BERZIET UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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# ENEE 4113

communication Laboratory.

**Experiment 4**

**Angle modulation (AM and FM)**


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**Section # :** 3


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# 1. Abstract:

In this experiment, the student will be introduced to how they can deal with different signals using written python code in GitHub simulator and produce some different signal to make message (sinusoidal or square) and carrier signals to modulate it by Frequency Modulation and plot for those in frequency and time domains, and know the difference between them and when to use this or that, Furthermore, the experiment will provide the student the possibility to thoroughly observe the effects of the modulation index (ß) on the modulated signal, after that they have to know how to demodulate the FM signal using discriminator, then they have to take another method of modulation called “phase modulation”. Finally, at the end of this experiment the student shall understand some different types of modulation on different types of message signal and how they can take back the original signal.

# Continent:

# Table of figure:

# 2. Procedure:

## 2.1 Frequency Modulation in the Time Domain:

the FM signal can be expressed as:

$$s(t) = A_c \cos\left(2\pi f_c t + \beta \sin 2\pi f_m t\right).$$

Where:

s(t): FM modulation signal.

$A_c$: The amplitude of the carrier signal.
$f_c$: The frequency of the carrier signal.
$f_m$: The frequency of the massage signal.
β: (kf.Am)/fm : the FM modulation index.
kf: the frequency-sensitivity factor.

Let :

```
Am=5        # amplitude of message signal
fm=100      # frequency of message signal
Ac=5        # amplitude of carrier signal
fc=1000     # frequency of carrier signal
Kf=100      # frequency sensitivity (Hz/volt)
B= Kf*Am/fm # beta, frequency modulation index
```

The signals were plotted in time domain as shown in fig below:

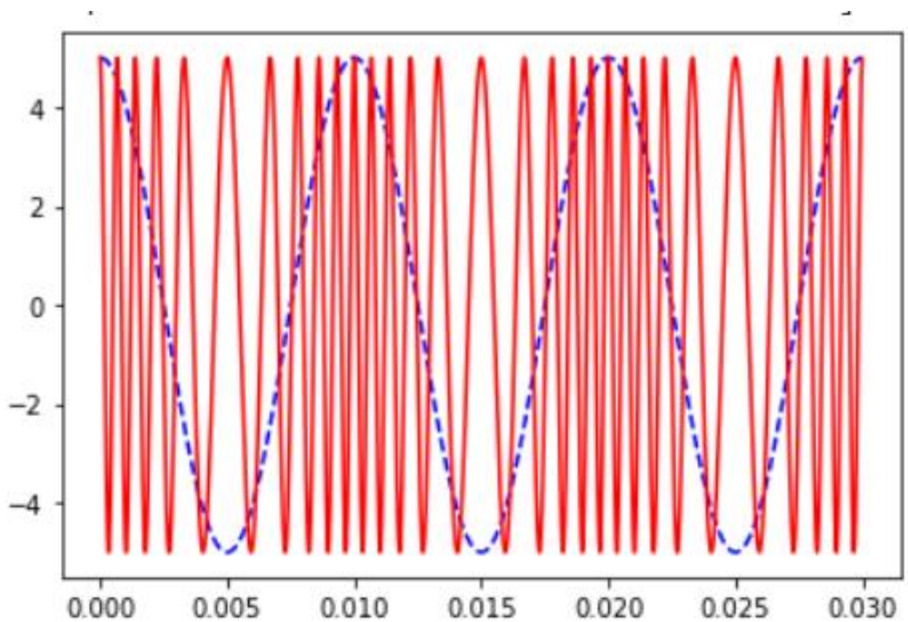


*Figure 1:Frequency Modulation of original massage and modulation signal in the Time Domain*

- **<u>Note</u>**: in the above figure, we show 2 signal, one in red color represent the instantaneous frequency of the modulated signal and the other in blue color represent the amplitude of the original message. We also note that the (red curve) increases with the increase of the (blue curve). To investigate the FM modulation. Also, if we focus by looking at the peak between the two period in the red curve, we see that the distance between them is not equal, and this is evidence that the frequency is variable.

Then we show the effect of change in amplitude of the message signal **Am1=9, Am2=5, Am3=1** as shown in Figure below.

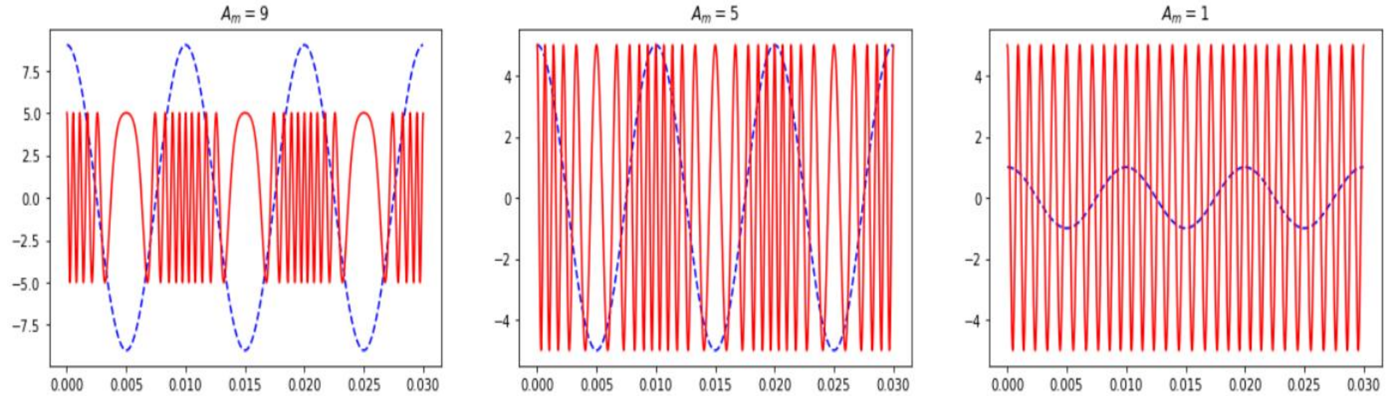


*Figure 2:vary the value of Am and how it affects the FM modulated signal.*

- **Note:** when change the amplitude of the message we observe that the changing of Amp affects the frequency deviation $\Delta f = kf Am$ of FM modulation. So In the first part of the above figure, when Am=9 the frequency deviation is bigger than when Am=5 and Am=1.While the difference in the amplitude between red carve and blue carve is that in the first part Am=9 but Ac=5, in the second part both curves are of the same amplitude Am=5 and Ac=5,but in last part Am=1 is less than Ac=5.

# Exercise :

## When change Am1=3, Am2=7, Am3=2:

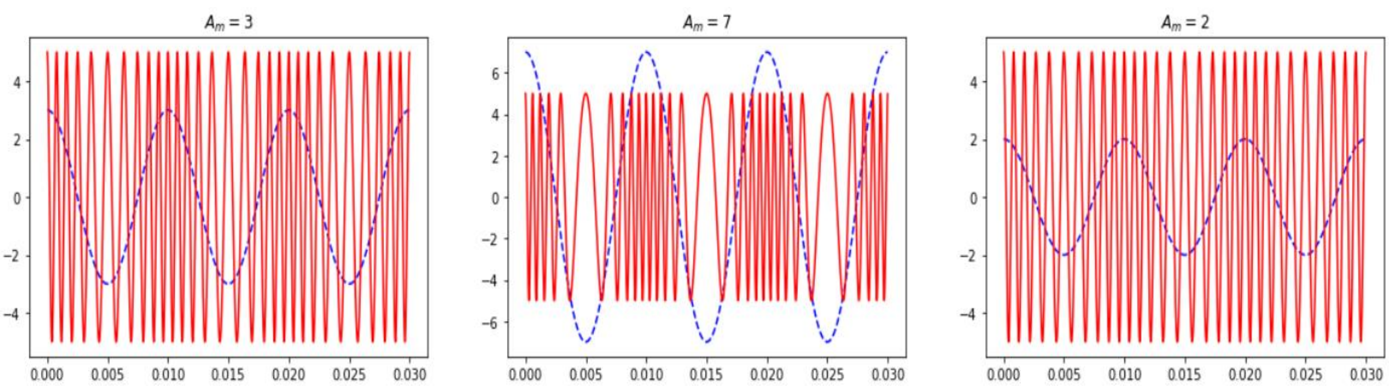


*Figure 3: change the value of Am and show how it affects the FM modulated signal.*

- **Note:** This confirms that when change the amplitude of the message we observe that the changing of Amp affects the frequency deviation $\Delta f = kf Am$ of FM modulation.

Then we show the effect of change in frequency of the message signal **<u>fm1=100 Hz, fm2=200 Hz, fm3=400 Hz</u>** as shown in Figure below.

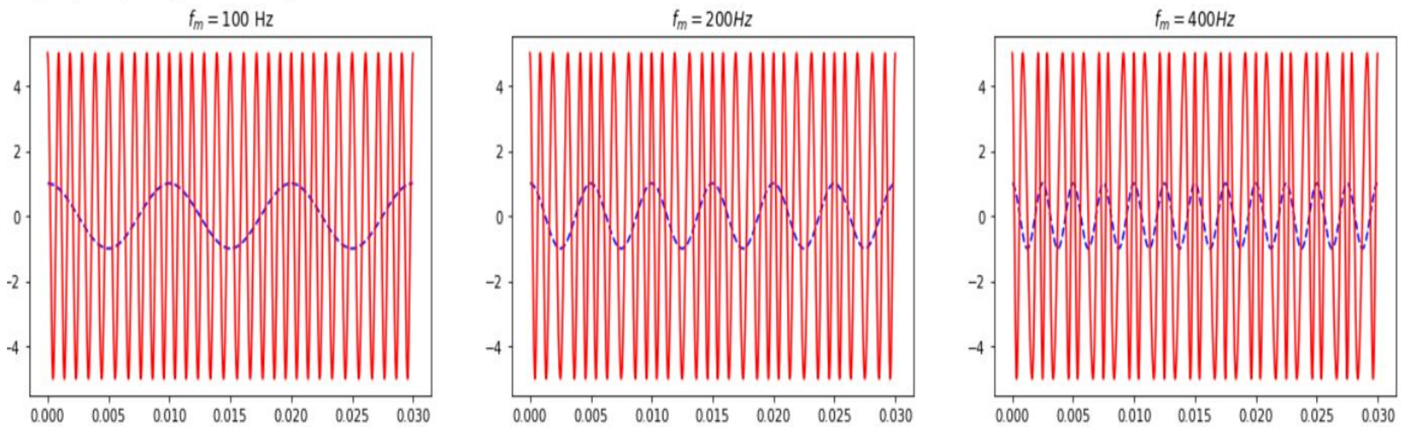


*Figure 4: vary the value of fm and how it affects the FM modulated signal*

- **<u>Note</u>**: we show that Changing in massage frequency didn't affect in frequency deviation $\Delta f = kf Am$, but it affects the number of cycles in the message signal.

