ECEN314- Fundamentals of communication

Project report

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single-sideband modulation (SSB)

It is a type of modulation used to transmit information, such as an audio signal, by radio waves. A refinement of amplitude modulation, it uses transmitter power and bandwidth more efficiently. Amplitude modulation produces an output signal the bandwidth of which is twice the maximum frequency of the original baseband signal. Single-sideband modulation avoids this bandwidth increase. SSB modulation is done by dividing the signal to upper sideband and lower sideband. Demodulating the signal is done by adding the upper sideband and lower sideband.

SSB Signal

$$u(t) = A_c m(t)\cos(2\pi f_c t) \mp A_c \hat{m}(t)\sin(2\pi f_c t)$$

Message Signal:

Figure 1 SSB message Signal

Demodulated Signal:

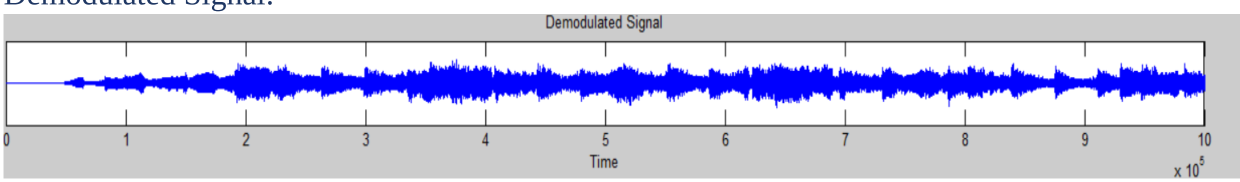

Figure 2 SSB Demodulated signal

Modulated Signal (USB, LSB)

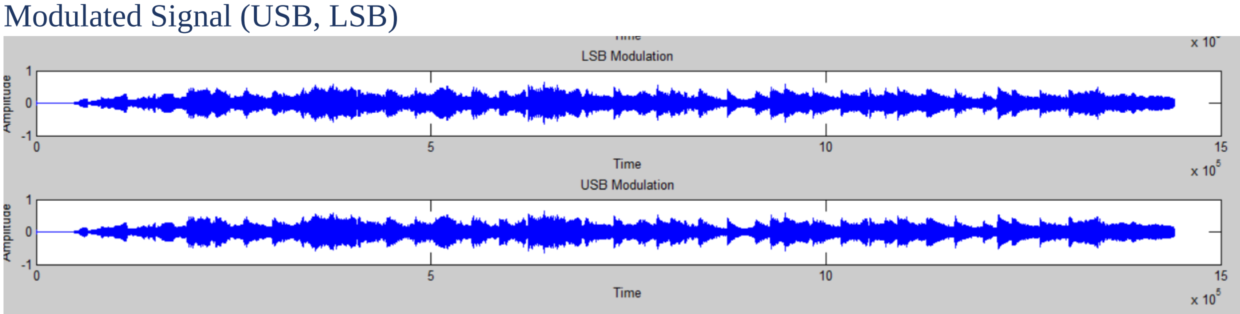

Figure 3 SSB Modulated Signal (USB,LSB)

Difference between Demodulated signal and original signal

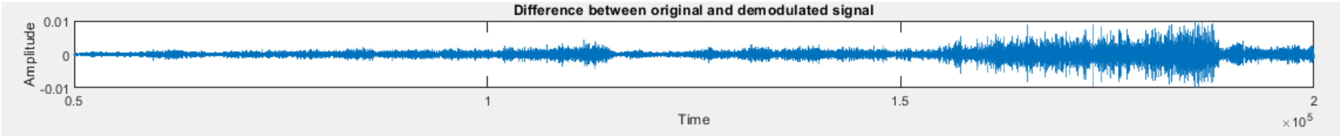

Figure 4:Difference between Demodulated signal and original signal

As we can see the difference between the original an demodulated signal doesn't exceed 0.01 and the difference take constant value in the most of time which tell us that there is no frequency difference , and there is only a slight phase difference.

QAM modulation

QAM modulator

QAM is a modulation scheme that transmits data by changing the amplitude, or power level, of two signals: first in-phase with the incoming data and the second 90 degrees out of phase.

As shown in the figure bellow the first message signal m1(t) is multiplied by the carrier signal (cos(2pi fc t)) and the second message signal m2(t) is multiplied by the carrier signal after shifting in phase (sin(2 pi fc t)).

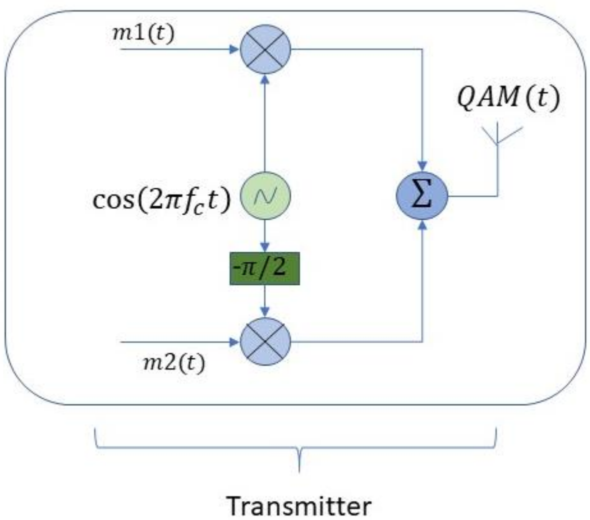

Figure 5 QAM modulator

Original message signals:

