Term Project - Part I

CIE 337 - University of Science and Technology- Zewail City

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1) Part A: Using MATLAB

In this part, we implemented the FM modulation using a MATLAB Script. Firstly, we generated the triangular message signal, then we integrated the message signal to obtain the phase deviation signal base on the following expression:

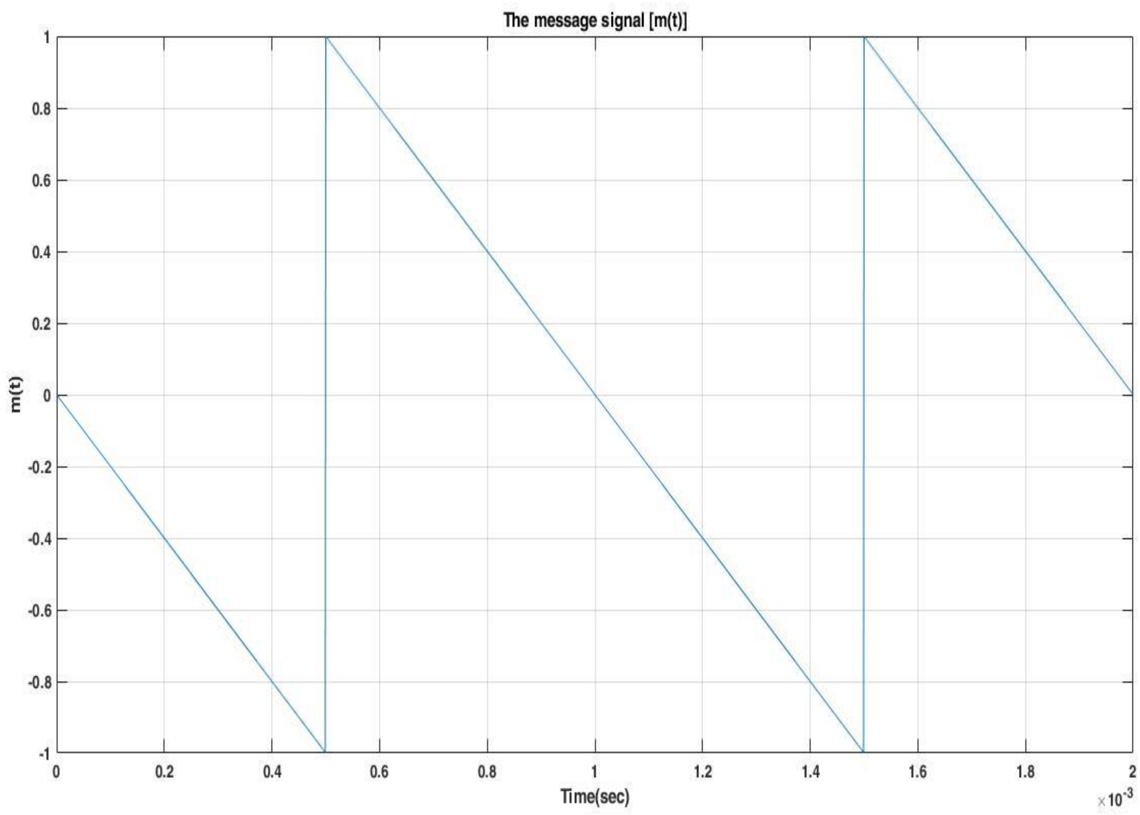
$$\boldsymbol{\Theta(t) = 2\pi\, K_f \int_0^t m(\tau)\, d\tau}$$

Then, we obtained the FM Signal for a carrier sinusoidal signal based on the following expression:

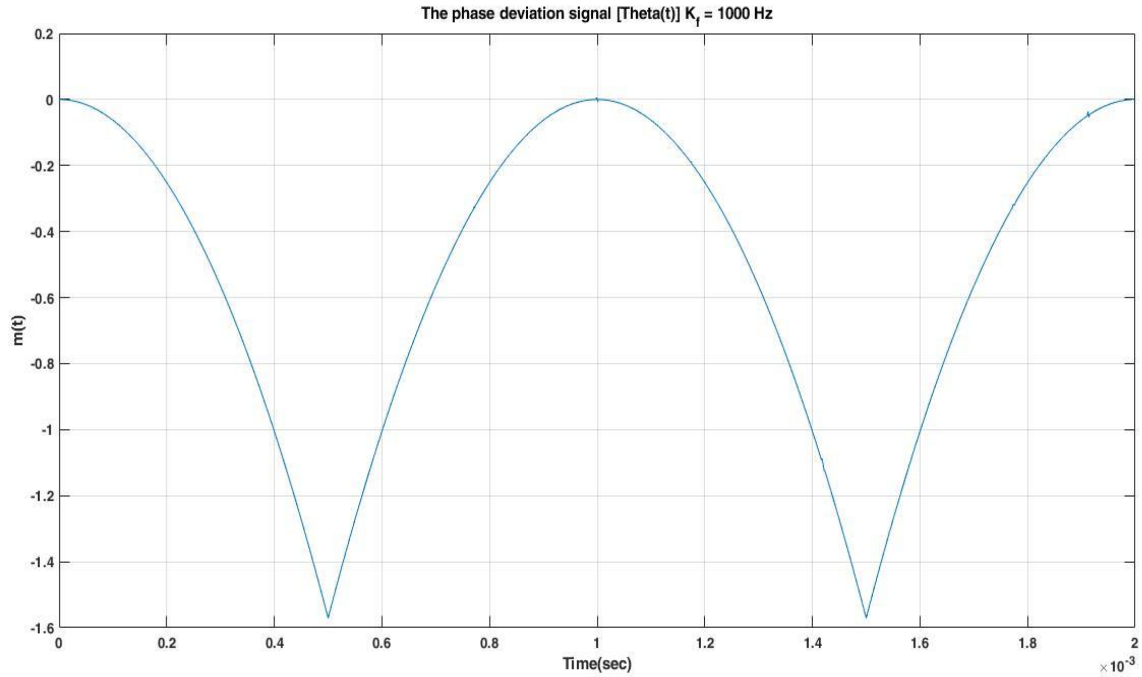
$$\boldsymbol{S_{FM}(\mathrm{t}) = \cos(\omega_c \mathrm{t} + \Theta(t)) = \cos\left(\omega_c \mathrm{t} + 2\pi\, K_f \int_0^t m(\tau)\, d\tau\right)}$$