# <u>Exercise</u>

## <u>When change fm1=3, fm2=7, fm3=2:</u>

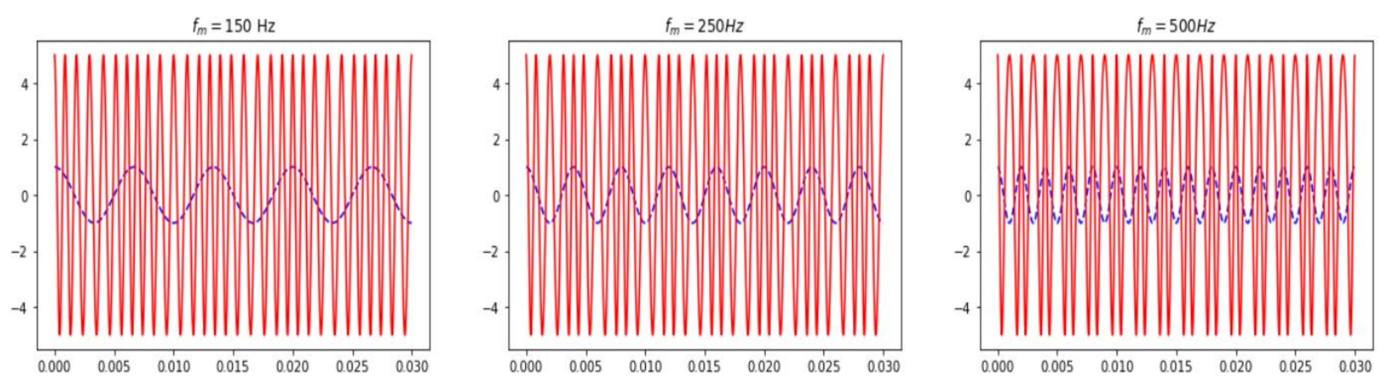


*Figure 5: change the value of fm and show how it affects the FM modulated signal.*

- **<u>Note</u>**: the effect of changing frequency almost affects in band width of the massage signal but we cannot be sure of that in time domain so let us take a look on frequency domain. Also affects in number of cycle in the massage signal.

## 2.2 FM in the Frequency Domain:

In this section we aim to plot the same message of Am=1 and fm=100Hz, the carrier with Ac=5 and fc=1000 kHz and the modulated signal in frequency domain.

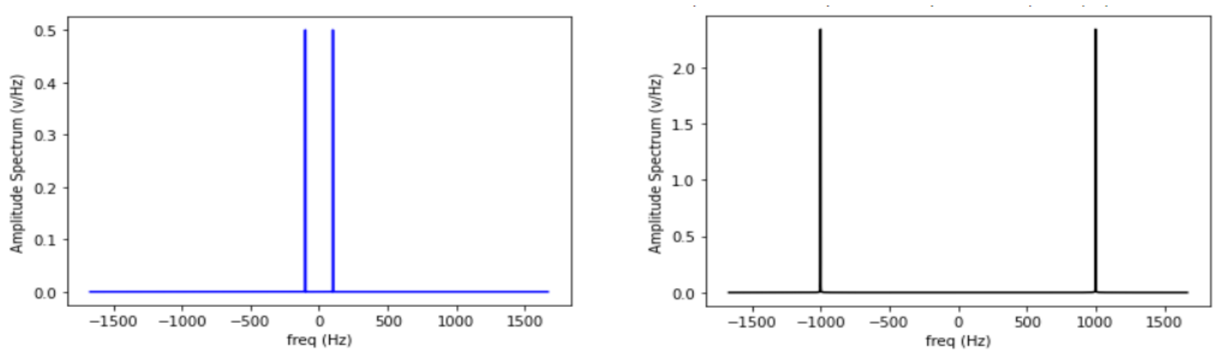


*Figure 6: m(t) and c(t) in frequency domain*

- **Note**: The message signal in part one of above figure show that the sinusoidal wave has two pulses on -100 , 100 with half amplitude of the sinusoidal =0.5.

  The carrier signal in part2 of above figure show that the sinusoidal wave has two pulses on -1000 , 1000 with half amplitude of the sinusoidal =2.5.

  The modulated signal shown in below figure and we can observe that, the amplitude spectrum of s(t) consists of summation of deltas located at integer multiples of $fm$.

$$S_{FM}(f) = \frac{A_c}{2} \sum_{n=-\infty}^{\infty} J_n(\beta)[\delta(f + (f_c + nf_m)) + \delta(f - (f_c + nf_m))]$$

where Jn(β) is the Bessel function of the first kind of order n.

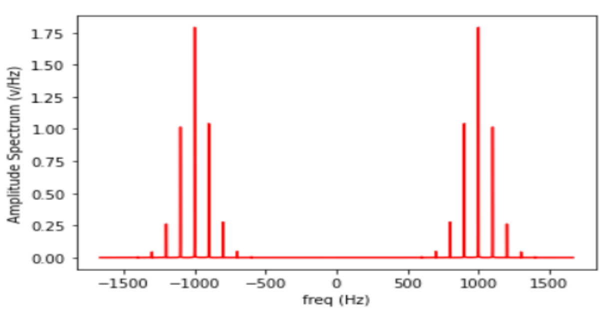


*Figure 7: FM modulated signal s(t).*

- **Note:** the modulation index=1 and BW=400 (its mean not equal 2fm) so it's Wide-band. And we will comment and make some changes in the next section.

## 2.3 FM in Time and Frequency:

In this part we put all the time and frequency together and show the effects of changing any of the signal parameters.

```
Am=1      # amplitude of the message signal
fm=100    # frequency of the message signal
Ac=5      # amplitude of the carrier signal
fc=1000   # frequency of the carrier signal
Kf=100    # frequency-sensitivity factor
```

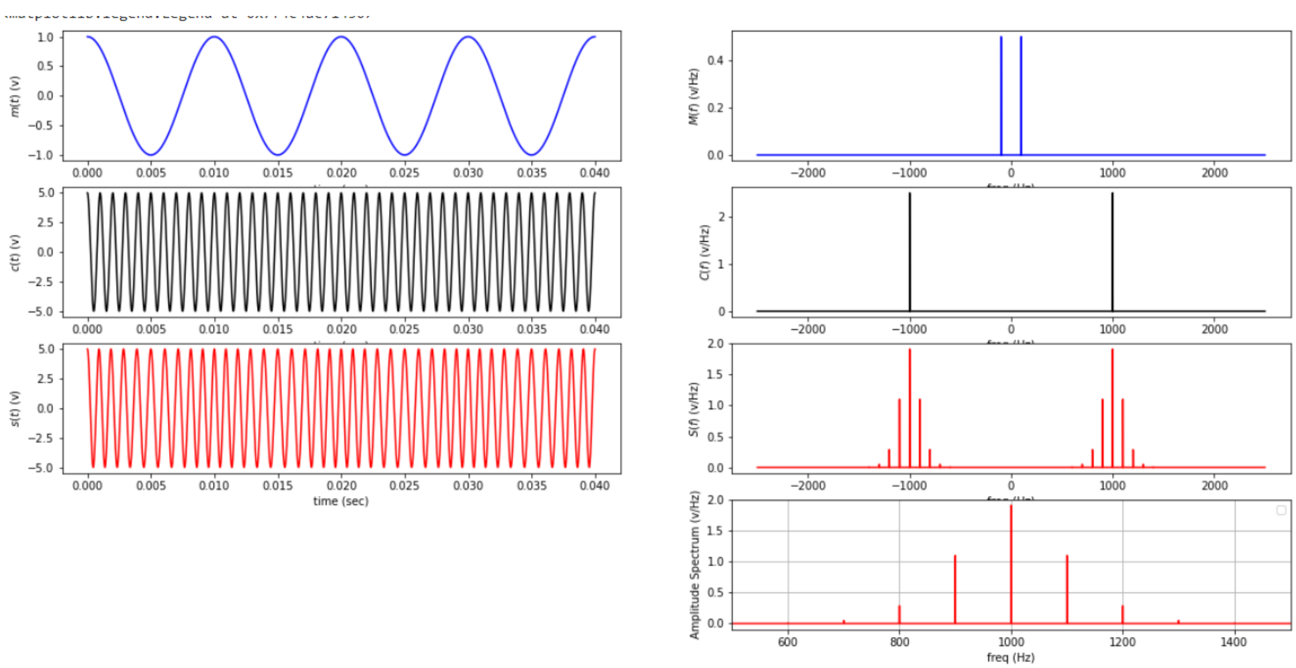


*Figure 8: m(t), c(t) and s(t) for FM signal in time and frequency domain*

- **Note:** We notice 3 signal in the above figure, m(t) -massage- ,c(t) - carrier - each with a different shape, amplitude and frequency. S(t) consists of summation of deltas located at integer multiples of FM.

