EC202

Analog and Digital Communication

Frequency Modulation and Demodulation

Assignment – Final Submission

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Modulation

When audio signals are transmitted over thousands of kilo meters through radio transmission, the audio frequencies that lie within the frequency range of 15 Hertz to 20 Kilo Hertz has very small signal power and thus cannot be transmitted via the antenna for communication purposes. The radiation of electrical energy is only possible at frequencies above 20 Kilo Hertz.

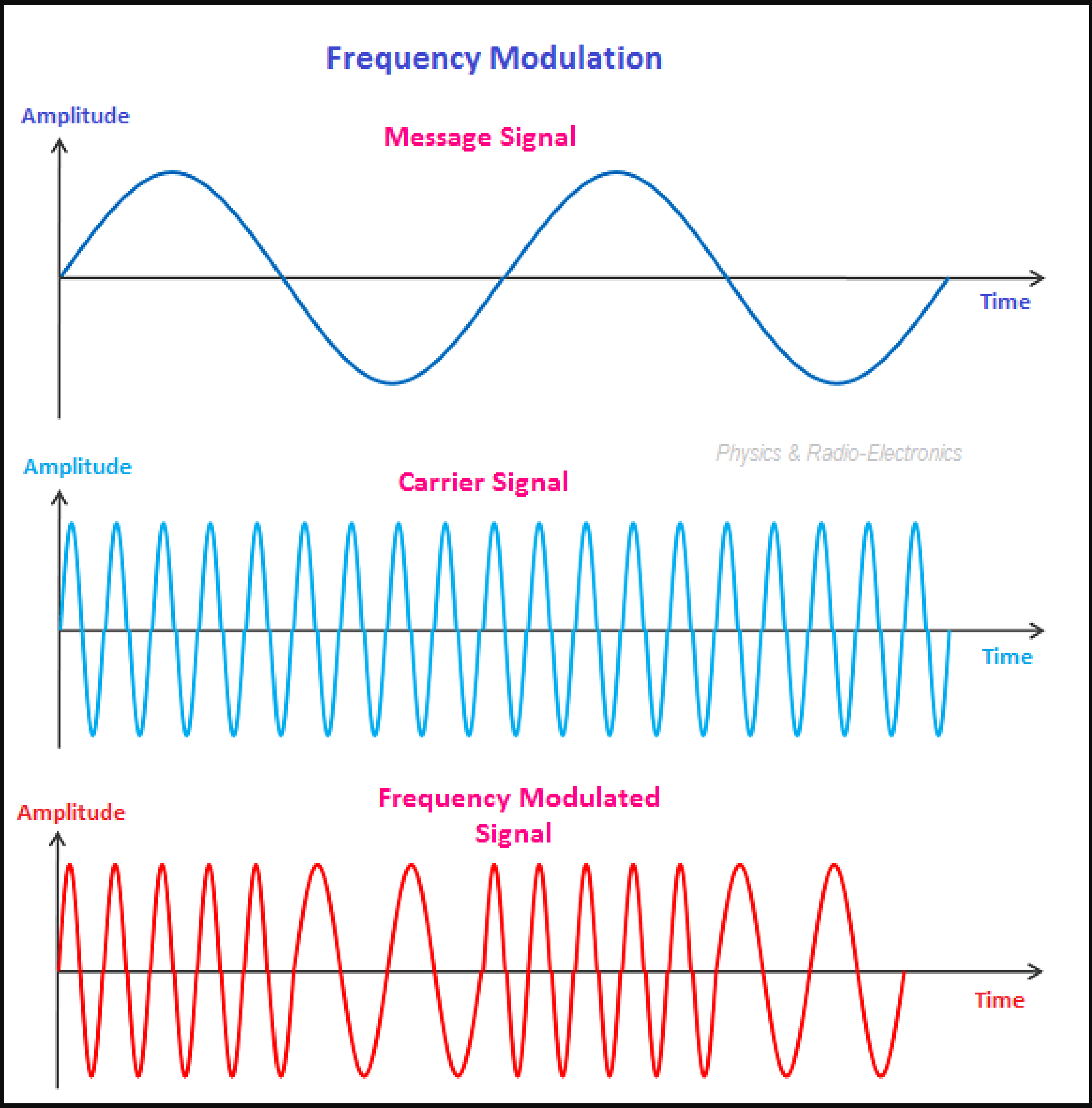
The main advantage of high-frequency signals is that they can be transmitted over very long distances by dissipating very small power.

Thus, the audio signals must be sent along with the high-frequency signals for communication. This can be done by superimposing electrical audio signals on a high-frequency wave called the carrier wave. The carrier wave is generated from radio-frequency oscillators and is undamped in nature. Thus, when the audio-frequency signal is superimposed on a carrier wave, the resulting wave gets all the characteristics of the audio signal. The method of superimposing an audio signal over the carrier wave is called modulation.

After modulation is done, the resulting wave can be given to the antenna and the signal can be transmitted over a long distance.

Frequency Modulation

Frequency Modulation (FM) is a form of modulation in which changes in the carrier wave frequency correspond directly to changes in the baseband signal. FM is considered an analog form of modulation because the baseband signal is typically an analog waveform without discrete, digital values.



As with any form of modulation there are several advantages and disadvantages to its use. These need to be considered before making any decision or choice about its use:

Advantages:

Resilience to noise: One particular advantage of frequency modulation is its resilience to signal level variations. The modulation is carried only as variations in frequency. This means that any signal level variations will not affect the audio output, provided that the signal does not fall to a level where the receiver cannot cope. As a result, this makes FM ideal for mobile radio communication applications including more general two-way radio communication or portable applications where signal levels are likely to vary considerably. The other advantage of FM is its resilience to noise and interference. It is for this reason that FM is used for high quality broadcast transmissions.

Easy to apply modulation at a low power stage of the transmitter: Another advantage of frequency modulation is associated with the transmitters. It is possible to apply the modulation to a low power stage of the transmitter, and it is not necessary to use a linear form of amplification to increase the power level of the signal to its final value.

It is possible to use efficient RF amplifiers with frequency modulated signals: It is possible to use non-linear RF amplifiers to amplify FM signals in a transmitter and these are more efficient than the linear ones required for signals with any amplitude variations (e.g., AM and SSB). This means that for a given power output, less battery power is required and this makes the use of FM more viable for portable two-way radio applications.

Disadvantages:

FM has poorer spectral efficiency than some other modulation formats: Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission than frequency shift keying, a form of frequency modulation. As a result, most data transmission system use PSK and QAM.

Requires more complicated demodulator: One of the minor disadvantages of frequency modulation is that the demodulator is a little more complicated, and hence slightly more expensive than the very simple diode detectors used for AM. However, this is much less of an issue these days because many radios integrated circuits incorporate a built-in frequency demodulator.

Some other modes have higher data spectral efficiency: Some phase modulation and quadrature amplitude modulation formats have a higher spectral efficiency for data transmission that frequency shift keying, a form of frequency modulation. As a result, most data transmission system use PSK and QAM. Sidebands extend to infinity either side: The sidebands for an FM transmission theoretically extend out to infinity. They are normally significant for wideband frequency modulation transmissions, although small for narrow band FM. To limit the bandwidth of the transmission, filters are often used, and these introduce some distortion of the signal. Normally this is not too much of an issue although care has to be taken to include these filters for wideband FM and to ensure they are properly designed.

Modulation Index

When using a frequency modulated signal it is very helpful to have a measure of what is effectively the level of the modulation. This is useful in defining parameters like whether the signal is a narrow band or a wide band frequency modulated signal. It is also very useful in ensuring that all transmitters or receivers in a system are set to accommodate a standardized level of modulation as it affects parameters like the receiver bandwidth, channel spacing and the like. To define the level of modulation, figures known as the modulation index and deviation ratio are used.

FM bandwidth

One of the key elements of an FM signal is its bandwidth. With any frequency modulated signal, sidebands extend out either side. These actually extend out to infinity, but the intensity of them falls away. Fortunately, it is possible to limit the bandwidth of an FM signal without affecting its quality unduly.

Frequency modulation is widely used in many areas of radio technology including broadcasting and areas of two-way radio communication. In these applications its particular advantages can be used to good effect.

Whilst other forms of modulation are being used in many areas, FM still offers the highest quality for broadcasting and many advantages for other forms of communication as well.

Mathematical Expression for FM

$$S_{FM}(t)=A_c cos[2\pi f_c t + 2\pi k_f \int m(t)dt]$$

Where,

K_f: is the frequency sensitivity of FM modulator

m(t): Message Signal $m(t)=A_m\cos(2\pi f_m t)$

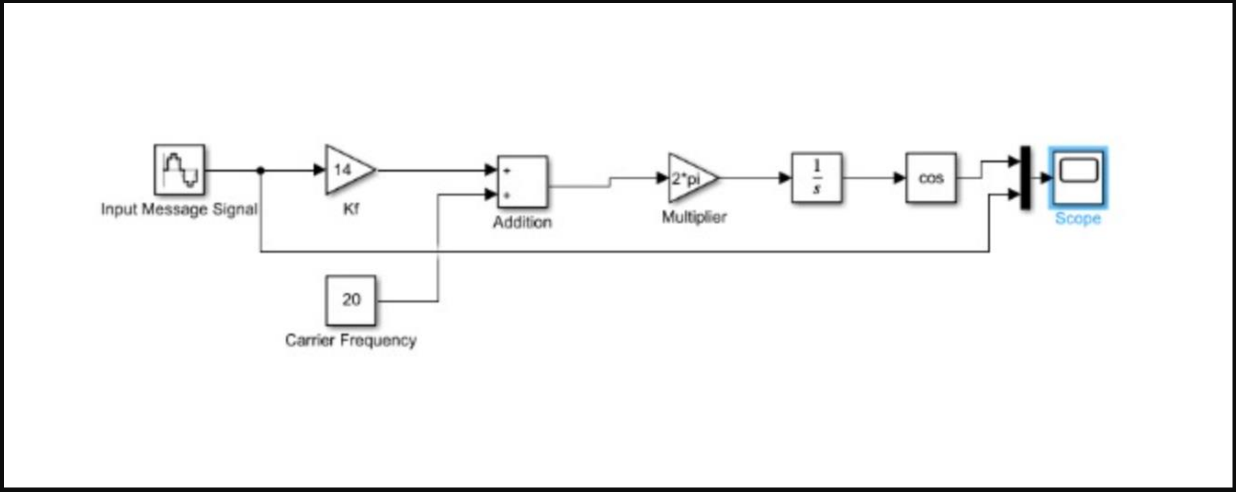
c(t): Carrier Signal $c(t)=A_c\cos(2\pi f_c t)$

β: Modulation Index

$$S_{FM}(t)=A_c cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$$

Simulation Model (Simulink)

In Simulink, we feed the input signal, which is a sine wave with an amplitude of 1, and frequency of 2 rad/sec. We then amplify this, by the factor of K_f, which is 14 in our case. Then, we know that we have to add the Carrier frequency which is 20 in our case, so we use an adder and add these 2. We have not considered 2π factor till now in our calculations. Hence, we use multiplier and multiply the signal by a factor of 2pi. Then, we integrate the equation, then we enclose the entire equation in a cos function, which is our Frequency Modulation.

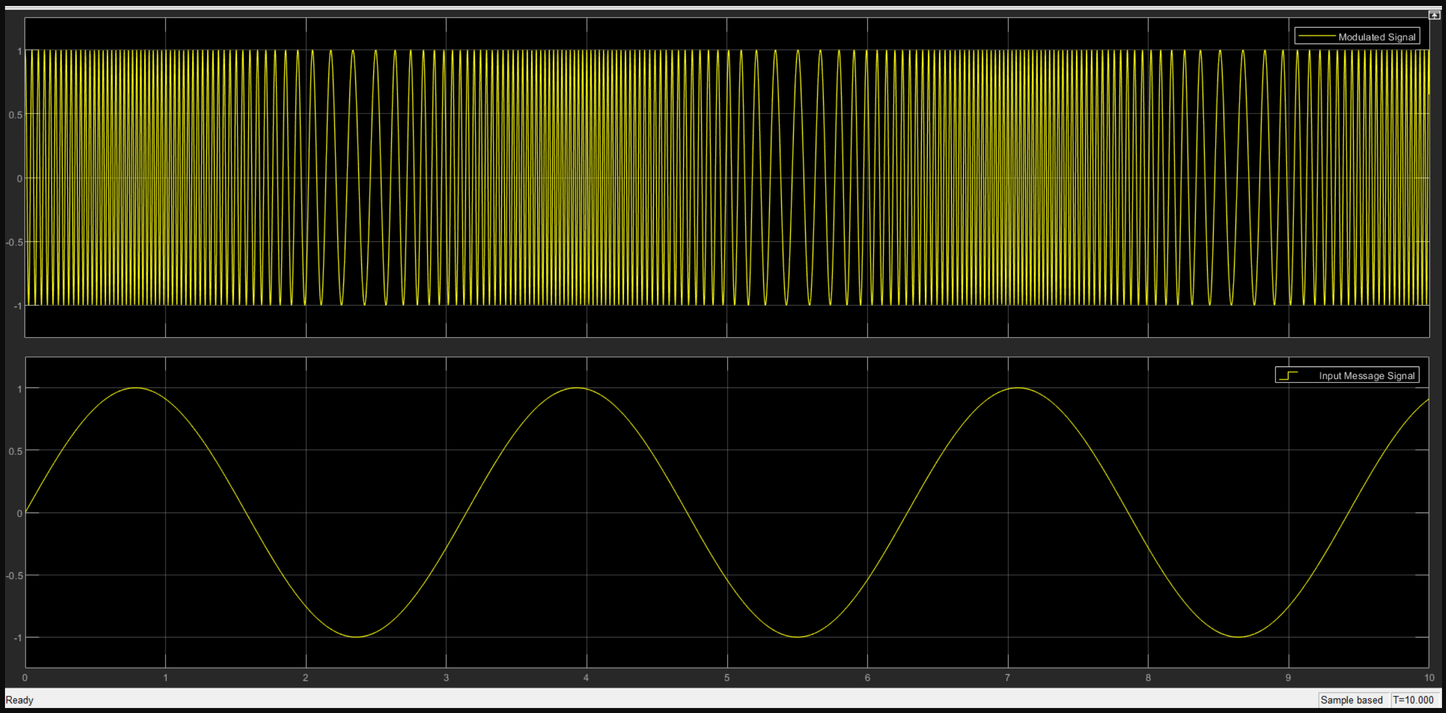


The code for the following can also be written in MATLAB as follows:

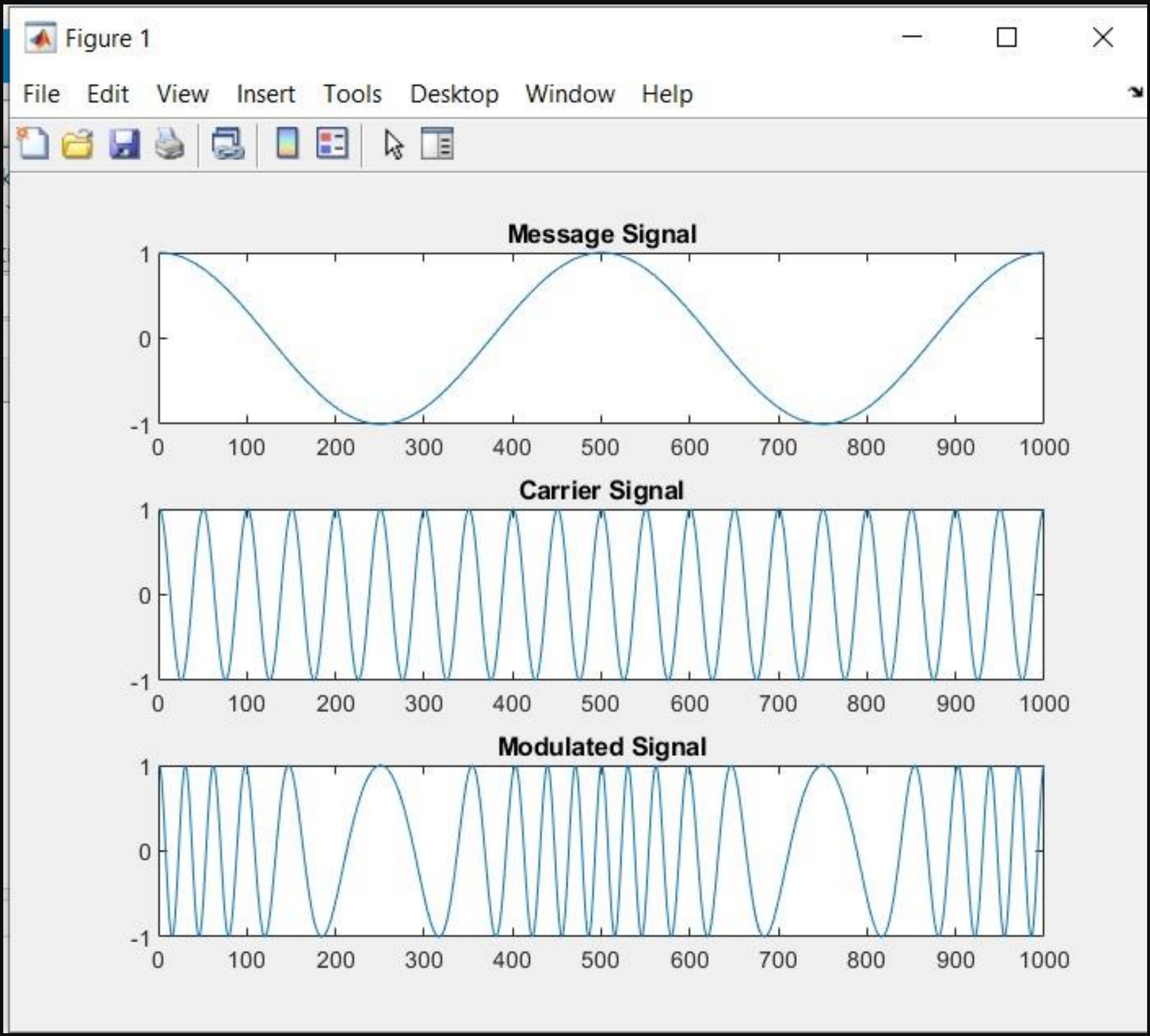
```
kf=14;
Am=1;
fm=2;
beta = (kf*Am)/fm;
t=linspace(0,1,1000);
Ac=1;
fc=20;
Sfm=Ac*cos(2*pi*fc*t + beta*(sin(2*pi*fm*t)));
mt=Am*cos(2*pi*fm*t);
ct=Ac*cos(2*pi*fc*t);
subplot(3,1,1);
plot(mt);
title('Message Signal');
subplot(3,1,2);
plot(ct);
title('Carrier Signal');
subplot(3,1,3);
plot(Sfm);
title('Modulated Signal');
```

Modulator waveform

For Simulink:



For MATLAB Code:



In the 1st evaluation, we discussed about the necessity of modulation of signals. Now we will see how and why we need to demodulate the modulated signal.

Demodulation

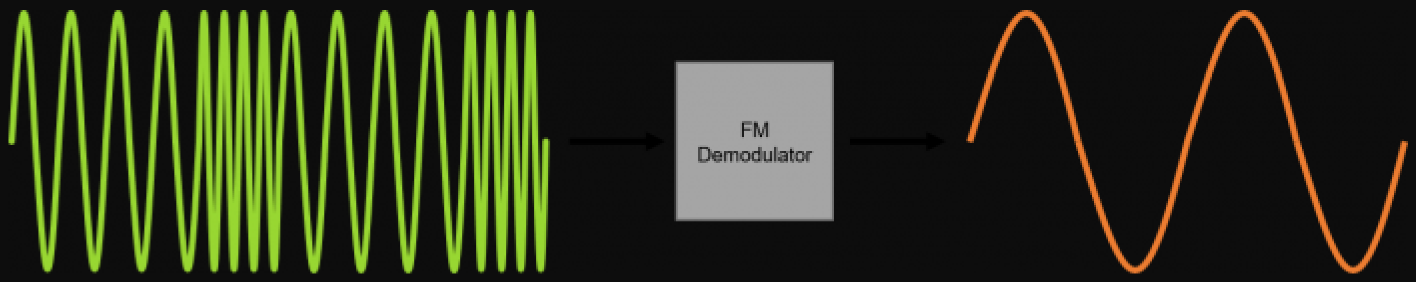
We have seen that Carrier modulation allows the transmission of modulating frequencies without the use of transmission wire as a medium. However, for the communication process to be completed or to be useful, the intelligence must be recovered in its original form at the receiving site. The process of recreating original modulating frequencies from the rf carrier is referred to as demodulation or detection.

In simple terms, if we take the example of why we needed to modulate the audio signals, we added a carrier signal with the audio signal in frequency modulation. The process of the receiver by which the audio frequency is separated from the carrier signal is called demodulation. The demodulated audio signal is sent to the loudspeakers for the user to hear. If there was no demodulation, the high-frequency currents would have reached the loudspeaker and would have caused signal errors. Radiofrequency current also cannot be heard by humans. This shows why modulation and demodulation are important in a communication system.

Frequency Demodulation

An FM demodulator recovers the message signal from the received FM waveform that is generally corrupted by noise.

This requires a circuit that produces an output that is linearly proportional to the instantaneous frequency of the input FM signal.



FM demodulators can be classified into the following three broad categories based on their principle of operation:

<u>Frequency discrimination</u>: In this the FM signal is converted into AM signal by a differentiator and then an envelope detector is used to recover the message signal from the converted waveform. This is a noncoherent demodulation method.

<u>Phase-shift discrimination</u>: An FM signal is converted into a PM signal and then a phase detector is used to recover the message signal. In practice, it is implemented using a quadrature detector. This is also a noncoherent demodulation method.

The quadrature detector offers significant advantages for many circuits, but as with any decision, a number of different advantages and disadvantages have to be considered when selecting a given circuit for FM demodulation.

Advantages of FM quadrature

- demodulator Offers good level of performance and including linearity.
- Can be incorporated into an integrated circuit.
- Very simple circuit - easy to ensure it operates correctly.

Disadvantages of FM quadrature demodulator

- Requires the use of a coil - this is not a major issue as a simple coil is used and an RF transformer is not needed as in the case of the ratio and Foster Seeley circuits.
- Some designs may require setting during manufacture.

<u>Phase-locked loop (PLL) detector</u>: A PLL detector uses a voltage-controlled oscillator (VCO) and feedback to extract the message signal. This is a coherent demodulation method.

A PLL detector (phase-locked loop) is a closed-loop feedback control circuit that's both frequency- and phase-sensitive. A PLL is not a single component, but a system that consists of both analog and digital components -- interconnected in a "negative feedback" configuration.

Bandpass Limiter

Although amplitude of an FM carrier is constant, the signal entering the FM discriminator may have amplitude variations due to addition of the channel noise. All FM discriminators are, therefore, preceded by a BP limiter to ensure that the discriminator input signal is constant in amplitude. A BP limiter consists of a hard limiter followed by a BP filter.

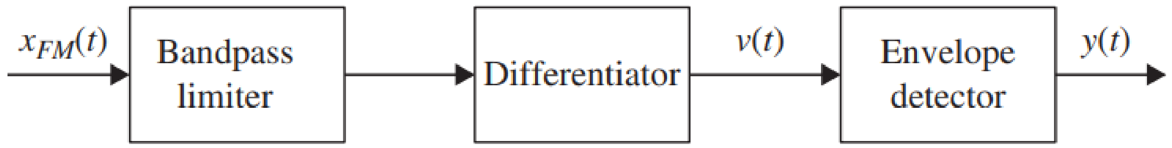
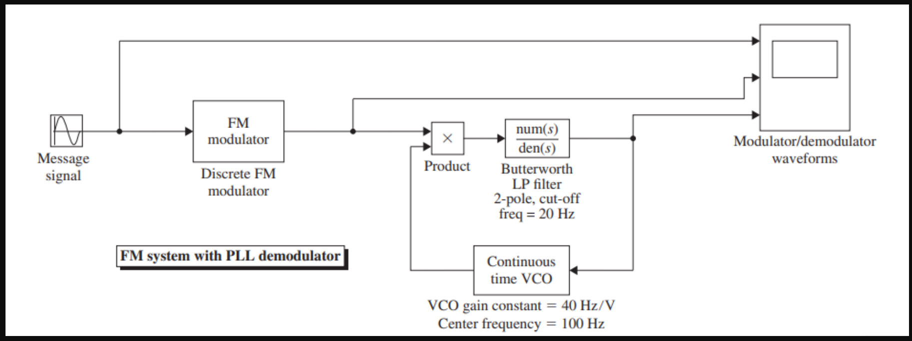


Figure 5.9 Frequency discriminator.

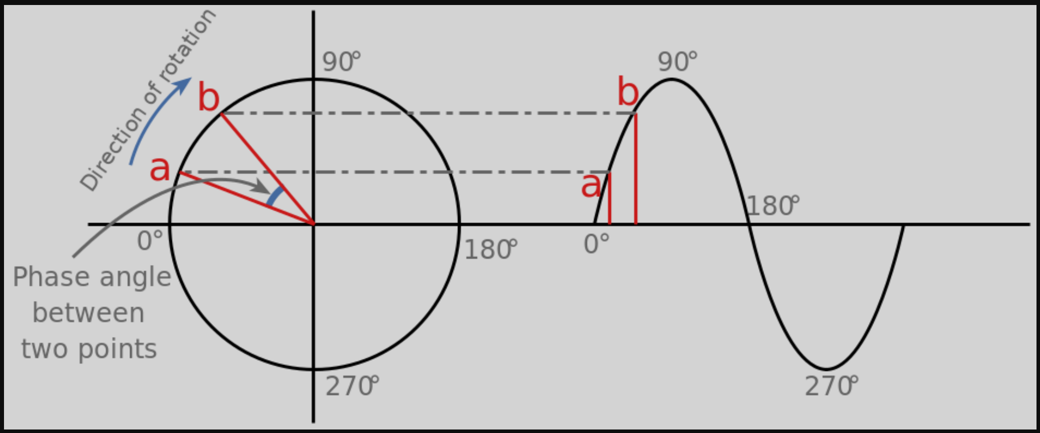
Demodulation using Phase Shift discrimination

The key to the operation of a phase locked loop, PLL, is the phase difference between two signals, and the ability to detect it. The information about the error in phase or the phase difference between the two signals is then used to control the frequency of the loop.



To understand more about the concept of phase and phase difference, it is possible to visualize two waveforms, normally seen as sine waves, as they might appear on an oscilloscope. If the trigger is fired at the same time for both signals, they will appear at different points on the screen.

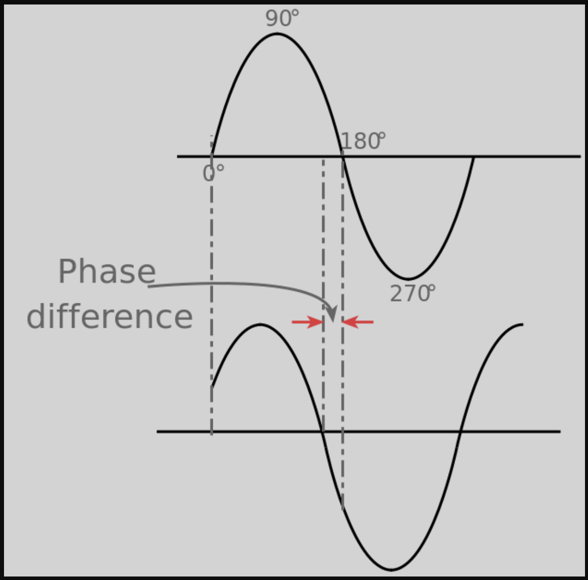
The linear plot can also be represented in the form of a circle. The beginning of the cycle can be represented as a particular point on the circle and as a time progresses the point on the waveform moves around the circle.



Thus, a complete cycle is equivalent to 360˚ or 2π radians. The instantaneous position on the circle represents the phase at that given moment relative to the beginning of the cycle.

Although the two signals we looked at before have the same frequency, the peaks and troughs do not occur in the same place.

There is said to be a phase difference between the two signals. This phase difference is measured as the angle between them. It can be seen that it is the angle between the same point on the two waveforms. In this case a zero-crossing point has been taken, but any point will suffice provided that it is the same on both.



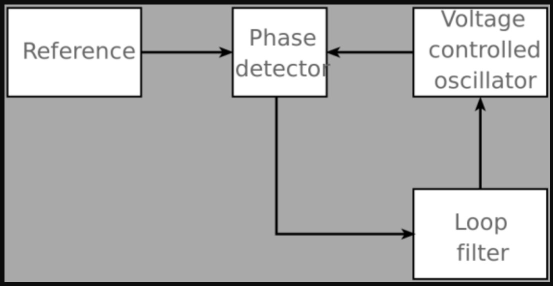
This phase difference can also be represented on a circle because the two waveforms will be at different points on the cycle as a result of their phase difference. The phase difference measured as an angle: it is the angle between the two lines from the center of the circle to the point where the waveform is represented.

When there two signals have different frequencies, it is found that the phase difference between the two signals is always varying. The reason for this is that the time for each cycle is different and accordingly they are moving around the circle at different rates.

It can be inferred from this that the definition of two signals having exactly the same frequency is that the phase difference between them is constant. There may be a phase difference between the two signals. This only means that they do not reach the same point on the waveform at the same time. If the phase difference is fixed it means that one is lagging behind or leading the other signal by the same amount, i.e., they are on the same frequency.

Phase locked loop:

A phase locked loop, PLL, is basically of form of servo loop. Although a PLL performs its actions on a radio frequency signal, all the basic criteria for loop stability and other parameters are the same. In this way the same theory can be applied to a phase locked loop as is applied to servo loops.



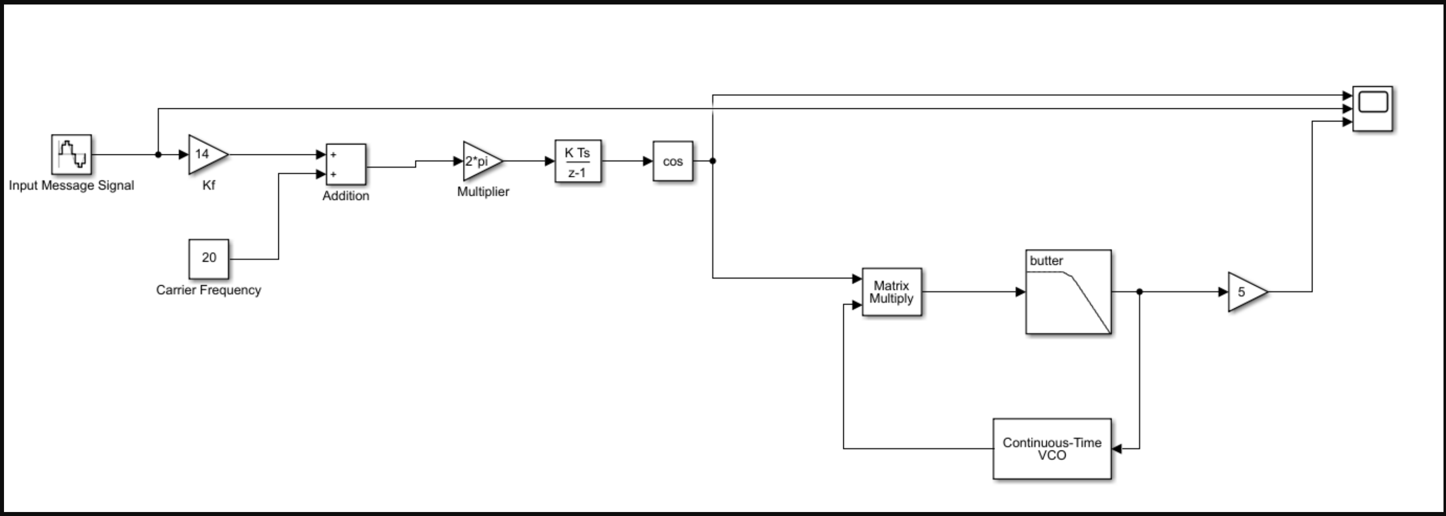
A basic phase locked loop, PLL, consists of three basic elements:

- Phase comparator / detector: As the name implies, this circuit block within the PLL compares the phase of two signals and generates a voltage according to the phase difference between the two signals
- Voltage controlled oscillator (VCO): The voltage-controlled oscillator is the circuit block that generates the radio frequency signal that is normally considered as the output of the loop. Its frequency can be controlled over the operational frequency band required for the loop.
- Loop filter: This filter is used to filter the output from the phase comparator in the phase locked loop, PLL. It is used to remove any components of the signals of which the phase is being compared from the VCO line. It also governs many of the characteristics of the loop including the loop stability, speed of lock, etc.

Simulation Model (Simulink)

for demodulation using PLL discrimination

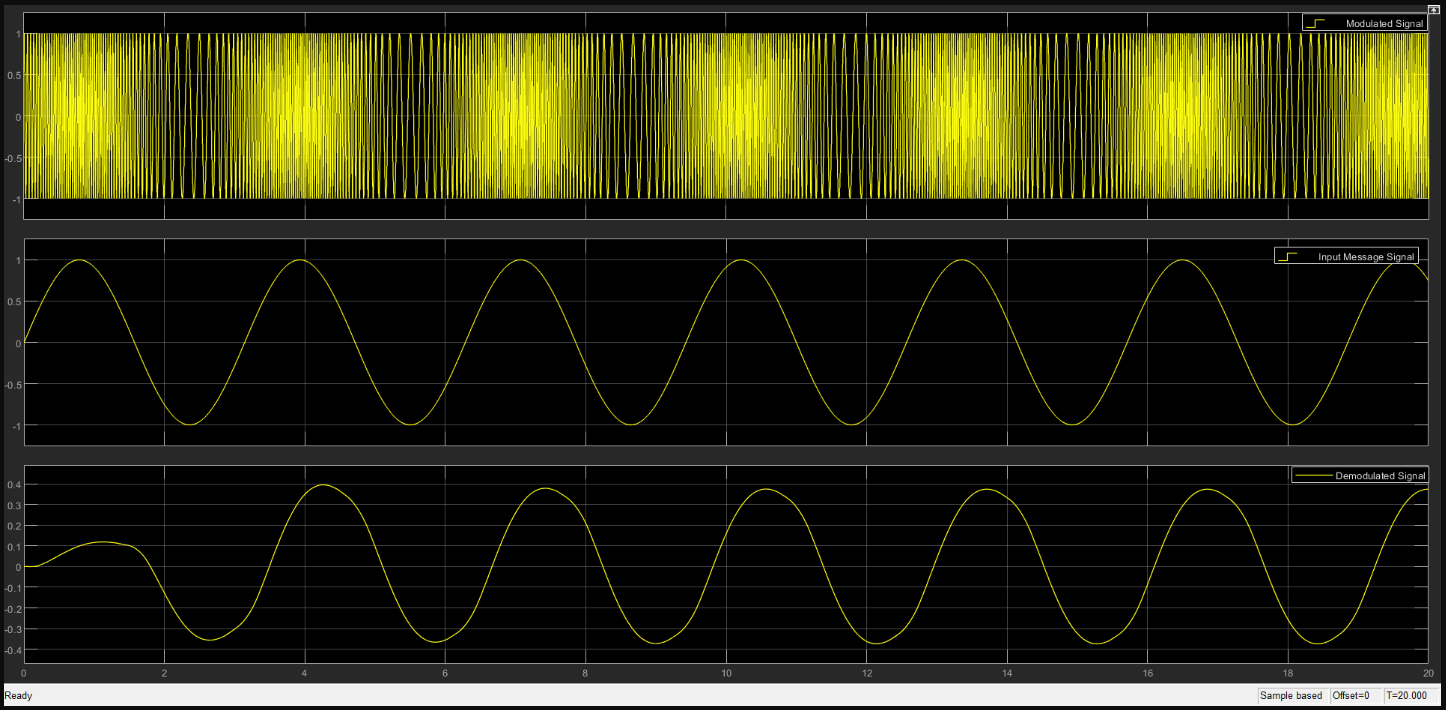
Our aim is to demodulate the previously modulated message signal so we can get back our message signal. We do it using phase locked loop, where in we have a Filter, and a Voltage controlled Oscillator, that works in feedback and gives back the input signal.



Results and Discussion:

Demodulator waveform

For Simulink:



As we can see, the output we get closely matches the input which we gave, which shows that our demodulator works as intended. But we can also notice a small hitch in the magnitude of the first cycle and a phase difference between the input message signal and demodulated signal.

We also want the Frequency Domain representation of our demodulated signal, which is why we use a Discrete Transfer Function, to sample our signal first, and then send it to a spectrum analyzer to analyze the frequency domain representation of our signal.

For Analyzing Output

For analyzing the frequency spectrum of the output, we will use the spectrum analyzer available in the Simulink. We will connect it to both the input message signal, modulated message signal and the output demodulated signal and see the difference.

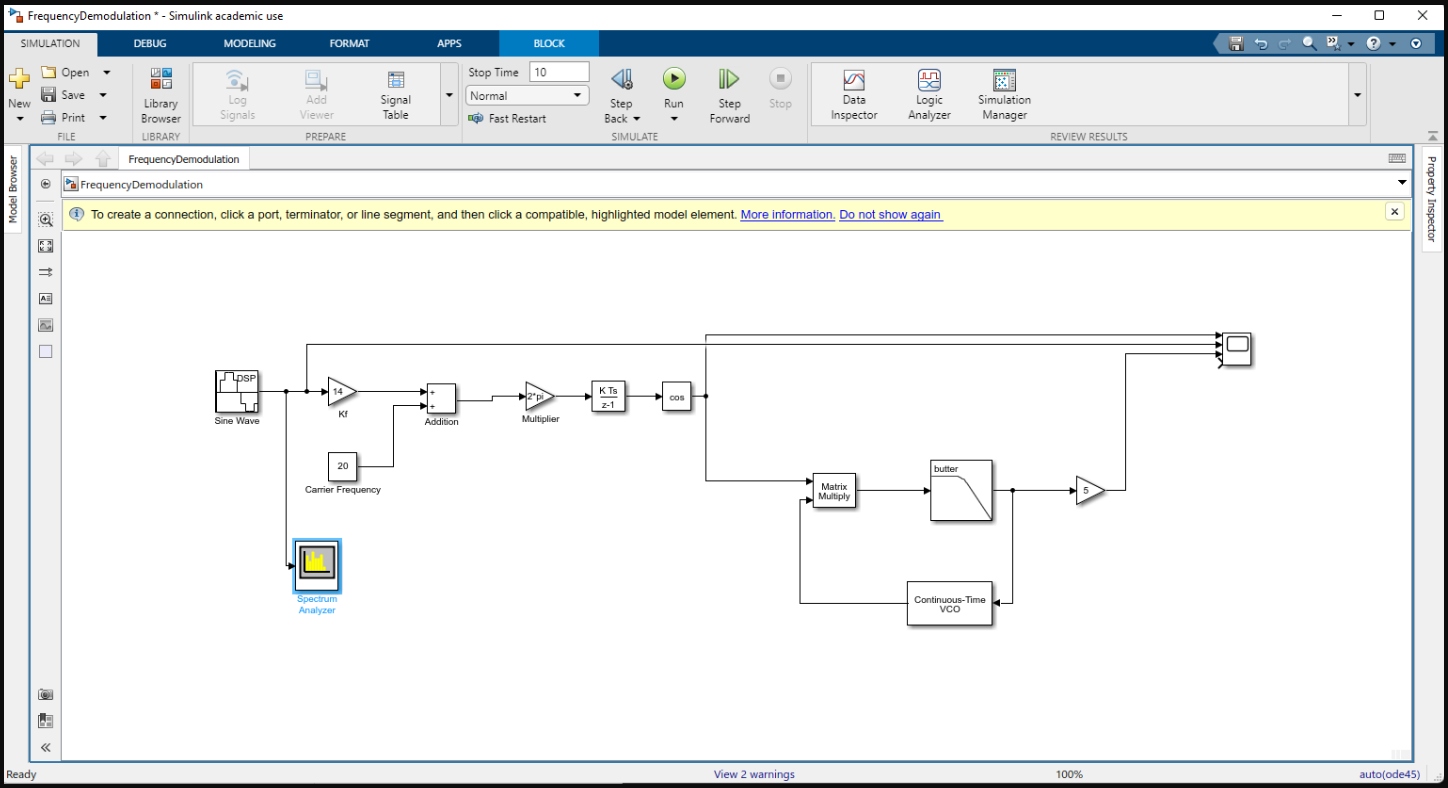
A spectrum analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of known and unknown signals.

Note:

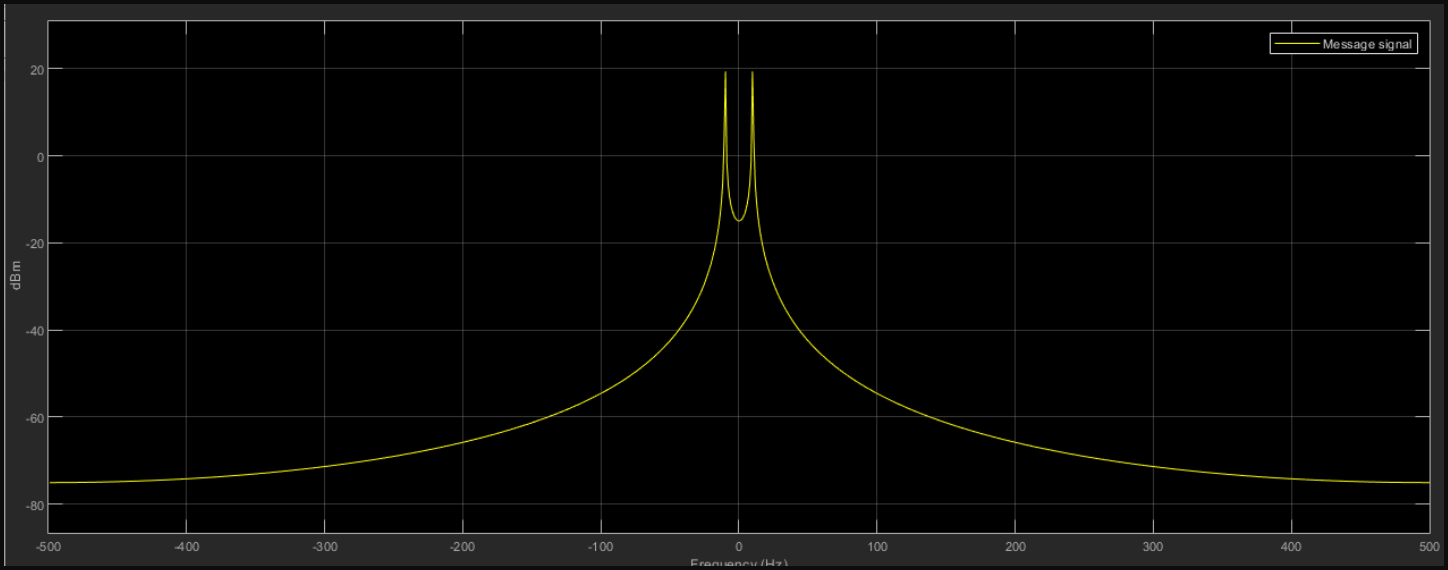
We will use a DSP input for easier calculation and display of frequency spectrum. We will use a higher frequency (10Hz) input message signal.

We will be using Zero-order Hold for converting continuous to discrete signals whenever required for Spectral Analyzer.

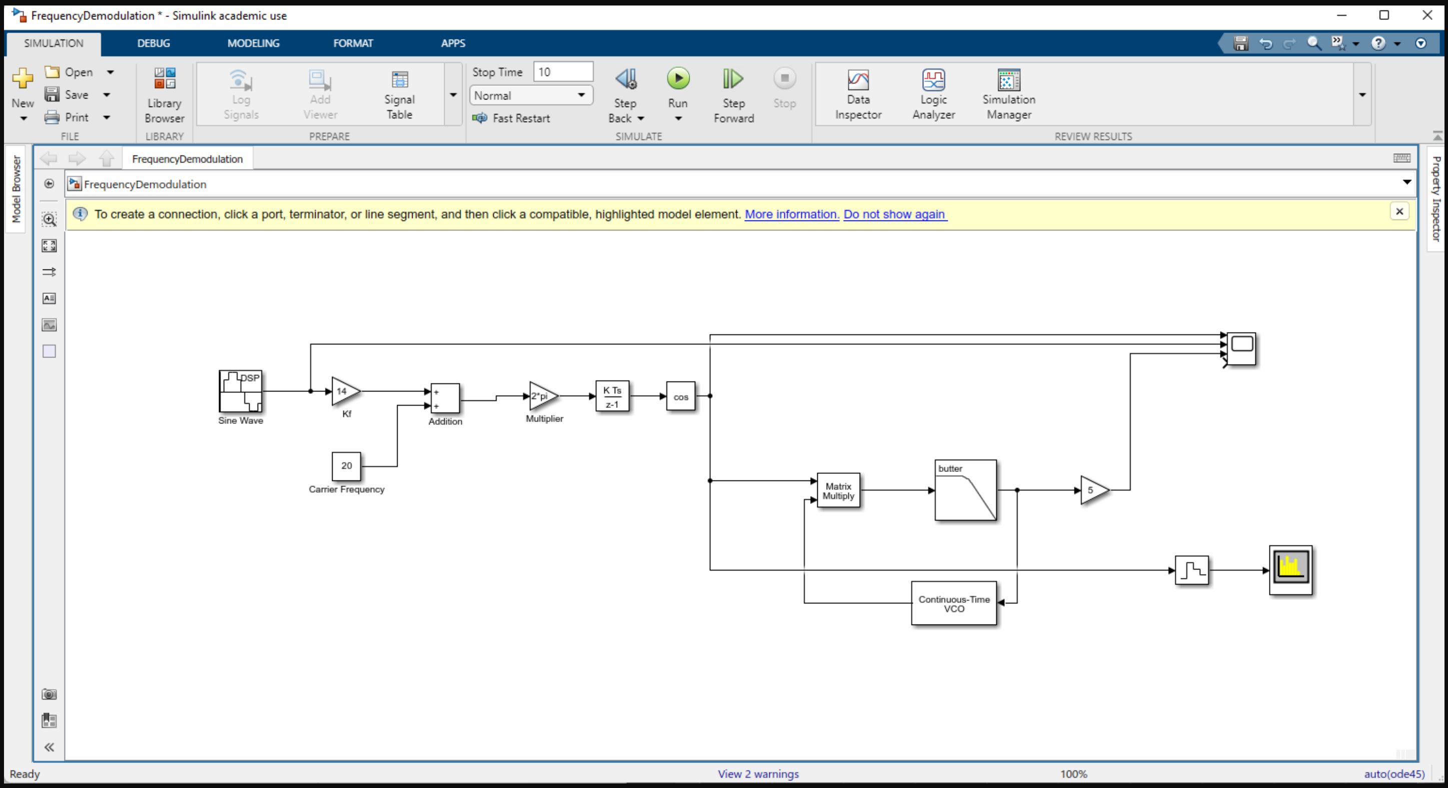
For Input message signal:



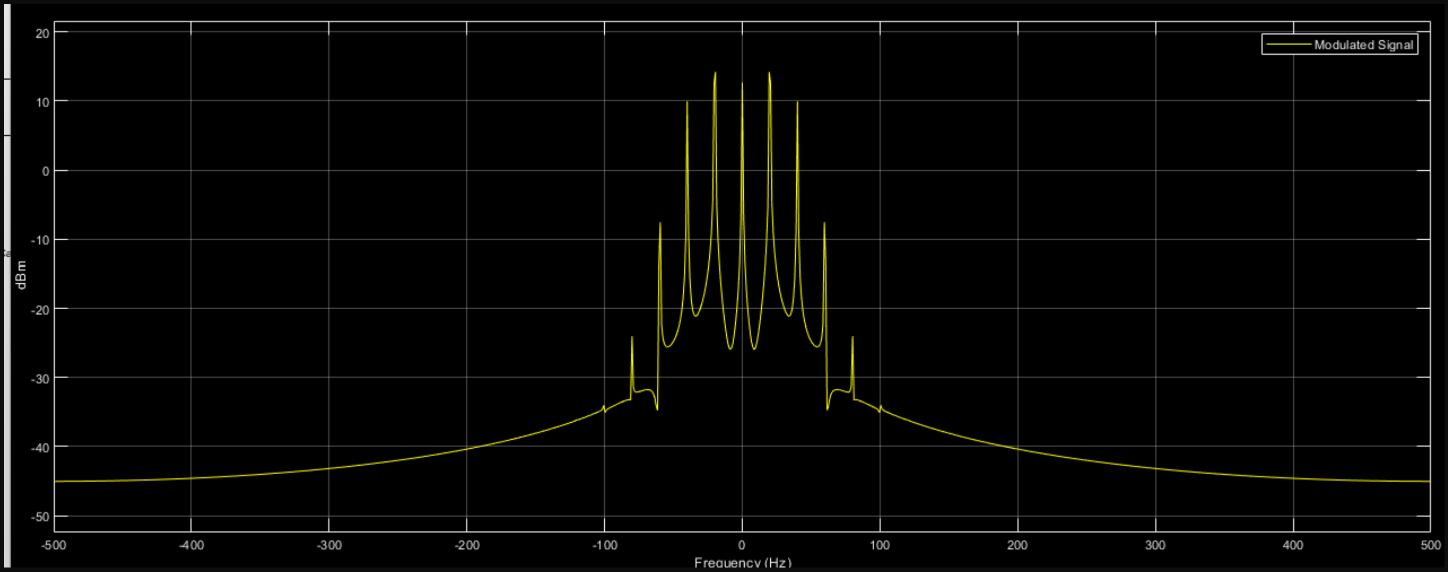
Frequency spectrum:



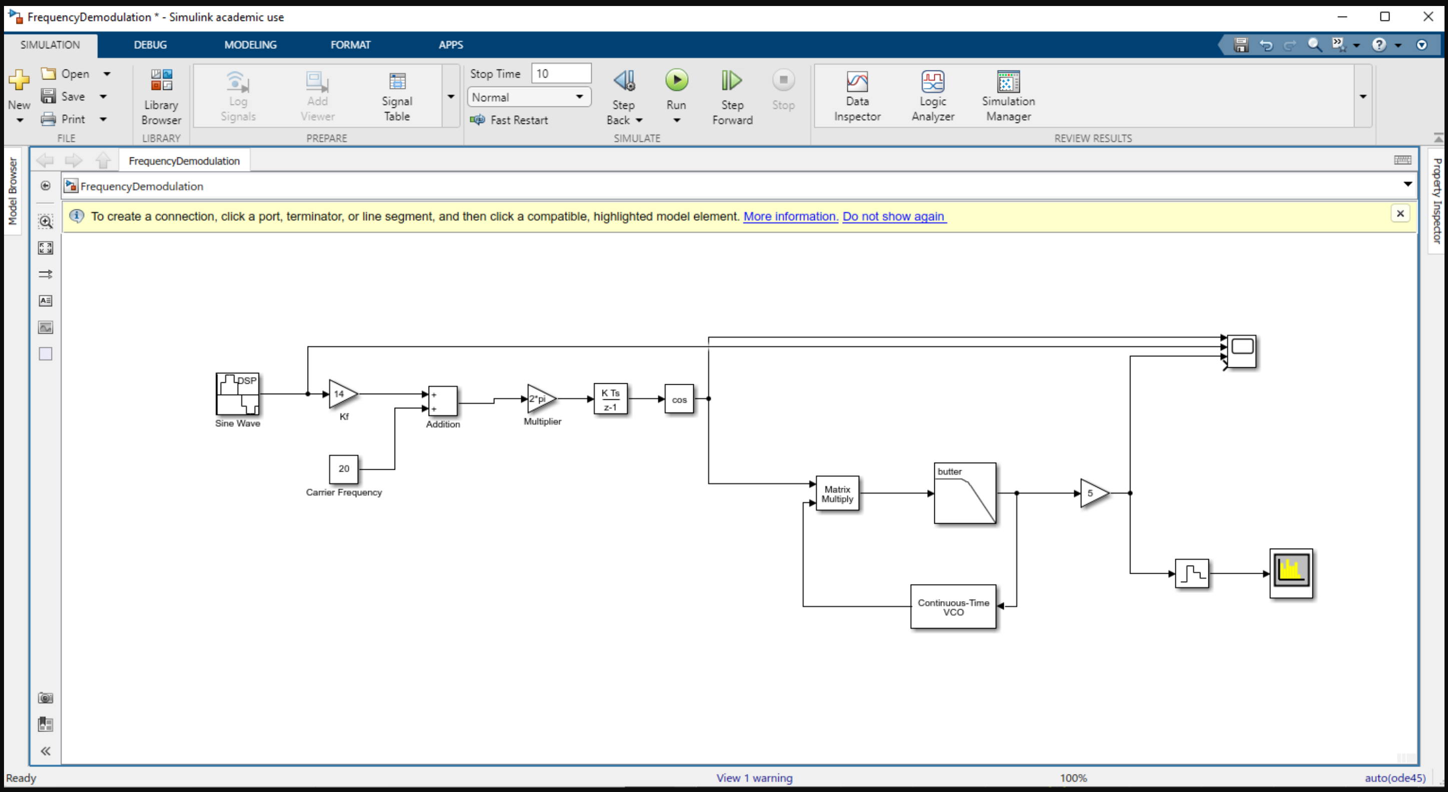
For Modulated Signal:



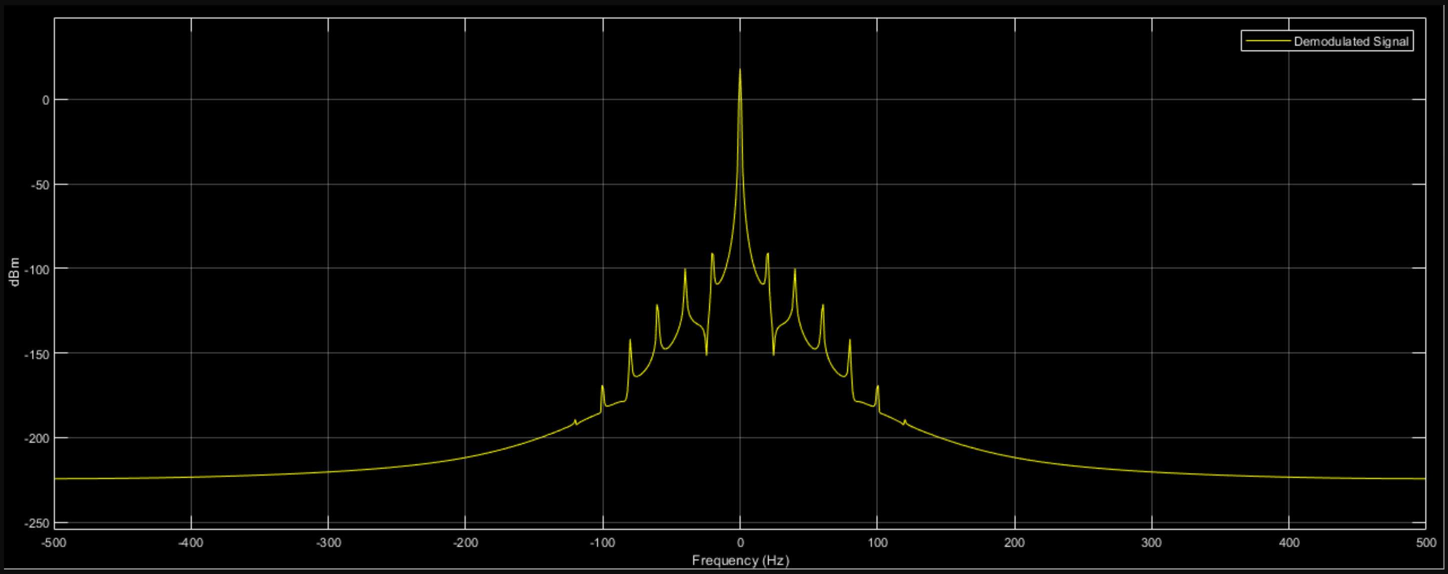
Frequency spectrum:



For Demodulated Signal:



Frequency spectrum:



Observations:

We can see that the Input message signals and the demodulated output message signal's frequency spectrum are quite different even though their magnitude-time graph kind of looks similar. This is because the final output signal isn't a perfect sinusoidal signal as we can see the hitch in the magnitude of the first cycle and a phase difference between the input message signal and demodulated signal in the magnitude-time graph..

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