Communication theory Project_CIE 337:

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Part A:

- Matlab code for variables:

```
%% Time space for simulation
fc = 5e3; % Carrier frequency in Hz
fs = 1000 * fc; % Sampling frequency (50 kHz) 1000 times the frequency of
the carrier for better visualization
Ts = 1 / fs; % Sampling period
T = 0.004; % Total simulation time (4 ms)
t = 0:Ts:T; % Time vector
```

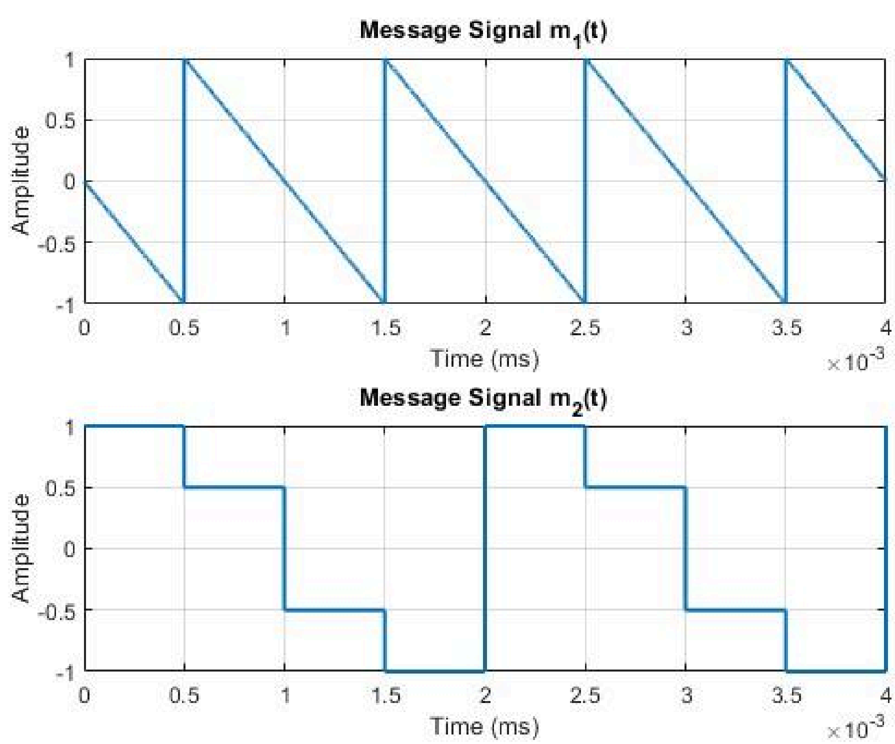
1- Message Signal Generation & plotting:

- Matlab code:

```
fm1 = 1000; % Frequency of m1 in Hz

Tm2 = 2e-3; % Period of m2 in seconds

fm2 = 1 / Tm2; % Frequency of m2 in Hz

m1 = sawtooth((2*pi*fm1*t) + pi, 0); % Corrected to start from 0

m2 = zeros(size(t));

shift = mod(t, Tm2); % Repeat the step function every period

m2(shift < 0.5e-3) = 1;

m2((shift >= 0.5e-3) & (shift < 1e-3)) = 0.5;

m2((shift >= 1e-3) & (shift < 1.5e-3)) = -0.5;

m2(shift >= 1.5e-3) = -1;

figure;

subplot(2,1,1);

plot(t, m1, 'LineWidth', 1.5);
```

```
title('Message Signal m_1(t)');

xlabel('Time (ms)');

ylabel('Amplitude');

grid on;

subplot(2,1,2);

plot(t, m2, 'LineWidth', 1.5);

title('Message Signal m_2(t)');

xlabel('Time (ms)');

ylabel('Amplitude');

grid on;
```

- m1(t)) is a **triangular waveform** (sawtooth-type), periodic and continuous, and m2(t) is a **piecewise constant signal** (digital-style steps).
- Message signals figures:



2-Generate & plot the modulated signal s(t):

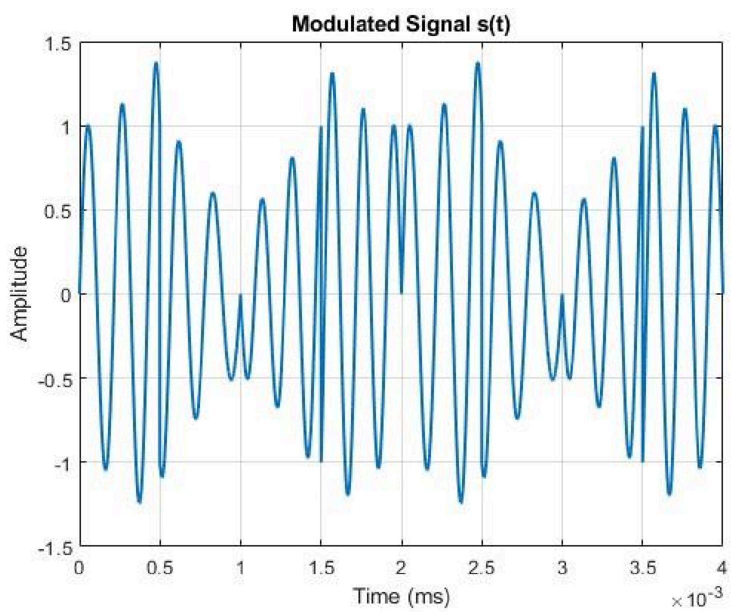
- s(t)=Acm1(t)cos(2πfct)+Acm2(t)sin(2πfct)

- Matlab code:

```
%% Generating the Carrier Signals.
c1 = cos(2*pi*fc*t);
c2 = sin(2*pi*fc*t);
%% Modulating the Signals using QAM Technique
s = (m1 .* c1) + (m2 .* c2);
figure;
plot(t, s, 'LineWidth', 1.5);
title('Modulated Signal s(t)');
xlabel('Time (ms)');
ylabel('Amplitude');
grid on;
```

☐ **DSB-QAM signal** uses orthogonal carriers (sine and cosine) to load two distinct signals into the same frequency spectrum.
☐ The envelope or shape of the modulated signal depends on both m1(t) and m2(t)
☐ The variations in the signal's amplitude *and* phase influence the zero-crossings and peak locations.

- Modulated Signal figure:



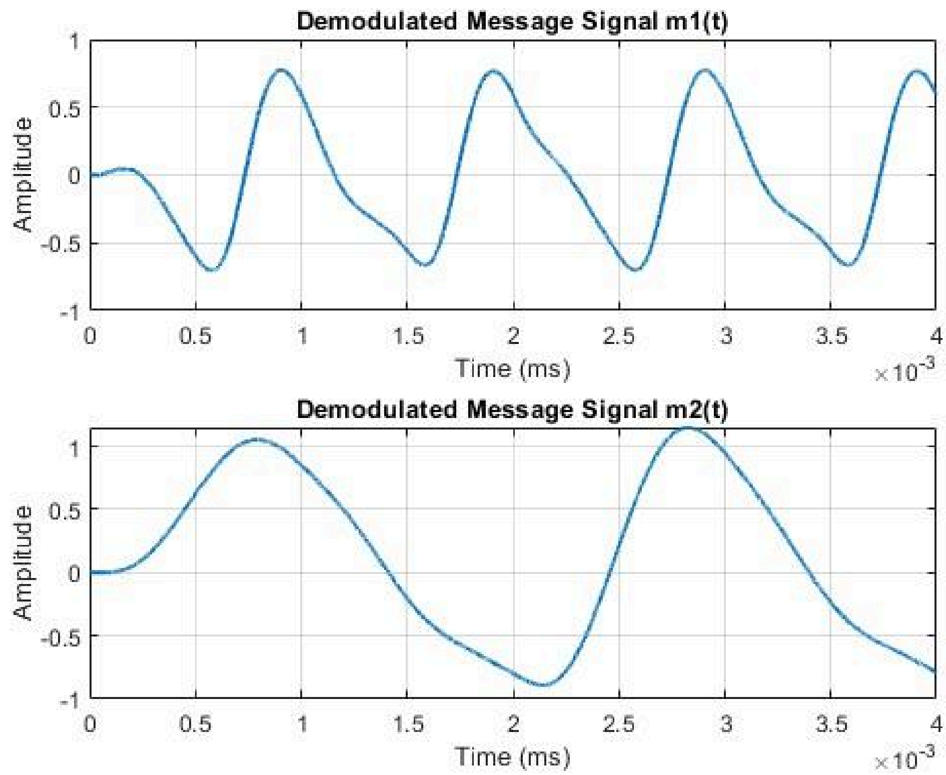
3- Implement receiver of DSB-QAM m1(t) and m2(t):