## Exercise:

### 1- When change Am =3:

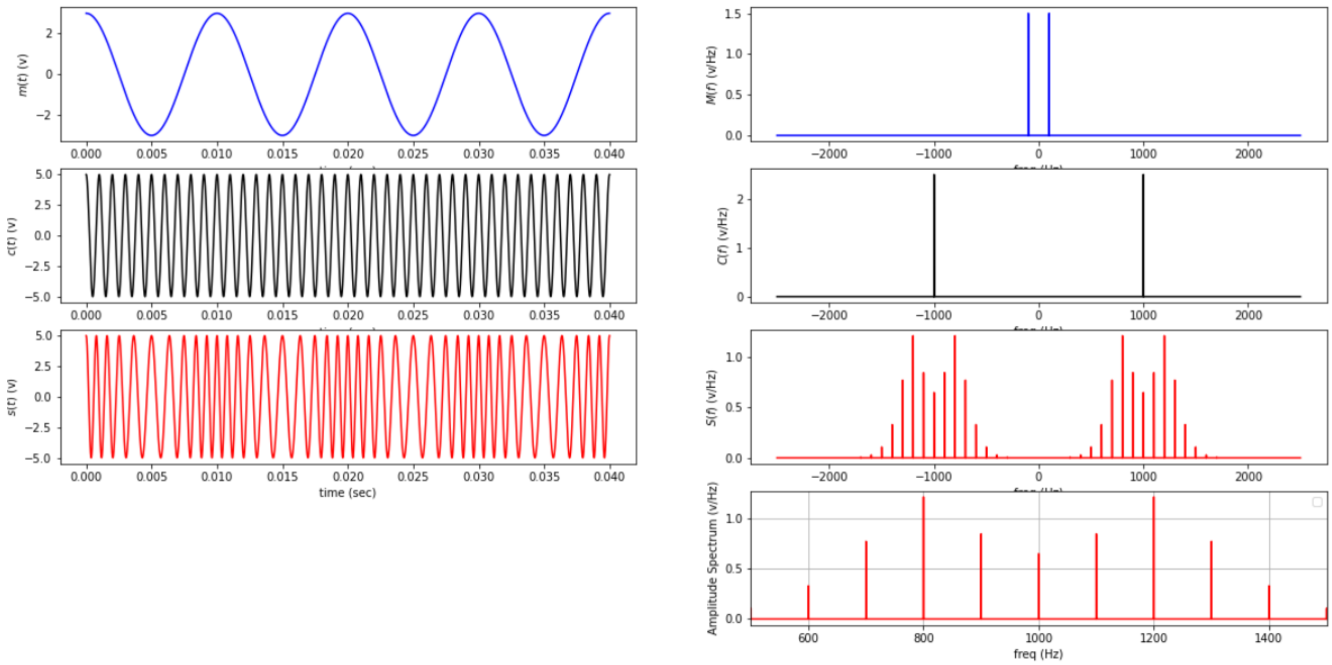


*Figure 9:m(t), c(t) and s(t) for FM signal in time and frequency domain with Am=3*

- **Note**: When Am increased/decreased:
  1- The peak of the massage change (Am) in time domain, (Am/2) in frequency domain.
  2- The carrier envelop and frequency were not affected.
  3- Effect on modulation index increase if Am increase or decrease if Am decrees because of B=(kf.Am)/fm.
  4- The FM modulation signals envelope amplitude doesn't affect, but when change Am the frequency variation change. So when we increase the value of Am, we notice that in a certain period the signal expands a little (frequency variation increase), but after that it returns narrow, but when the value of Am is decrees, we cannot notice this matter clearly (frequency variation decrease). While in frequency domain the amplitude of frequency change by $(Ac/2).J_n(B)$,but its position is not affected.
  5- The BW of signal change because B change(B=3,Wide-band), so its change by (2(B+1)fm).

## 2- When change fm=150 Hz:

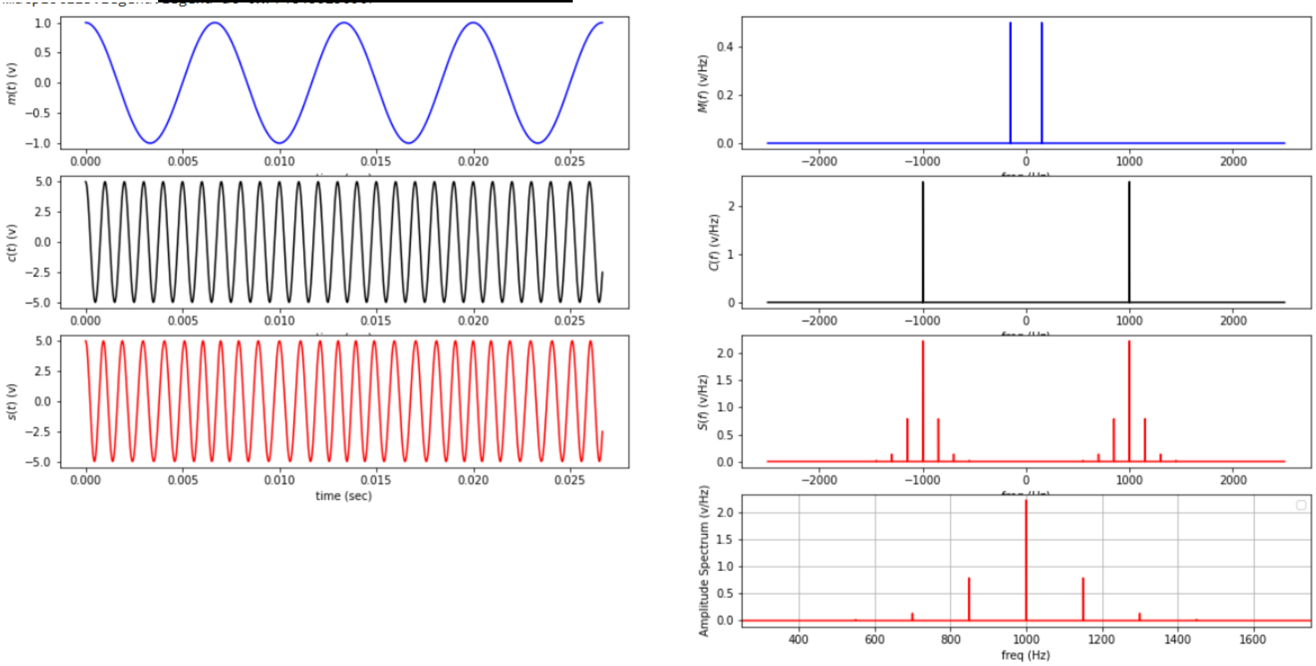


*Figure 10:m(t), c(t) and s(t) for FM signal in time and frequency domain with fm=150 Hz*

- **Note:** When fm was decreased/increased:
  1- The envelop, frequency and BW for massage signal were affected.
  2- The envelop and frequency for carrier signal were not affected.
  3- Effect on modulation index increases if fm decreases or decreases if fm increases because of B=(kf.Am)/fm.
  4- The FM modulation signals envelope amplitude doesn't affect and the frequency variation doesn't affect. While in frequency domain the amplitude of frequency change by (Ac/2).$J_n$(B),and its position change by (fc-nfm , fc+nfm) and (-fc-nfm , -fc+nfm).
  5- The BW of signal change because B change (B=0.7,Narrow-band), so its change by (2fm).

### 3- When change Ac=2:

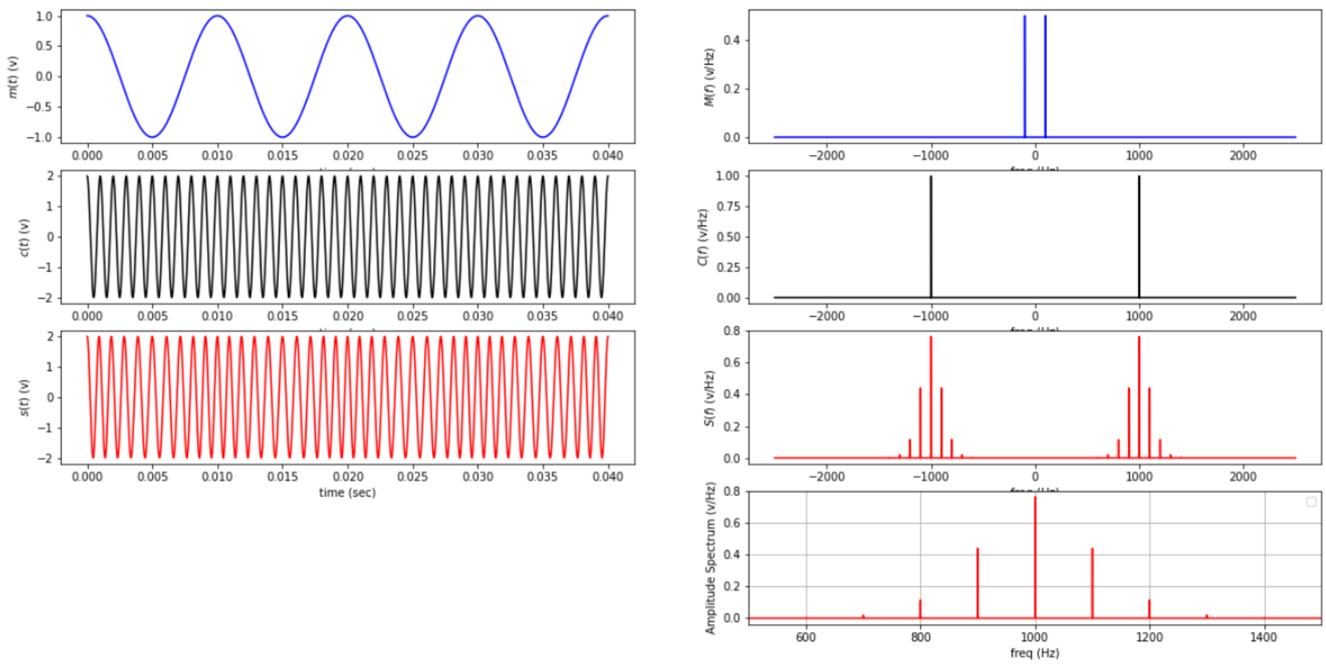


*Figure 11:m(t), c(t) and s(t) for FM signal in time and frequency domain with Ac=2*

- **Note:** When Ac increased/decreased:
  1- The massage envelop and frequency were not affected
  2- The peak of the carrier change (Ac) in time domain, (Ac/2) in frequency domain.
  3- Doesn't Effect on modulation index(B).
  4- The FM modulation signals envelope amplitude affect and change as same as change in carrier signal. While in frequency domain the amplitude of frequency change by (Ac/2).$J_n$(B), but its position is not affected.
  5- When change Ac The BW of signal doesn't change.