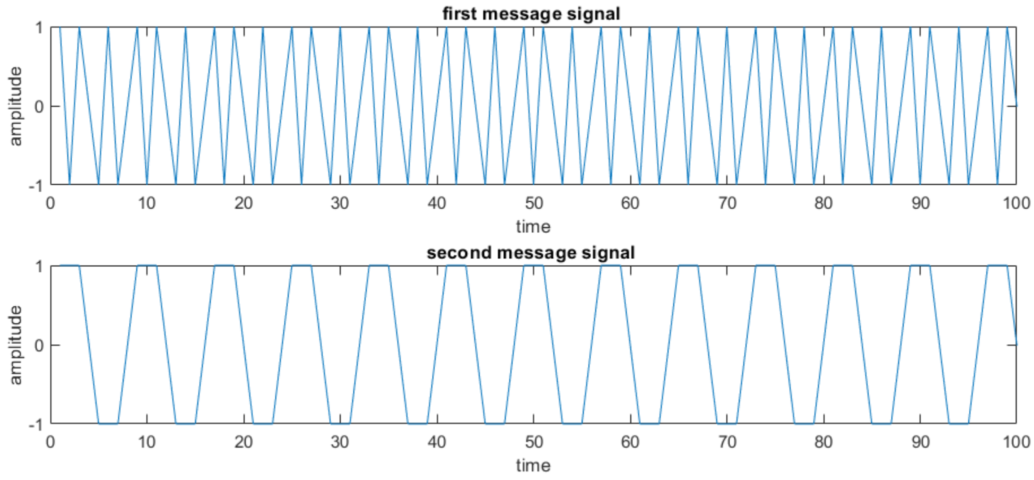

Figure 6 The two message input signals in time domain

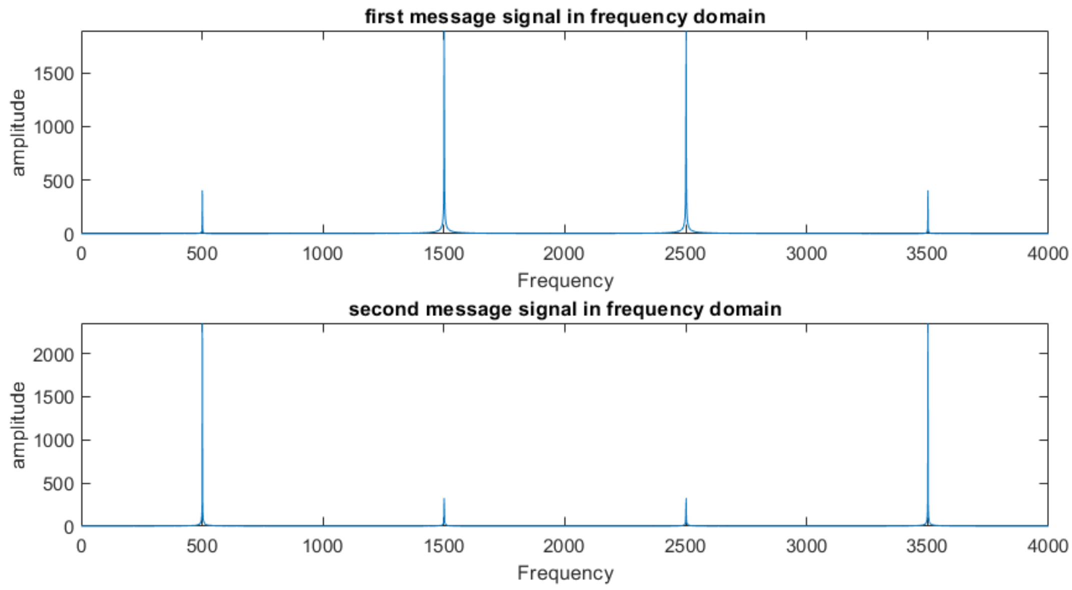

Figure 7 The two message input signals in frequency domain

Modulation:

As shown i figure bellow m1 is sent to the I channel.

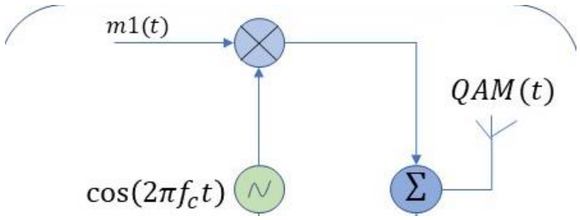

Figure 8 message 1 in the I channel.

And m2 is sent to the Q channel.

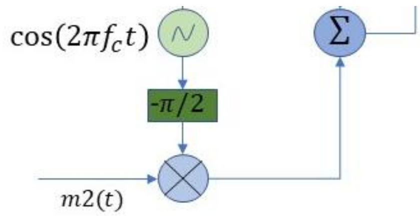

Figure 9 message 2 in the Q channel.

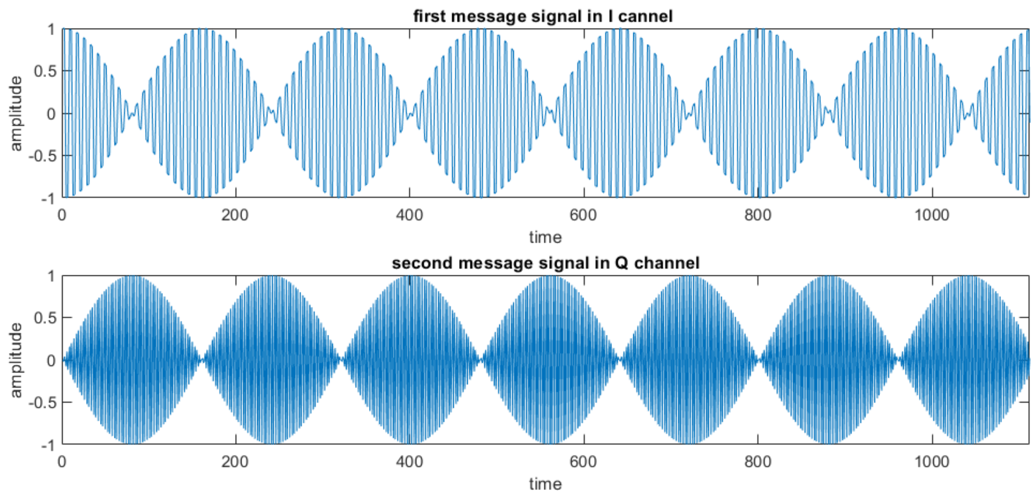

Figure 10 The two message signals after multiplying with carriers in time domain.

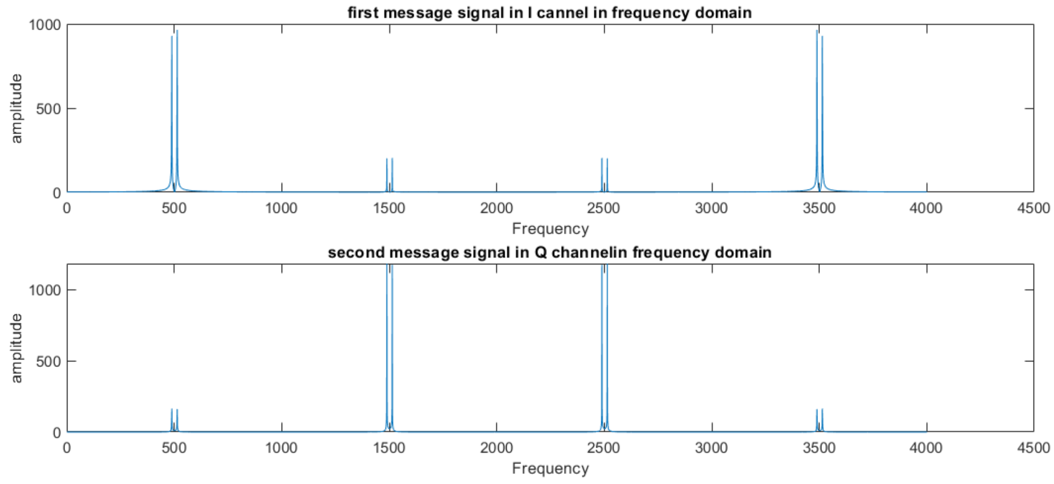

Figure 11 The two message signals after multiplying with carriers in frequency domain.

Demodulation

As shown in the figure bellow, the received signal is multiplied by the same carrier signals in the transmitter. then each signal pass by low pass filter to extract the signal but in half amplitude.

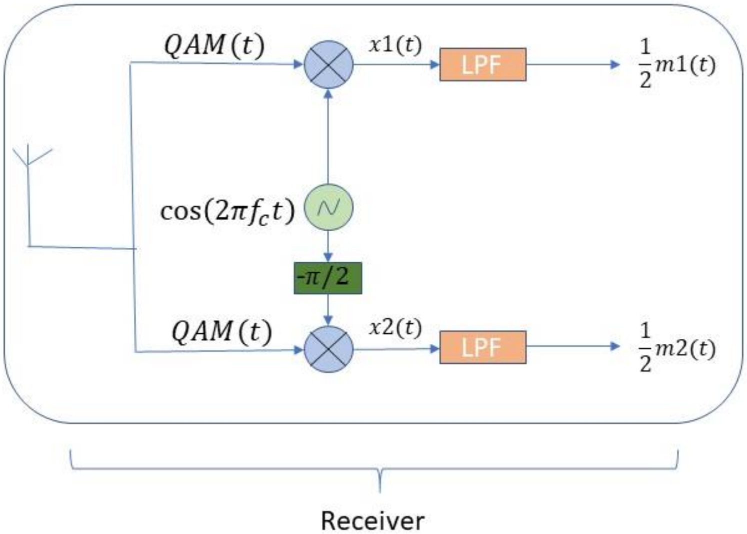

Figure 12 QAM demodulator

Received signal:

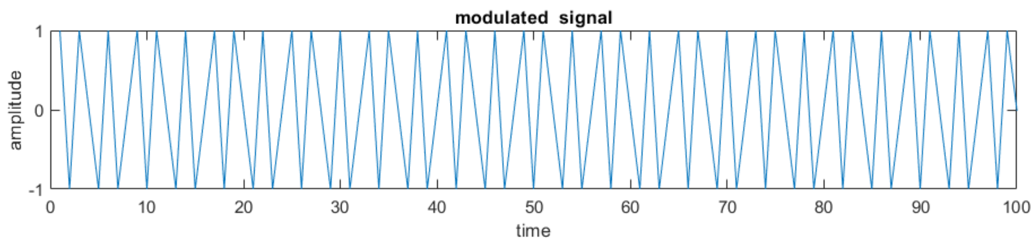

Figure 13 QAM signal after modulating in time domain.