- c1(t) = cos(2 pi fct)
- c2(t) = sin(2 pi fct)
- Matlab code:

```
%% Implementing the QAM Receiver
% Implementing the carrier signal (normal case)
rc1 = 2 * cos(2*pi*fc*t);
rc2 = 2 * sin(2*pi*fc*t);
x1 = s .* rc1;
x2 = s .* rc2;
% Design Butterworth low-pass filters
[b1, a1] = butter(4, 2*fm1/(fs/2)); % Filter for m1_demodulated
[b2, a2] = butter(4, 2*fm2/(fs/2)); % Filter for m2_demodulated
% Apply the Butterworth filters
m1_demodulated = filter(b1, a1, x1);
m2_demodulated = filter(b2, a2, x2);
```

- [ ] Following low-pass filtering and coherent demodulation (multiplication by 2*cos(2*pi*fc*t), and 2*sin(2*pi*fc*t) this plot displays the restored original signals. The apparent smoothness and loss of sharp details are caused by the low-pass filter's inability to filter part of the original message signal's higher frequency components, even while it effectively eliminates the high-frequency components (about 2fc) produced during demodulation. Nonetheless, the essential form and content of the material are mainly maintained.
- [ ] The used filter is a Butterworth low-pass filter with order 4, and 2*fm1/(fs/2) is the cut-off frequency.
- [ ] However, the receiver has successfully separated m1(t) and m2(t) due to the orthogonality of the carriers used in modulation and demodulation.

- Demodulated Signals:



4- Receiver with phase offset (cos(2 pi fct+pi/3)):

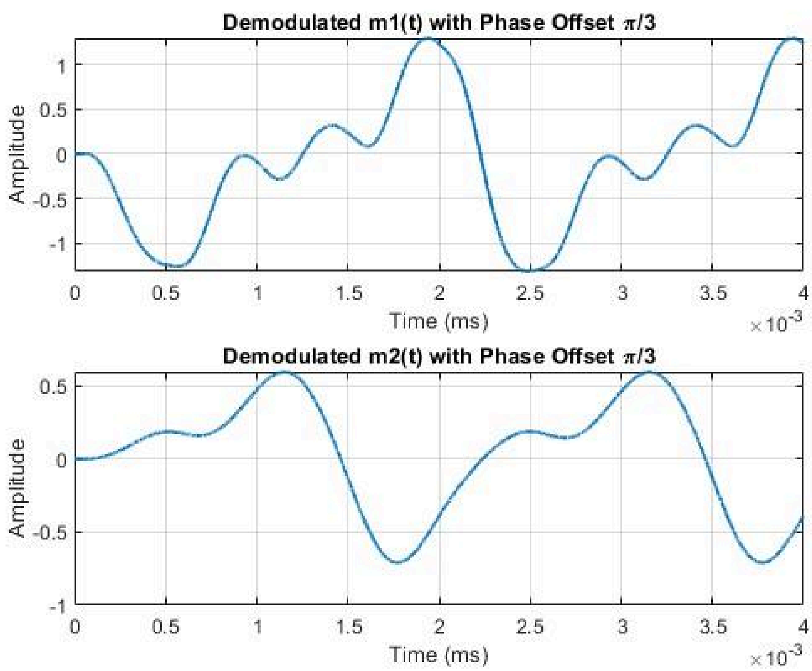
- Matlab code:

```
%% POINT 4: Phase Offset at Receiver (π/3)
% New receiver carrier with phase offset
rc1_offset = 2 * cos(2*pi*fc*t + pi/3);
rc2_offset = 2 * sin(2*pi*fc*t + pi/3);
% Multiply the modulated signal with the phase-shifted carrier
x1_offset = s .* rc1_offset;
x2_offset = s .* rc2_offset;
% Apply the same filters
m1_phase_offset = filter(b1, a1, x1_offset);
m2_phase_offset = filter(b2, a2, x2_offset);
```