## 4- When change fc=1500 Hz:

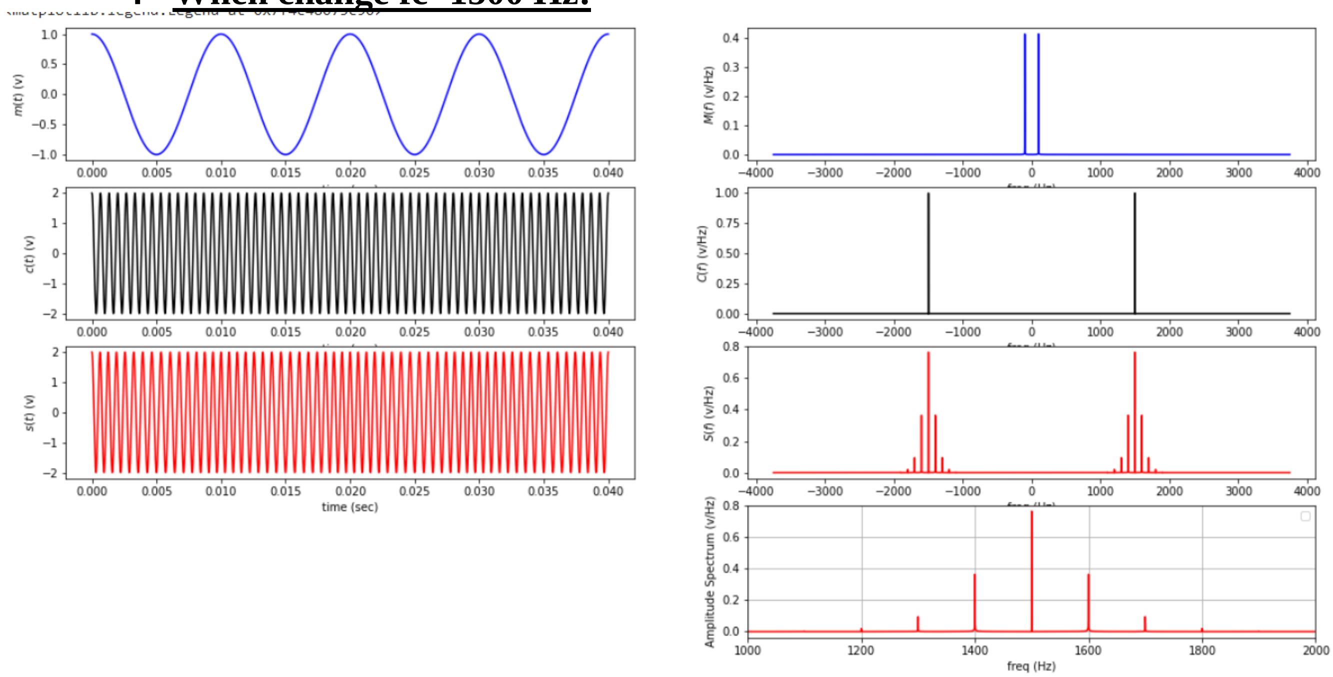


*Figure 12:m(t), c(t) and s(t) for FM signal in time and frequency domain with fc=1500 Hz*

- **<u>Note</u>**: When fc was decreased/increased:
  1- The envelop and frequency for massage signal were not affected.
  2- The envelop and frequency for carrier signal were affected.
  3- Doesn't Effect on modulation index(B).
  4- The FM modulation signals envelope amplitude affect and change as same as change in carrier signal. While in frequency domain the amplitude of frequency doesn't change, but its position change by (fc-nfm , fc+nfm) and (-fc-nfm , -fc+nfm).
  5- When change fc The BW of signal doesn't change.

## 2.4 Effect of The Frequency Modulation Index β on the Modulated Signal Bandwidth:

$$\beta = \frac{\Delta f}{f_m} = \frac{k_f A_m}{f_m}$$

where:

β: (kf.Am)/fm : the FM modulation index.
kf: the frequency-sensitivity factor.
Am: Amplitude of massage signal.
fm: frequency of massage signal.

- **Note:** if $\beta$ is less or equal 1 then it's narrow-band, but if not then you will see wide-band

### 1- **<u>Narrow-Band (β=0.1):</u>**

First of all we consider message signal with Am=1 and fm=100Hz, carrier signal with Ac=1 and fc=1000 Hz and Kf=10 to get a narrow-band modulated signal with $\beta$=0.1 so it's << 1 and plot all the message, carrier and modulated signal in below figure .

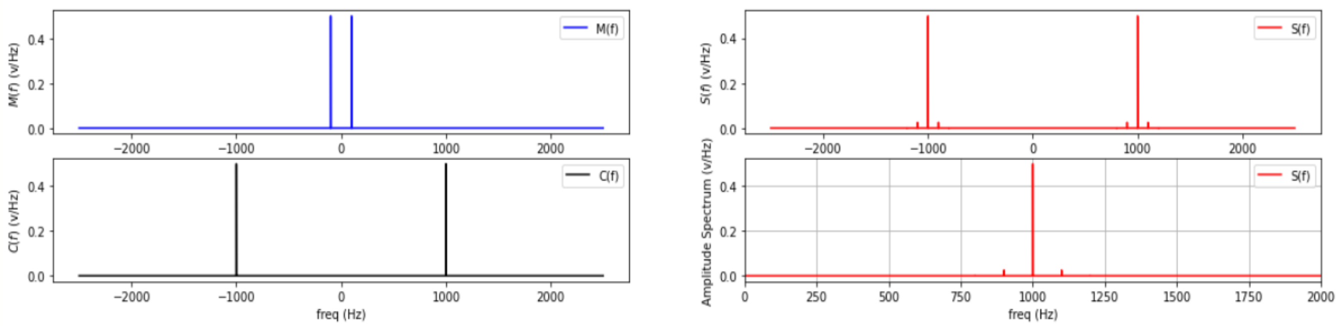


*Figure 13:Effect of The Frequency Modulation Index β on the Modulated Signal Bandwidth when β=0.1*

- **<u>Note</u>**: As we see in above figure the bandwidth of an FM signal has a more complicated dependency than in the AM case. In FM both the modulation index and the modulating frequency affect the bandwidth according to this equation: BW=2($\beta$+1)Fm so it's small because it's narrow band "$\beta$ <<1" , while the band-width of AM signals depend only on the maximum modulation frequency.

## 2- Wide-band ($\beta$=5):

Let's change some values that affect the modulation index to see what will happen, so we set message signal with Am=25 and fm=500Hz, carrier signal with Ac=5 and fc=5000 Hz and Kf=100 to get a wide-band modulated signal with $\beta$=5 so it's >> 1 , and plot all the message, carrier and modulated signal in below figure.

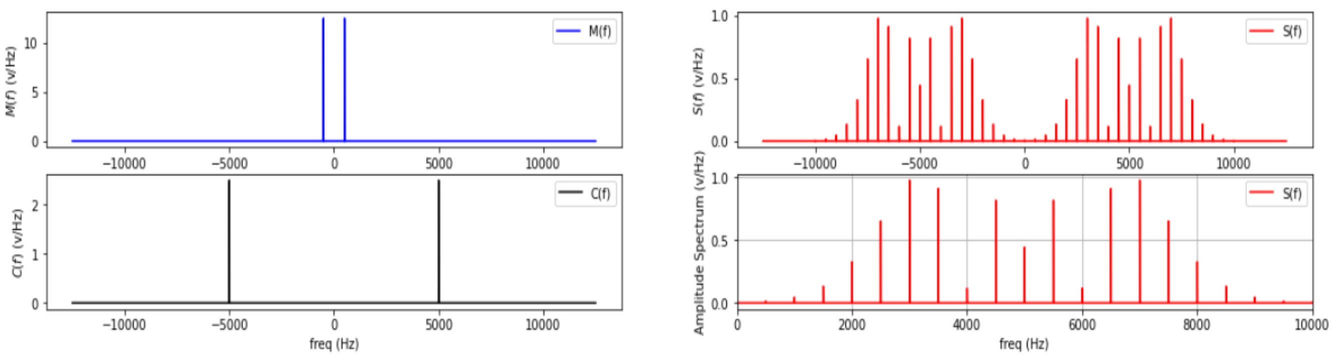


*Figure 14:Effect of The Frequency Modulation Index β on the Modulated Signal Bandwidth when β=5*

- **Note**: We notes from the spectrum of modulated signals that it's wide-band, because the modulation index is >> 1 and BW=2($\beta$+1).fm .

# Exercise:

## 1- When frequency of the modulating wave and kf are fixed, but its amplitude is varied.(Am=30):

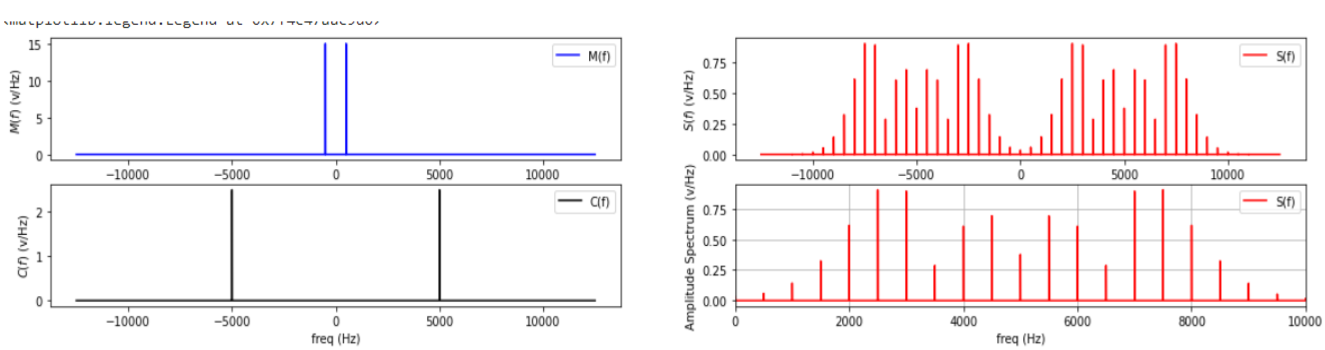


*Figure 15:Effect of The Frequency Modulation Index β on the Modulated Signal Bandwidth when Am=30*

- **Note:** if the amplitude(Am) increase then the modulation index will increase too and vice versa.
- in this case $\boldsymbol{\beta}=\mathbf{6}$, so its **wide-band** because $\beta$>>1.

2- **<u>when the amplitude of the modulating wave and kf are fixed, but its frequency is varied(fm=800 Hz):</u>**

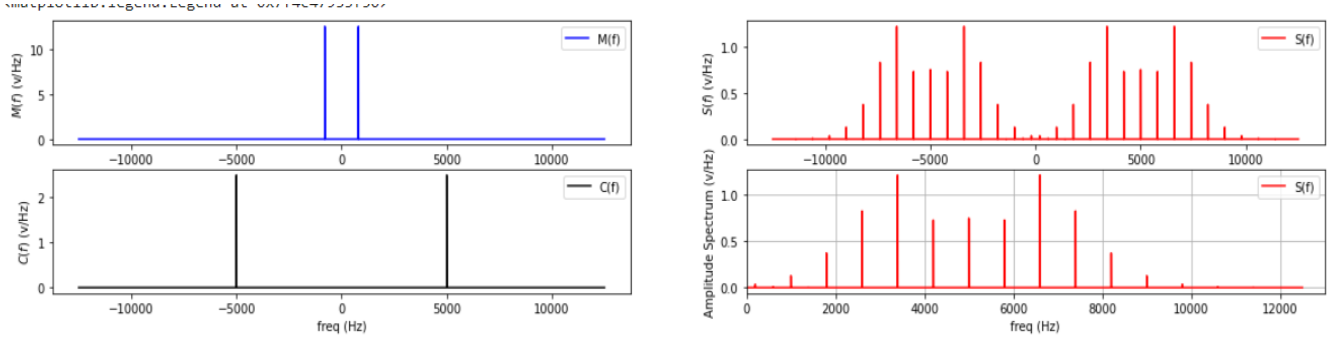


*Figure 16:Effect of The Frequency Modulation Index β on the Modulated Signal Bandwidth when fm=800 Hz*

- **<u>Note:</u>** if the frequency increase then the modulation index will decrease and vice versa.