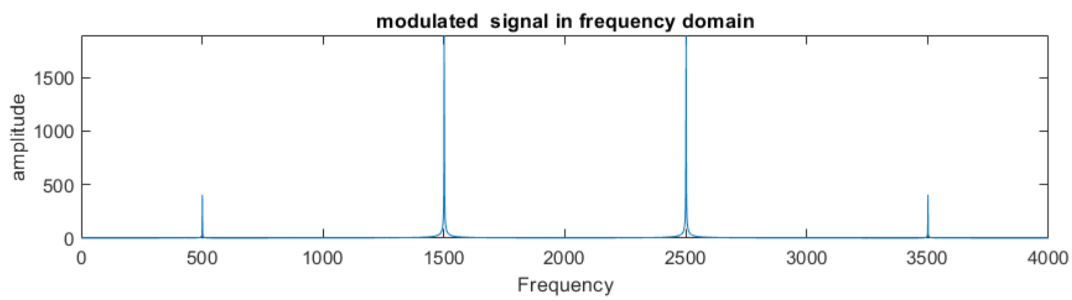

Figure 14 QAM signal after modulating in time domain.

Signals after Demodulating

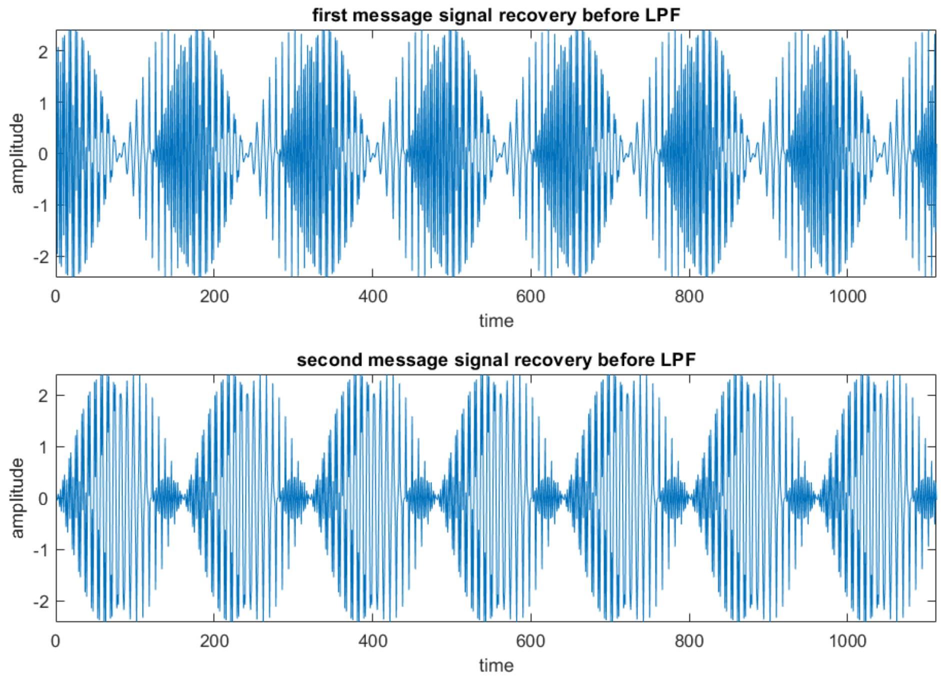

Figure 15 message signals after demodulating in time domain

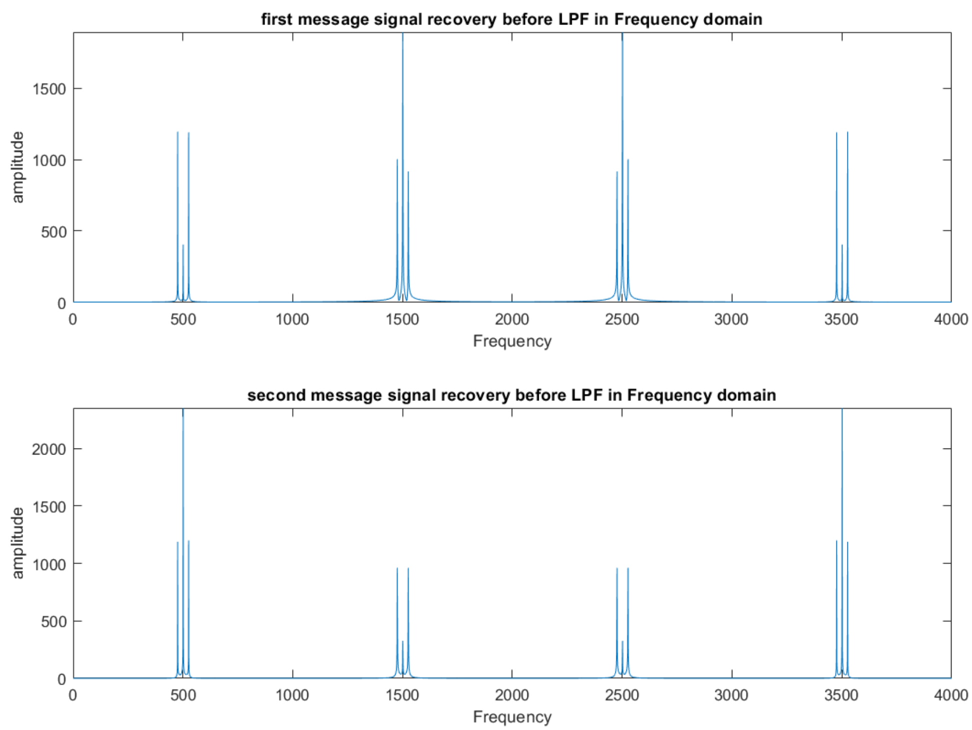

Figure 16 message signals after demodulating in frequency domain

Received message signals after applying LPF:

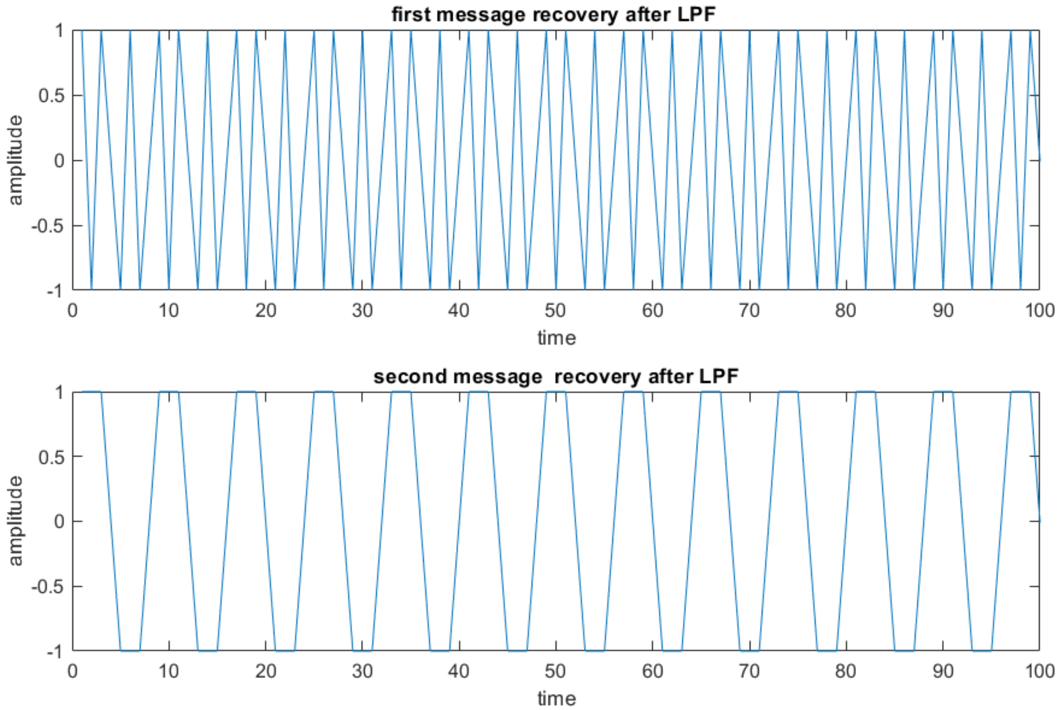

Figure 17 message signals after LPF in time domain

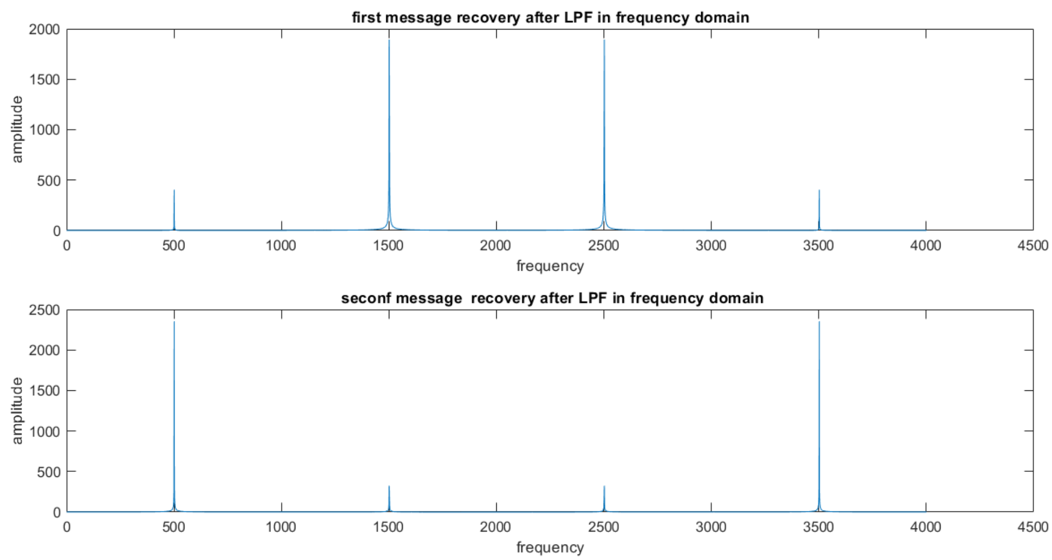

Figure 18 message signals after LPF in frequency domain

Applying frequency error between transmitter and receiver

The smallest change in frequency between transmitter and receiver would cause a huge change in the signal The figure bellow shows the original signal with synchronized transmitter and receiver frequencies, and the signal after changing the receiver carrier frequency by 100.

(fc= fc-100)

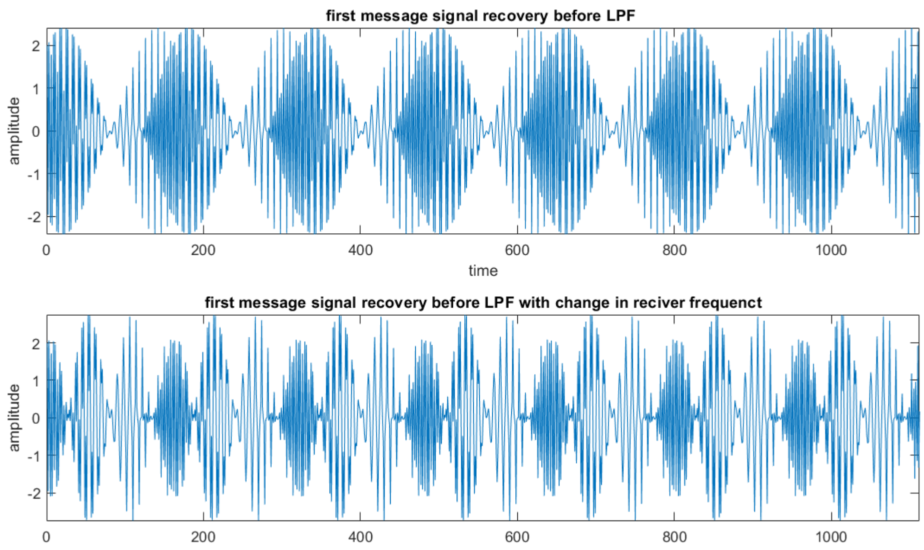

Figure 19 The difference between original message and shifted frequency message.

Applying phase error between transmitter and receiver

The change in the phase in the receiver affects the retrieved signals phase. The applied shift is (+40)

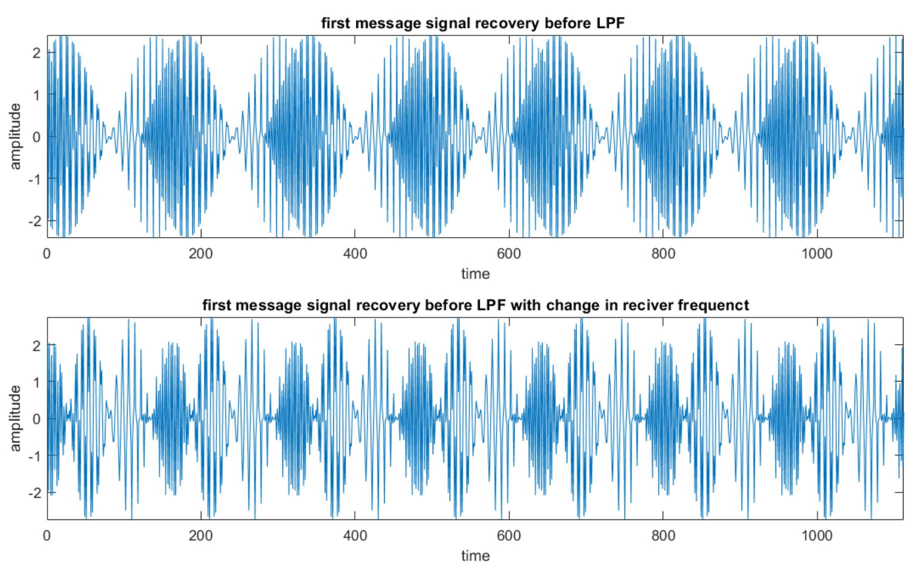

Figure 20 The difference between original message and shifted phase message

Double-sideband suppressed-carrier Modulation and demodulation (DSB-SC)

DSB-SC is an amplitude modulated wave transmission scheme in which only sidebands are transmitted and the carrier is not transmitted as it gets suppressed. DSB-SC is an acronym for Double Sideband Suppressed Carrier. The carrier does not contain any information and its transmission results in loss of power. Thus only sidebands are transmitted that contains information. This results in saving of power used in transmission. This saved power can be inserted into the 2 sidebands. Hence, ensuring a stronger signal that transmits over long distances. As during suppression, the baseband signal does not get affected in any way. Let's have a look at the block diagram of the DSB-SC system shown below:

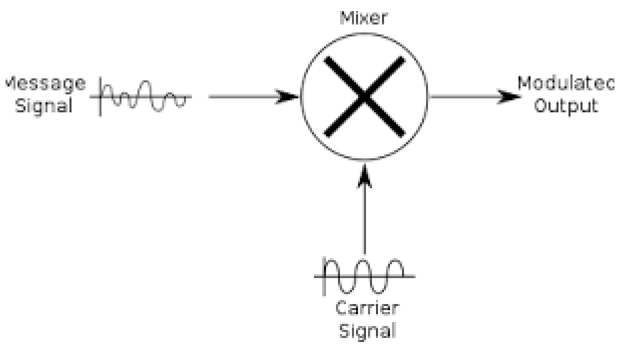

Figure 21 DSB_SC

Mathematical Expressions for Modulation

Modulating signal

$$\boldsymbol{m(t) = A_m cos(2\pi f_m t)}$$

Carrier signal

$$\boldsymbol{c(t) = A_c cos(2\pi f_c t)}$$

Mathematically, we can represent the equation of DSBSC wave as the product of modulating and carrier signals.