☐ The used filter is the same LPF used in part 3.

- [ ] This displays the output of the demodulator branch when 2cos(2πfct + π/3) is multiplied by the local oscillator's phase error = pi/3 with respect to the transmitter's carrier. The orthogonality between the carriers is lost as a result of the phase error. Theoretically, m1(t)cos(φ) - m2(t)sin(φ) equals the output. The output, plus filtering effects, is approximately 0.5m1(t) - 0.866*m2(t), since cos(π/3)=0.5 and sin(pi/3)= 0.866. Since the output is 0.886*m1(t)+05m2(t), this explains the significant distortion and the emergence of features from m2(t) in the m1(t) plot and the same in m2(t) plot. This is referred to as crosstalk.

- Demodulated signals figure using phase offset:



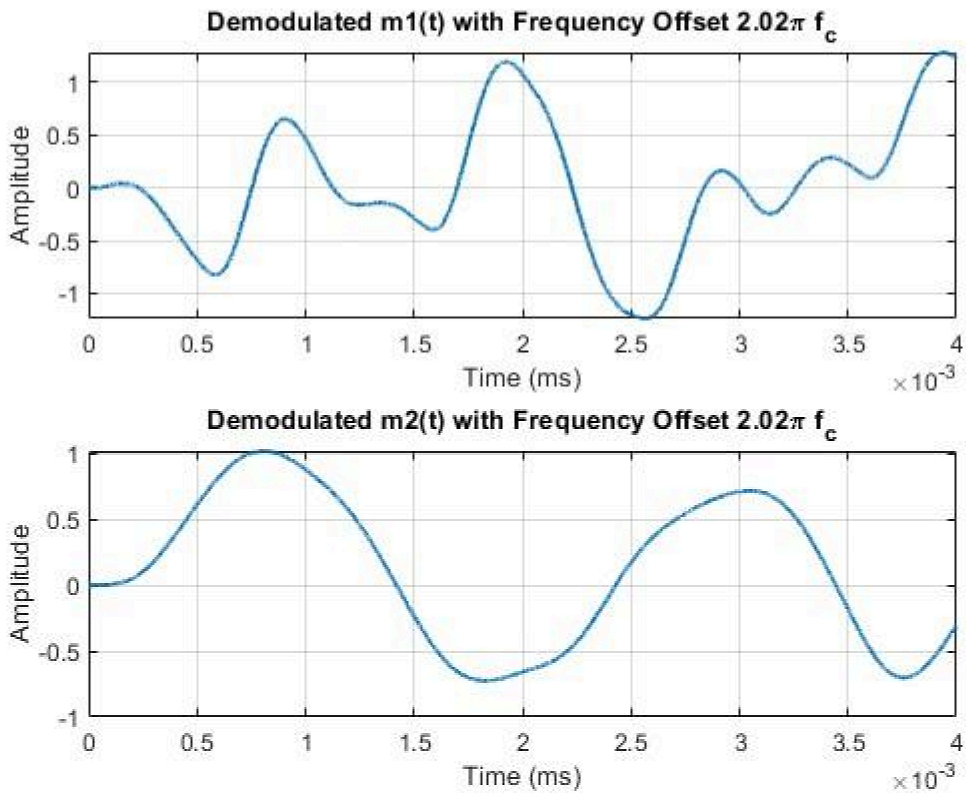
5- Receiver with frequency offset (cos(2.02 pi fct)):

