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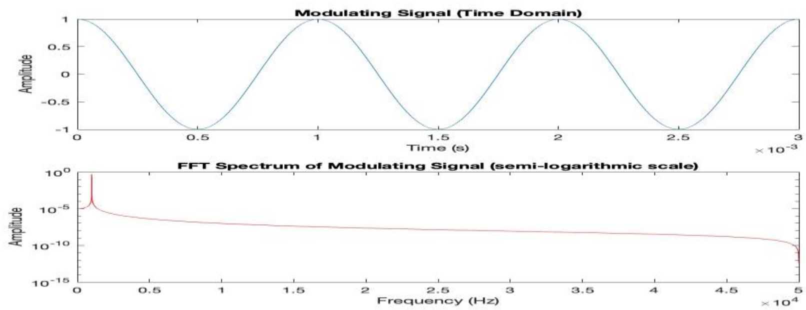
TP 1: Introduction to Amplitude Modulation (AM)

Question 1:

To generate the modulating signal:

$$S_{modulating}(t) = A_{modulant} \cdot \cos(2\pi\, f_{modulant}\, t)$$

With: $A_{modulant}$ = 1 kHz and $f_{modulant}$ = 1 kHz



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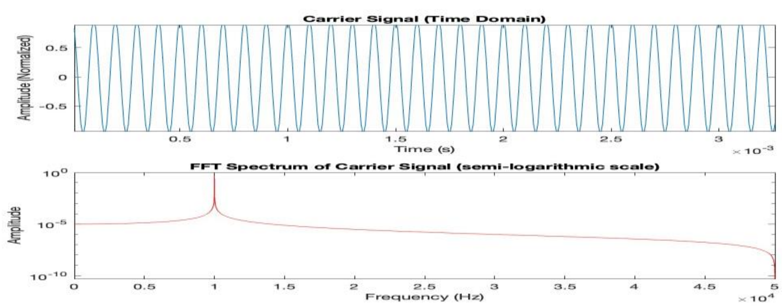
To generate the carrier signal:

$$S_{carrier}(t) = A_{carrier} \cdot \cos(2\pi\, f_{carrier}\, t)$$

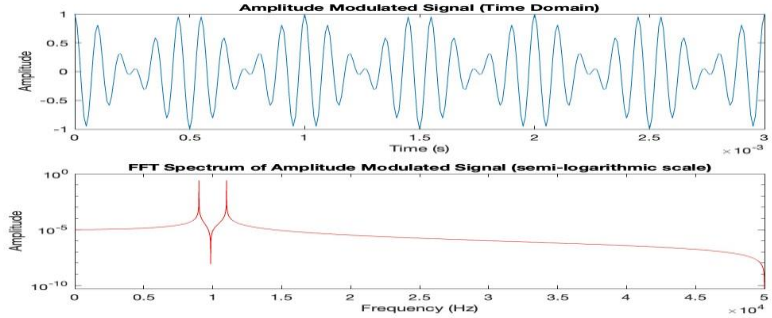
With: $A_{carrier}$ = 1 kHz and $f_{carrier}$ = 10 kHz



Question 2:

To generate the modulated signal:

$$S_{modulated}(t) = S_{carrier}(t) \,.\, S_{modulating}(t)$$

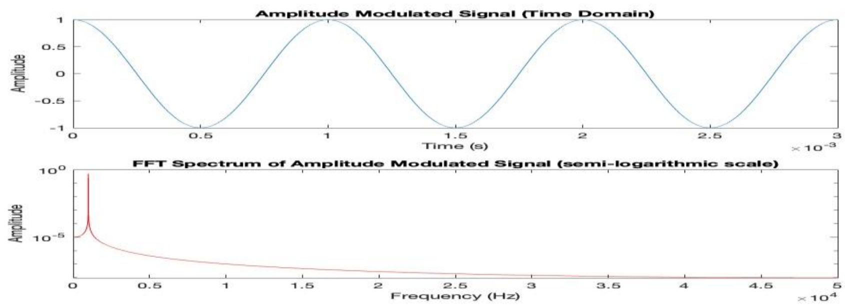


Conclusion:

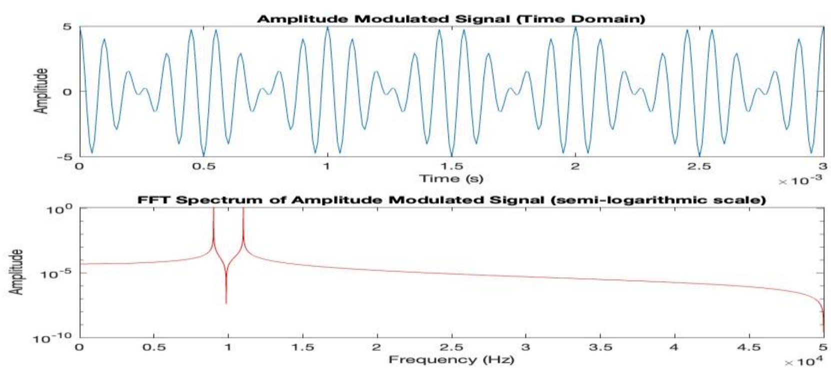
The type of modulation, known as Amplitude Modulation (AM), is achieved by varying the amplitude of a carrier signal with a modulating signal. This modulation method creates sidebands around the carrier frequency, carrying the information from the modulating signal.

Question 3:

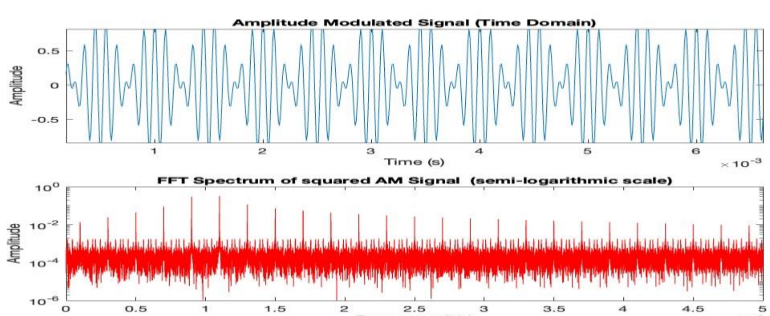
- Changing the carrier's frequency $F_{carrier}$ to 100khz gives the following modulated signal:



- Changing $F_{modulating}$ to 5khz and $A_{modulating}$ to 5 gives the following modulated signal:



- Changing the modulating signal to a squared signal with $F_{modulating}$ = 1 khz gives the following modulated signal:



Matlab code:

```matlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sampling_frequency = 10e4;
time = 0:1/sampling_frequency:1;

modulating_frequency = 1e3; % Change to 5e3 / 1e3 for question 1-3
modulating_amplitude = 1;

carrier_frequency = 10e3; % Change to 100e3 for question 1-3
carrier_amplitude = 5;

f_modulant_square = 1e3;
A_modulant_square = 1;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
modulating_signal = modulating_amplitude * cos(2 * pi * modulating_frequency * time);
carrier_signal = carrier_amplitude * cos(2 * pi * carrier_frequency * time);
amplitude_modulated_signal = modulating_signal .* carrier_signal;

T_modulating = 1/modulating_frequency;
T_carrier = 1/carrier_frequency;
T_amplitude_modulated = 1/modulating_frequency;
normalized_carrier_signal = carrier_signal / max(abs(carrier_signal));

modulant_square = A_modulant_square * sign(sin(2 * pi * f_modulant_square * time));
amplitude_modulated_squared_signal = modulant_square .* carrier_signal;

N_modulating = length(modulating_signal);
frequencies_modulating = linspace(0, sampling_frequency/2, N_modulating/2);
fft_modulating = abs(fft(modulating_signal)/N_modulating);


N_carrier = length(normalized_carrier_signal);
frequencies_carrier = linspace(0, sampling_frequency/2, N_carrier/2);
fft_carrier = abs(fft(normalized_carrier_signal)/N_carrier);

N_amplitude_modulated = length(amplitude_modulated_signal);
frequencies_amplitude_modulated = linspace(0, sampling_frequency/2, N_amplitude_modulated/2);
fft_amplitude_modulated = abs(fft(amplitude_modulated_signal)/N_amplitude_modulated);


N_amplitude_modulated_squared = length(amplitude_modulated_squared_signal);
frequencies_amplitude_modulated_squared = linspace(0, sampling_frequency/2, N_amplitude_modulated_squared/2);
fft_amplitude_modulated_squared = abs(fft(amplitude_modulated_squared_signal)/N_amplitude_modulated_squared);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Plots %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure;
            %%%%%%%%%%%% 1.1 %%%%%%%%%%%%%
% Modulating Signal
subplot(2,1,1);
plot(time, modulating_signal);
title('Modulating Signal (Time Domain)');
xlabel('Time (s)');
ylabel('Amplitude');
xlim([0, 3*T_modulating]);

% FFT Modulating Signal
subplot(2,1,2);
semilogy(frequencies_modulating, fft_modulating(1:length(frequencies_modulating)), 'r');
title('FFT Spectrum of Modulating Signal (semi-logarithmic scale)');
xlabel('Frequency (Hz)');
ylabel('Amplitude');

figure;

% Carrier Signal
subplot(2,1,1);
plot(time, normalized_carrier_signal);
title('Carrier Signal (Time Domain)');
xlabel('Time (s)');
ylabel('Amplitude (Normalized)');
xlim([0, 3*T_carrier]);

% FFT Carrier Signal
subplot(2,1,2);
semilogy(frequencies_carrier, fft_carrier(1:length(frequencies_carrier)), 'r');
title('FFT Spectrum of Carrier Signal (semi-logarithmic scale)');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
            %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
            %%%%%%%%%%%% 1.2 %%%%%%%%%%%%%
% Amplitude Modulated Signal
subplot(2,1,1);
plot(time, amplitude_modulated_signal);
title('Amplitude Modulated Signal (Time Domain)');
xlabel('Time (s)');
ylabel('Amplitude');
xlim([0, 3*T_amplitude_modulated]);

% FFT Amplitude Modulated Signal
subplot(2,1,2);