- in this case $\boldsymbol{\beta}$= **3.125**, so its **wide-band** because $\beta >> 1$.

3- **<u>we fixed the amplitude and frequency of the modulating wave while changing kf (kf=200):</u>**

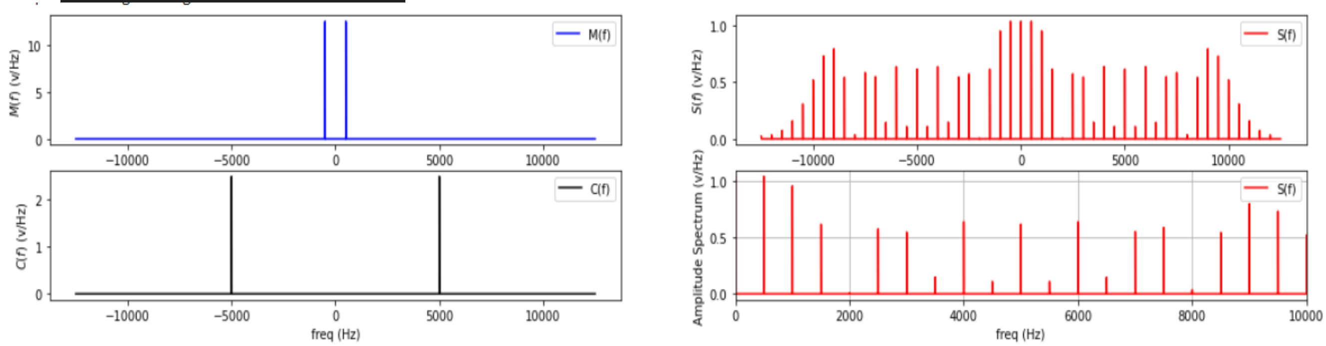


*Figure 17:Effect of The Frequency Modulation Index β on the Modulated Signal Bandwidth when kf=200*

- **<u>Note</u>**: if the $kf$ increase then the modulation index will increase too and vice versa.
- in this case $\boldsymbol{\beta}$= **10**, so its **wide-band** because $\beta >> 1$.

## 2.5 FM modulation zero-crossing:

The amplitude spectrum of s(t) consists of a summation of impulses located at integer multiples of $fm$. The amplitudes of these impulses depend on the values of $\beta$ and $Jn(\beta)$. To investigate this, let us determine the values of $\beta$ which makes the amplitude of the $\delta(fc)$ of $s(f)$ equals zero. Based on the $Jn(\beta)$ is the Bessel function of the first kind of order n, the first null (zero) of $J0(\beta)$ occurs at $\beta$=2.41, the message, carrier and modulated signal shown in figure below.

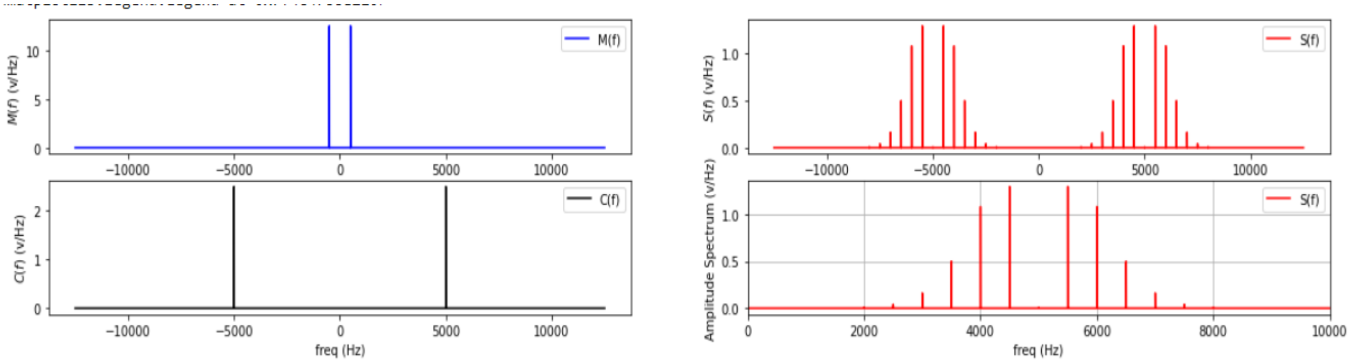


*Figure 18:FM modulation zero-crossing*

- **Note**: As observed from the $s(f)$ plot in above figure, we obtained a zero at $fc$=5000 $Hz$. The frequency-sensitivity in this case is 48.2 Hz/Volt.

# Exercise:

**1- Determine another two values of β at which the impulse at fc is zero. Plot the curves in each case and determine the frequency sensitivity.**

**A- The first value which make it zero : 5.52**

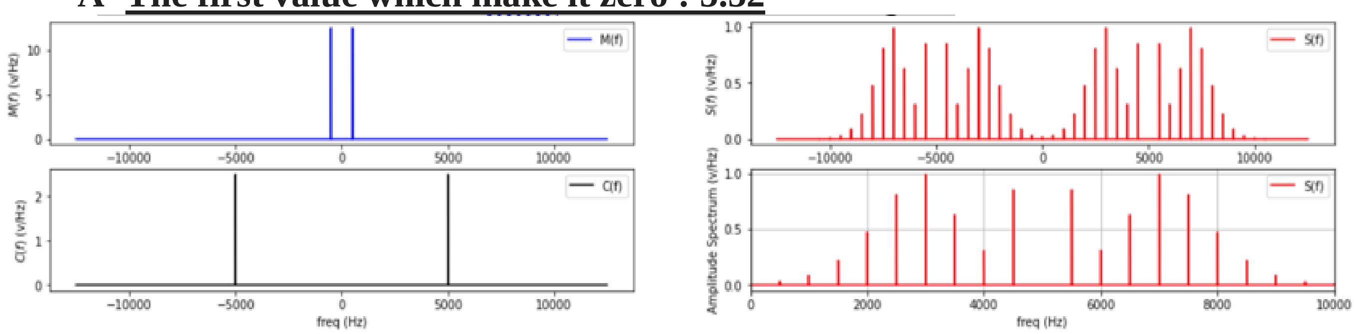


*Figure 19:FM modulation when zero-crossing=5.52*

- **Note:** As observed from the $s(f)$ plot in above figure, we obtained a zero at $fc$=5$KHz$. The frequency-sensitivity in this case is 110.4 Hz/Volt.

### B- The second value which make it zero = 8.65

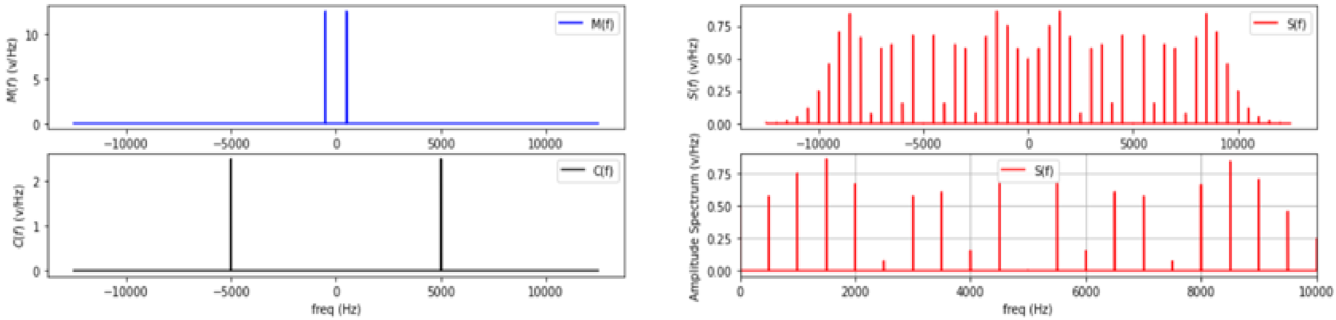


*Figure 20:FM modulation when zero-crossing=8.65*

- **Note:** As observed from the $s(f)$ plot in Fig5.3, we obtained a zero at $fc$=5$KHz$. The frequency-sensitivity in this case is 173 Hz/Volt.

## 2- Plot the curves and determine the frequency sensitivity at which the impulse at $fc$ is zero (first zero-crossing at $\beta$=2.41) for each of the following cases:

### A- Am=15,fm=250 Hz:

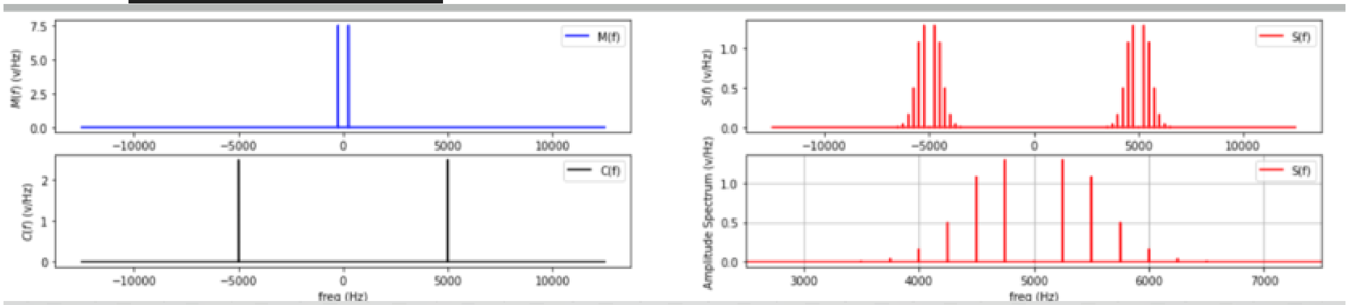


*Figure 21:M(f) and C(f) when Am=15,fm=250 Hz*

- **Note:** the frequency sensitivity = 40.16 Hz/Volt.