$$\boldsymbol{s(t) = m(t)c(t)}$$

$$\boldsymbol{s(t) = A_m A_c cos(2\pi f_m t) cos(2\pi f_c t)}$$

$$\boldsymbol{s(t) = A_c A_c 2cos[2\pi(f_c + f_m)t] + A_m A_c 2cos[2\pi(f_c - f_m)t]}$$

The same sequence is being implement in the matlab code, and a noise is added to the modulated signal using the built-in function in matlab awgn

$$z = awgn(in , snr)$$

and for the demodulation a built-in function *amdemod.*

$$z = amdemod(y, Fc, Fs)$$

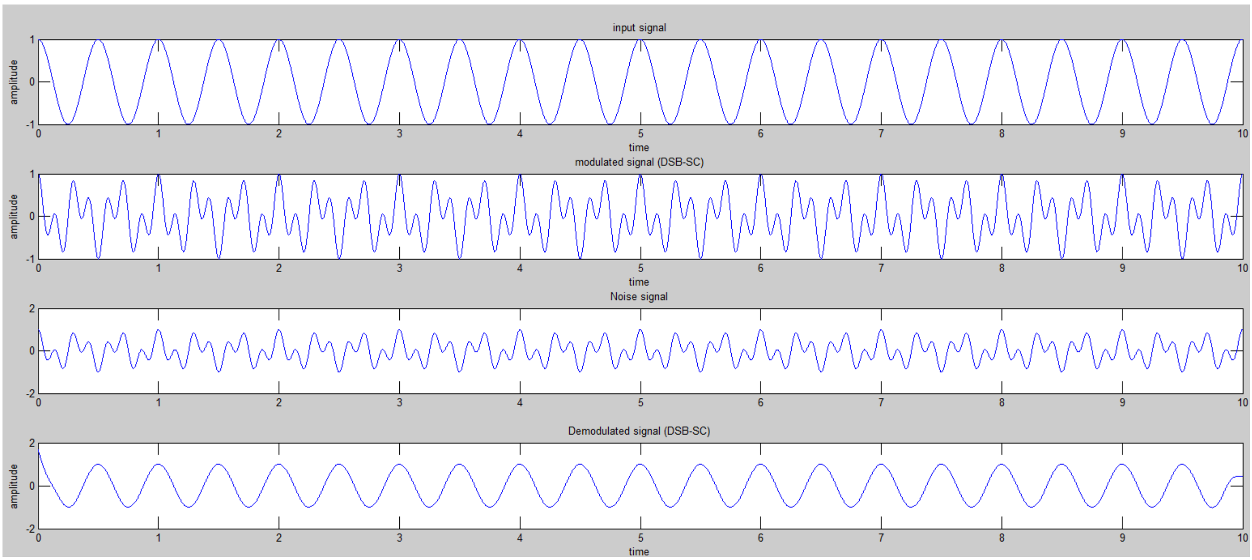

Figure 22 Modulation, noise and demodulated signals

Frequency Modulation and Demodulation (FM)

Frequency Modulation is a modulation in which the frequency of the carrier wave is altered in accordance with the instantaneous amplitude of the modulating signal, keeping phase and amplitude constant. Modification of carrier wave frequency is performed for the purpose of sending data or information over small distances. FM modulation is done by adding the carrier signal to the integration of the message signal, this were done by the built-in function "`fmmod`" in the MATLAB code.

A gaussian white noise is added to the modulated signal to test the performance of FM

Demodulation.

$$A_c \cos\left(2\pi f_c t + 2\pi f_\Delta \int_0^t x_m(\tau) d\tau\right)$$

FM demodulation is done by differentiating the modulated signal and passing an envelope detector then a DC blocker, this were done by the built-in function "`fmdemod`" in the MATLAB code.

Message Signal:

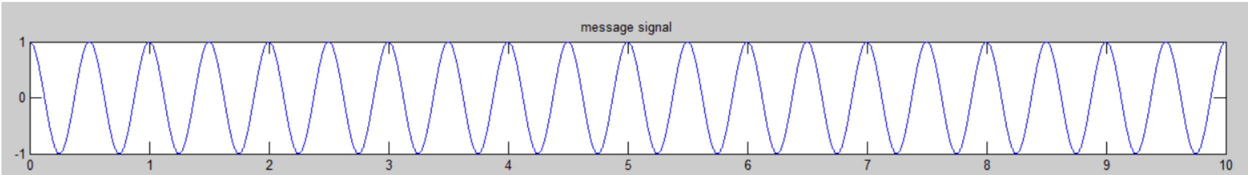

Figure 23 Message signal

Modulated Signal:

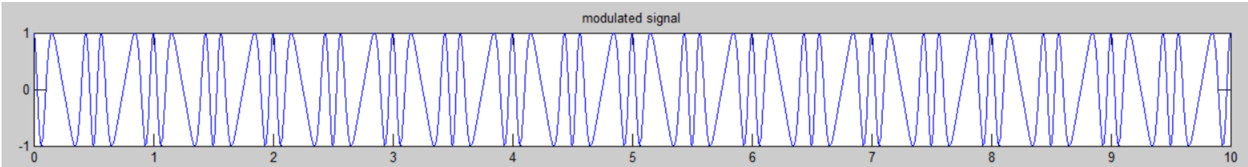

Figure 24 Modulated Signal

Noise Signal:

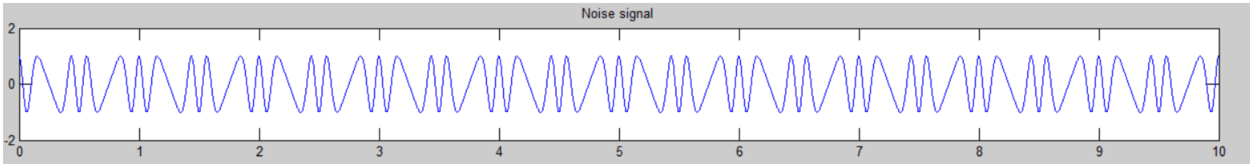

Figure 25 Noise Signal

Demodulated Signal:

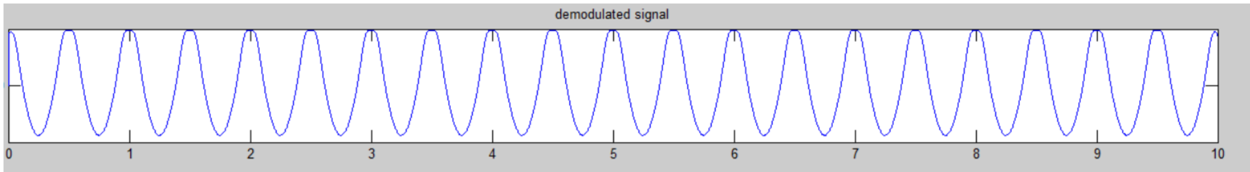

Figure 26 Demodulated signal

Study the Effect of noise on FM and DSB-SC modulation

In this section we aim to study the effect of different noise levels on the FM and DSB-SC modulation. Generally, we want to study the behaviour of noise in MATLAB, how to generate different levels of noise and the effect of each level on the FM and DSB-SC modulation.

Noise:

noise is an unwanted disturbance in an electrical signal that can appear due to many reasons. Noise can be simulated in different forms in MATLAB one of them is to use the built-in function.

out = awgn(in , snr)

where in is the input signal that noise should be added on, snr is the signal to noise power ratio and out is the output signal.

Awgn stands for Additive white Gaussian noise which is a basic noise model used in information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics:

- **Additive** because it is added to any noise that might be intrinsic to the information system.
- **White** refers to the idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emissions at all frequencies in the visible spectrum.
- **Gaussian** because it has a normal distribution in the time domain with an average time domain value of zero.

Noise in the time domain:

Suppose we have a constant signal with an amplitude of 1 that we want to add noise to it, then the signal shape in the time domain will look like that.

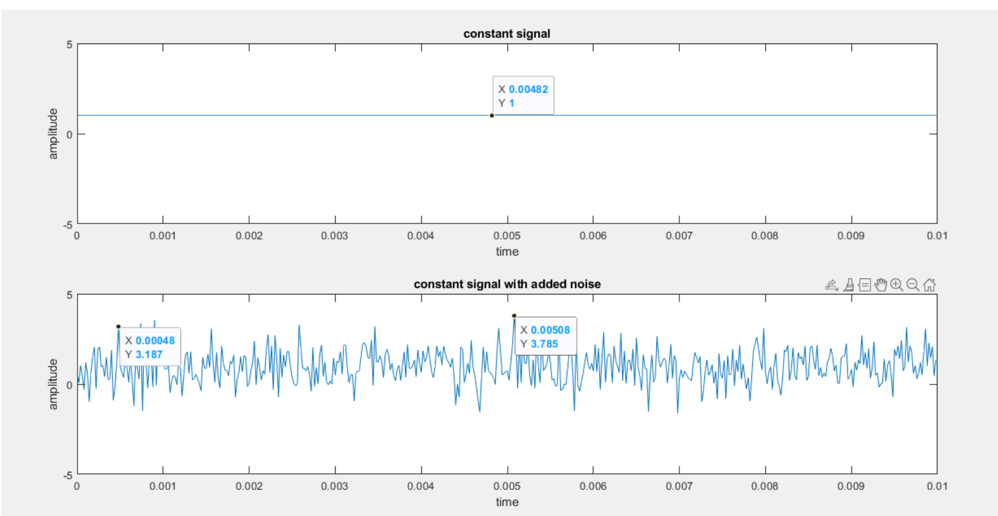

Figure 27 Noise added to a constant signal in time domain

Noise spectrum in the frequency domain:

To have a better understanding of the Noise signal, we need to see its frequency spectrum (this will help in filters design).

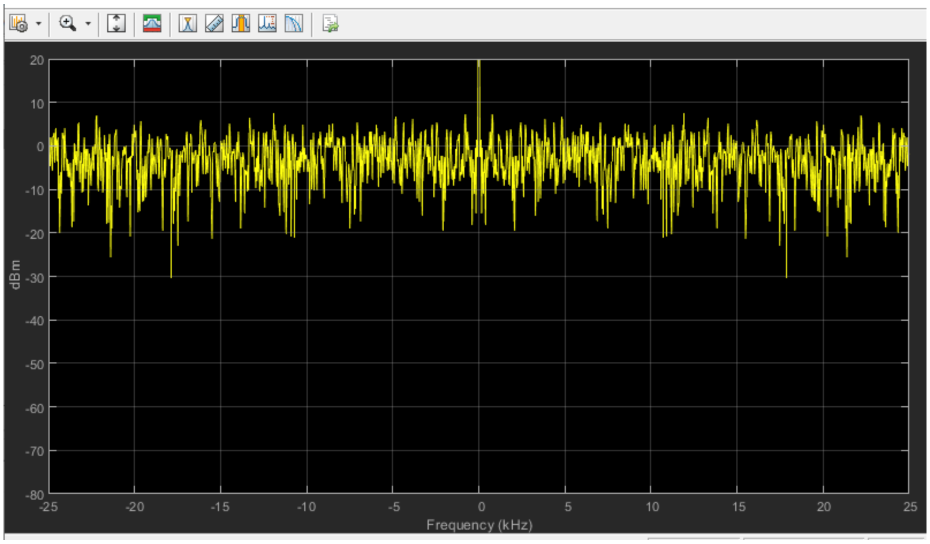

Figure 28 general shape of Gaussian noise spectrum of noise signal

Generate different noise levels:

Suppose we have a fixed signal (modulationg_signal) ,we can control the noise level added to the modulationg_signal through modifying the snr value in awgn(modulationg_signal, snr) , by increasing the value of snr we increase the signal to noise power ratio and because of we have a fixed signal that means the noise signal maximum amplitude will decrease. On the contrary, by decreasing the value of snr the noise maximum amplitude will increase. So, for having high quality signals the snr value must be as maximum as possible.

The effect of each level on the FM and DSB-SC modulation:

Now we will set different values for snr to see the effect of different noise levels on FM and DSB-SC modulation.

But first we assume fixed values for the single tone message that is to be transmitted.

fs=1000.

fm=12.

fc=20.

kf=pi.

1. Snr=20

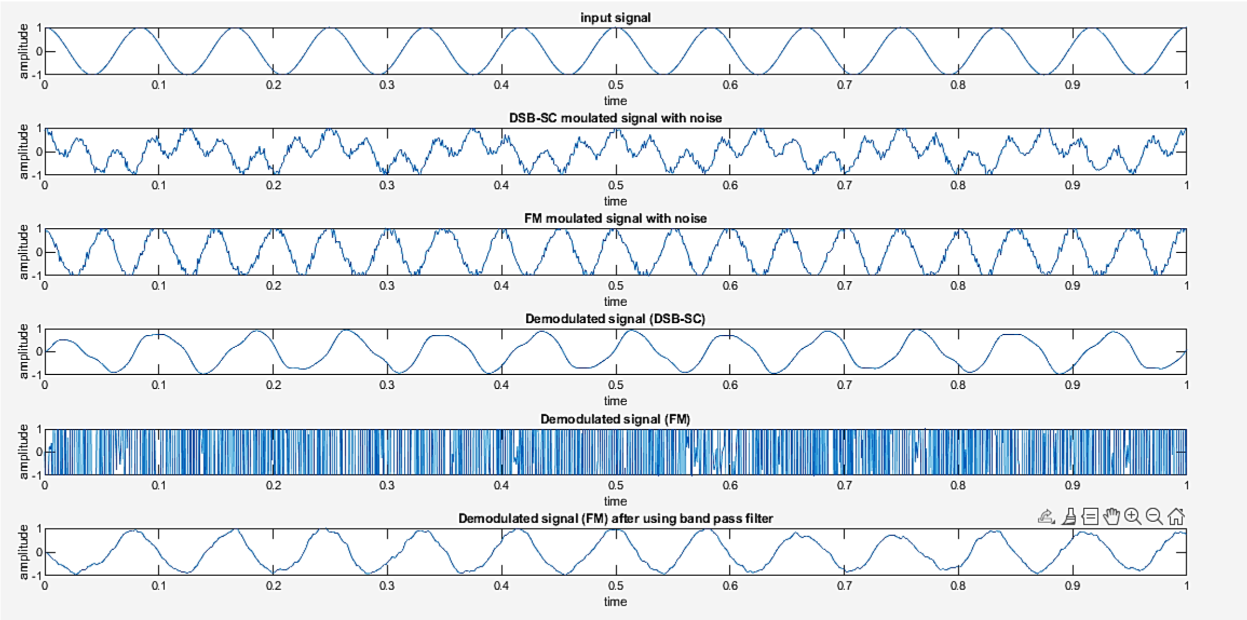

Figure 29 output when snr=20

As we can see, the Demodulated signal (FM) has a huge distortion due to the high frequency components of the noise signal, to get a better performance we can pass the Demodulated signal(FM) on low pass filter to get rid out of the high frequency components.

2. Snr=40

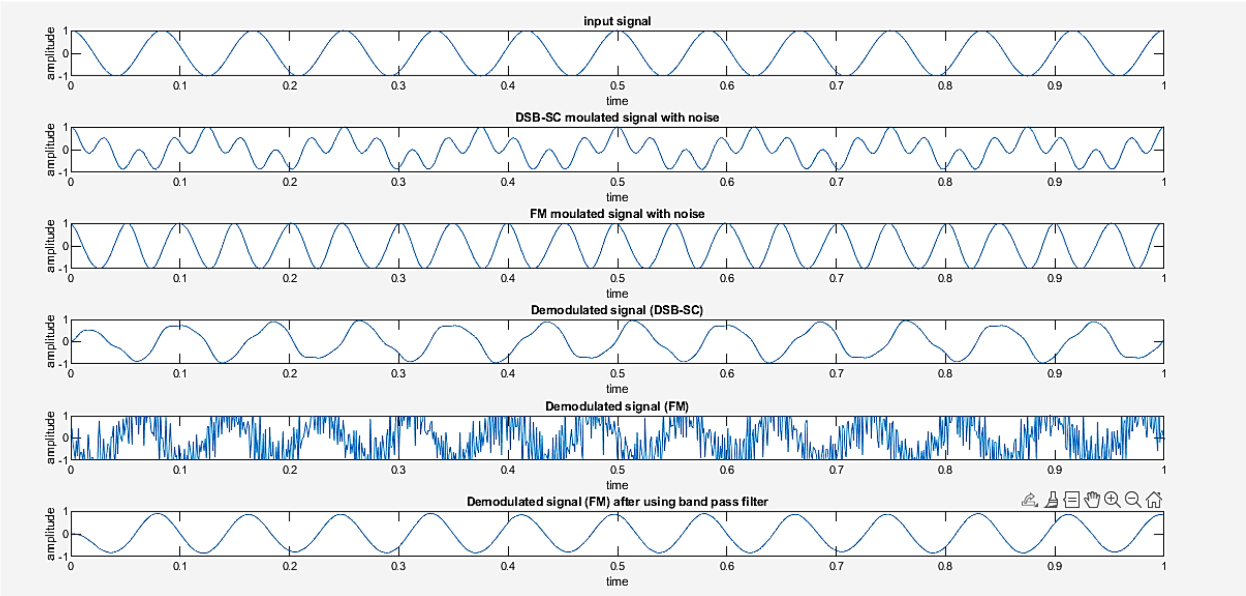

Figure 30 output when snr=40

As we can see, by increasing the value of snr we get better performance for the Demodulated signal (FM) and Demodulated signal (DSB-SC), and again by passing the Demodulated signal(FM) we get a better performance that may reach to original signal.

3. Snr=60

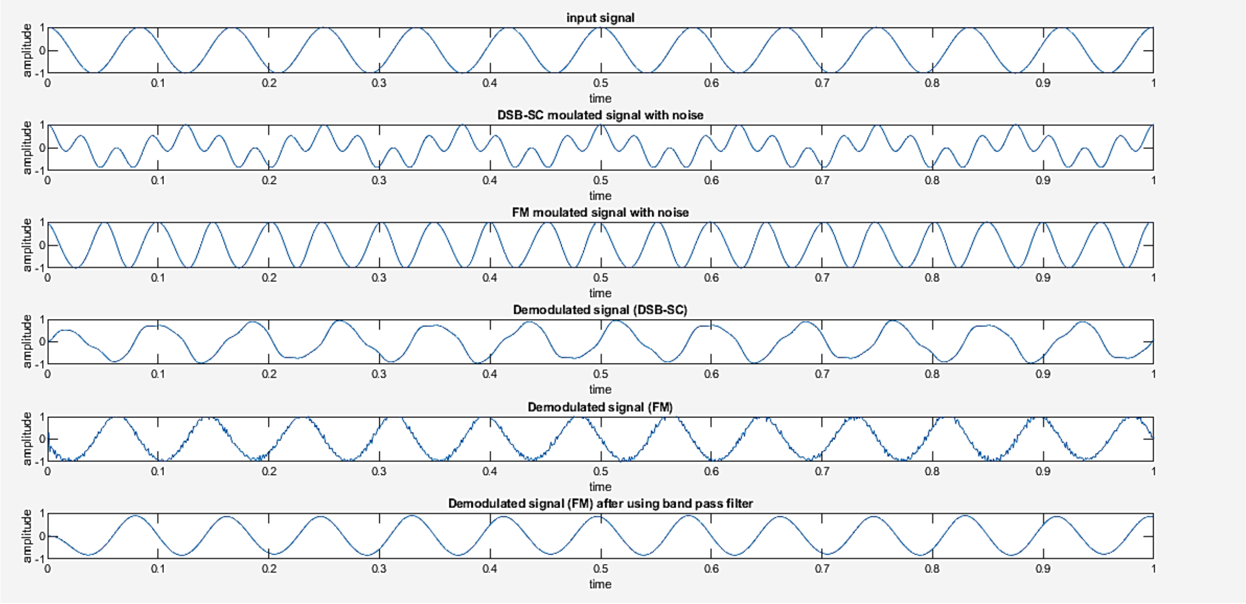

Figure 31 output when snr=60

The Demodulated signal (FM) after passing it to band-pass is almost the same as the original input signal. However, the Demodulated signal (DSB-SC) is not good as The Demodulated signal (FM).

Conclusion:

As we can conclude, increasing the value of snr give us better quality for transmitting signals. Also, we can notice that the FM-modulation is more immune to noise signals than DSB-SC modulation. However, its more complex to be implemented in real life.

Analysis of the Effect of varying the frequency deviation of the FM modulator on the FM demodulated signal in the time domain.

Generally, FM occupies much more bandwidth than AM. This bandwidth varies according to the modulation index (β) which is directly affected by the frequency deviation (Δf) at constant signal bandwidth (f_m), as shown below:

$$B_T = 2(\Delta f + f_m)$$

$$B_T = 2\Delta f\left(1 + \frac{1}{\beta}\right)$$

Thus, varying the frequency deviation (Δf), affects the modulated signal bandwidth (B_T). There are five cases in varying frequency deviation:

- $\Delta f = k_f m_p$
- $\Delta f << f_c$
- $k_f m_p < \Delta f < f_c$
- $\Delta f = f_c$
- $\Delta f > f_c$

The following table shows the values used for f_m, f_c, f_s, k_f throughout the 5 experiments

Parameter	Value (Hz)
k_f	π
f_s	1000
f_c	5
f_m	2

Testing the cases:

Case (1): $\Delta f = k_f m_p$:

This is the case used in the FM modulation section. Since m_p=1, then $\Delta f = k_f$. As shown in figure below, the modulated signal is moving smoothly from $f_{i(min)}$ to $f_{i(max)}$ with no distortion in the demodulated signal. Thus, this case is the optimum.

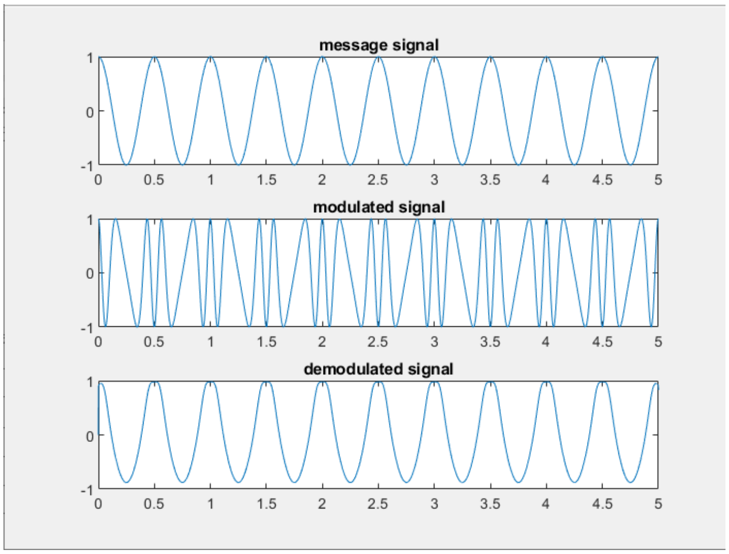

Figure 32 message, modulated and demodulated signals when $\Delta f = k_f m_p$

Case (2): $\Delta f << f_c$:

In the previous case, Δf was at its optimum value. In this case, we will test the effect if we reduced the value of Δf less than its optimum value ($\Delta f = k_f$); for instance let Δf =1Hz. As shown in figure below, the modulated signal varies quickly and tightly (faster transition) from $f_{i(min)}$ to $f_{i(max)}$, but still with no distortion in the demodulated signal except that the amplitude of the demodulated signal decreased to its half m_p=0.5.

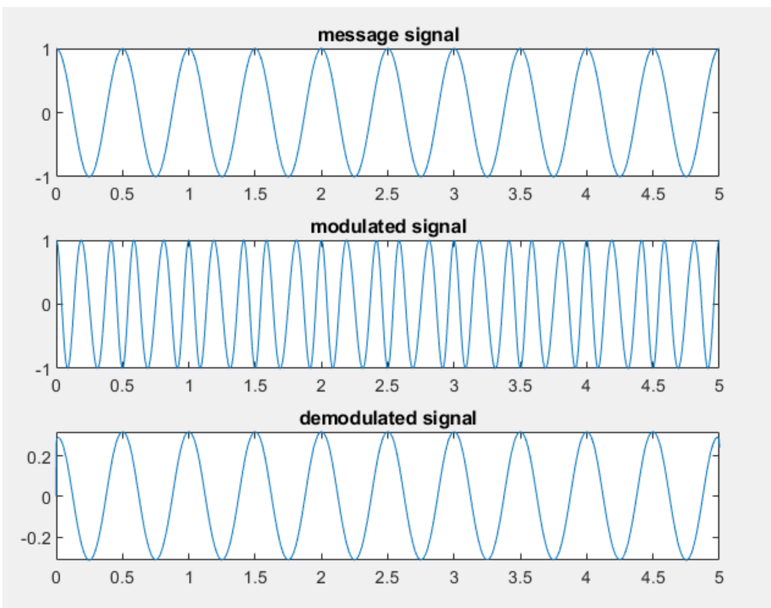

Figure 33 message, modulated and demodulated signals when Δf<< fc

Case (3): $k_f m_p < \Delta f < f_c$:

In the previous case, we noticed a decrease in demodulated signal amplitude. Thus, in this case we will increase the value of Δf above its optimum value ($\Delta f = k_f$), while keeping still below the carrier frequency (f_c); for instance let Δf =4Hz. As shown in figure (33), there are slower transitions from $f_{i(min)}$ to $f_{i(max)}$ in the modulated signal, but still with no distortion in the demodulated signal.

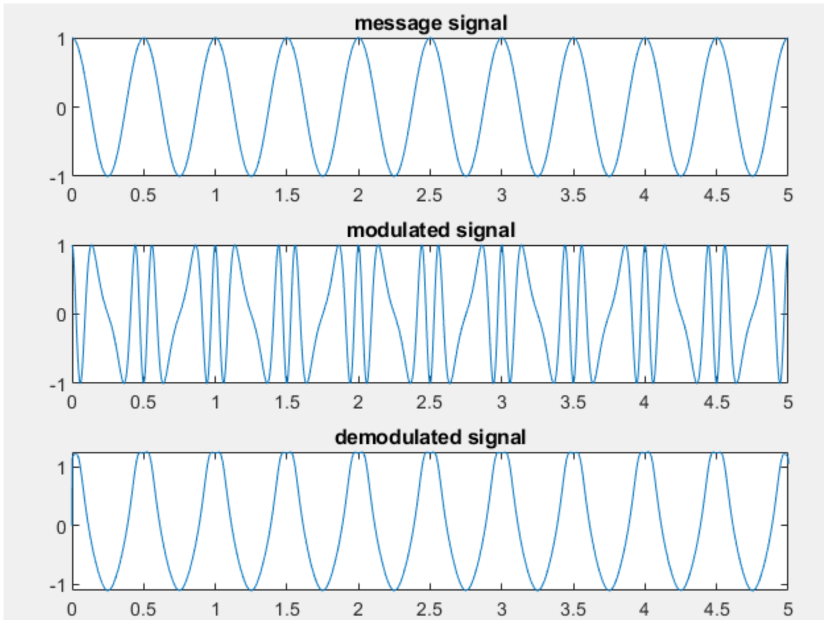

Figure 34 message, modulated and demodulated signals when $k_f m_p < \Delta f < f_c$:

Case (4): $\Delta f = f_c$:

In this case we will increase the value of Δf such that ($\Delta f = f_c$) . As shown in figure (34), distortion appeared in both the modulated and the demodulated signals.

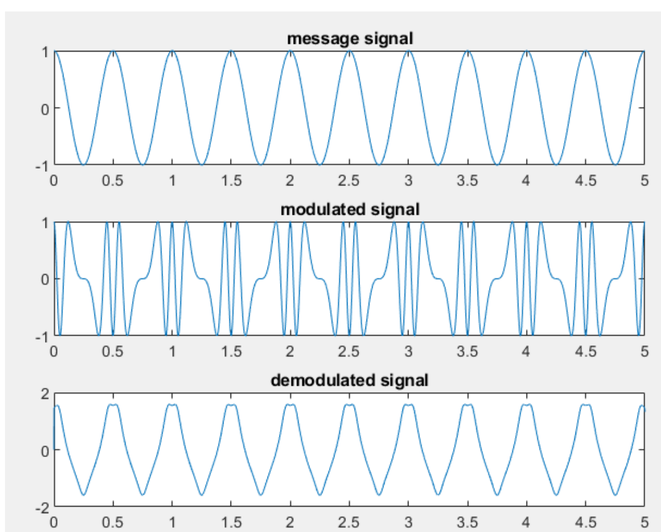

Figure 35 message, modulated and demodulated signals when Δf=f_c:

Case (5):$\Delta f > f_c$:

In this case we will increase the value of Δf such that ($\Delta f > f_c$); for instance let Δf =6Hz . As shown in figure (35), further distortion appeared in both the modulated and the demodulated signals even more than what happened in the previous case.

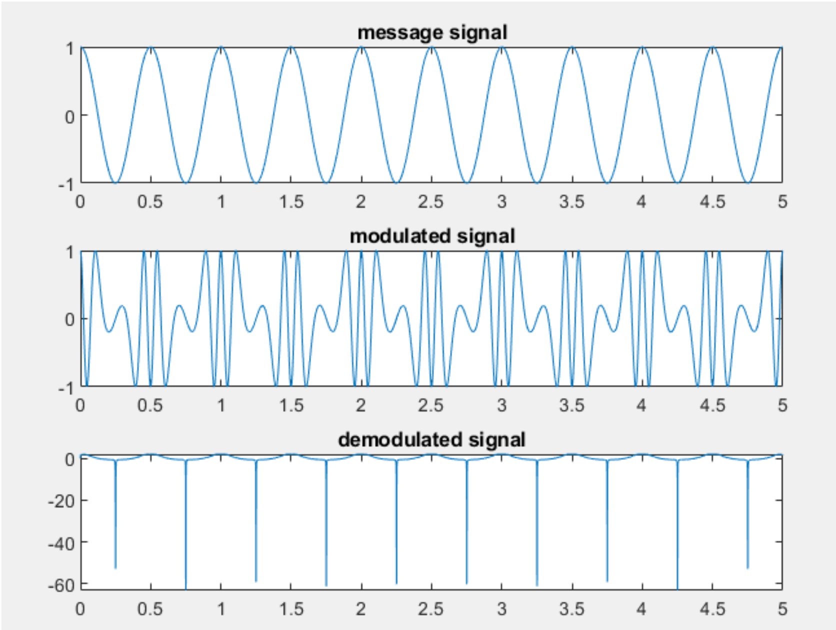

Figure 36 message, modulated and demodulated signals when Δf>f_c

conclusion

As long as Δf is below $k_f m_p$, only the amplitude of the demodulated signal is affected. As for the modulated signal, transitions from $f_{i(min)}$ to $f_{i(max)}$ become faster as we decrease Δf, moreover its spectrum becomes wider. In the band between f_c and $k_f m_p$, the amplitude of the demodulated signal is not affected. On the other hand, transitions from $f_{i(min)}$ to $f_{i(max)}$ become slower as we increase Δf, and the spectrum bandwidth becomes narrower. If $\Delta f \geq f_c$, distortion happens to both the modulated and the demodulated signals and increases as we increase Δf.