semilogy(frequencies_amplitude_modulated, fft_amplitude_modulated(1:length(frequencies_amplitude_modulated)), 'r');
title('FFT Spectrum of Amplitude Modulated Signal (semi-logarithmic scale)');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
            %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
            %%%%%%%%%%%% 1.3 %%%%%%%%%%%%%
% Amplitude Modulated Squared Signal
subplot(2,1,1);
plot(time, amplitude_modulated_signal);
title('Amplitude Modulated Signal (Time Domain)');
xlabel('Time (s)');
ylabel('Amplitude');
xlim([0, 3*T_amplitude_modulated]);

% FFT Amplitude Modulated Squared Signal
subplot(2,1,2);
semilogy(frequencies_amplitude_modulated_squared, fft_amplitude_modulated_squared(1:length(frequencies_amplitude_modulated_squared)), 'r');
title('FFT Spectrum of squared AM Signal  (semi-logarithmic scale)');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
            %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

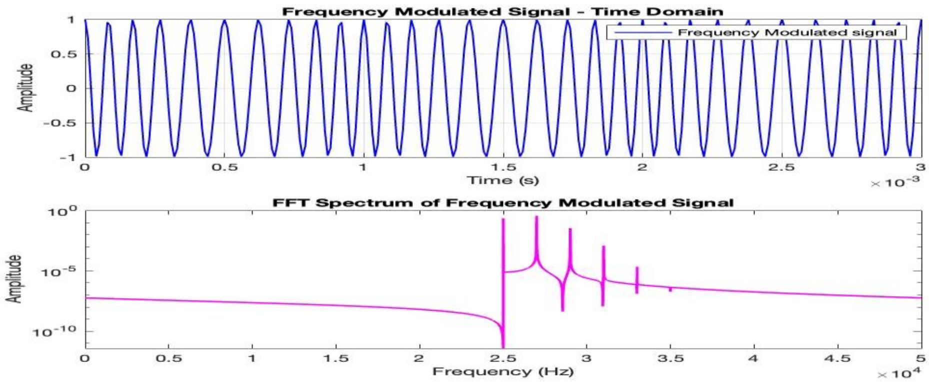
TP 2: Introduction to Angular Modulation.

Question 1:

To generate a frequency-modulated (FM) signal we can use the following formula:

$$S(t) = A_{modulating} \cdot \cos(2\pi \cdot F_{carrier} \cdot t + \beta \sin(2\pi F_{modulating} t))$$

With the given parameters: $A_{modulating} = 1$; $F_{carrier} = 10$ kHz ; $F_{modulating} = 1$ KHz ; $\beta = 2$



Carson_band determination:

$$\text{Carson\_band} = 2*(\text{ß\_index} + 1) \times F_{modulating} = 6\,000 \text{ Hz}$$

Question 2:

- Changing the carrier's frequency $F_{carrier}$ to 100khz gives the following Carson Band:

$$\text{Carson\_band} = 2(ß + 1) \times F_{modulating} = 6\,000 \text{ Hz}$$

- Changing the modulating's frequency $F_{modulating}$ to 5khz gives the following Carson Band:

$$\text{Carson\_band} = 2(ß + 1) \times F_{modulating} = 30\,000 \text{ Hz}$$

- Changing the modulating's frequency $F_{modulating}$ to 1khz and the amplitude $A_{modulating}$ to 5 gives the following Carson Band:

$$\text{Carson\_band} = 2(ß + 1) \times F_{modulating} = 30\,000 \text{ Hz}$$

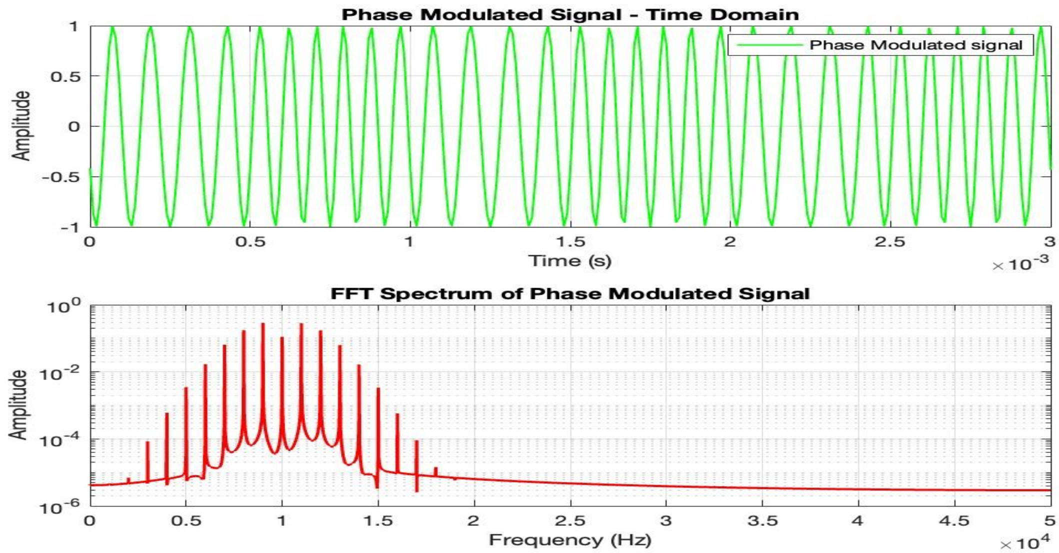
With: $ß = \frac{k_f \cdot A_{modulating}}{f_{modulating}}$

Conclusion: The bandwidth of a frequency-modulated signal, known as Carson's bandwidth, is directly proportional to the amplitude of the modulating signal and inversely proportional to the frequency of the modulating signal. Higher modulating signal amplitudes and lower modulating signal frequencies result in wider Carson's bandwidth, affecting the overall spectral occupancy of the modulated signal.

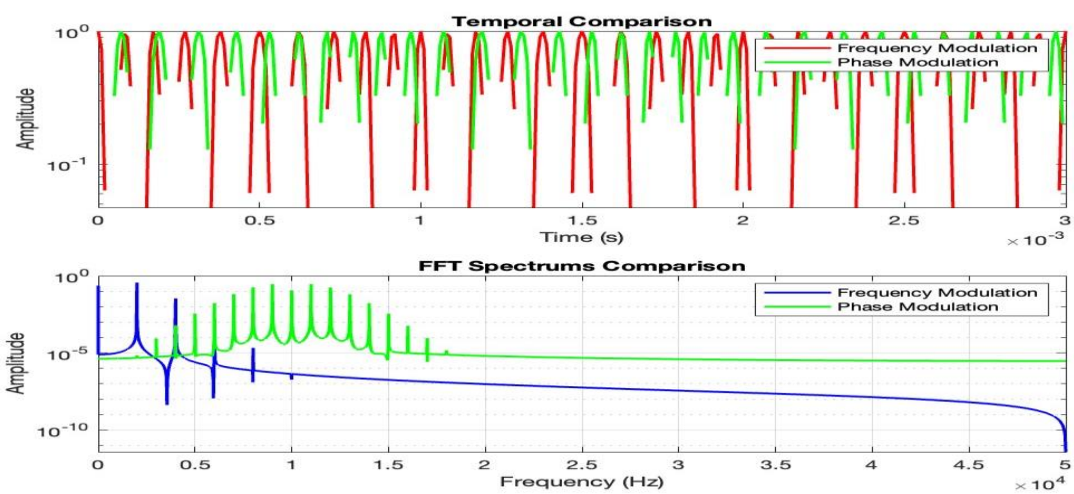
Question 3:

To generate a Phase-modulated (PM) signal with the earlier given parameters you provided, we can use the following formula:

$$S(t) = A_{modulating} \cdot \cos(2\pi \cdot F_{carrier} \cdot t + \beta \cos(2\pi F_{modulating} t))$$



Comparisons between the frequency modulated signal and the phase modulated signal:



Conclusion: A phase-modulated signal's bandwidth is influenced by the modulating signal's amplitude, while a frequency-modulated signal's bandwidth is primarily determined by the frequency deviation. Phase modulation is more sensitive to amplitude variations, resulting in wider bandwidth changes compared to frequency modulation, where the bandwidth is predominantly controlled by the frequency deviation.

<u>Matlab Code:</u>

```matlab
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Parameters %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
sampling_rate = 10e4;
time = 0:1/sampling_rate:1;
f_modulating = 1e3; % change to 5e3 (question 2-b) % change to 1e3 (question 2-c)
A_modulating = 1; % change to 5 (question 2-c)
f_carrier = 10e3; % change to 100e3 (question 2-a)
A_carrier = 1;
beta_index = 2;
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Calculations %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
modulating_signal = A_modulating * cos(2 * pi * f_modulating * time);
carrier_signal = A_carrier * cos(2 * pi * f_carrier * time);
% frequency modulation (FM)
signal_freq_modulation = A_carrier .* cos(2 * pi * f_carrier * time + beta_index * sin(2 * pi * f_modulating * time));
T_freq_modulation = 1/f_modulating;
% phase modulation (PM)
signal_phase_modulation = A_carrier .* cos(2 * pi * f_carrier * time + beta_index * cos(2 * pi * f_modulating * time));
T_phase_modulation = 1/f_modulating;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Plots %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

         %%%%%%%%%%%% 2.1 %%%%%%%%%%%%%
% Time-domain visualization of the frequency modulated signal
figure;
subplot(2, 1, 1);
plot(time, signal_freq_modulation, 'b', 'LineWidth', 1);
title('Frequency Modulated Signal - Time Domain');
xlabel('Time (s)');
ylabel('Amplitude');
legend('Frequency Modulated signal');
xlim([0, 3*T_freq_modulation]);
grid on;
% FFT of the frequency modulated signal:
subplot(2, 1, 2);
semilogy(frequencies_freq_modulation, fftshift(ff_freq_modulation(1:length(frequencies_freq_modulation))), 'm', 'LineWidth', 1.5);
title('FFT Spectrum of Frequency Modulated Signal');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
          %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

          %%%%%%%%%%%% 2.2 %%%%%%%%%%%%%
% change to 5e3 (question 2-b) % change to 1e3 (question 2-c)
% change to 5 (question 2-c)
% change to 100e3 (question 2-a)
          %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
          %%%%%%%%%%%% 2.3 %%%%%%%%%%%%%
% Time-domain visualization of the phase modulated signal
figure;
subplot(2, 1, 1);
plot(time, signal_phase_modulation, 'g', 'LineWidth', 1);
title('Phase Modulated Signal - Time Domain');
xlabel('Time (s)');
ylabel('Amplitude');
legend('Phase Modulated signal');
xlim([0, 3*T_phase_modulation]);
grid on;

% FFT of the phase modulated signal:
subplot(2, 1, 2);
semilogy(frequencies_phase_modulation, ff_phase_modulation(1:length(frequencies_phase_modulation)), 'r', 'LineWidth', 1.5);
title('FFT Spectrum of Phase Modulated Signal');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
grid on;
%%
% Time comparison:
subplot(2, 1, 1);
semilogy(time, signal_freq_modulation, 'r', 'LineWidth', 1.5);
hold on;
semilogy(time, signal_phase_modulation, 'g', 'LineWidth', 1.5);
hold off;
title('Temporal Comparison');
xlabel('Time (s)');
ylabel('Amplitude');
legend('Frequency Modulation', 'Phase Modulation');
xlim([0, 3*T_freq_modulation]);

% FFT Spectrums comparison:
subplot(2, 1, 2);
semilogy(frequencies_freq_modulation, ff_freq_modulation(1:length(frequencies_freq_modulation)), 'b', 'LineWidth', 1.5);
title('FFT Spectrums Comparison');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
legend('Frequency Modulation');
grid on;
hold on;
N_phase_modulation = length(signal_phase_modulation);
frequencies_phase_modulation = linspace(0, sampling_rate/2, N_phase_modulation/2);
ff_phase_modulation = abs(fft(signal_phase_modulation)/N_phase_modulation);
plot(frequencies_phase_modulation, ff_phase_modulation(1:length(frequencies_phase_modulation)), 'g', 'LineWidth', 1.5);
hold off;
title('FFT Spectrums Comparison');
xlabel('Frequency (Hz)');
ylabel('Amplitude');
legend('Frequency Modulation', 'Phase Modulation');
              %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```