### B- Am=15,fm=500 Hz:

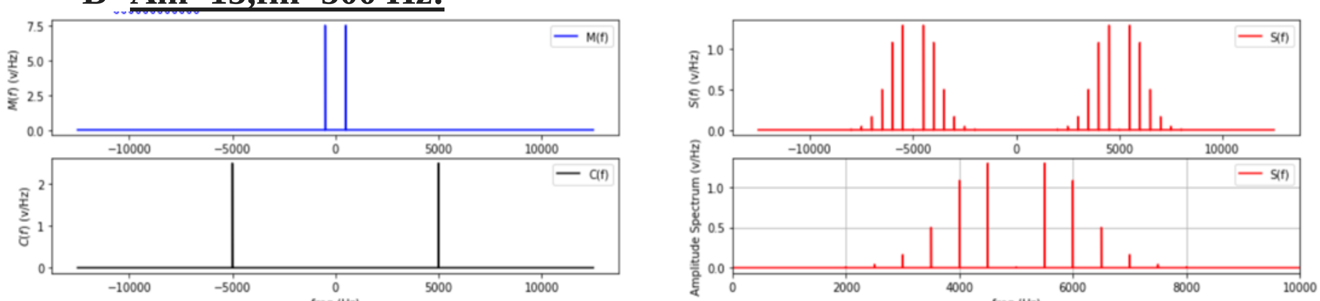


*Figure 22M(f) and C(f) when Am=15,fm=500 Hz*

- **Note:** the frequency sensitivity = 80.33 Hz/Volt.

## C- Am=15,fm=750Hz:

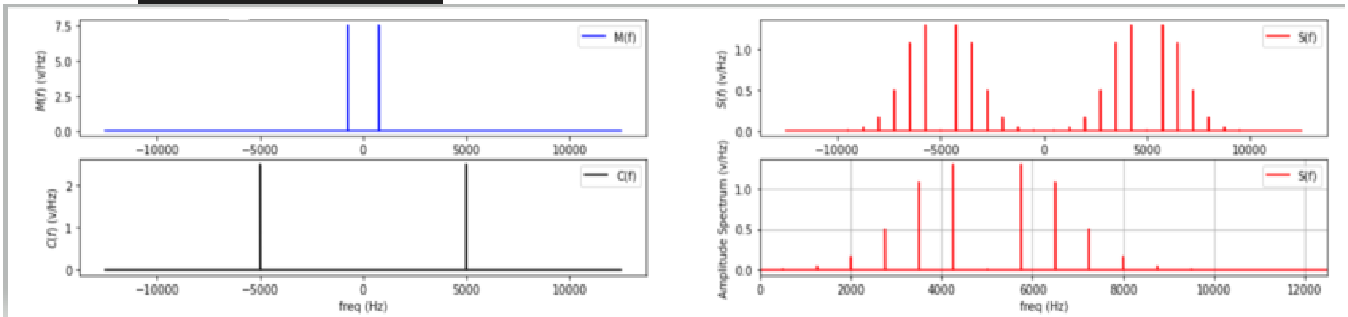


*Figure 23:M(f) and C(f) when Am=15,fm=750 Hz*

- **Note:** the frequency sensitivity = 120.5 Hz/Volt.

## D- Am=10,fm=500Hz:

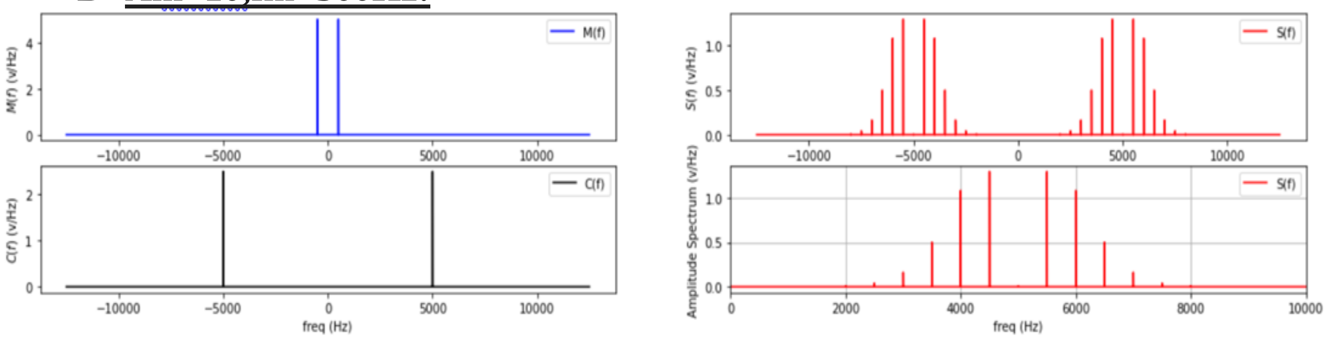


*Figure 24:M(f) and C(f) when Am=10,fm=500 Hz*

- **Note:** the frequency sensitivity = 120.5 Hz/Volt.

## E- Am=20,fm=500 Hz:

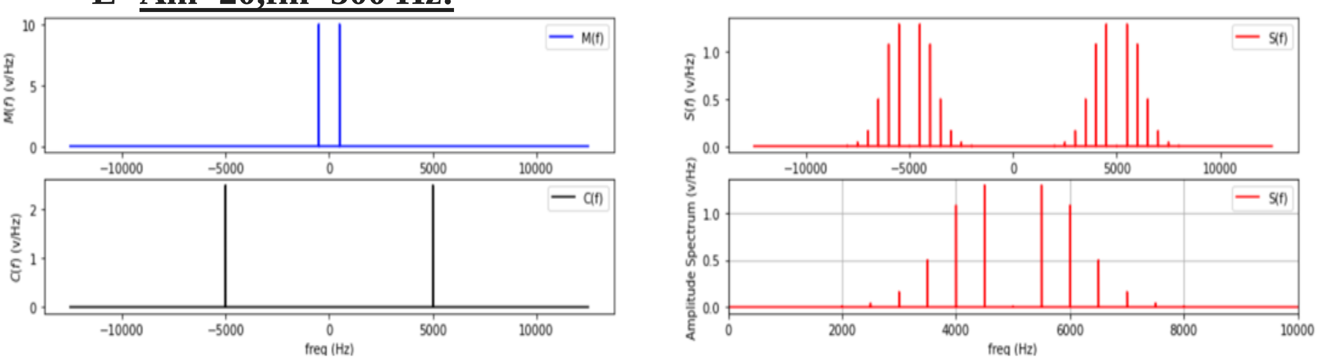


*Figure 25:M(f) and C(f) when Am=20,fm=500 Hz*

- **Note:** the frequency sensitivity = 60.25 Hz/Volt.

## F- Am=30,fm=500 Hz:

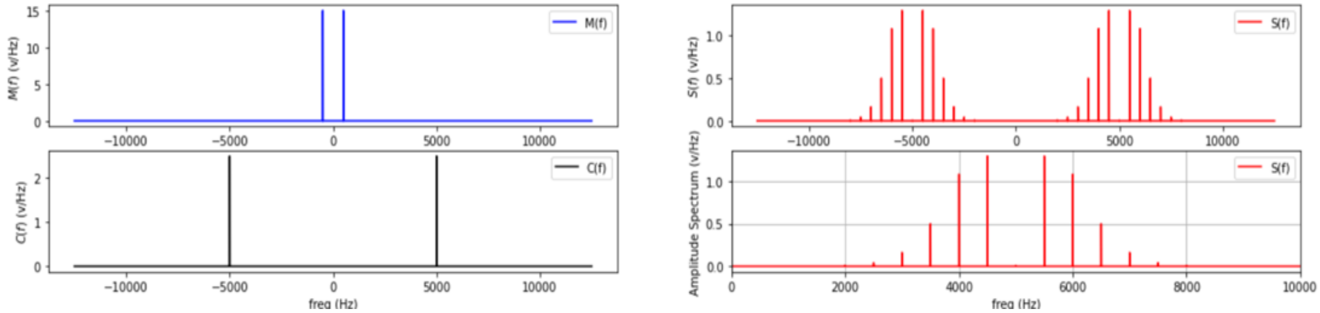


*Figure 26:M(f) and C(f) when Am=30,fm=500 Hz*

- **Note:** the frequency sensitivity = 40.166 Hz/Volt.

## 2.6 FM Demodulation:

In this section we use the discriminator to demodulate the FM signal, The discriminator used here is a differentiator followed by an envelope detector. The output of the differentiator is:

$$\frac{ds}{dt} = -2\pi A_c \left[f_c + k_f Am \cos(2\pi f_m t)\right] \sin(2\pi f_c t + \beta \sin(2\pi f_m t))$$

the modulating signal Am=5 and fm=150 Hz modulated over carrier Ac=5 and fc=1500 Hz .

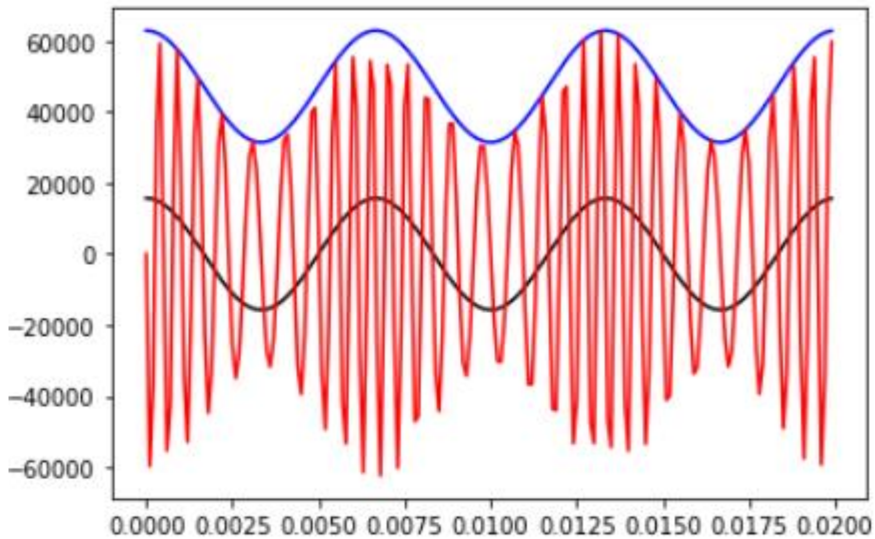


*Figure 27:FM Demodulation*

- **Note**: If fc is large enough (fc>10*fm) which leads to that the carrier is not over modulated, then we can recover the message signal. In this case our modulation is not over modulated so we can recover the message signal from modulated signal with an envelope detector, above figure shows the modulated signal (Red color) and the envelop detector (Blue color) and the restored signal (Black color), as we can see we could recover the message signal because that the carrier frequency is large enough such that the carrier is not over modulated.