- Matlab code:

```
%% POINT 5: Frequency Offset at Receiver (2.02πfₐt)
fc_offset = 1.01 * fc; % 1% frequency offset
rc1_freq_offset = 2 * cos(2*pi*fc_offset*t);
rc2_freq_offset = 2 * sin(2*pi*fc_offset*t);
% Multiply modulated signal with frequency offset carrier
x1_freq_offset = s .* rc1_freq_offset;
x2_freq_offset = s .* rc2_freq_offset;
% Filter to demodulate
m1_freq_offset = filter(b1, a1, x1_freq_offset);
m2_freq_offset = filter(b2, a2, x2_freq_offset);
```

- [ ] The outcome of demodulating using a local carrier frequency that differs somewhat from the transmitter's carrier (f_local = 1.01 * fc) is displayed in this plot. Δf is equal to 0.01 * fc, which is equal to 0.01 * 5 kHz, or 50 Hz. Terms such as m1(t)cos(2πΔft) and m2(t)sin(2πΔft) are present in the demodulated output. The target signal and the crosstalk component are multiplied by the slow sinusoidal variation (50 Hz) represented by the cos(2πΔft) and sin(2πΔft) terms. The original signal is totally jumbled by this time-varying strength and crosstalk, making recovery impossible.

- Demodulated signal using frequency offset:



Part B

❖ Matlab code for variables:

```
%% Time space for simulation
fc = 10e3; % Carrier frequency in Hz
fs = 1000 * fc; % Sampling frequency (10 MHz)
Ts = 1 / fs; % Sampling period
T = 0.004; % Total simulation time (4 ms)
t = 0:Ts:T; % Time vector
Ac = 1;
```

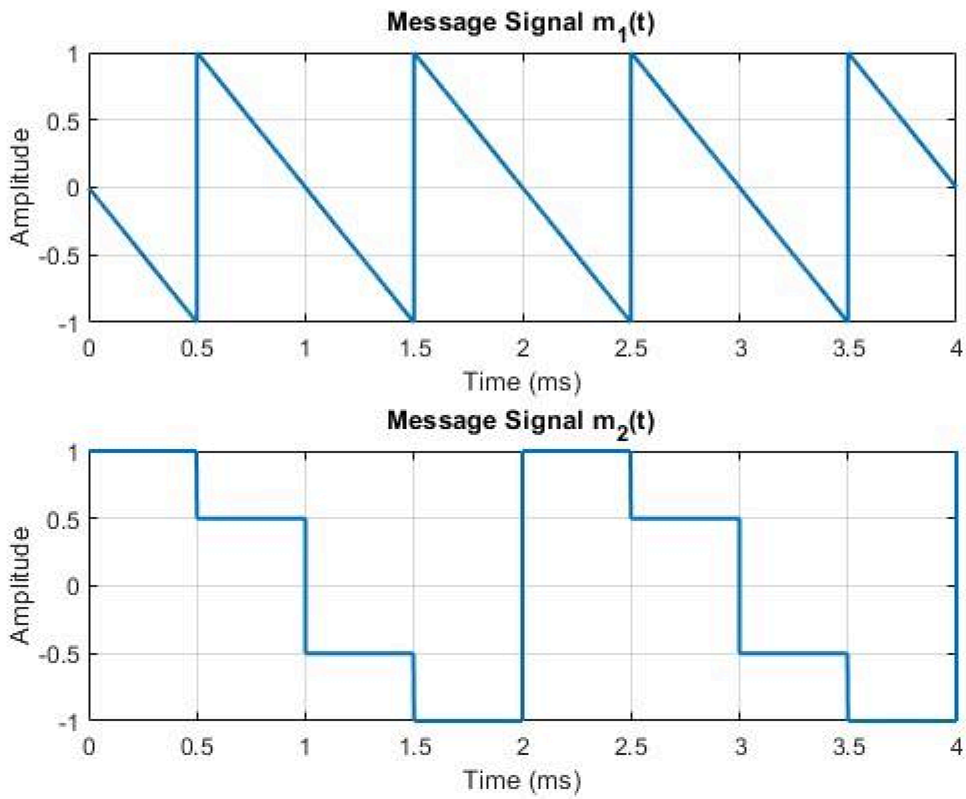
1- Message Signal Generation & plotting:

- Matlab code:

```
%% Generating the Message Signals

fm1 = 1000; % Frequency of m1 in Hz

Tm2 = 2e-3; % Period of m2 in seconds

fm2 = 1 / Tm2; % Frequency of m2 in Hz

m1 = sawtooth((2*pi*fm1*t) + pi, 0); % Sawtooth wave for m1

m2 = zeros(size(t)); % Step function for m2

shift = mod(t, Tm2); % Repeat every Tm2

% Step levels for m2

m2(shift < 0.5e-3) = 1;

m2((shift >= 0.5e-3) & (shift < 1e-3)) = 0.5;

m2((shift >= 1e-3) & (shift < 1.5e-3)) = -0.5;

m2(shift >= 1.5e-3) = -1;
```

☐ m1(t)) is a **triangular waveform** (sawtooth-type), periodic and continuous and m2(t) is a **piecewise constant signal** (digital-style steps).

- Generated message signals figure:



2- Phase Modulated Signal s1(t) with various kp:

- Matlab code:

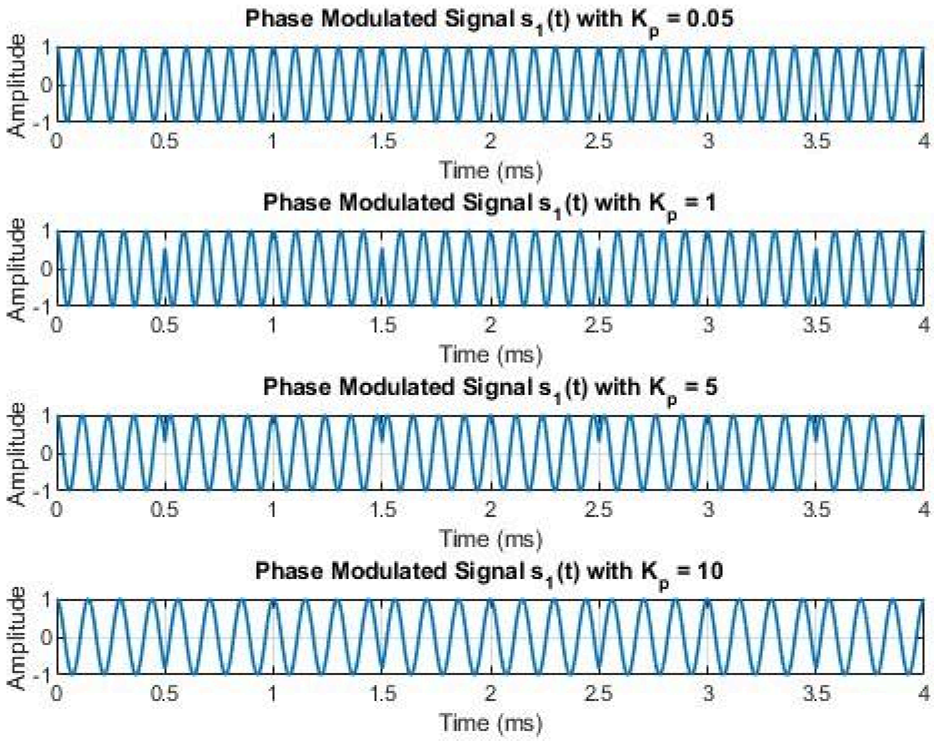
```
%% Phase Modulation for different values of Kp
Kp_values = [0.05, 1, 5, 10];
figure;
for i = 1:length(Kp_values)
    Kp = Kp_values(i);
    s1 = Ac * cos(2*pi*fc*t + Kp .* m1); % Phase modulation

    subplot(length(Kp_values),1,i);
    plot(t*1000, s1, 'LineWidth', 1.2);
    title(['Phase Modulated Signal s_1(t) with K_p = ', num2str(Kp)]);
    xlabel('Time (ms)');
```

```
    ylabel('Amplitude');
    grid on;
end
```