- **Here are the obtained graphs for the required plots:**

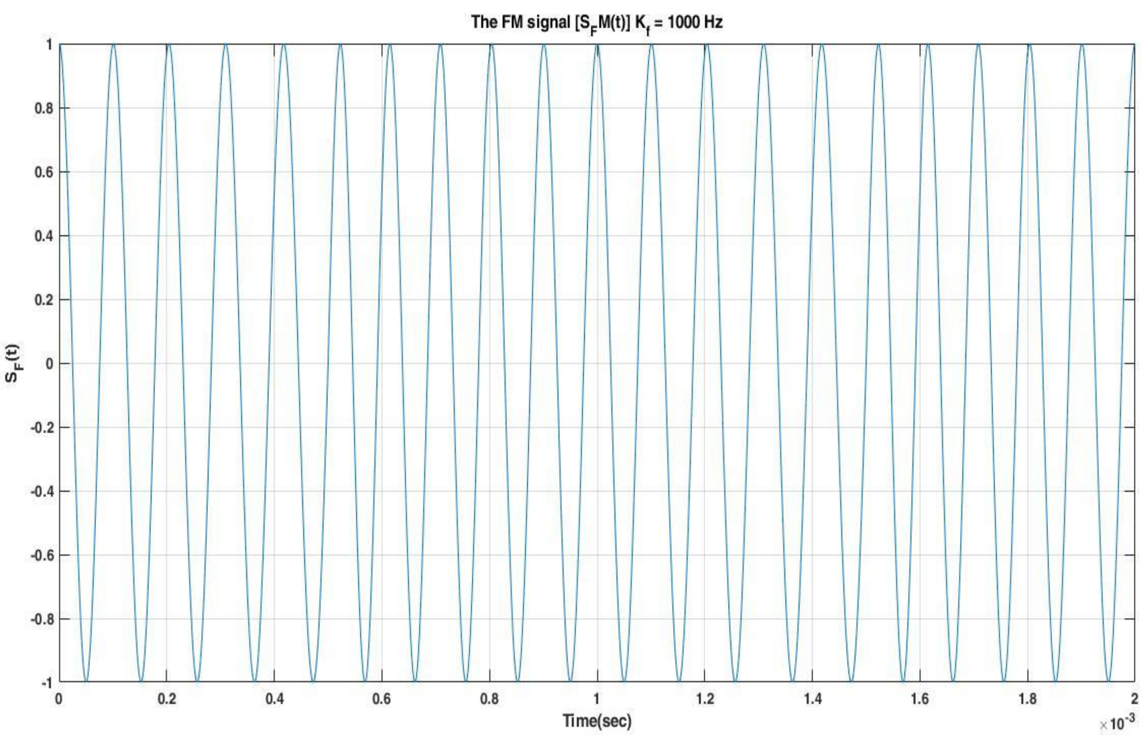
➢ **Plot the message signal m(t):**



- **Plot phase deviation signal $\theta(t)$ for $K_f = 1000\ Hz$:**



- **Plot the FM signal $S_{FM}(t)$ for $K_f = 1000\ Hz$:**

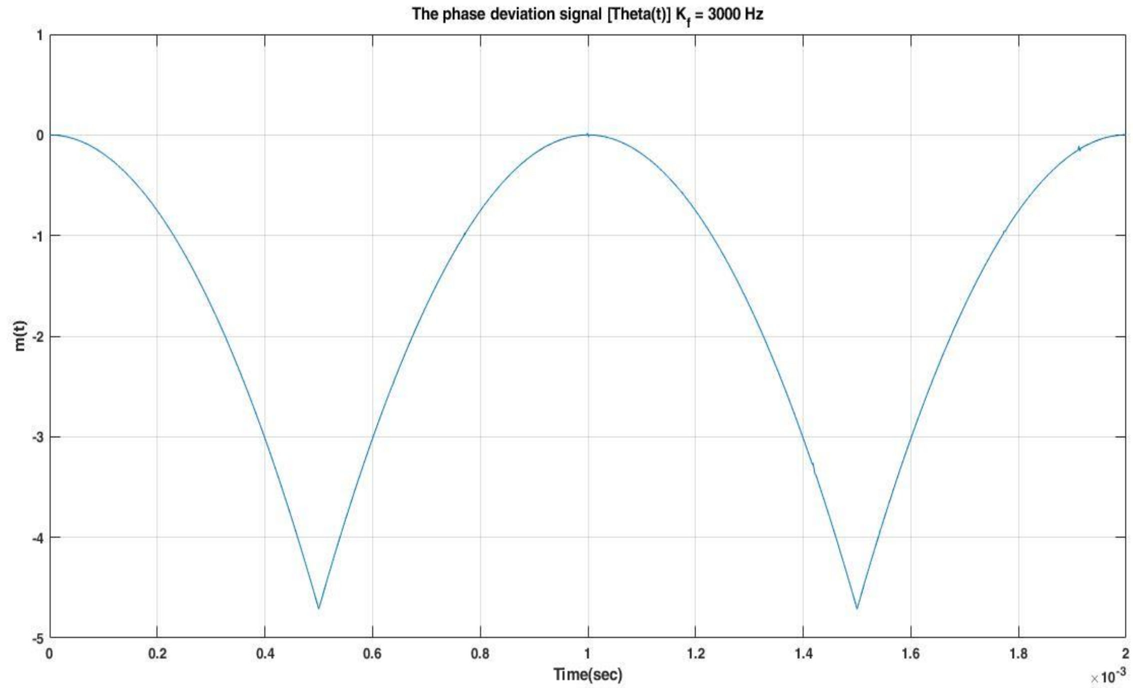


- **Comment:**

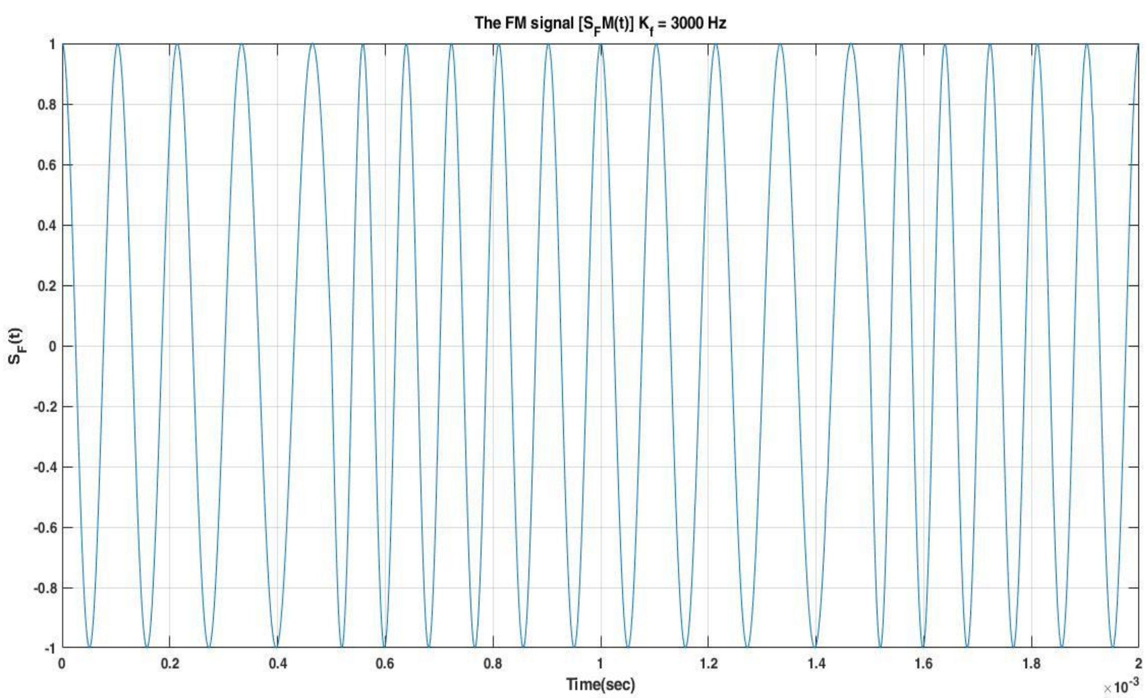
-The Triangular message signal $m(t)$, which is shown in the first figure, is plotted using a sawtooth MATLAB built-in function. It's a periodic function with $T = 1\ mS$. The message signal was integrated and multiplied by $(2\pi K_f)$ to obtain the phase deviation signal $\Theta(t)$, which is shown in the second figure. The phase deviation signal is used to modulate the message signal and obtain the FM modulated signal $S_{FM}(t)$, which is shown in the third figure.

-In this part, the carrier frequency is $\omega_c = 10\ KHz$, while the frequency modulation constant is $K_f = 1000\ Hz$. So, the frequency modulation constant is about $\frac{1}{10}$ of the carrier frequency. The maximum amplitude of the integrated signal is 0, while the minimum amplitude is $-2.5 * 10^{-4}$. So, after obtaining the phase deviation signal, the maximum and minimum phase deviations will be small values relative to the carrier phase. All of these reasons illustrate why the figure of the FM Signal is not showing a noticeable phase and frequency deviations.

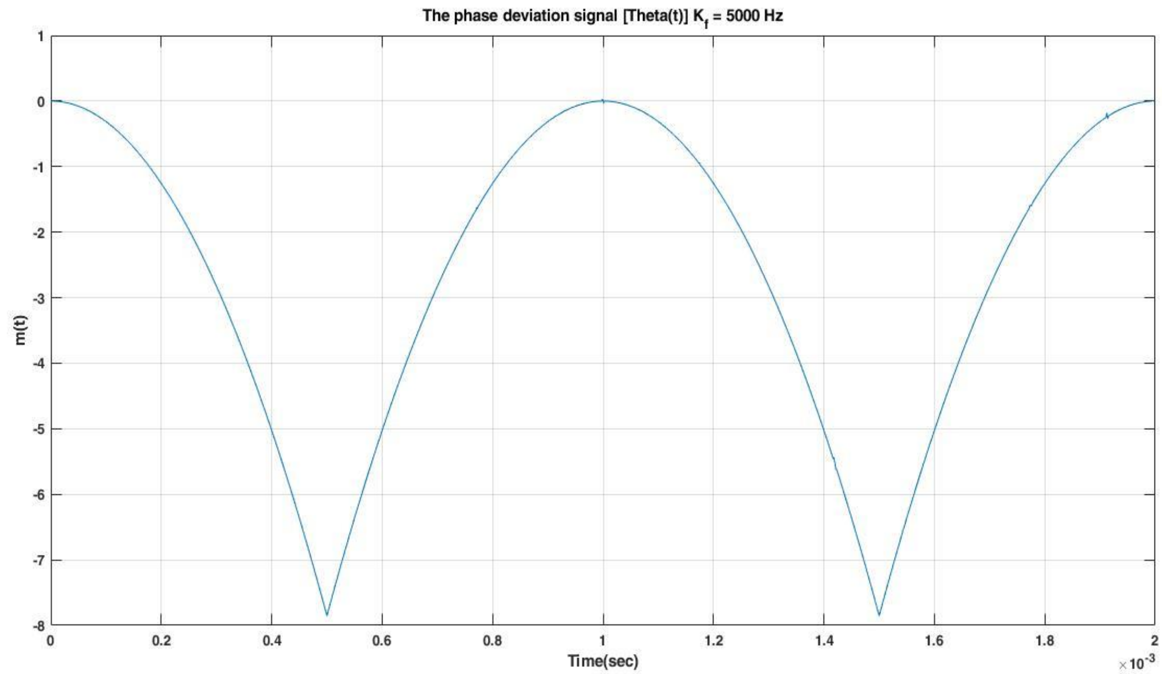
- **Plot phase deviation signal $\theta(t)$ for $K_f = 3000\ Hz$:**



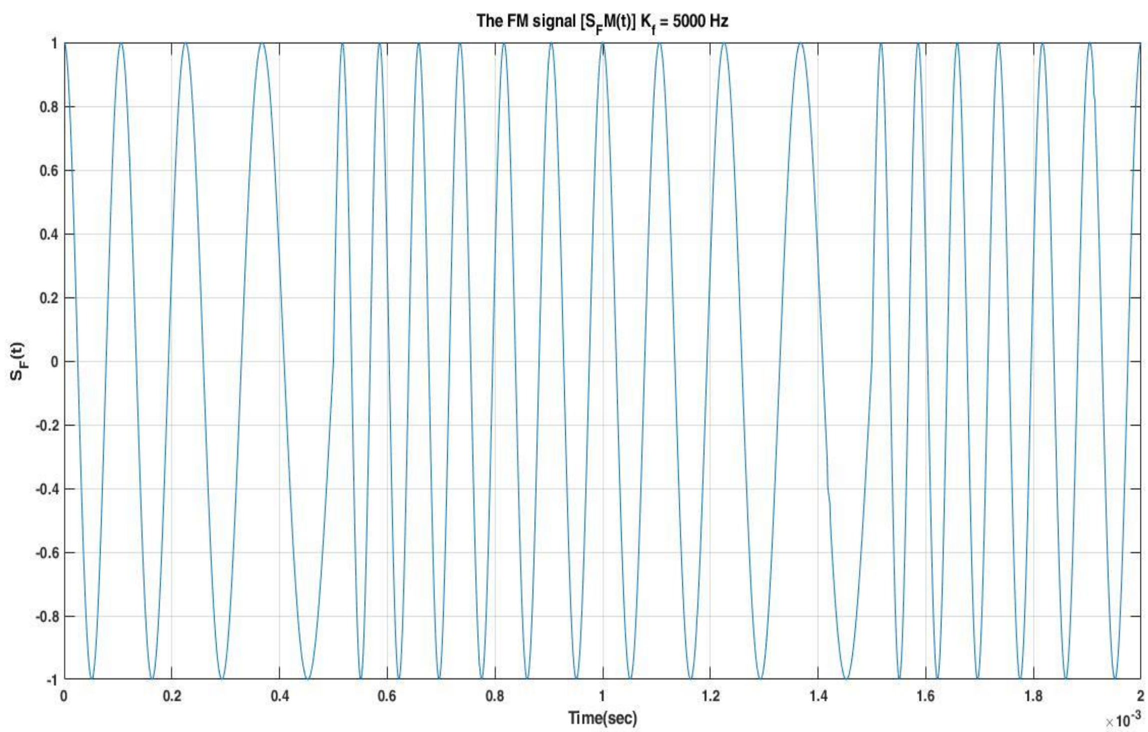
- **Plot the FM signal $S_{FM}(t)$ for $K_f = 3000\ Hz$:**



➢ **Plot phase deviation signal $\theta(t)$ for $K_f = 5000\ Hz$:**



➢ **Plot the FM signal $S_{FM}(t)$ for $K_f = 5000\ Hz$:**



- **Comment:**

-In this part, the carrier frequency is $\omega_c = 10\, KHz$, while the frequency modulation constant is changed to $K_f = 3000\, , 5000\, Hz$.

For $K_f = 3000\, Hz$, the frequency modulation constant is about $\frac{3}{10}$ of the carrier frequency. The maximum amplitude of the integrated signal is 0, while the minimum amplitude is $-2.5 * 10^{-4}$. So, after obtaining the phase deviation signal, the maximum and minimum phase deviations will be small values relative to the carrier phase, but larger than what we obtained when $K_f = 1000\, Hz$. So, the FM Signal is showing a slight noticeable phase and frequency deviations rather than what was shown when using $K_f = 1000\, Hz$.

-For $K_f = 5000\, Hz$, the frequency modulation constant is about $\frac{5}{10}$ of the carrier frequency. The maximum amplitude of the integrated signal is 0, while the minimum amplitude is $-2.5 * 10^{-4}$. So, after obtaining the phase deviation signal, the maximum and minimum phase deviations will a comparable value to the carrier phase, So, the FM Signal is showing a noticeable phase and frequency deviations.