## 2.7 FM of Square Wave:

First of all we plot the FM signal as shown in figure below when the modulating signal is a square wave with Am=4 , fm=100 Hz, duty cycle=0.2 and the carrier with Ac=4 , fc=1000 Hz .

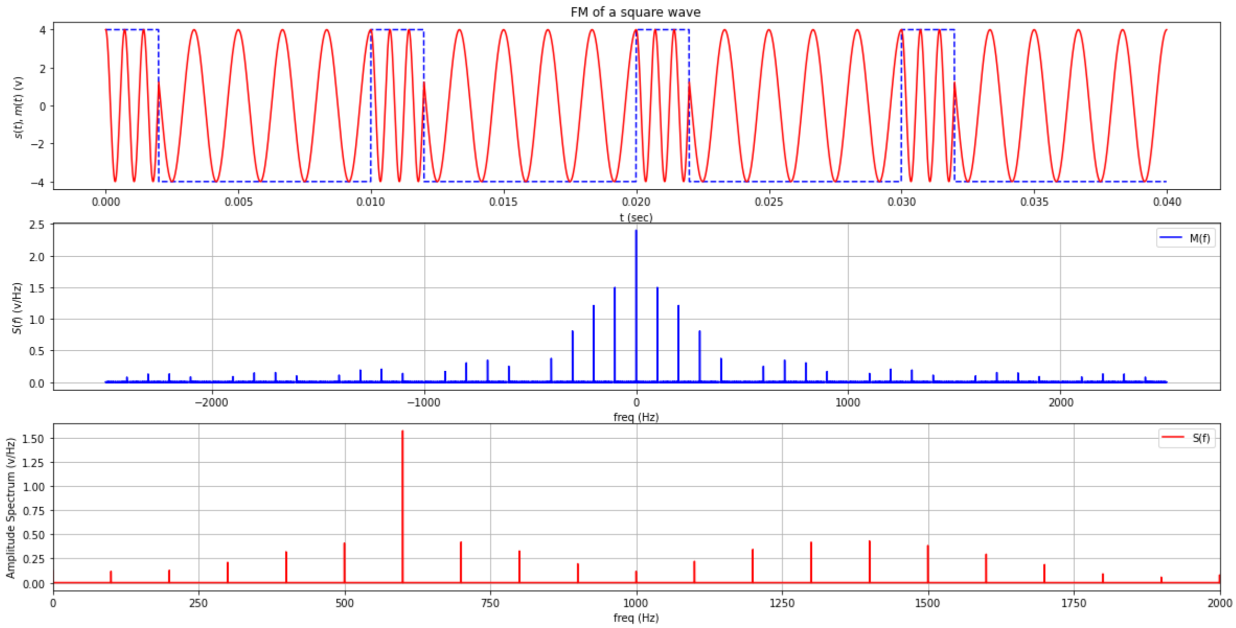


*Figure 28:FM of Square Wave*

- **Note**: As shown in Fig7.1, the resulting carrier signal changes between two distinct frequency states. Each frequency state represents the high and low state of the message signal, when the input is high then the frequency is high and vice versa.

# Exercise:

## 1- When change Am=9:

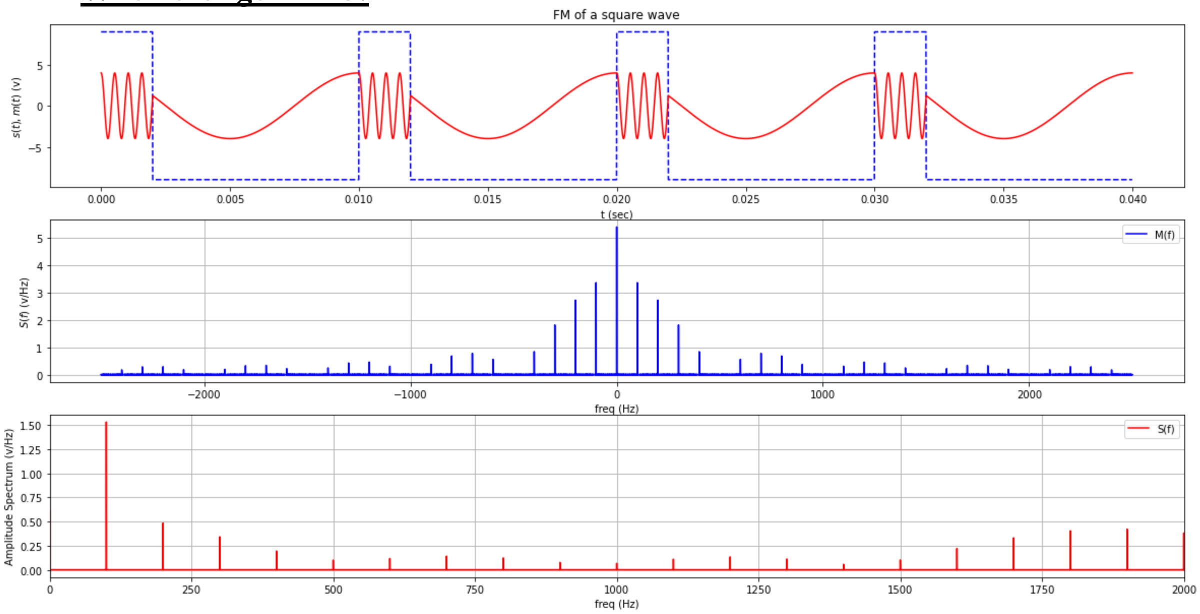


*Figure 29:FM of Square Wave when Am=9*

- **Note:** we notes when increase the amplitude for massage signal the frequency deviation will increase too according to this linear equation: ΔF=Kf.Am, for the delta will increase as shown in figure above

## 2- When change du(duty cycle)=0.8:

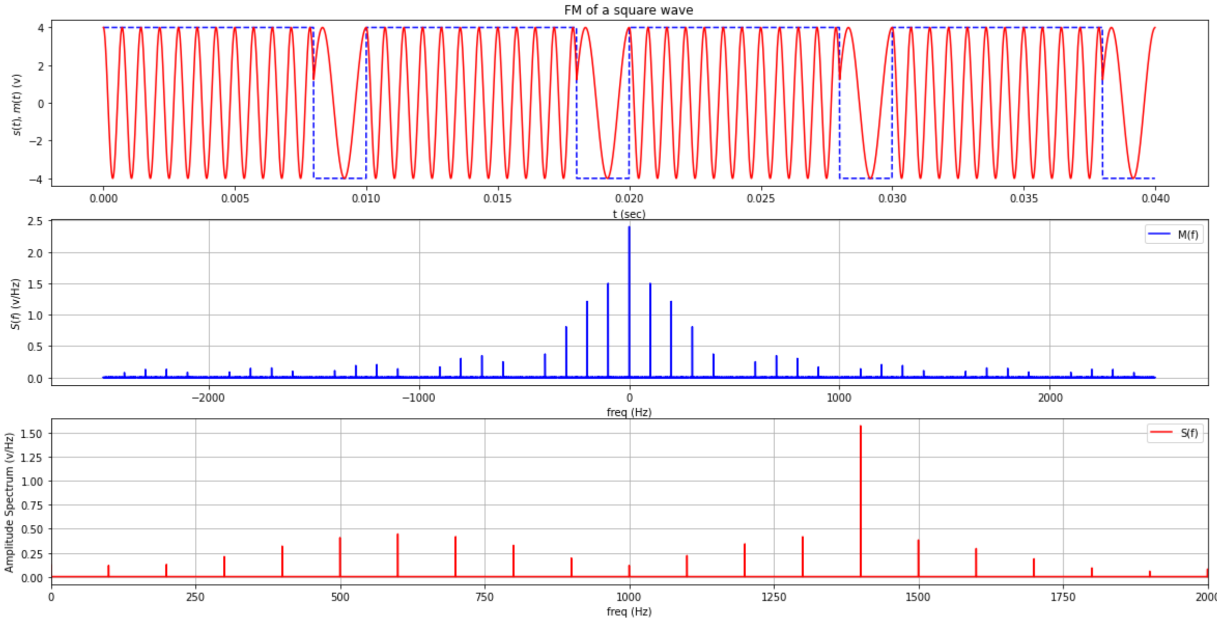


*Figure 30:FM of Square Wave when du=0.8*

- **Note:** we notes If we vary the duty cycle the range of the on and off states will vary too according to this equation: duty cycle= $\frac{on\ duration}{on\ duration+off\ duration}$ , if we increase the duty cycle then the on range will increase this leads to increase the range that high frequency appears.

## 2.8 Phase Modulation:

The phase modulated signal is given by: $sPM(t)=Ac\cos(2\pi fct+kpm(t))$, when the message $m(t)=Amcos(2\pi fmt)$. Then the PM modulated signal is $s(t)=Ac\cos(2\pi fct+kpAm\cos(2\pi fmt))$.

The figure shows us both of phase and frequency modulation when Am=5, fm=100 Hz, Ac=5, fc=1000 Hz.

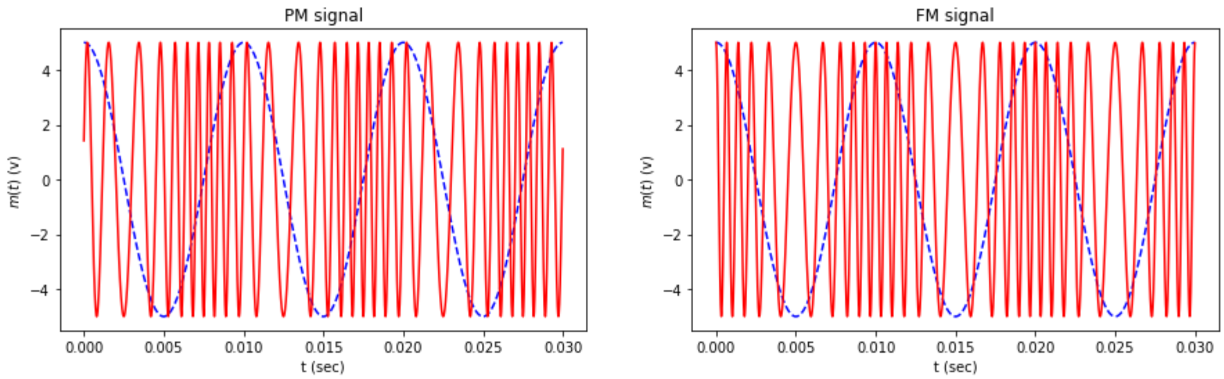


*Figure 31:m(t) for PM signal and m(t) for FM signal*

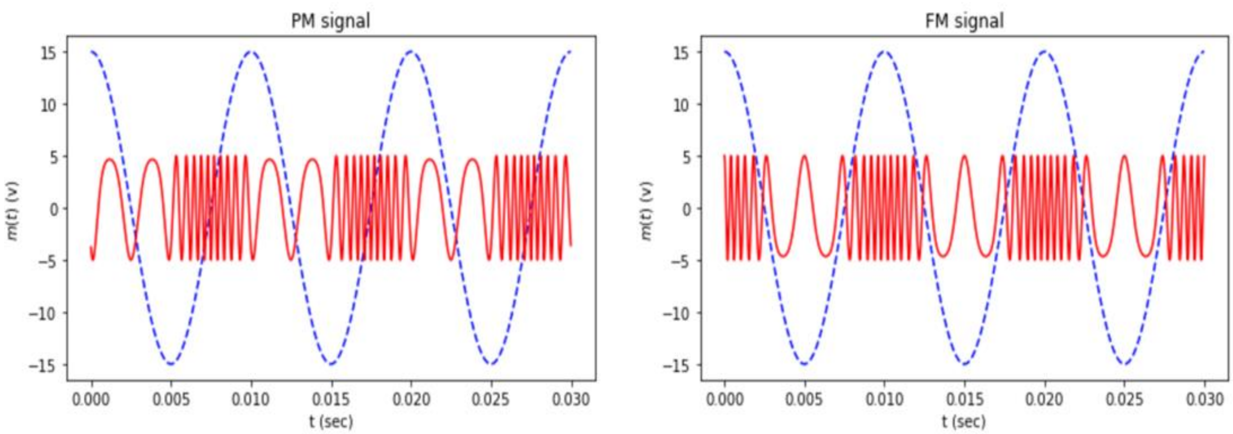


*Figure 32:m(t) for PM signal and m(t) for FM signal when Am=15*

- **Note: When we increase the Am to Am=15** the frequency deviation will increase too based on this linear equation: ΔF=Kf.Am, we can see it's effect in figure 31 as how the frequency of modulated signal will be varied, the difference will be bigger than figure 32.

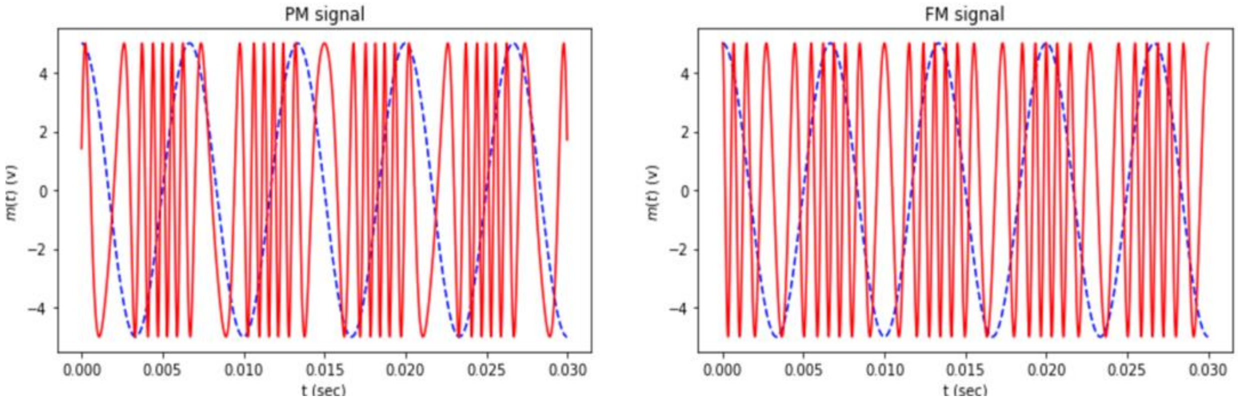

*Figure 33:m(t) for PM signal and m(t) for FM signal when fm=130 Hz*

- **Note: When we increase fm to fm=130 Hz** the time when the PM signal have high frequency. will increase too, while in FM the changing of Fm effects the frequency. of the message which changes its period and that effect the modulated signal, in both cases the wave's frequency. and phase vary from moment to moment as shown in figure below.

Phase modulation is indirect method to produce Frequency modulation. The changing in phase leads to change in freq. of the modulated signal and vice versa, this leads us to conclude that there is a relation between them but this relation is not linear.

we can compute $m1(t)=dm(t)/dt$ and then apply $m1(t)$ to the FM modulator, from this we can compute and plot the PM modulation of m(t), we can see of applying PM of m(t) and FM of m1(t) which is the same to m'(t).

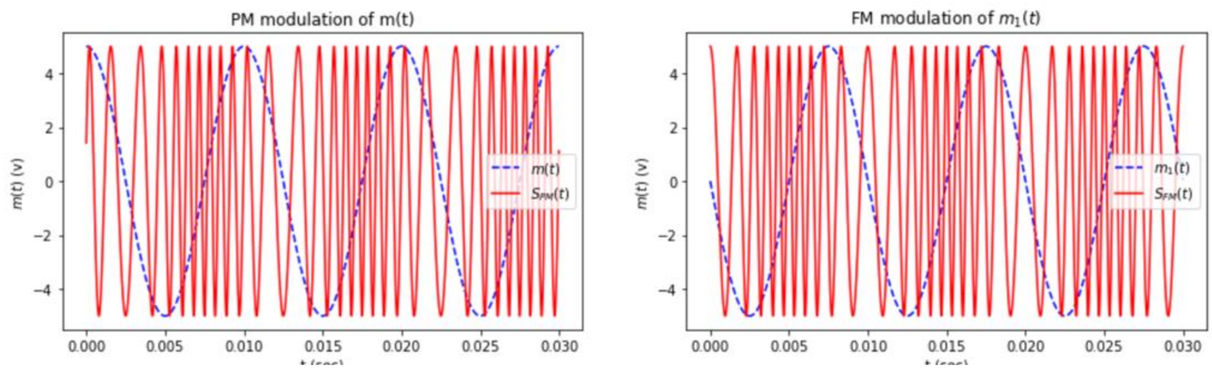


*Figure 34: PM modulation and FM modulation*

- **<u>Note</u>**: As we can see in above figure the both PM and FM have the same wave but phase shifted. Let us work in some theory to know how this work.

Mathematically, The FM modulated signal of a message $m1(t)$ can be expressed as: $\boldsymbol{sFM(t)=Ac\cos(2\pi fct+kf\int t0m1(\tau)d\tau)}$. And thus if $\boldsymbol{m1(t)=dm(t)dt}$ , then $\boldsymbol{sPM(t)=sFM(t)}$. In other words, to compute the Phase modulation of $m(t)$, we can compute $m1(t)=dm(t)dt$ and then apply $m1(t)$ to the FM modulator.

Now let's go ahead and vary the Am to be Am=8 the output shown in figure 35, and then vary the fm to be fm=150Hz the output shown in figure 36.

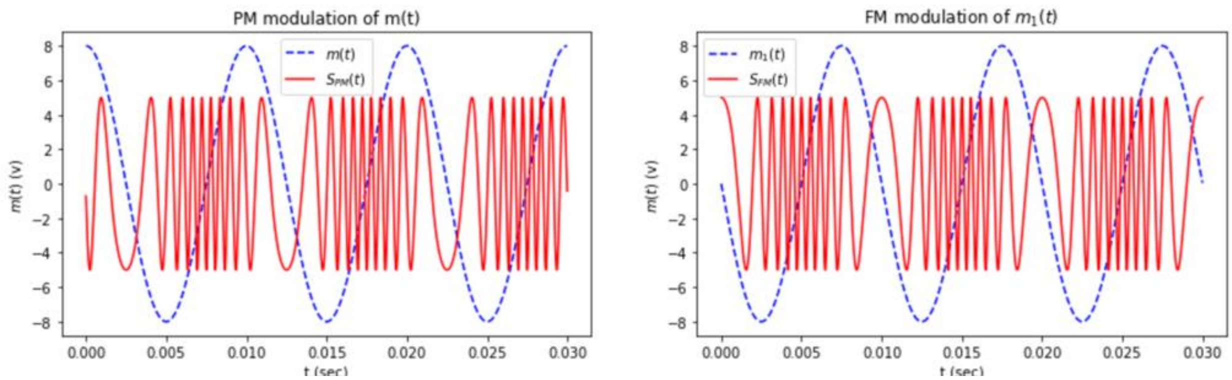


*Figure 35:PM modulation and FM modulation when Am=8*

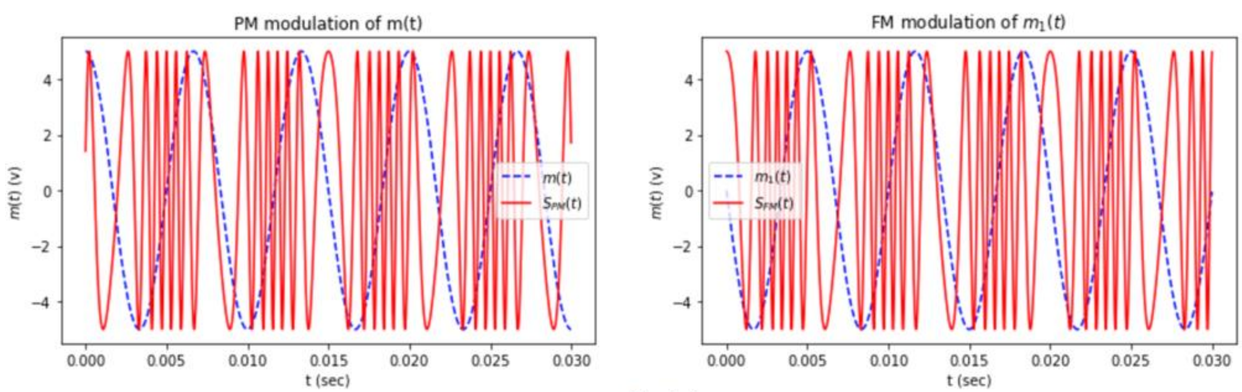


*Figure 36:PM modulation and FM modulation when fm=150 Hz*

- **Note**: As we can see from figure 35 (when we vary the amplitude of the message) and from figure 36 (when we vary the message frequency) if we vary the amplitude or the frequency of the signal the relation between the PM and FM of the modulated signal remains as we mentioned before.

## 3. Conclution:

In conclusion, we were able to understand the Working mechanism of Angular in modulation case and demodulation case. Also, we were able to understand the effect of changing the parameters on the recovered signal. We were able to understand the purpose of using different modulators and demodulators based on the type of the signal. Finally, the experiment ran smoothly using the Colab and our results were logical and convincing.