- [ ] For kp=0.05, the maximum phase deviation = kp * max|m1(t)| = 0.05 * 1 = 0.05 radians, which is very small and characteristic of narrowband PM. This is making the signal visually similar to the carrier. The oscillations appear very regular, almost like an unmodulated carrier.
- [ ] Forkp=1, the maximum phase deviation is 1 radian (approx. 57.3 degrees). The phase variations are more significant. The instantaneous frequency deviations are larger, causing visible compression/expansion of cycles corresponding to the slope of m1(t).

- [ ] For kp=5,the maximum phase deviation= 5 radians, or around 286 degrees,. This is referred to as Wideband PM. The instantaneous frequency changes dramatically as a result of the phase deviance. One can clearly see the optical distortion from a pure sinusoid.
- [ ] For kp = 10, the maximum phase deviation= 10 radians (about 573 degrees). This PM is very wideband. More than one full cycle ($2\pi \approx 6.28$ rad) separates the phases. The sharp apparent variations in cycle density are caused by the extremely huge instantaneous frequency swings.

- Modulated signal using different Kp values figure:



3-**Frequency Modulated Signal s2(t) using m2(t):**

- **s2(t) = Ac*cos(2πfct + kf * ∫m2(τ)dτ).**

- **Matlab code:**

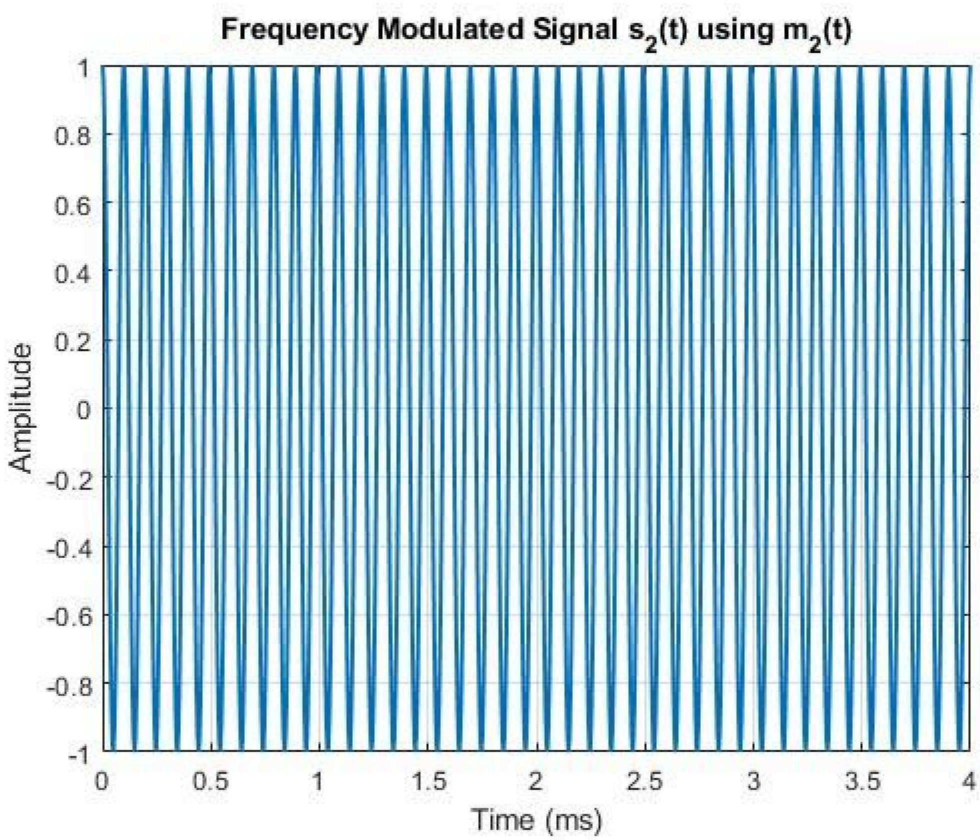
```
%% Frequency Modulation using m2(t), m1(t)
Kf = 1000; % Frequency sensitivity
Kf3 = 2000;
% Integrate m2(t) over time
int_m1 = cumsum(m1) * Ts;
int_m2 = cumsum(m2) * Ts; % Numerical integration
% Frequency modulated signal
s2 = Ac * cos(2*pi*fc*t + Kf * int_m2);
s3 = Ac * cos(2*pi*fc*t + Kf3 * int_m1);
```