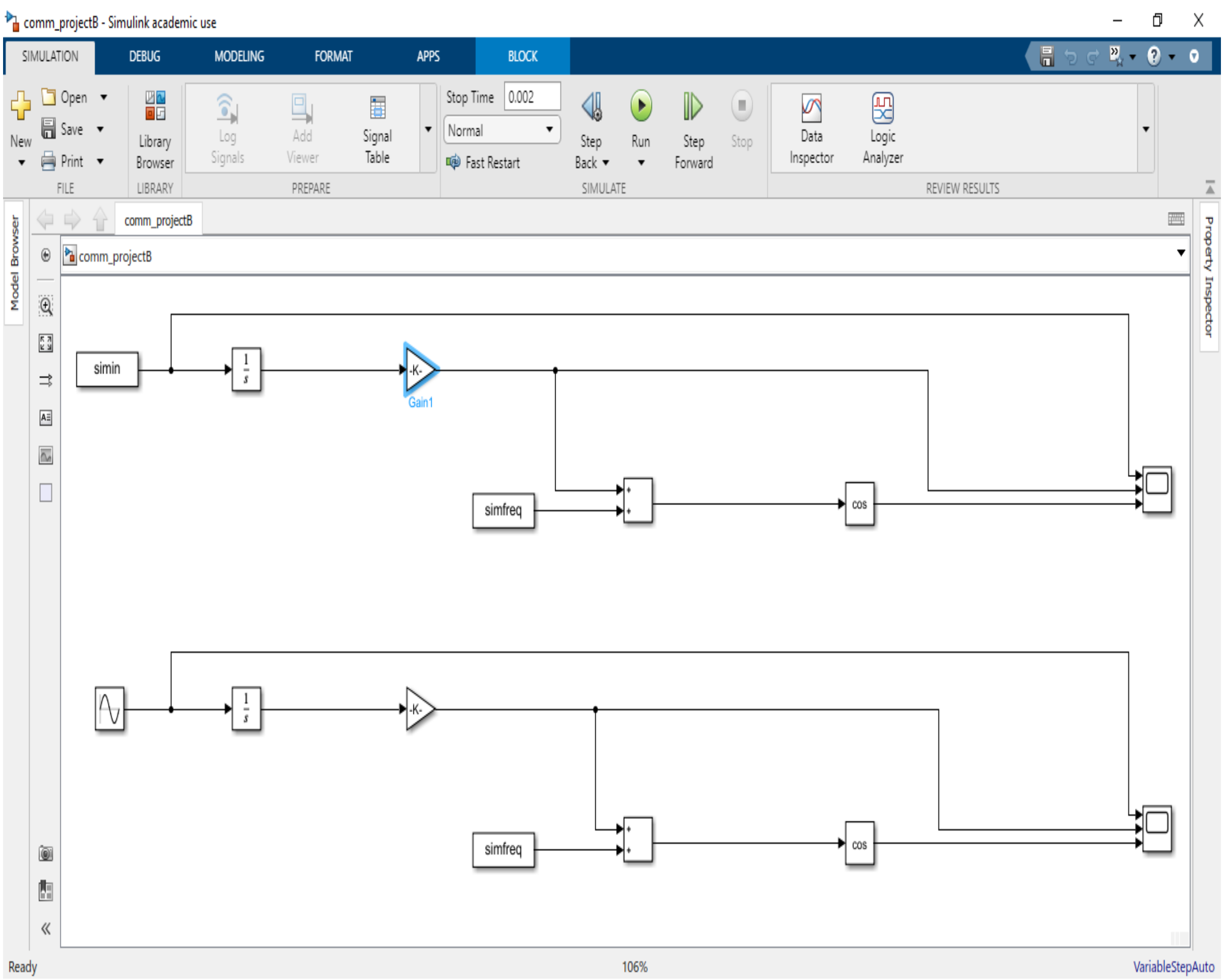
-In conclusion, the phase and frequency deviations are directly proportional to the frequency modulation constant K_f, and the amplitude of the integrated message signal. This can be easily concluded from the mathematical expression of the FM Modulated Signal, and from the obtained graphs too.

$$\boldsymbol{S_{FM}(\mathrm{t}) = \cos(\omega_c \mathrm{t} \;+\; \Theta(t)) = \cos(\omega_c \mathrm{t} \;+ 2\pi\, K_f \int_0^t m(\tau)\, d\tau)}$$

2) Part B: Using Simulink

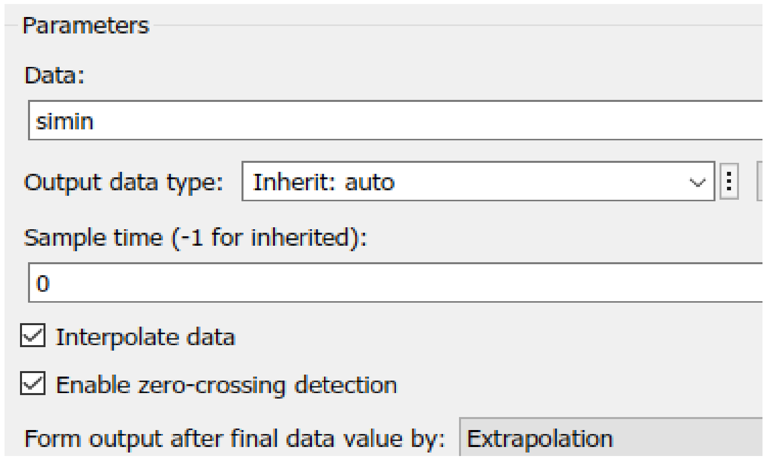
In this part we implmented the FM Modulator using Simulink. The message signals that we used in this part are: triangular signal and sinusoidal message signal, while the carrier signal is a sinusoidal signal with carrier frequency $\omega_c = 10\ KHz$. Here is the Block Diagram for the FM Modulator using Simulink:

- **Block Diagram of the system in Simulink:**

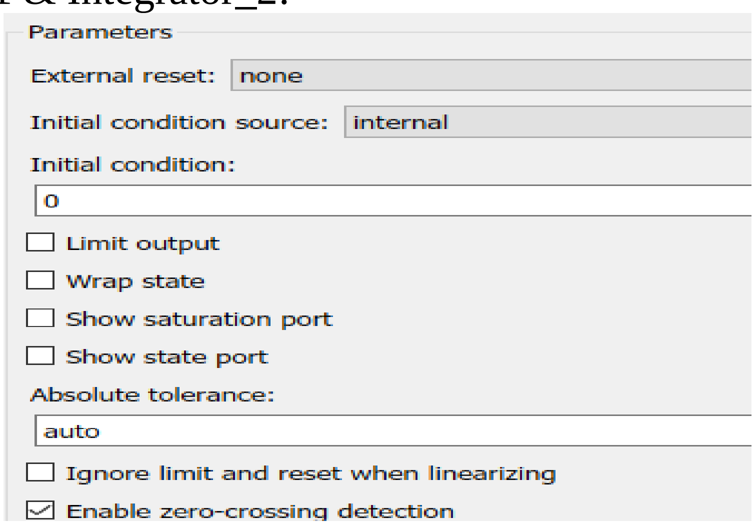


➢ Parameters of each block used in the system:

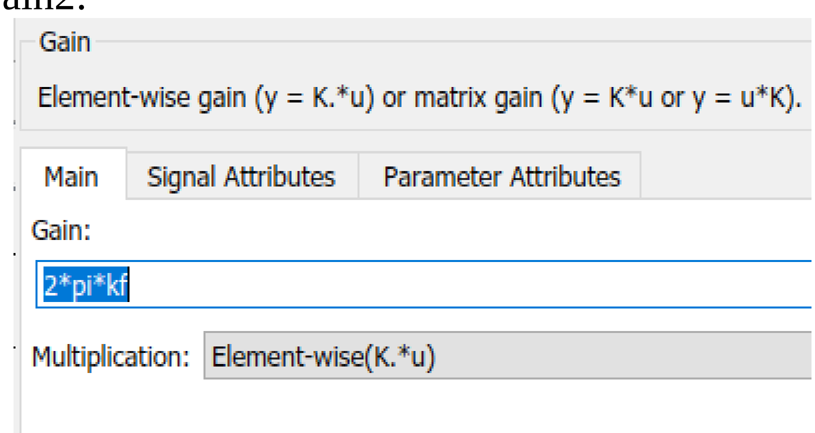
- SimIn:



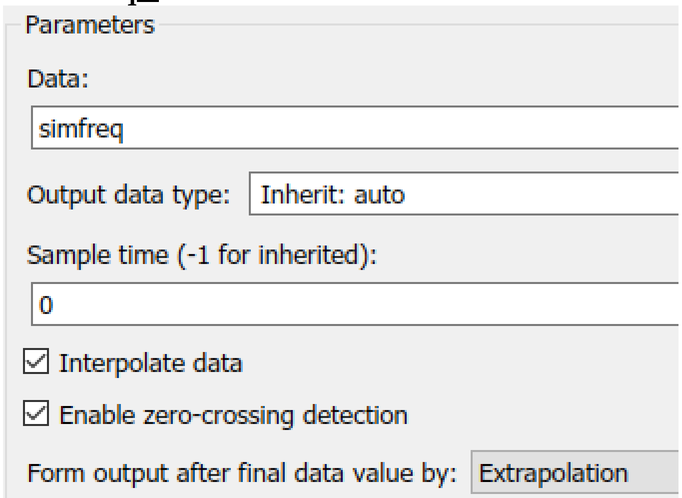
- Integrator_1 & Integrator_2:



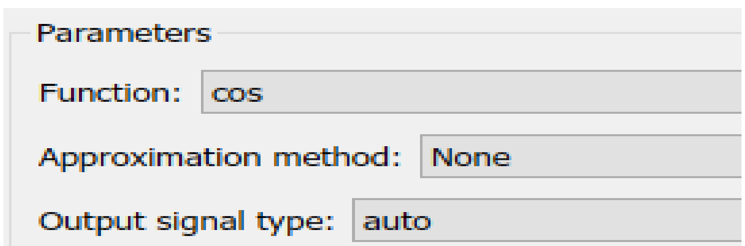
- Gain1 & Gain2:



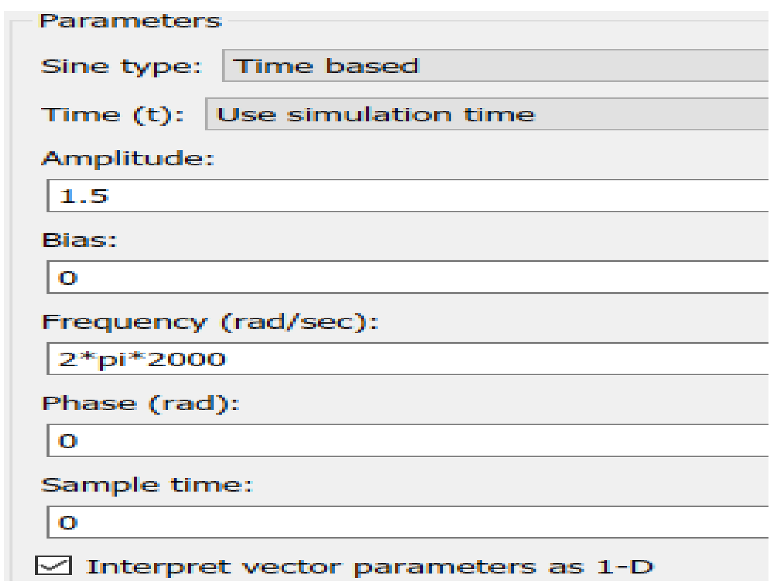
- Simfreq_1 & Simfreq_2:



- Cos_1 & Cos_2:



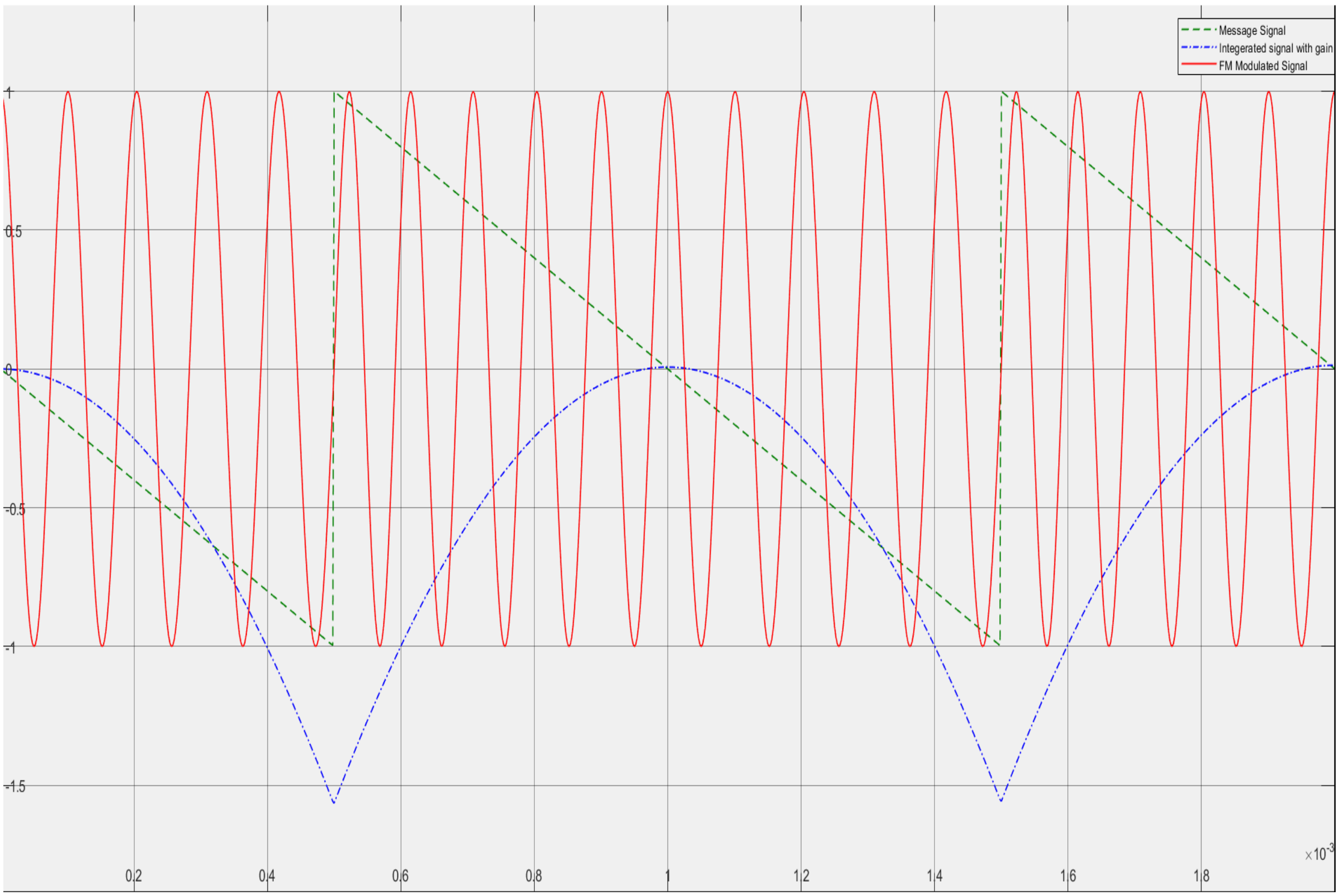
- SinWave:



I. Scope Outputs for Triangular Message Signal:

We used 3 different values for $K_f = 1000, 3000, 5000\ Hz$ for the both message signals, triangular signal and sinusoidal message signal as requisted, and here are the scope outputs of the Triangular message:

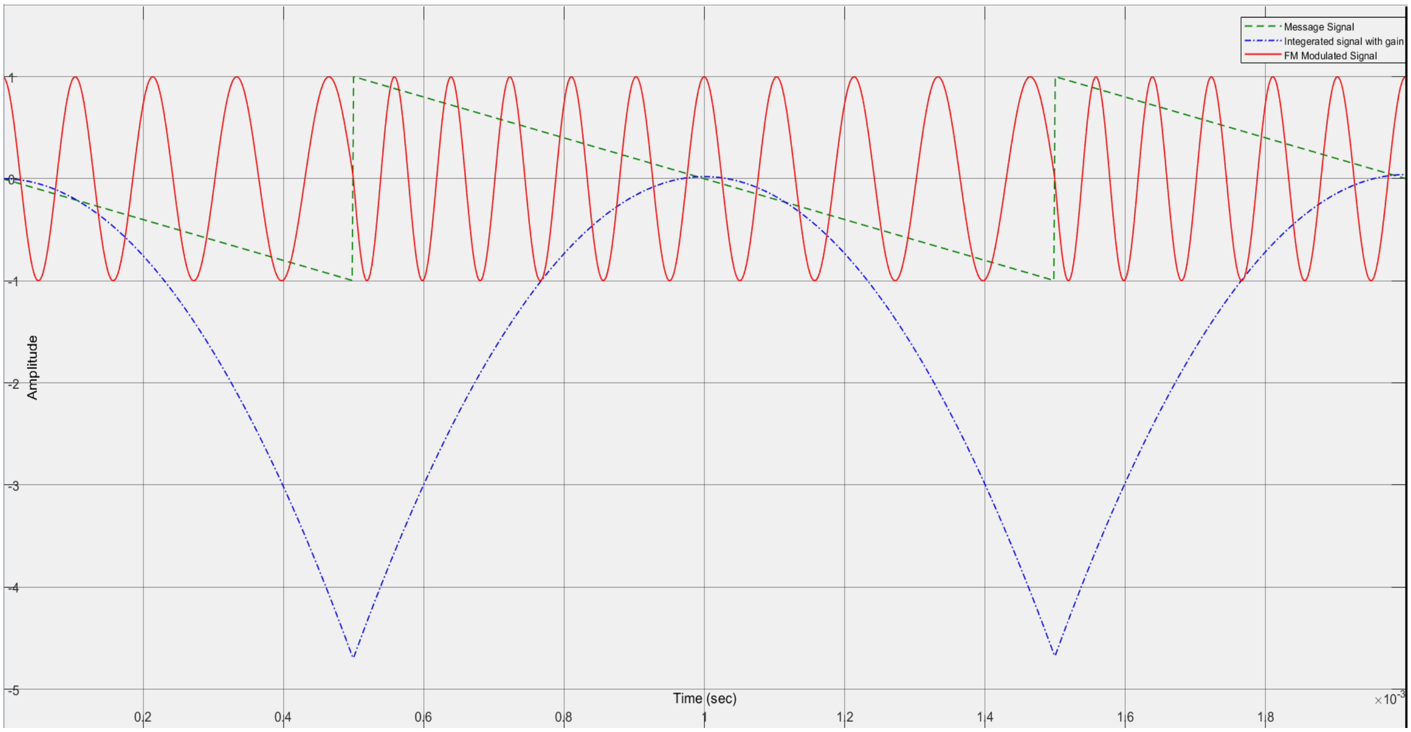
- **Plot the message, phase deviation, modulated signals for $K_f = 1000\ Hz$:**



- **Comment:**

This figure shows the scope output for FM modulation for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a triangular signal. The green line shows the original message signal $m(t)$, the blue line shows the phase deviation signal $\Theta(t)$, and the red line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 1000\ Hz$ agree with the graphs that we obtained in (Part A). The FM Signal is not showing a noticeable phase and frequency deviations.

- **Plot the message, phase deviation, modulated signals for $K_f = 3000\ Hz$:**

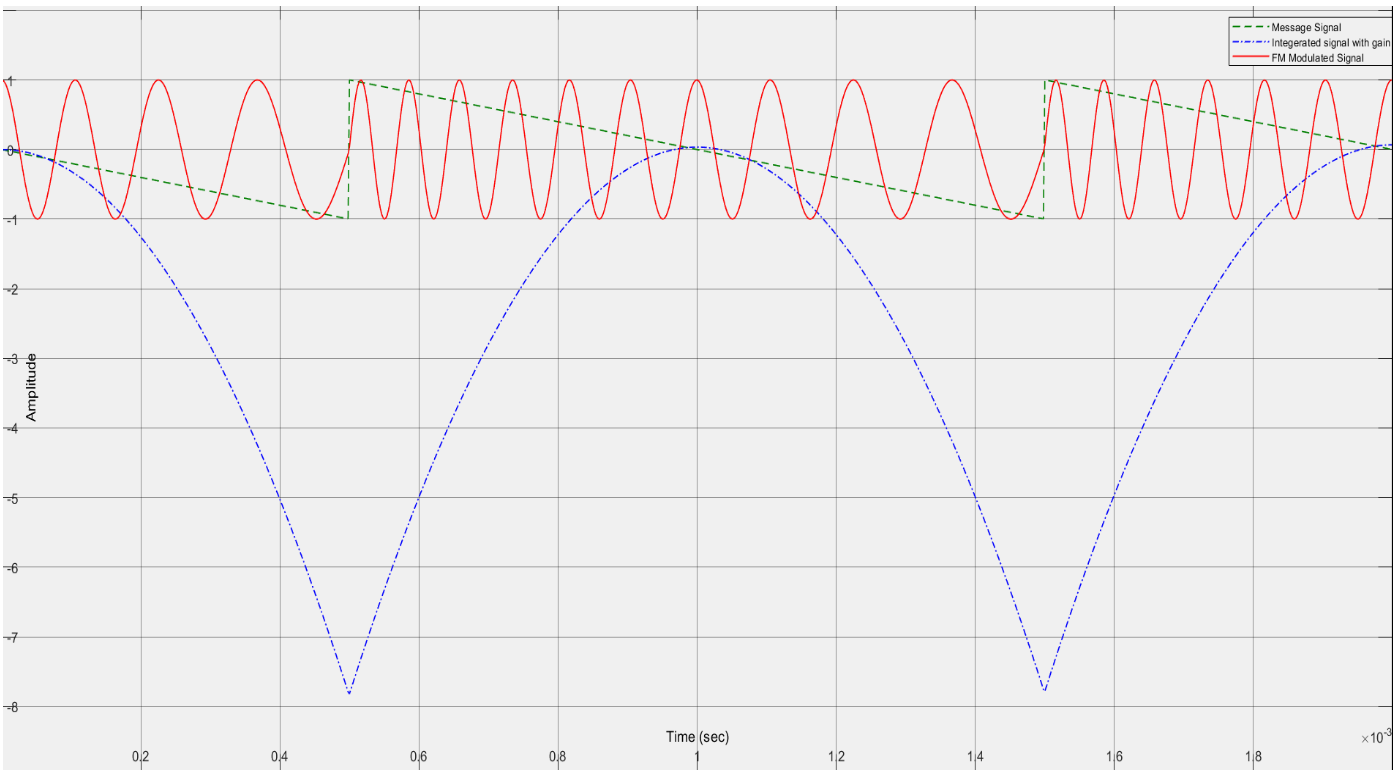


- **Comment:**

This figure shows the scope output for FM modulation for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a triangular signal. The green line shows the original message signal $m(t)$, the blue line shows the phase deviation signal $\Theta(t)$, and the red line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 3000\ Hz$ agree with the graphs that we obtained in (Part A).

For $K_f = 3000\ Hz$, the frequency modulation constant is about $\frac{3}{10}$ of the carrier frequency. The maximum amplitude of the integrated signal is 0, while the minimum amplitude is $-2.5 * 10^{-4}$. So, after obtaining the phase deviation signal, the maximum and minimum phase deviations will be small values relative to the carrier phase, but larger than what we obtained when $K_f = 1000\ Hz$. So, the FM Signal is showing a slight noticeable phase and frequency deviations rather than what was shown when using $K_f = 1000\ Hz$.

- **Plot the message, phase deviation, modulated signals for $K_f = 5000\ Hz$:**



- **Comment:**

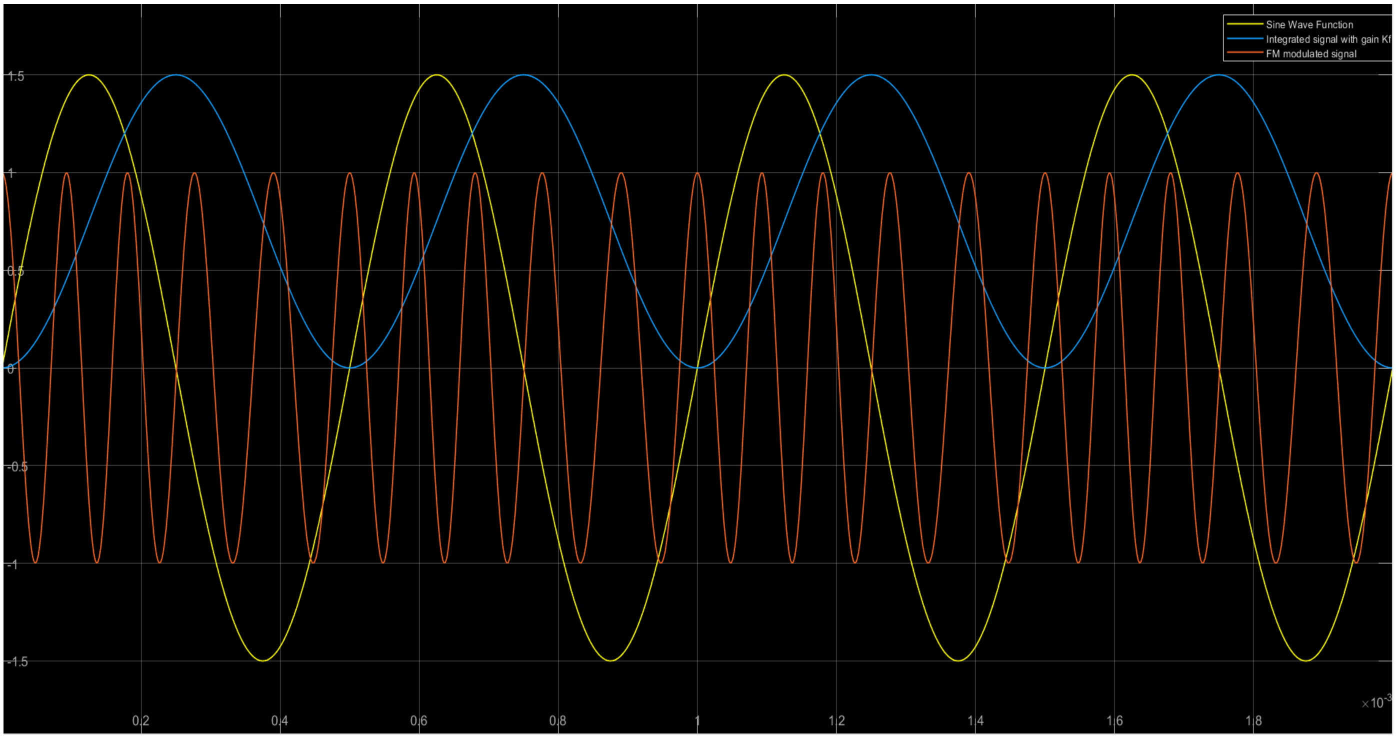
This figure shows the scope output for FM modulation for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a triangular signal. The green line shows the original message signal $m(t)$, the blue line shows the phase deviation signal $\Theta(t)$, and the red line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 5000\ Hz$ agree with the graphs that we obtained in (Part A).

-For $K_f = 5000\ Hz$, the frequency modulation constant is about $\frac{5}{10}$ of the carrier frequency. The maximum amplitude of the integrated signal is 0, while the minimum amplitude is $-2.5 * 10^{-4}$. So, after obtaining the phase deviation signal, the maximum and minimum phase deviations will a comparable value to the carrier phase, So, the FM Signal is showing a noticeable phase and frequency deviations.

II. Scope Outputs for Sinusoidal Message Signal:

In this part, a Sinusoidal message signal with an amplitude of 1.5 $volts$ and a frequency of 2 KHz and Here are the scope outputs.

➢ **Plot the message, phase deviation, modulated signals for $K_f = 1000\ Hz$:**

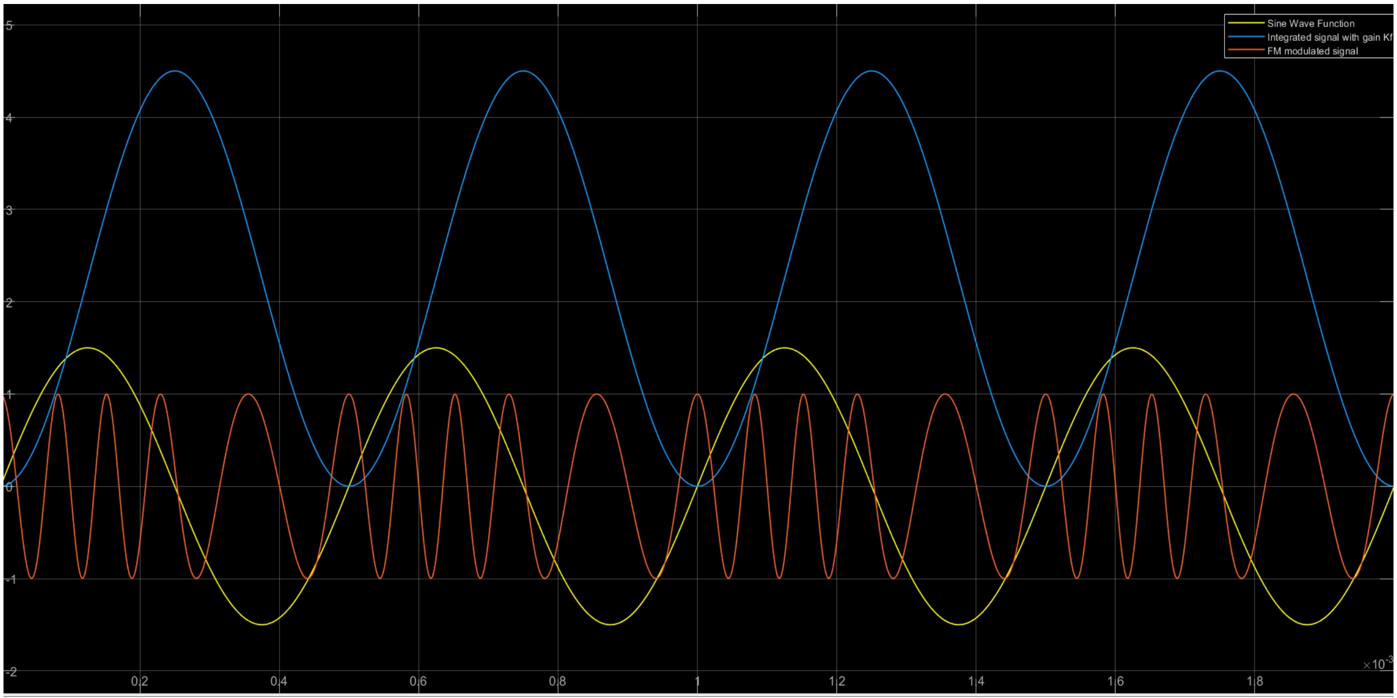


- **Comment:**

This figure shows the scope output for FM modulation ($K_f = 1000\ Hz$) for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal with an amplitude of 1.5 volts and a frequency of 2 KHz. The yellow line shows original message signal $m(t)$, the blue line shows phase deviation signal $\Theta(t)$, and orange line shows FM modulated signal $S_{FM}(t)$. The deviation in the FM signal is not noticeable as it is directly proportional to the multiplication of K_f and the integration of m(t). This multiplication results in a small value, which causes the deviation not to be noticeable.

Note: The integrated signal (the output of the integrator block) is shifted above the x-axis because the function of the block is to perform a continuous time integration so the amplitude doesn't take negative values, it still has the same wave characteristics but with a DC shift.

- **Plot the message, phase deviation, modulated signals for $K_f = 3000\ Hz$:**

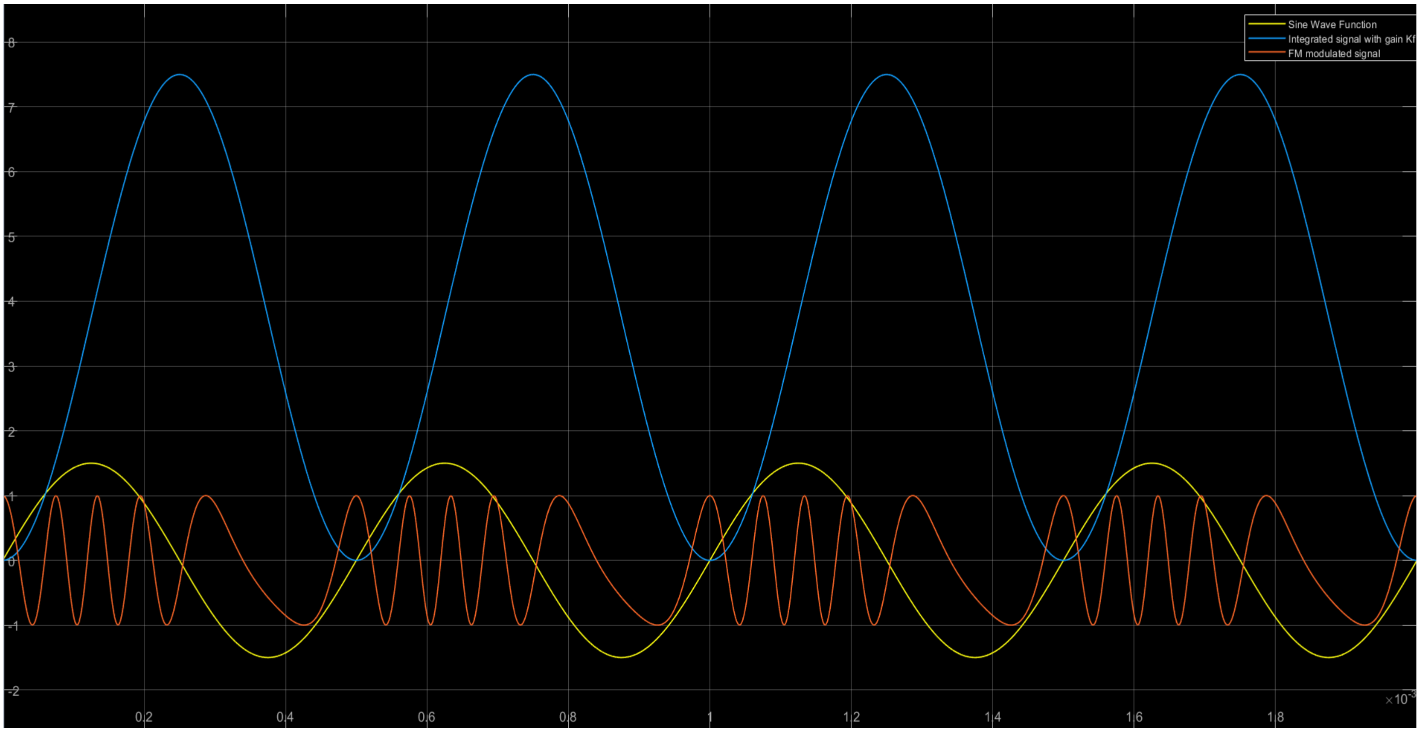


- **Comment:**

This figure shows the scope output for FM modulation ($K_f = 3000\ Hz$) for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The yellow line shows the original message signal $m(t)$, the blue line shows the phase deviation signal $\Theta(t)$, and the orange line shows the FM modulated signal $S_{FM}(t)$.

The phase and frequency deviations in the FM signal are noticeable slightly as it is directly proportional to the multiplication of K_f and the integration of m(t). This multiplication results in a slight large value, which causes the deviation to be slightly noticeable.

➢ **Plot the message, phase deviation, modulated signals for $K_f = 5000\ Hz$:**



- **Comment:**

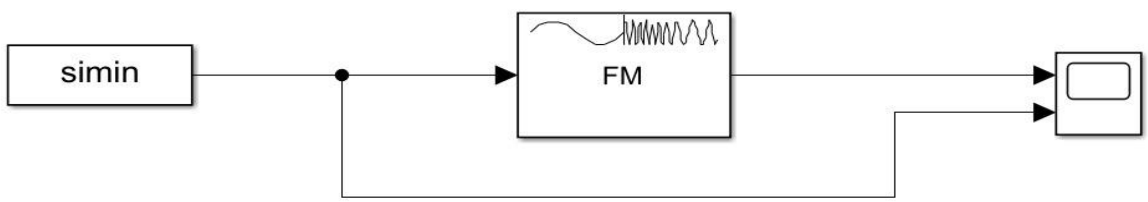
This figure shows the scope output for FM modulation ($K_f = 5000\ Hz$) for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The yellow line shows the original message signal $m(t)$, the blue line shows the phase deviation signal $\Theta(t)$, and the orange line shows the FM modulated signal $S_{FM}(t)$.

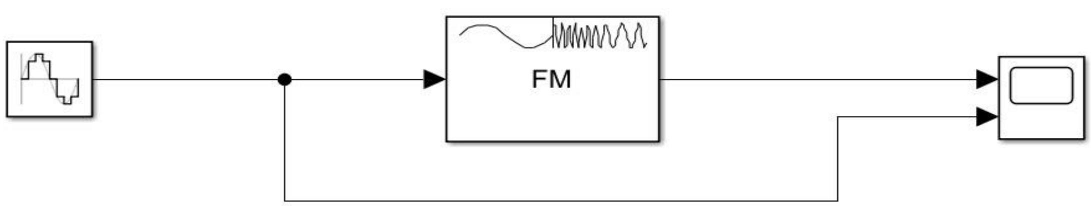
The phase and frequency deviations in the FM signal are noticeable as it is directly proportional to the multiplication of K_f and the integration of m(t). This multiplication results in a large value, which causes the deviation to be noticeable.

3) Part C: Using Simulink communications toolbox:

In this part we implmented the FM Modulator using the Communications Toolbox of Simulink . The message signals that we used in this part are: triangular signal and sinusoidal message signal, while the carrier signal is a sinusoidal signal with carrier frequency $\omega_c = 10\ KHz$. Here is the Block Diagram for the FM Modulator:

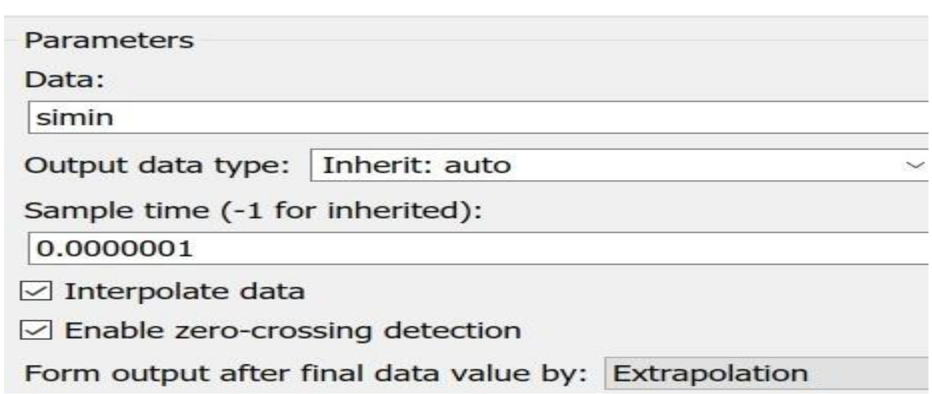
- **Block Diagram of the system in Simulink:**



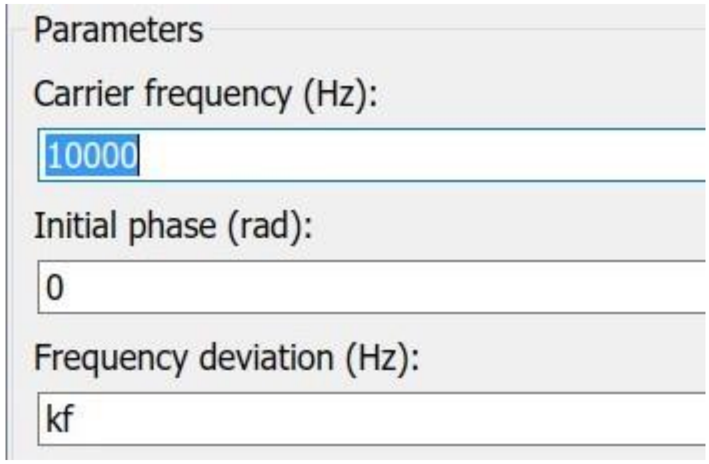


- **Parameters of each block used in the system:**

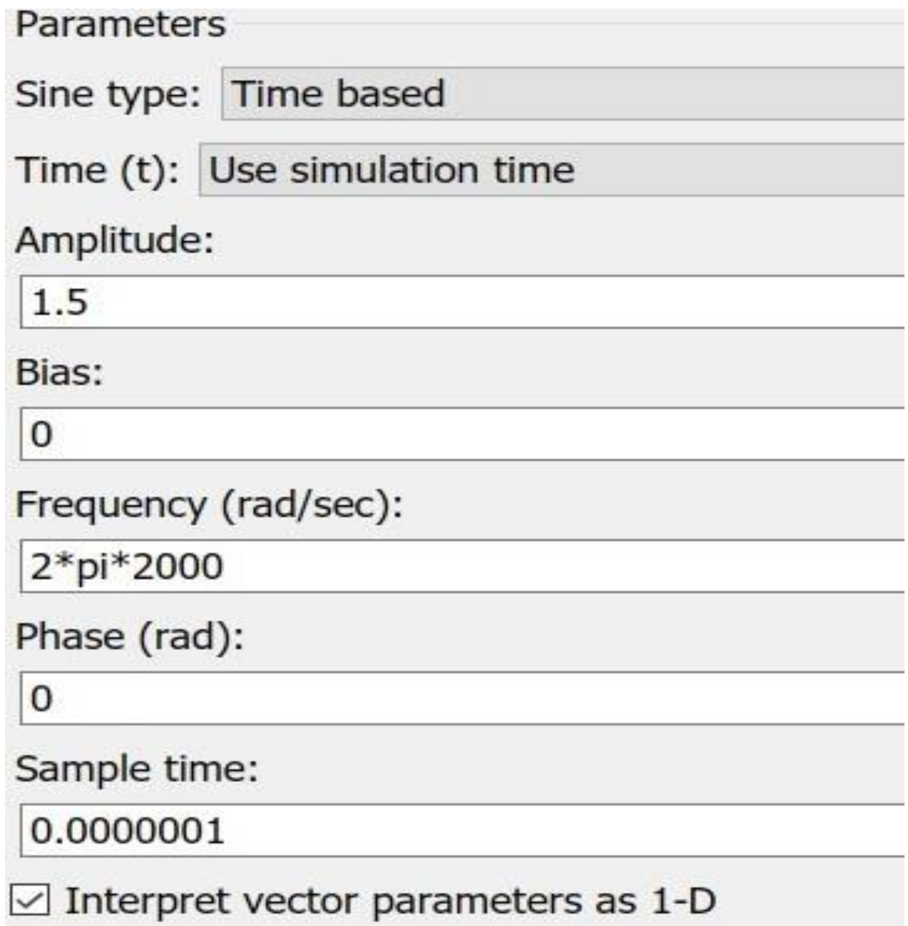
  - SimIn:



- FM modulator:



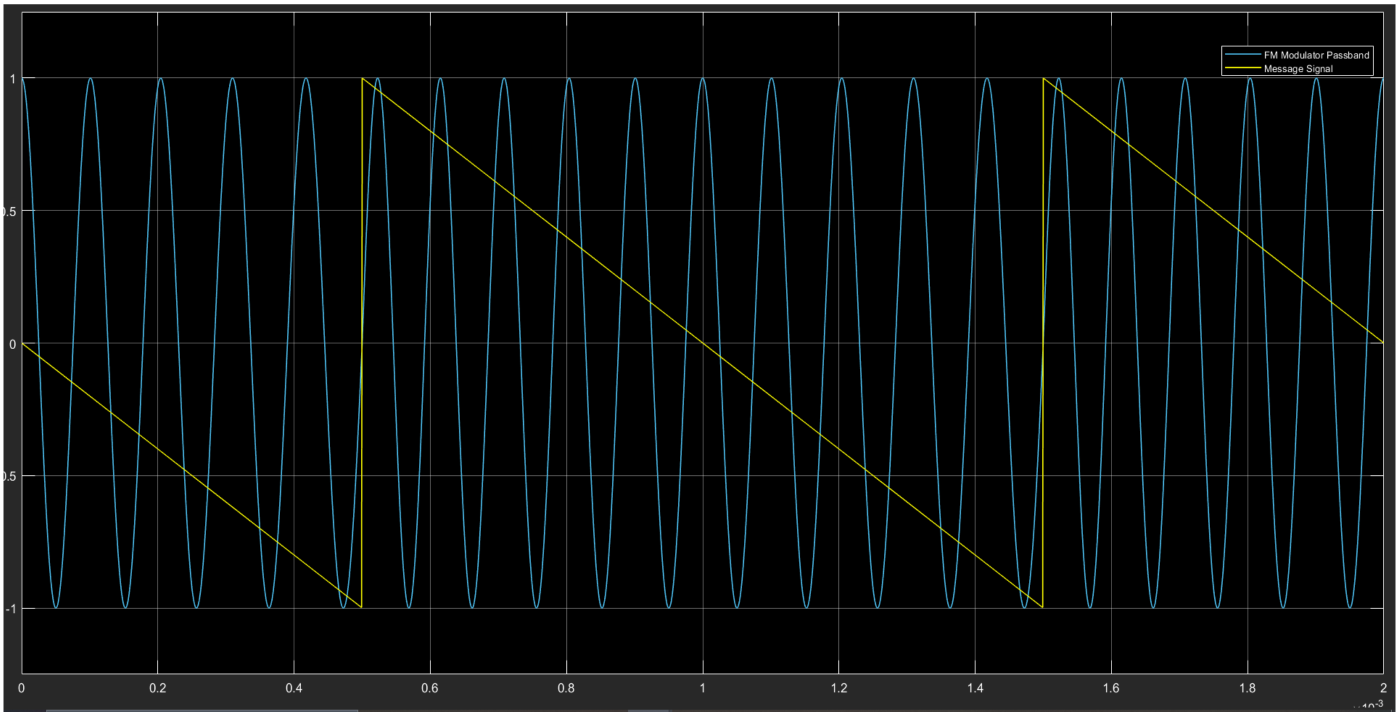
- SineWave:



I. Scope Outputs for Triangular Message Signal:

We used 3 different values for $K_f = 1000, 3000, 5000\ Hz$ for the both message signals, triangular signal and sinusoidal message signal, as requisted and here are the scope outputs of the Triangular message:

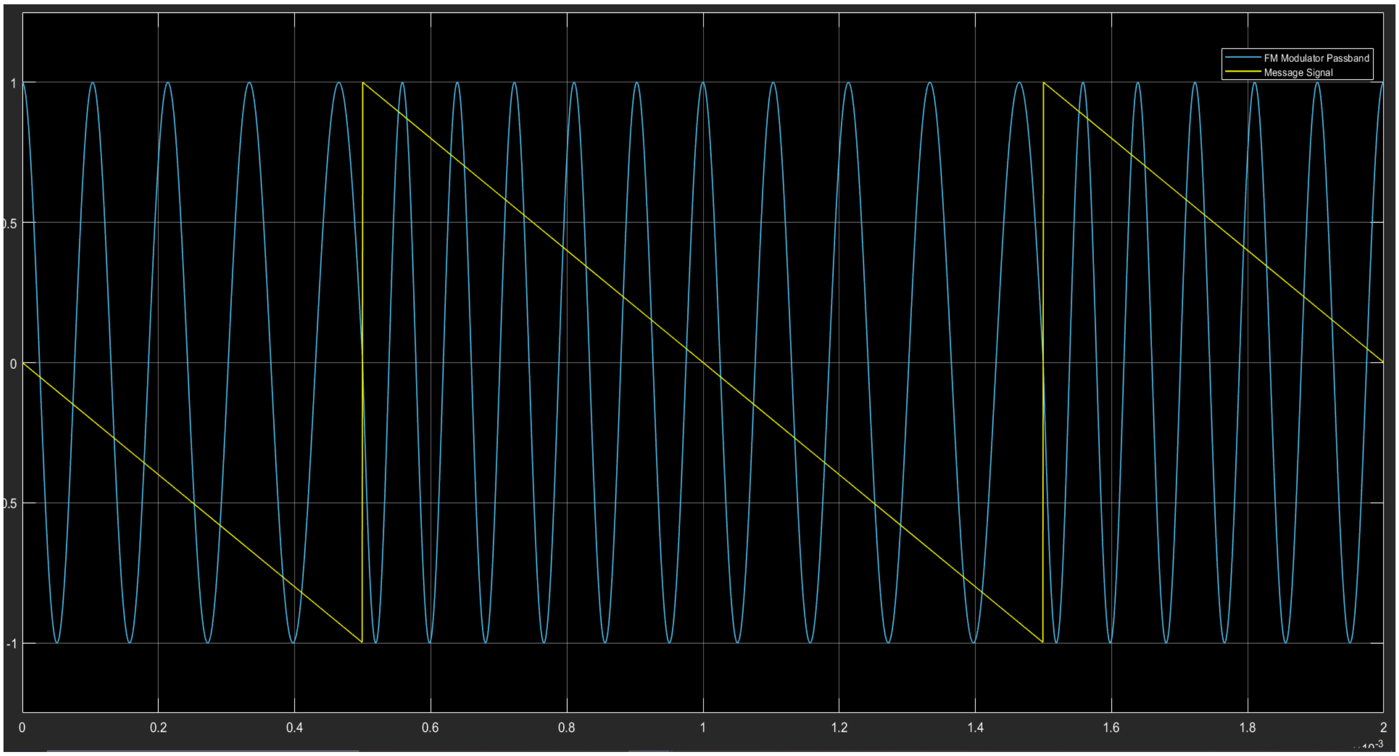
- **Plot the message, modulated signals for $K_f = 1000\ Hz$:**



- **Comment:**

This figure shows the scope output for FM modulation for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The yellow line shows the original message signal $m(t)$, and the blue line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 1000\ Hz$ agree with the graphs that we obtained in both (Part A) and (Part B). The FM Signal is not showing a noticeable phase and frequency deviations.

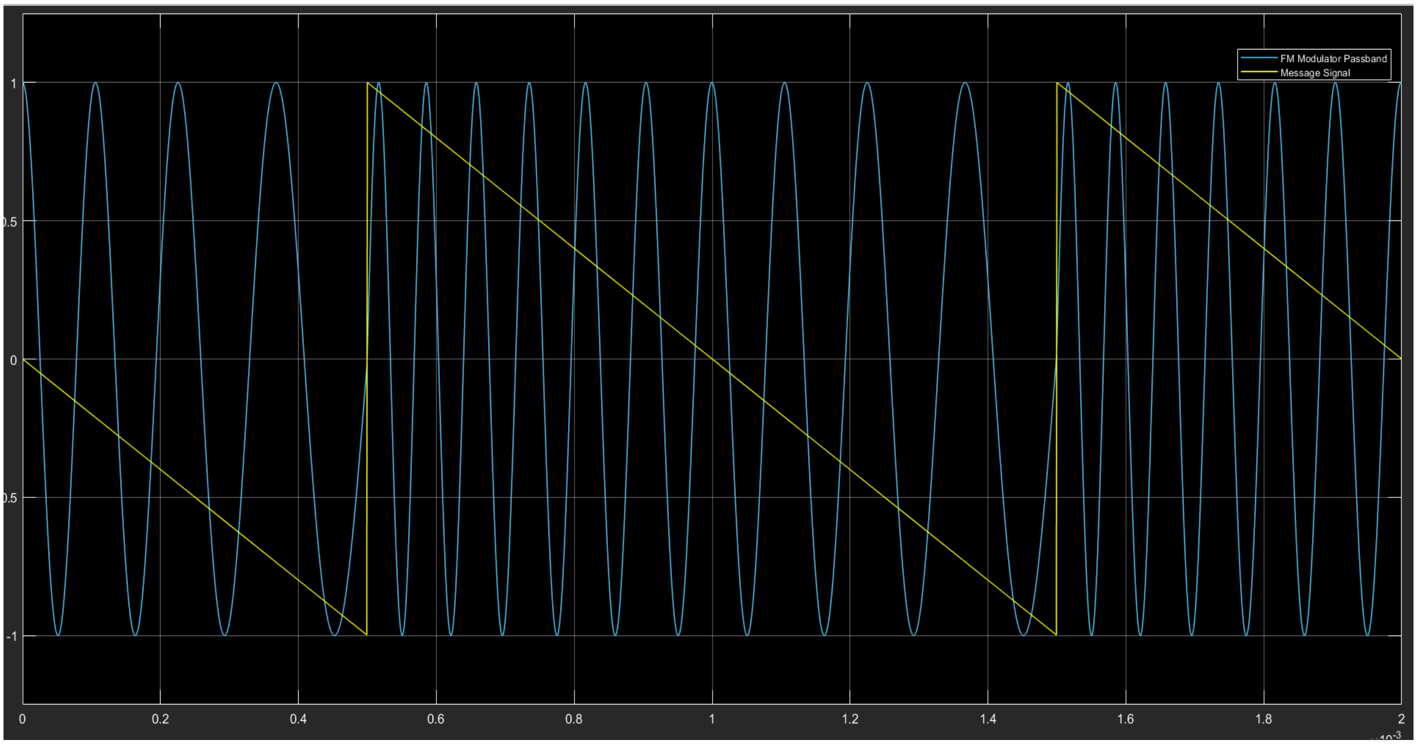
- **Plot the message, phase deviation, modulated signals for $K_f = 3000\ Hz$:**



- **Comment:**

This figure shows the scope output for FM modulation for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The yellow line shows the original message signal $m(t)$, and the blue line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 3000\ Hz$ agree with the graphs that we obtained in both (Part A) and (Part B). The FM Signal is showing a slight noticeable phase and frequency deviations.

- **Plot the message, phase deviation, modulated signals for $K_f = 5000\ Hz$:**



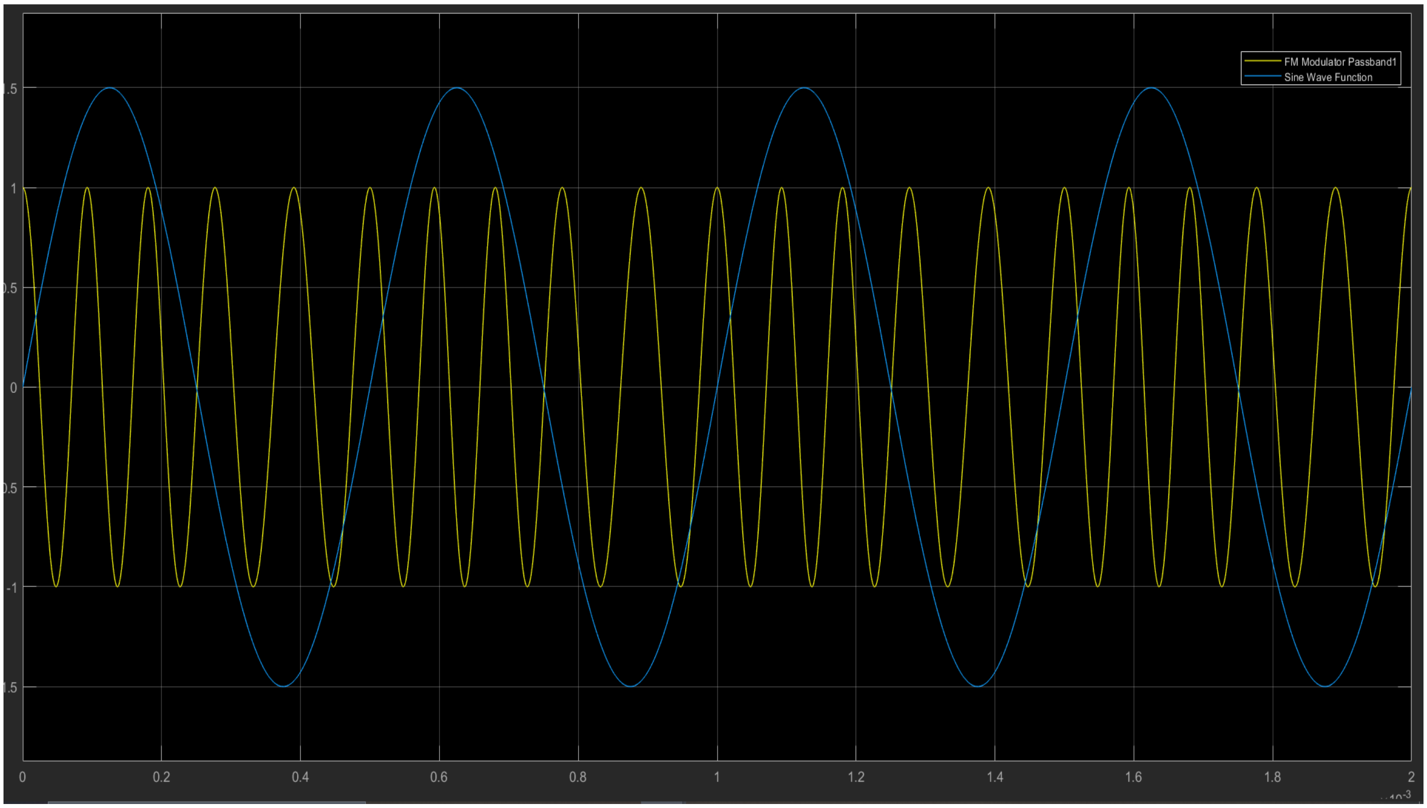
- **Comment:**

This figure shows the scope output for FM modulation for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The yellow line shows the original message signal $m(t)$, and the blue line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 5000\ Hz$ agree with the graphs that we obtained in both (Part A) and (Part B). The FM Signal is showing a noticeable phase and frequency deviations.

II. Scope Outputs for Sinusoidal Message Signal:

In this part, a Sinusoidal message signal with an amplitude of 1.5 $volts$ and a frequency of 2 KHz and Here are the scope outputs.

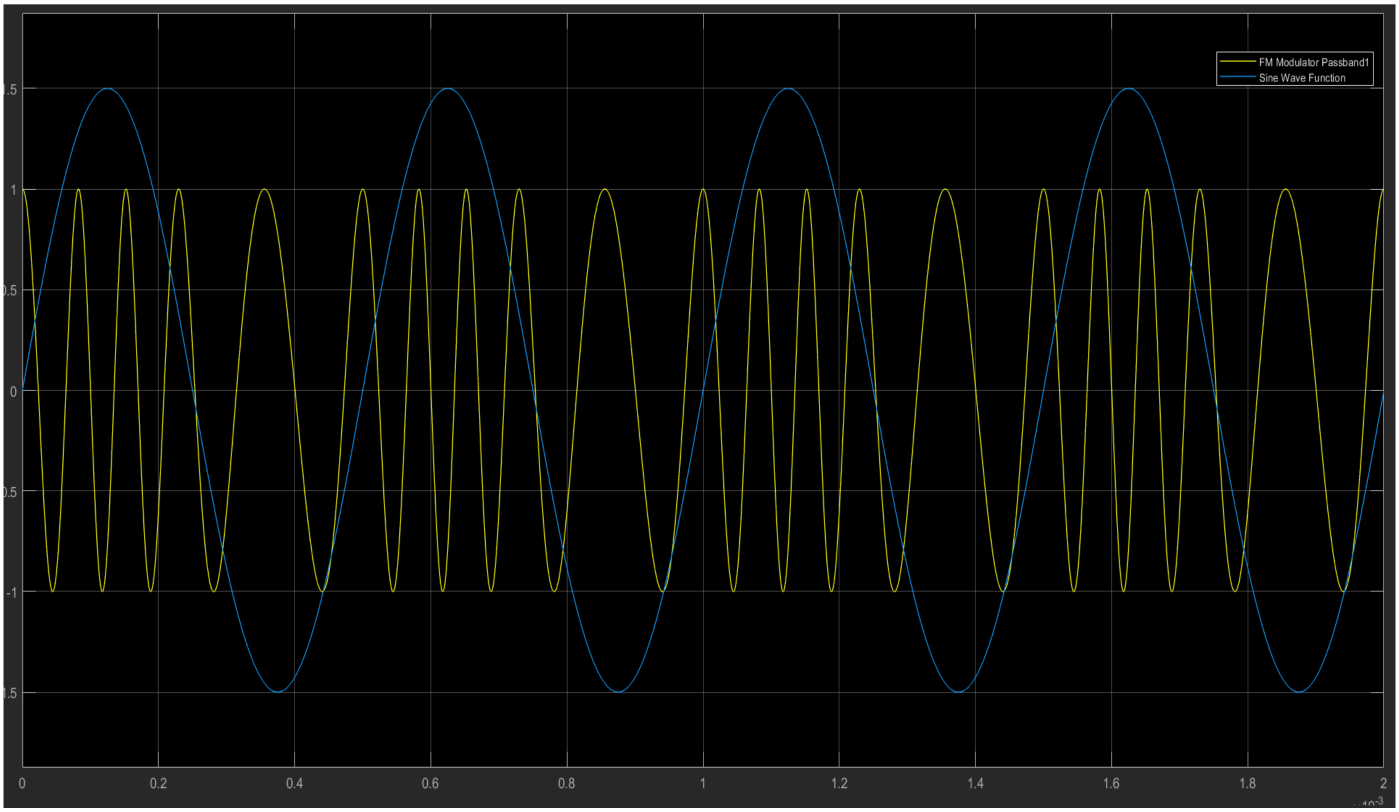
- **Plot the message, phase deviation, modulated signals for $K_f = 1000\ Hz$:**



- **Comment:**

This figure shows the scope output for FM modulation ($K_f = 1000\ Hz$) for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The blue line shows the original message signal $m(t)$, and the yellow line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 1000\ Hz$ agree with the graphs that we obtained in both (Part B). The FM Signal is not showing a noticeable phase and frequency deviations.

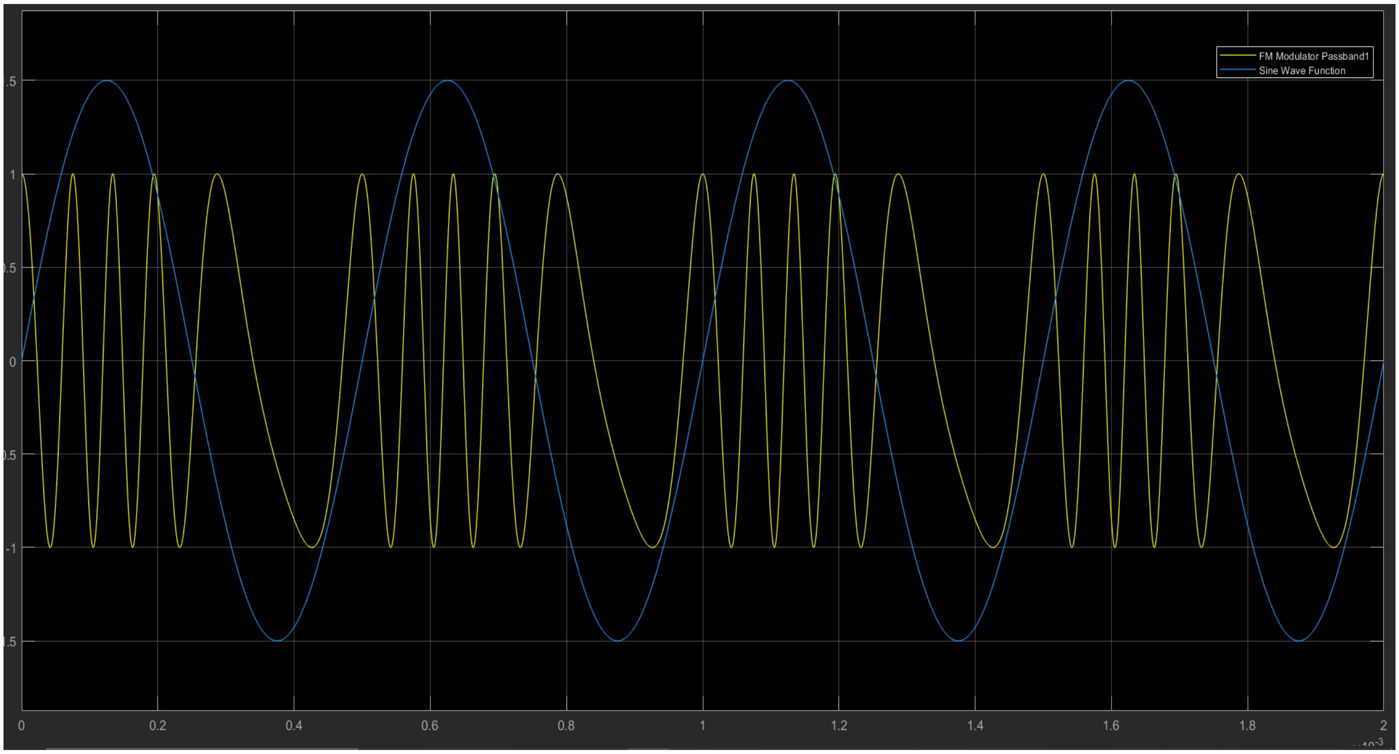
- **Plot the message, phase deviation, modulated signals for $K_f = 3000\ Hz$:**



- **Comment:**

This figure shows the scope output for FM modulation ($K_f = 3000\ Hz$) for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The blue line shows the original message signal $m(t)$, and the yellow line shows the FM modulated signal $S_{FM}(t)$. The scope outputs for $K_f = 3000\ Hz$ agree with the graphs that we obtained in both (Part A). The FM Signal is showing a slightly noticeable phase and frequency deviations.

- **Plot the message, phase deviation, modulated signals for $K_f = 5000\ Hz$:**



- **Comment:**

This figure shows the scope output for FM modulation ($K_f = 5000\ Hz$) for which a sinusoidal signal ($\omega_c = 10\ KHz$) is used as a carrier signal, while the message signal is a sinusoidal signal. The blue line shows the original message signal $m(t)$, and the yellow line shows the FM modulated signal $S_{FM}(t)$.

The scope outputs for $K_f = 5000\ Hz$ agree with the graphs that we obtained in both (Part A). The FM Signal is showing a noticeable phase and frequency deviations.