objectives

1. To understand the Amplitude Modulation Scheme used in Wireless Communication
2. To mathematically model the square law modulation and demodulation
3. To implement Square Law Modulation and Demodulation using MATLAB

Abstract

Amplitude Modulation is the process of mixing a low frequency signal with a high frequency one to increase the transmission efficiency. Square law modulation technique is done by passing the modified versions of these carrier and message signal into a non-linear device such as diode to receive the squared output. Filtering is done to extract the necessary terms representing amplitude modulation. Amplitude Demodulation is the reverse process of this. In this project we have done a mathematical study on these techniques and experimented the concepts using MATLAB.

Keywords: Amplitude Modulation, Square Law, MATLAB

Introduction

A signal may be generated from electromagnetic disturbances and modelling the disturbance in such a way that it can be used for transmission is achieved in wireless communication systems. The transmitter section of the communication model is answerable for creating such a disturbance, and also the transmitter antenna helps in propagating this disturbance into the free space. This propagated signal requires to be understandable by human senses which the receiver helps in doing so. The receiver antenna captures the energy of the disturbances, and receiver converts them into sensible message signal.

When several transmitter antennas work together, there's a high chance of interference between the signals. Such a scenario is avoided by restricting the frequency specifically for every transmitter. By doing so, we'd be able to keep a narrow band filter on the receiver side, to extract the frequency which is required.

Speech transmission is one among the first objectives for a communication system. Human speech varies between an exceptionally low whisper to an improbable shout i.e., between 100Hz to 5kHz. Transmitting such a spread of frequency by different antennas results in two concerns. the primary one being the interference issue as discussed above, because of sharing the identical medium of propagation. The other occurs mainly due to the magnitude of frequency. The high frequency waves can effectively be transmitted at long range, while low frequency waves cannot. Frequencies above 20 kHz can't be audible by humans but is that the best frequency for transmission. These problems with transmitting a signal is resolved if we will model a high frequency signal that contains the properties of the signal which we'd like to transmit. this concept is achieved through the concept of Modulation. When the amplitude of the high frequency signal is varied in accordance with the message signal characteristics, it's cited as amplitude modulation, or AM for brief. Similarly, frequency or phase may be varied to get FM and PM, respectively.

Related Works

Different modulation techniques available in analog and digital modulation and their effective tabular and graphical comparisons are discussed. Study examining the power to detect AM signals carried by broad logarithmic frequency sweeps employing a 2-alternative forced-choice adaptive psychophysical design are discussed in “Detection of sinusoidal amplitude modulation in logarithmic frequency sweeps across wide regions of the spectrum”. AM has caused nuisances in US windfarms because of the AM of the aerodynamic noise from the blades. Such a natural occurring phenomenon is discussed as a review in “turbine Noise- A Review of the Evidence”. A unique method of incorporating digital signatures into images using AM technique is expressed in works. A noise suppression method that may be applied to one microphone to estimate the signal to noise ratio across different frequency channels has been described in “Supported modulation Analysis With Applications to Noise Suppression”.

Modulation of Signals

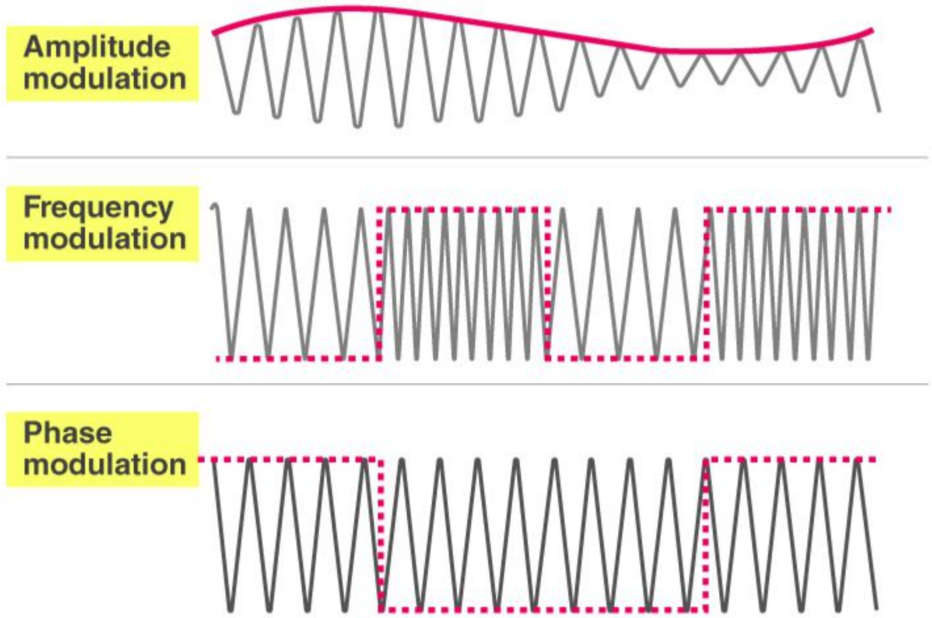
Superimposing of a low-frequency signal on a high-frequency carrier signal is the process of modulation. Electromagnetic signals like radio waves use modulation.

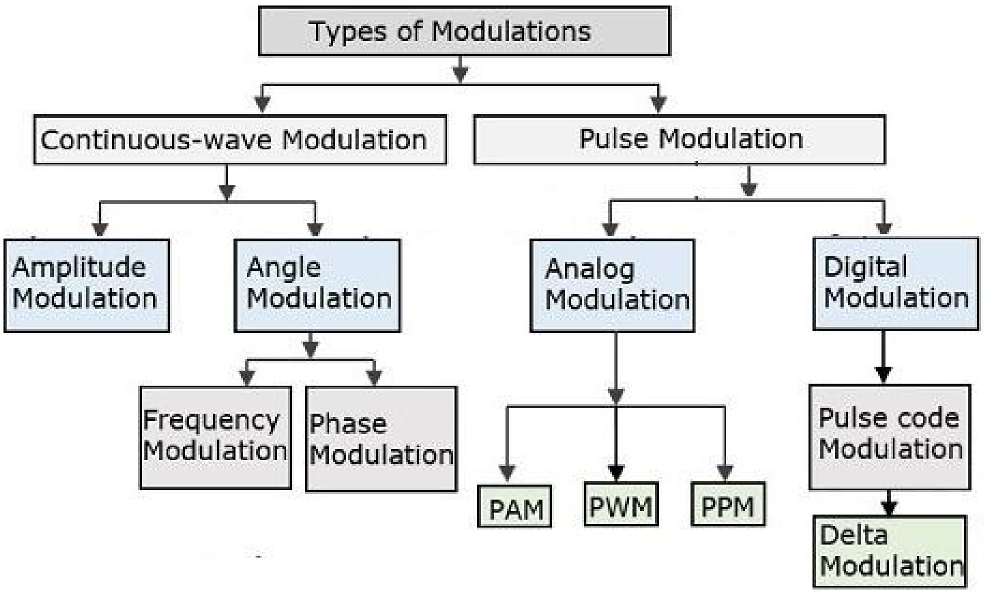
There are two main types of modulation:

1.Continous-wave modulation

2.pulse modulation

Continuous wave modulation is further divided into Amplitude Modulation and Angle Modulation. Pulse Modulation is divided into Analog Modulation and Digital Modulation.





Amplitude modulation

Amplitude modulation could be a process by which wave signal is transmitted by modulating the amplitude of the message signal. There are two ways of modulating the amplitude of the signal.

1. square-law modulator

Square law modulation methods circuits make use of nonlinear current-voltage characteristics of diodes, triodes, or transistors and are, in general, fitted to use at low voltages.

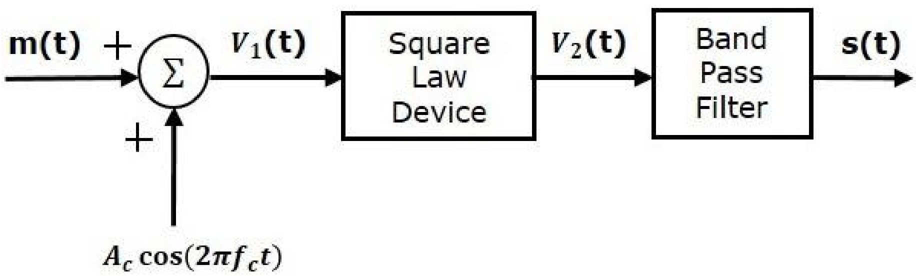
2. switching modulator

The switching modulator is just like the square law modulator. The sole difference is that within the square law modulator, the diode is operated in a very non-linear mode, whereas, within the switching modulator, the diode must operate as a perfect switch.

Square Law Modulation

We will be specializing in how square-law modulator modulates the message signal to provide AM signal.

Below is the block diagram of the square law modulator:



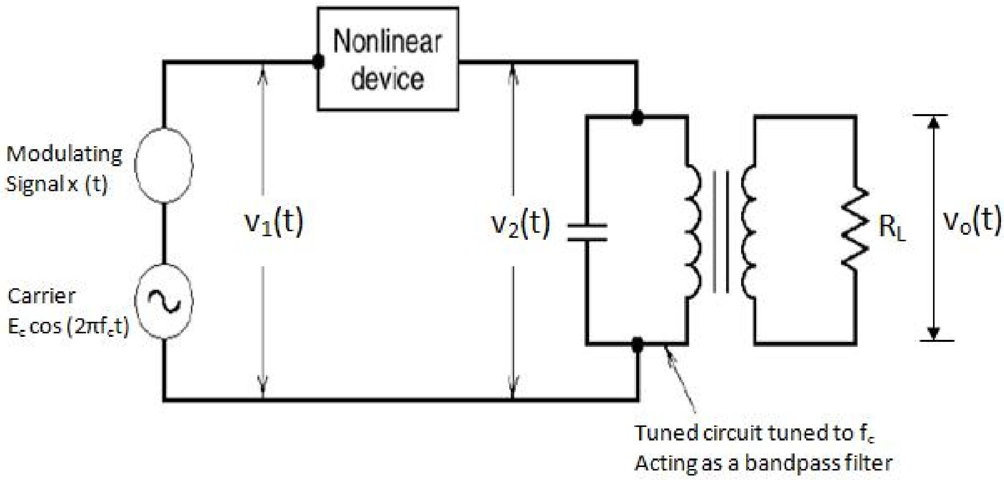
The circuit consists of the subsequent components:

1. Non-linear device

2. Bandpass filter

3. Carrier source and modulating signal

Circuit Diagram:



The modulating signal and carrier signal are both connected serial with one another which results in the sum of those two signals. V1(t) is given as input to the non-linear device like diode, transistor, etc.

Let the modulating signal and carrier signals be denoted as x(t) and $E_c\cos(2\pi f_c t)$

Writing them mathematically,

$$v_1(t) = x(t) + E_c \cos(2\pi f_c t)$$

The nonlinear device has an input-output relation:

$$v_2(t) = a v_1(t) + b {v_1}^2(t)$$

Where a, b are constants.

Now substituting v_1 in v_2 we get:

$$v_2(t) = a[x(t) + E_c \cos(2\pi f_c t)] + b[x(t) + E_c \cos(2\pi f_c t)]^2$$

$$v_2(t) = a x(t) + a E_c \cos(2\pi f_c t) + b[x^2(t) + 2x(t)\cos(2\pi f_c t) + {E_c}^2 cos^2(2\pi f_c t)]$$

ax(t) : Modulating signal

aE_c cos (2π f_ct) : Scaled Carrier Signal

b x^2 (t) : Squared modulating Signal

2bx(t)cos(2πf_ct) : AM wave with only sidebands

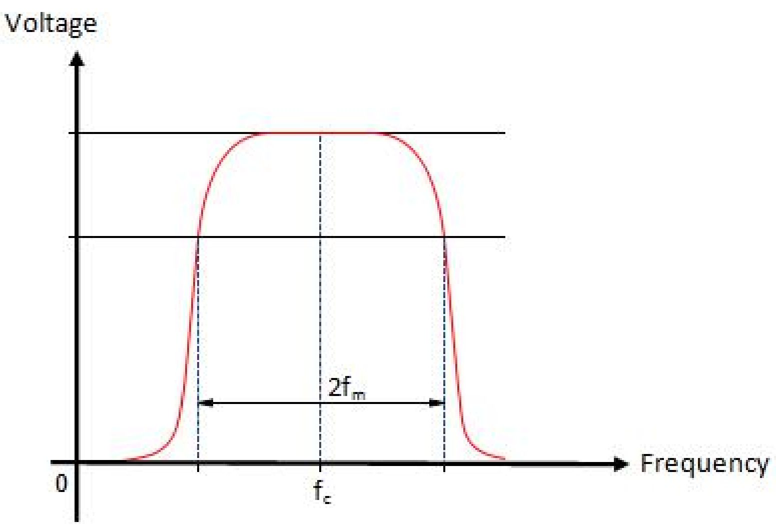
b $Ec^2cos^2(2\pi f_c t)$: Squared Carrier

Out of these terms, $aE_c \cos(2\pi f_c t)$ and $2b\, x(t) \cos(2\pi f_c t)$ are only useful for us.

$$v_2(t) = \underbrace{ax(t) + bx^2(t) + bE_c{}^2cos^2(2\pi f_c t)}_{\text{Unuseful Terms}} + \underbrace{aE_c\cos(2\pi f_c t) + 2bx(t)E_c\cos(2\pi f_c t)}_{\text{Useful Terms}}$$

To remove the unwanted terms, we'll be employing a LC tuned circuit that acts as a bandpass filter. The circuit is tuned to frequency f_c and bandwidth of $2f_m$.

The frequency response of the bandpass filter is shown below:



Now the output voltage $v_o(t)$ contains only useful terms:

$$V_o(t) = aE_c\cos(2\pi f_c t) + 2bx(t)E_c\cos(2\pi f_c t)$$

$$V_o(t) = [aE_c + 2bx(t)E_c]\cos(2\pi f_c t)$$

Therefore: $V_o(t) = aE_c[1 + \frac{2b}{a}x(t)]\cos(2\pi f_c t)$

The equation of standard AM wave is:

$$s(t) = E_c[1 + mx(t)]\cos(2\pi f_c t)$$

Comparing above two expressions, we will conclude that $V_o(t)$ represents an AM wave with m = (2b/a) where m is the amplitude sensitivity.

A few of the limitations when using a square-law modulator include:

1. As non-linear devices are used it only works within the non-linear region of the characteristics curve.

2. Bandpass filter must tune f_c which is ideally difficult.

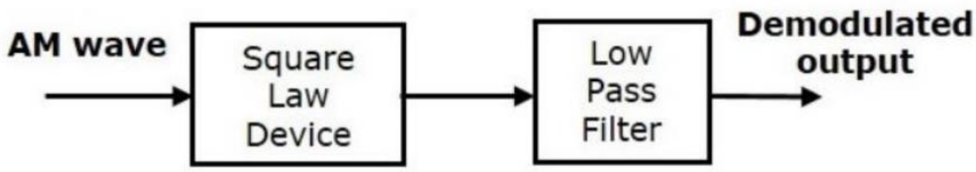
Demodulation

The process of recovering message signal from received modulated signal is generally known as demodulation. There are three methods of demodulation:

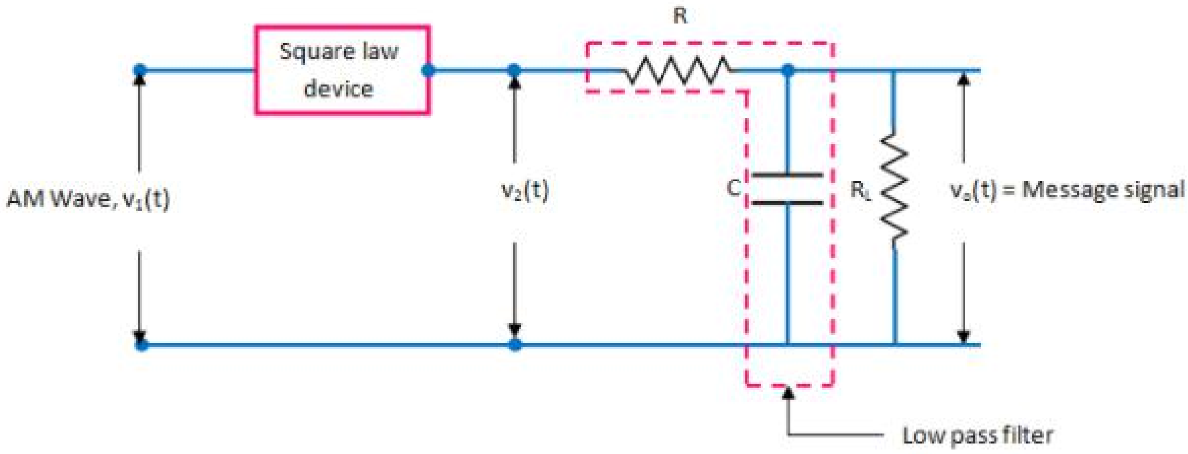
1. Square law demodulation.
2. Envelope demodulation.
3. Synchronous demodulation.

Square Law Demodulation

Square law demodulators are used to demodulate low level AM wave. This demodulator comprises of a square law device and a low pass filter. The input output characteristics is nonlinear in nature.



The Circuit Diagram is:



$V_1(t)$ is the AM wave and which is applied as an input to the square law demodulator.

The standard form of AM wave is:

$$V_1(t) = A_c\,[1+K_a\, m(t)]\cos(2\pi f_c t)$$

The relationship of input and output of the square law device is:

$$V_2(t) = k_1V_1(t) + k_2V_1^2(t)$$

Where $V_2(t)$ is the output of the square law device. k_1 and k_2 are constants.

Substituting V1(t) in the mathematical relation of square law device,

$$V_2(t) = k_1(A_c[1+k_a m(t)]\cos(2\pi f_c t)) + k_2(A_c[1+k_a m(t)]\cos(2\pi f_c t))^2$$

Implies, $V_2(t) = k_1A_c\cos(2\pi f_c t) + k_1A_ck_a\, m(t)\cos(2\pi f_c t) +$
$k_2A_c^2[1+k_a^2\, m^2(t)+2k_a m(t)]\ \ (1+\cos(4\pi f_c t)/2)$

$V_2(t) = k_1A_c\cos(2\pi f_c t) + k_1\, A_c\, k_a\, m(t)\cos(2\pi f_c t) +$

$(k_2A_c^2/2) + (k_2A_c^2/2)\cos(4\pi f_c t) +$
$(k_2Ac^2ka^2m^2(t)/2) + (k_2Ac^2ka^2m^2(t)/2)\cos(4\pi f_c t) +$
$k_2Ac^2k_a m(t) +$
k2Ac^2 ka m(t) cos(4πfct)

This above expression is the final equation and from here, the term,

$k_2A_c^2\ k_a\ m(t)$ is a scaled version of the message signal.

This can be extracted by passing the above signal through a low pass filter.

coupling capacitor can be used to eliminate the DC component $k_2A_c^2/2$.

Distortion in the square law demodulator output

After demodulation from square law demodulator, the signal passes to the low pass filter in the circuit, there some other components also get passed through LPF to the load resistance RL.

This component is an unwanted signal and gives rise to a signal distortion.

The ratio of desired to the undesired signal is given by:

Ratio = (Desired o/p)**/**(Undesired o/p)

$= [k_2A_c^2k_a\ m(t)]/[k_2A_c^2k_a^2m(t)/2]$

$= 2/k_a\ m(t)$

This ratio must be maximized to minimize the distortion.

To achieve this proportion, we should choose the absolute magnitude of

$k_a\ m(t)$ small as compared to unity for all values of t.

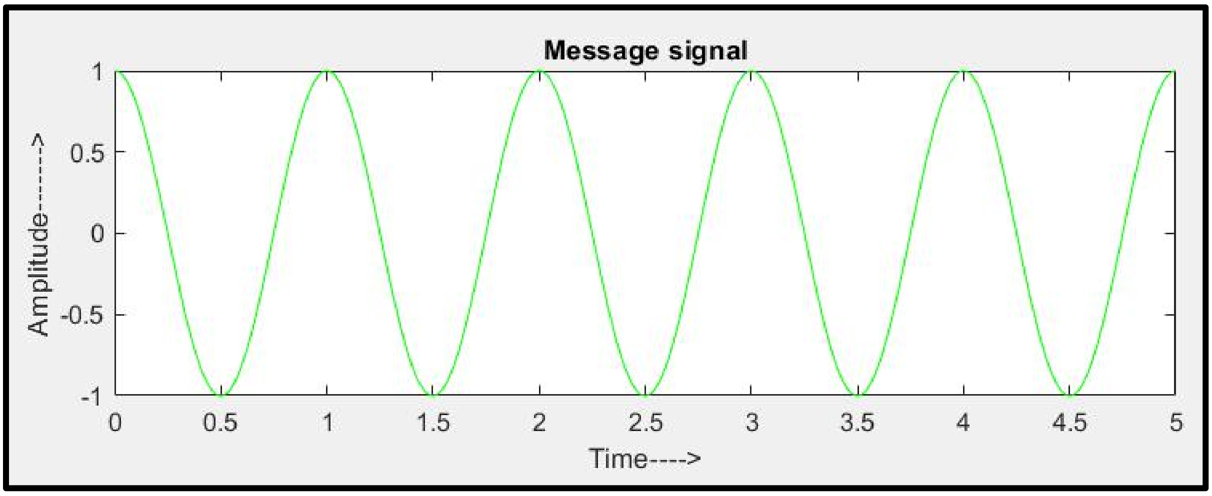
AM wave is weak when 'm' is small. hence, the square-law distortion detector's output is low only if the AM applied is weak and if the percentage of modulation is very small.

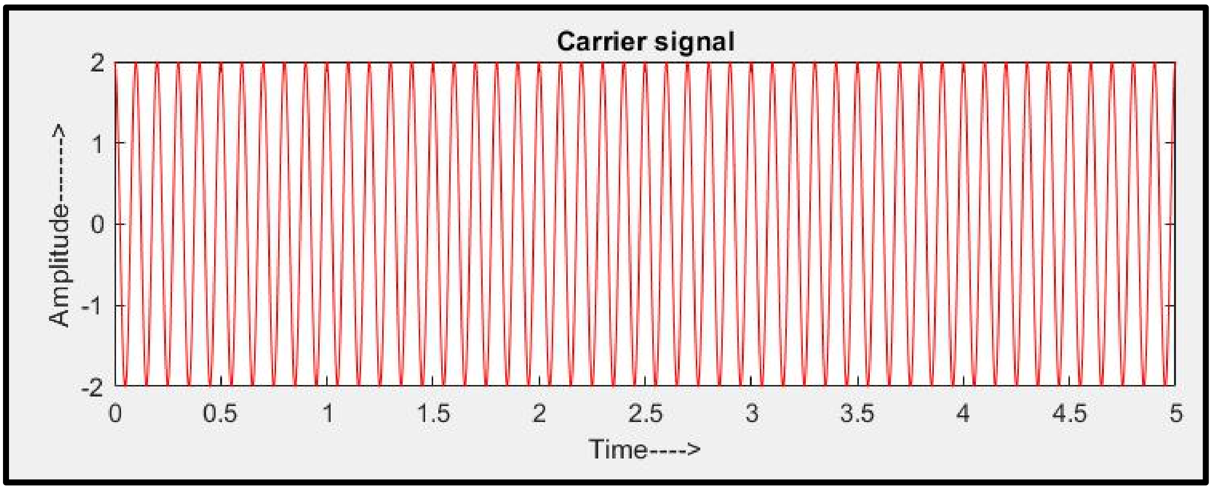
Simulation using MATLAB

(i) Square Law Modulation

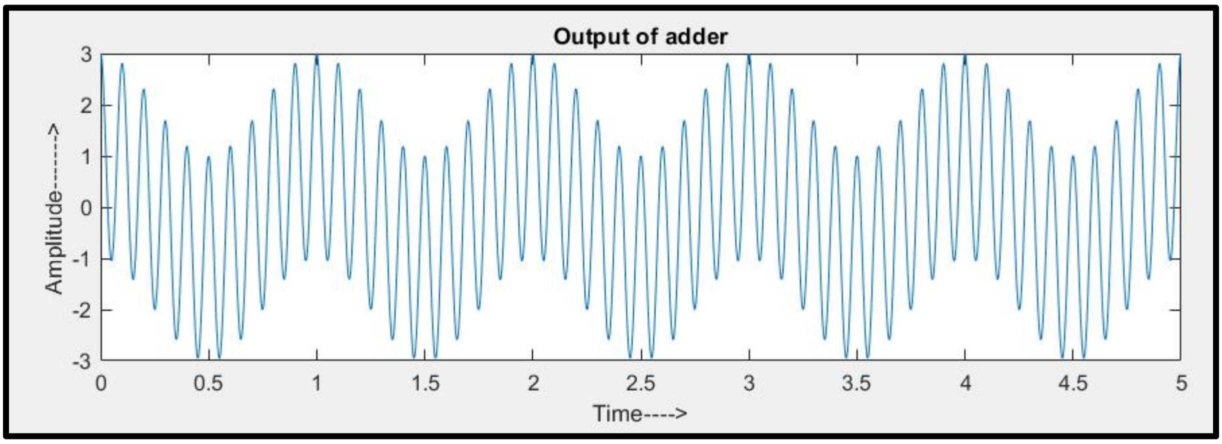
The Message Signal and Carrier signal are as follows:

The carrier signal posses higher frequency and message signal represents low frequency signal, namely the human voice.

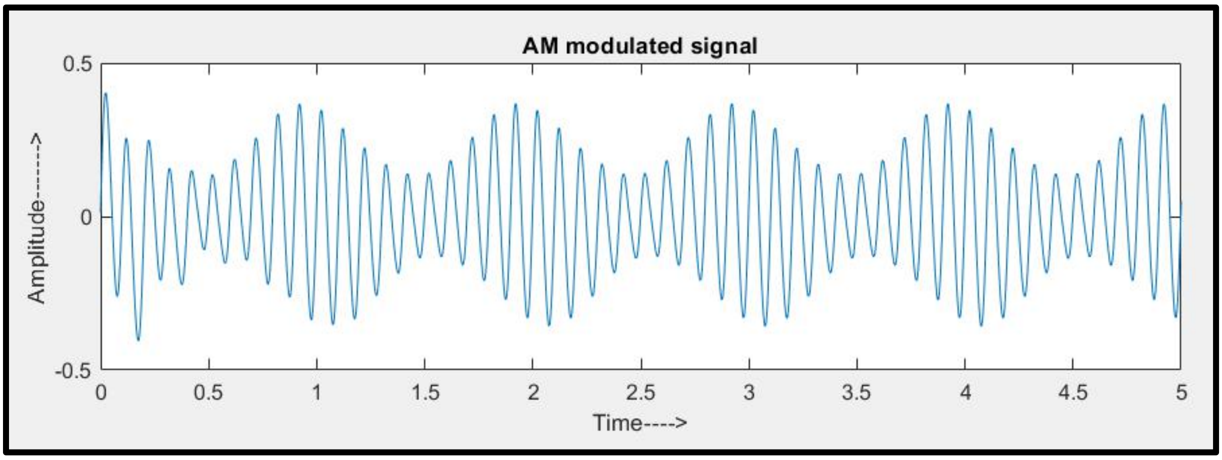




v_1 is the output of the adder. That is the sum of message and carrier signal.

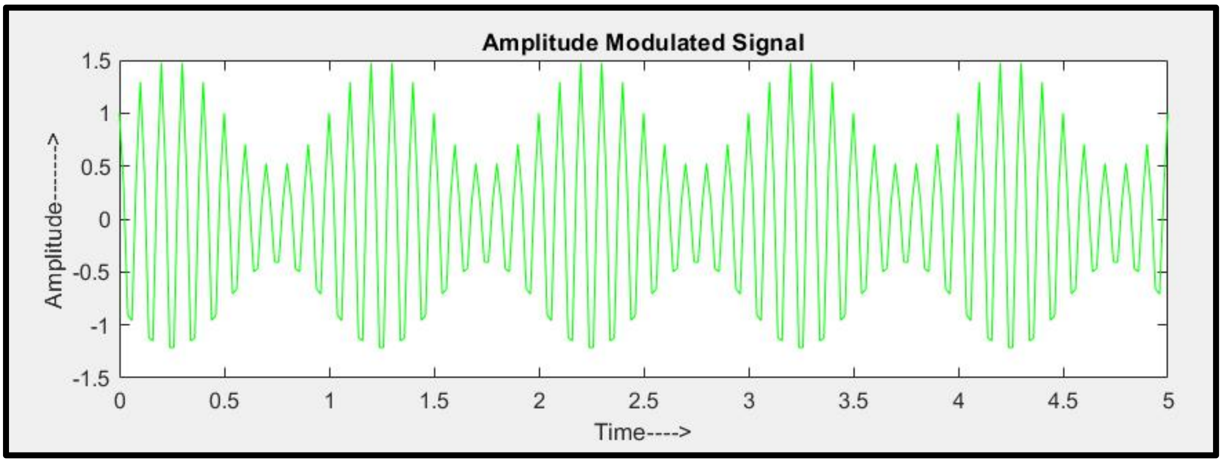


Output of adder passed through the band pass filter produce:

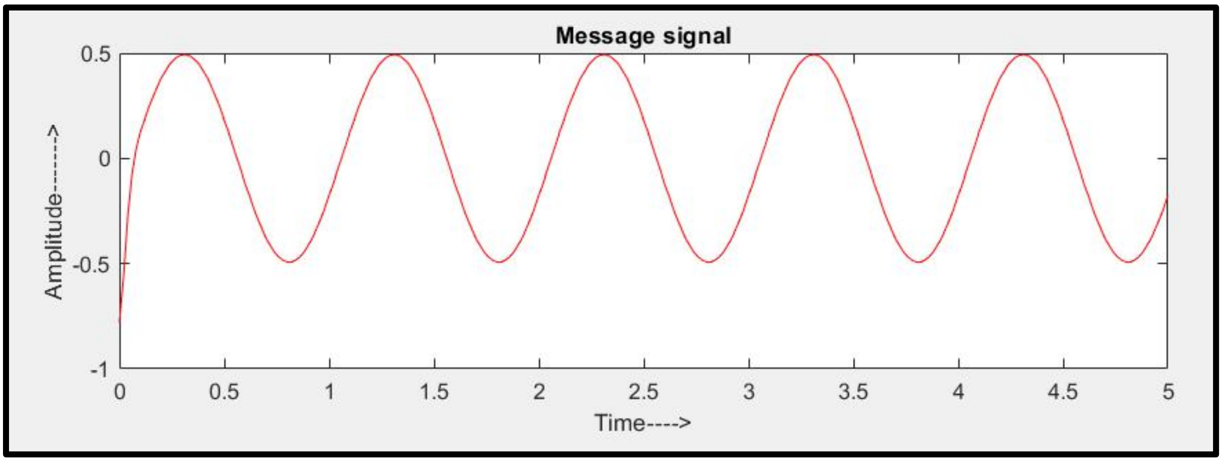


(ii) Square Law Demodulator

The input to the demodulator is :



The extracted output that is, the message signal:



Appendix – MATLAB Code

Amplitude Modulation – Square Law

```
fs = 1000; %sampling frequency
fc = 10; %carrier frequency
fm = 1; %message frequency
am = 1; %amplitude of message signal
ac = 2; %amplitude of carrier signal
t = 0:0.001:5; %time for x axis

m = am*cos(2*pi*fm*t); %message signal
c = ac*cos(2*pi*fc*t); %carrier signal

%Step1: Adding message and carrier to generate v1
v1 = m+c; %summer



%Step2: Passing v1 into non-linear device
a1 = 0.9;
a2 = 0.2;
v2 = a1*v1 + a2*(v1.^2); %non-linear device

[b,a]=butter(1,[((fc-fm)/fs),((fc+fm)/fs)]);%butterworth band pass filter
to generate transfer coefficients
y=filter(b,a,v2); %applying transfer to v2


figure(1)
subplot(211)
plot(t,m,'g')
xlabel('Time---->');
ylabel('Amplitude------->');
title('Message signal');
subplot(212)
plot(t,c,'r')
xlabel('Time---->');
ylabel('Amplitude------->');
title('Carrier signal');

figure(2)
subplot(211)
plot(t,v1)
xlabel('Time---->');
ylabel('Amplitude------->');
title('Output of adder');
subplot(212)
plot(t,v2)
xlabel('Time---->');
ylabel('Amplitude------->');
title('output of non linear device');

plot(t,y)
xlabel('Time---->');
ylabel('Amplitude------->');
title('AM modulated signal');
```

Amplitude Demodulation - Square Law

```
Fs = 100 %sampling freq
fm=1; %message freq
fc=10; %carrier freq
Ac=1; %amplitude carrier
Am=1; %amplitude message
ka=0.5; %amplitude sensitivity 2k2/k1


t=0:0.02:5;
m=Am*sin(2*pi*fm*t);
c=Ac*cos(2*pi*fc*t);
s=Ac*(1+ka*m).*c;

%square law demodulator
squared =s.*s; %square law operation

%filter
order_par=4;



d =
designfilt('lowpassfir','FilterOrder',6,'CutoffFrequency',fm,'Sample
Rate',Fs); %low pass filter


filt_data=filter(d,squared);
demod_m=sqrt(2*filt_data)-1;

figure(1)
subplot(211)
plot(t,s,'g')
xlabel('Time---->');
ylabel('Amplitude------->');
title('Amplitude Modulated Signal');
subplot(212)
plot(t,demod_m,'r')
xlabel('Time---->');
ylabel('Amplitude------->');
title('Message signal');
```