- [ ] The instantaneous frequency is fi(t) = fc + (kf/2π) * m2(t). The frequency deviation constant Δf_unit is equal to kf/2π ≈ 159 Hz/Volt in this case, where fc=10kHz and kf=1000 (assuming units of rad/s/Volt).

- ☐ Fi = 10000 + 159 * 1 ≈ 10159 Hz for m2(t) = +1 (0-0.5ms).
- ☐ Fi = 10000 + 159 * 0.5 ≈ 10080 Hz for m2(t) = +0.5 (0.5-1ms).
- ☐ Fi = 10000 + 159 * (-0.5) ≈ 9920 Hz when m2(t) = -0.5 (1-1.5 ms).
- ☐ Fi is equal to 10000 + 159 * (-1) ≈ 9841 Hz for m2(t) = -1 (1.5-2ms).

- ☐ Alternatively, frequencies would be 11 kHz, 10.5 kHz, 9.5 kHz, and 9 kHz if kf=1000 Hz/Volt was the intended value.
- ☐ As the instantaneous frequency is precisely proportional to the amplitude of the message signal, the graphic effectively depicts FM via a staircase signal. The frequency changes to match constant values when m2(t) moves between constant levels; this is seen in the figure as varying cycle density.

- Frequency Modulated Signal s2(t) using m2(t) figure:



4- Frequency Modulated Signal s3(t) using m1(t):

- s3(t) = Ac*cos(2* pi*fc*t + kf * ∫m1(τ)dτ).

- Matlab code:

```
%% Frequency Modulation using m2(t), m1(t)
Kf = 1000; % Frequency sensitivity
Kf3 = 2000;
% Integrate m2(t) over time
int_m1 = cumsum(m1) * Ts;
int_m2 = cumsum(m2) * Ts; % Numerical integration
% Frequency modulated signal
s2 = Ac * cos(2*pi*fc*t + Kf * int_m2);
s3 = Ac * cos(2*pi*fc*t + Kf3 * int_m1);
```

- [ ] The shape of the wave m1(t), which varies linearly throughout linear ramps of m1(t), determines the instantaneous frequency, fi(t). The lowest frequency is 9682 Hz, and the highest frequency is 10000 + 318 * 1. With continuous changes in m1(t) translating into continuous changes in the instantaneous frequency, the graphic effectively illustrates FM with the sawtooth wave m1(t). At the peak of m1(t), the frequency is at its highest, and at the minimum of m1(t), it is at its lowest.

- Frequency Modulated Signal s3(t) using m1(t) figure: