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EXPERIMENT NO: 9

Frequency Division Multiplexing using MATLAB

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Abstract:

In this experiment, we're using MATLAB to explore something called Frequency Division Multiplexing (FDM). The goal is to achieve two main things: first, to get comfortable using MATLAB for solving communication problems, and second, to understand how FDM works and how to make it happen using MATLAB. This experiment is like a hands-on journey, helping us practice and learn how to use MATLAB for communication challenges and making FDM work. It's a cool way to connect what we learn in theory with real-life applications, making MATLAB and FDM concepts more understandable.

Theory:

Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted. In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link. Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel. Channels can be separated by strips of unused bandwidth—guard bands—to prevent signals from overlapping. In addition, carrier frequencies must not interfere with the original data frequencies.

Figure 1 gives a conceptual view of FDM. In this illustration, the transmission path is divided into three parts, each representing a channel that carries one transmission.

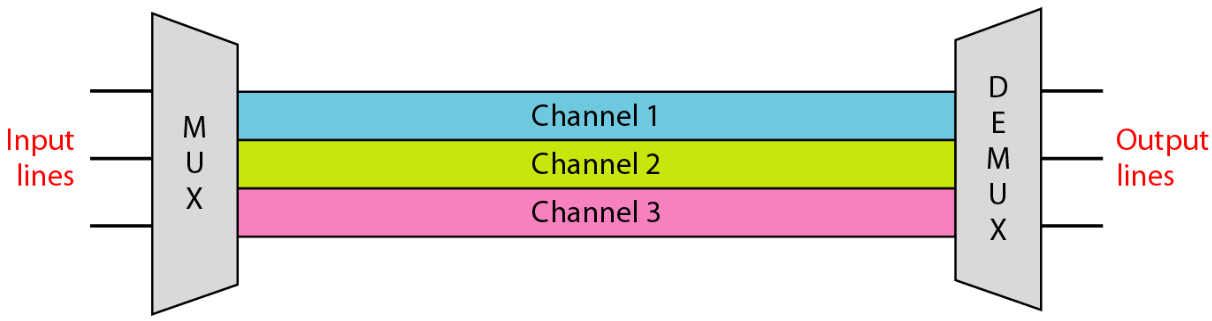


Figure 1: Frequency Division Multiplexing (FDM)

We consider FDM to be an analog multiplexing technique; however, this does not mean that FDM cannot be used to combine sources sending digital signals. A digital signal can be converted to an analog signal (Using ASK, FSK, PSK, QAM) before FDM is used to multiplex them.

Multiplexing Process: Figure 2 is a conceptual illustration of the multiplexing process. Each source generates a signal of a similar frequency range. Inside the multiplexer, these similar signals modulate different carrier frequencies (f_1, f_2, and f_3). The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

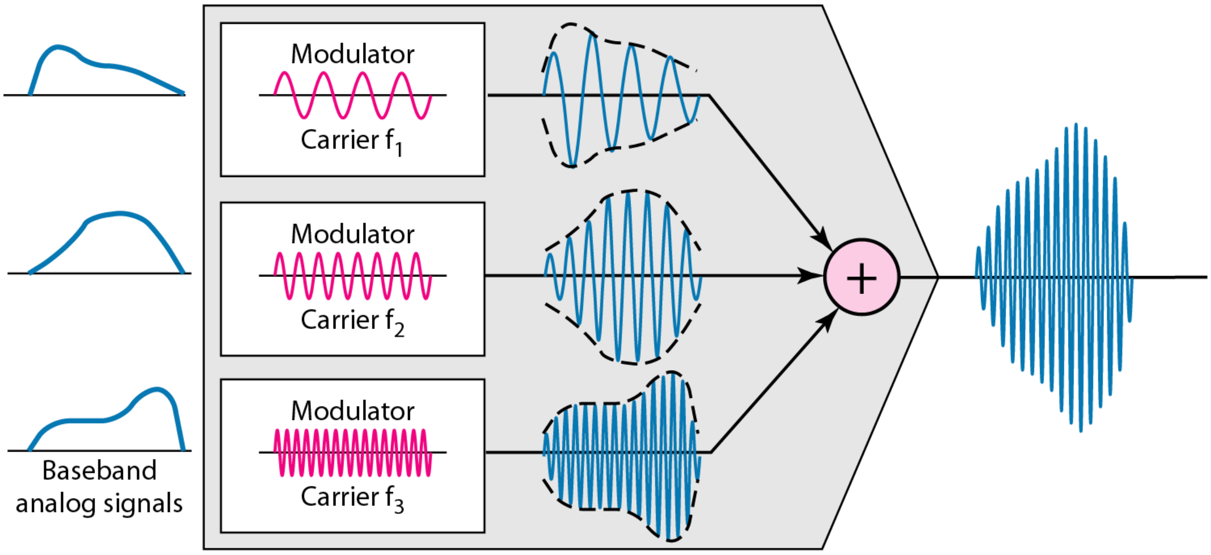


Figure 2: Multiplexing Process in FDM

Demultiplexing Process: The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines. Figure 3 is a conceptual illustration of demultiplexing process.

Implementation: FDM can be implemented very easily. In many cases, such as radio and television broadcasting, there is no need for a physical multiplexer or demultiplexer. As long a the stations agree to send their broadcasts to the air using different carrier frequencies, multiplexing is achieved. **To make sure we are transmitting signals in different frequencies we need to use AM, FM, PM with suitable carrier frequencies.** In other cases, such as the cellular telephone system, a base station needs to assign a carrier frequency to the telephone user. There is not enough bandwidth in a cell to permanently assign a bandwidth range to every telephone user. When a user hangs up, her or his bandwidth is assigned to another caller.

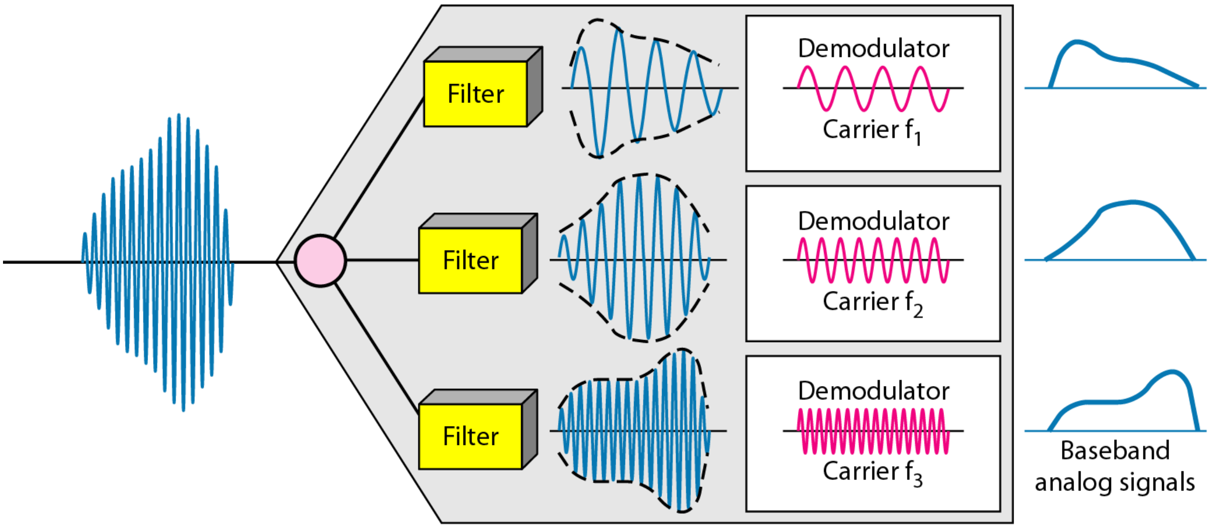


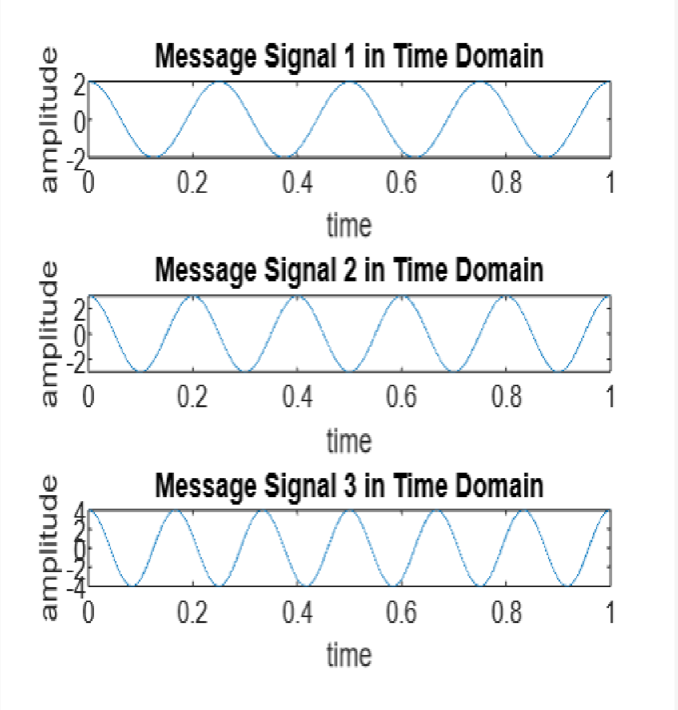
Figure 3: De-multiplexing Process in FDM

Results:

```
>> %Matlab Program for Frequency Division Multiplexing
clc
clear all
close all
%% Message Signal Generation
fs = 4001; %Sampling Frequency
t = 0:1/fs:1-1/fs; %Generating Time axis
Am1 = 2; %Amplitude of First Message Signal
fm1 = 4; %Frequency of First Message Signal
m1 = Am1*cos(2*pi*fm1*t); % First Message Signal
Am2 = 3; %Amplitude of Second Message Signal
fm2 = 5; %Frequency of Second Message Signal
m2 = Am2*cos(2*pi*fm2*t); % Second Message Signal
Am3 = 4; %Amplitude of Third Message Signal
fm3 = 6; %Frequency of Third Message Signal
m3 = Am3*cos(2*pi*fm3*t); % Third Message Signal
%%
%% Carrier Signal Generation
Cm1 = 1; %Amplitude of First Carrier Signal
fc1 = 100; %Frequency of First Carrier Signal
```

```
c1 = Cm1*cos(2*pi*fc1*t); % First Carrier Signal
Cm2 = 1; %Amplitude of Second Carrier Signal
fc2 = 170; %Frequency of Second Carrier Signal
c2 = Cm2*cos(2*pi*fc2*t); % Second Carrier Signal
Cm3 = 1; %Amplitude of Third Carrier Signal
fc3 = 250; %Frequency of Third Carrier Signal
c3 = Cm3*cos(2*pi*fc3*t); % Third Carrier Signal
%%
%% Composite Signal Generation
x = (m1).*c1+(m2).*c2+(m3).*c3;
%%%% Plotting the Signals in Time-Domain and Frequency-Domain
figure
subplot(3,1,1)
plot(t,m1)
xlabel('time')
ylabel('amplitude')
title('Message Signal 1 in Time Domain')
ylim([-Am1 Am1])
subplot(3,1,2)
plot(t,m2)
```

```
xlabel('time')
ylabel('amplitude')
title('Message Signal 2 in Time Domain')
ylim([-Am2 Am2])
subplot(3,1,3)
plot(t,m3)
xlabel('time')
ylabel('amplitude')
title('Message Signal 3 in Time Domain')
ylim([-Am3 Am3])
M1 = abs(fftshift(fft(m1)))/(fs/2); %Fourier Transformation of m1
M2 = abs(fftshift(fft(m2)))/(fs/2); %Fourier Transformation of m2
M3 = abs(fftshift(fft(m3)))/(fs/2); %Fourier Transformation of m3
X = abs(fftshift(fft(x)))/(fs/2); %Fourier Transformation of x
f = fs/2*linspace(-1,1,fs);
figure
subplot(3,1,1)
stem(f,M1)
xlabel('frequency')
ylabel('amplitude')
title('Message Signal 1 in Frequency Domain')
```



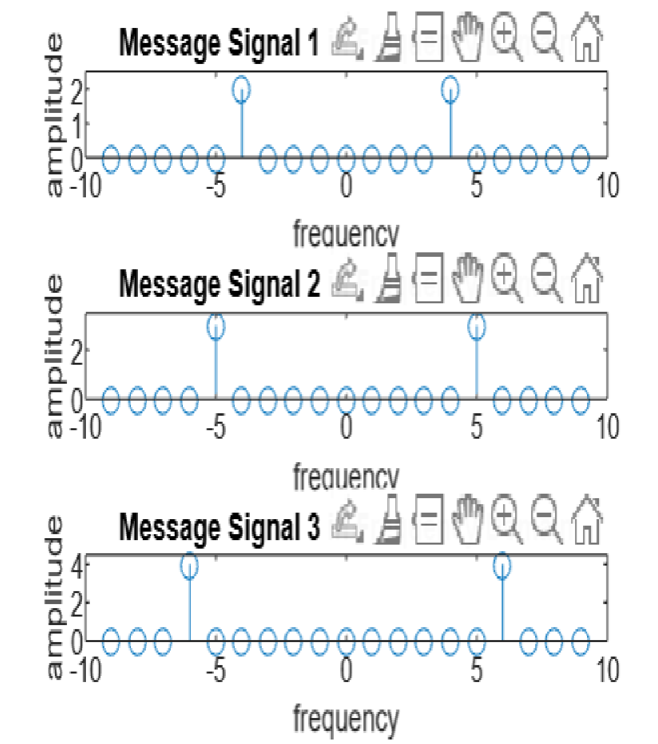


Figure 4.1: Frequency Division Multiplexing

```
axis([-10 10 0 2.5])
subplot(3,1,2)
stem(f,M2)
xlabel('frequency')
ylabel('amplitude')
title('Message Signal 2 in Frequency Domain')
axis([-10 10 0 3.5])
subplot(3,1,3)
stem(f,M3)
xlabel('frequency')
ylabel('amplitude')
title('Message Signal 3 in Frequency Domain')
axis([-10 10 0 4.5])
figure
subplot(2,1,1)
plot(t,x)
xlabel('time')
ylabel('amplitude')
title('Composite Signal in Time Domain')
subplot(2,1,2)
stem(f,X)
xlabel('frequency')
ylabel('amplitude')
title('Composite Signal in Frequency Domain')
axis([-270 270 0 2.5])
%%
%% Passing the Composite Signal Through Bandpass Filter
[num1, den1] = butter(5, [(fc1-fm1-6)/(fs/2),(fc1+fm1+6)/(fs/2)]);
%Butterworth Filter Window Determining for Bandpass Filter
bpf1 = filter(num1,den1,x); %Filtering is done here
[num2, den2] = butter(5, [(fc2-fm2-6)/(fs/2),(fc2+fm2+6)/(fs/2)]);
%Butterworth Filter Window Determining for Bandpass Filter
bpf2 = filter(num2,den2,x); %Filtering is done here
[num3, den3] = butter(5, [(fc3-fm3-6)/(fs/2),(fc3+fm3+6)/(fs/2)]);
%Butterworth Filter Window Determining for Bandpass Filter
bpf3 = filter(num3,den3,x); %Filtering is done here
%%
%% Mixing
z1 = 2*bpf1.*c1;
z2 = 2*bpf2.*c2;
z3 = 2*bpf3.*c3;
%% Passing the Mixed Signals Through Lowpass Filter
[num4, den4] = butter(5, (fm1+3)/(fs/2)); %Low pass filter is made here
rec1 = filter(num4,den4,z1); %Filtering is done here
[num5, den5] = butter(5, (fm2+3)/(fs/2)); %Low pass filter is made here
rec2 = filter(num5,den5,z2); %Filtering is done here
[num6, den6] = butter(5, (fm3+3)/(fs/2)); %Low pass filter is made here
rec3 = filter(num6,den6,z3); %Filtering is done here
%%
%% Plotting the Received Signals in Time-Domain and Frequency Domain
figure
subplot(3,1,1)
plot(t,rec1)
xlabel('time')
ylabel('amplitude')
title('received signal 1 in time domain')
ylim([-Am1 Am1])

subplot(3,1,2)
plot(t,rec2)
xlabel('time')
ylabel('amplitude')
title('received signal 2 in time domain')
ylim([-Am2 Am2])

subplot(3,1,3)
plot(t,rec3)
xlabel('time')
ylabel('amplitude')
title('received signal 3 in time domain')
ylim([-Am3 Am3])

R1 = abs(fftshift(fft(rec1)))/(fs/2); %Fourier Transformation is done here
R2 = abs(fftshift(fft(rec2)))/(fs/2); %Fourier Transformation is done here
R3 = abs(fftshift(fft(rec3)))/(fs/2); %Fourier Transformation is done here

figure
subplot(3,1,1)
stem(f,R1)
xlabel('frequency')
ylabel('amplitude')
title('received signal 1 in frequency domain')
xlim([-10 10])

subplot(3,1,2)
stem(f,R2)
xlabel('frequency')
ylabel('amplitude')
title('received signal 2 in frequency domain')
xlim([-10 10])

subplot(3,1,3)
stem(f,R3)
xlabel('frequency')
ylabel('amplitude')
title('received signal 3 in frequency domain')
xlim([-10 10])
%% End
```

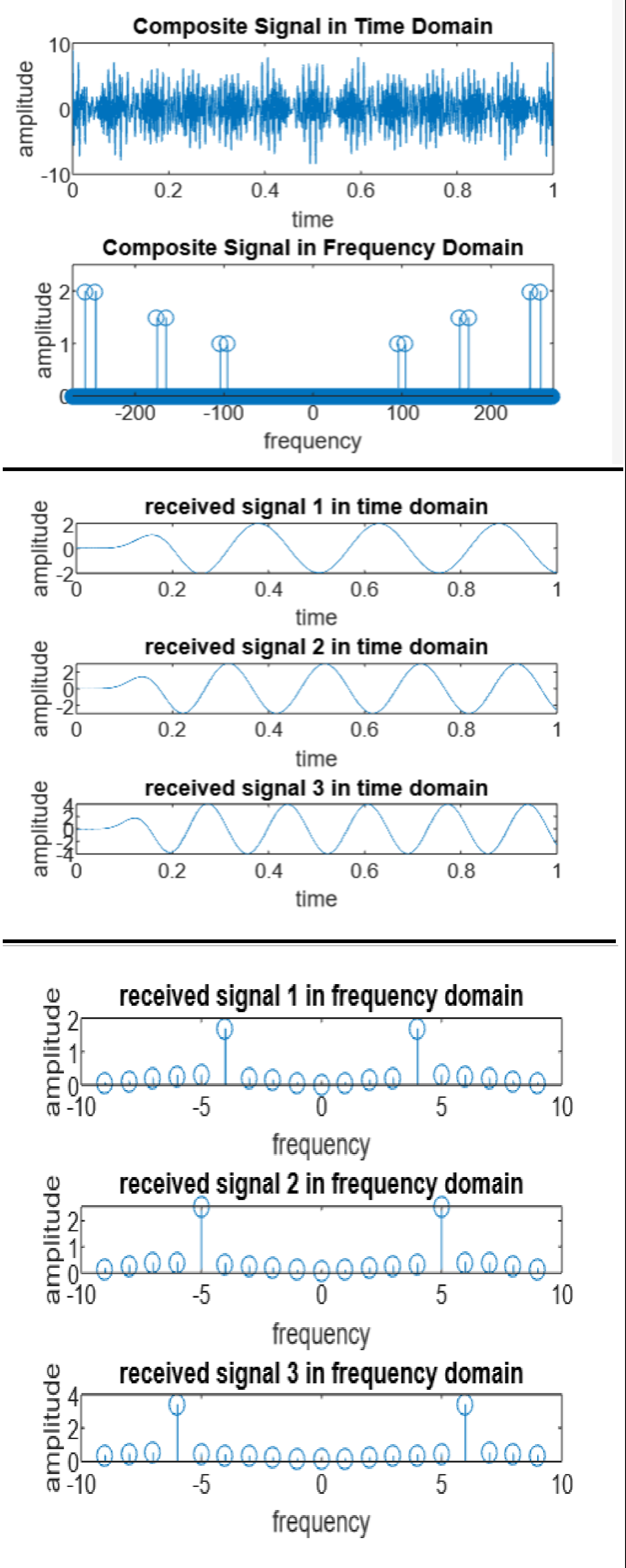
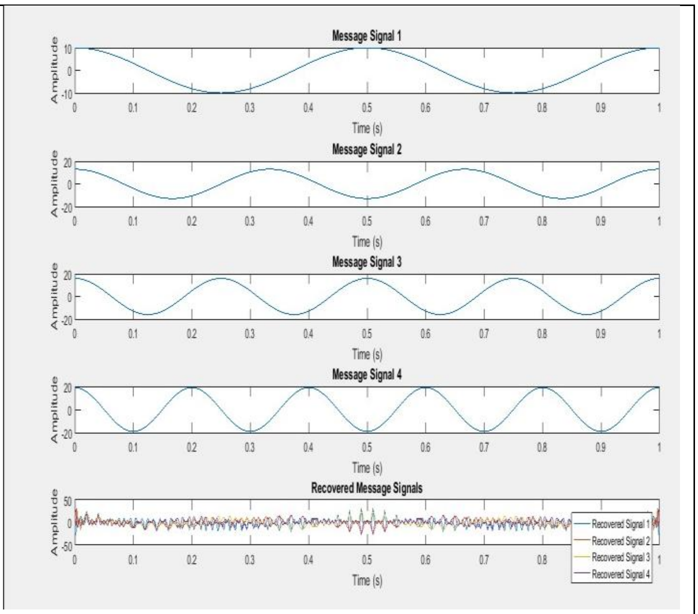


Figure 4.2: Frequency Division Multiplexing

Performance Task:

ID=AB-CDEFG-H **ID=21-45081-2**	**F=8** **G=1**

```
% Parameters
F = 8;
G = 1;
fs = 1000; % Sampling frequency
t = 0:1/fs:1; % Time vector
% Message signals
am1 = F + 2;
am2 = F + 5;
am3 = F + 8;
am4 = F + 11;
fm1 = G + 1;
fm2 = G + 2;
fm3 = G + 3;
fm4 = G + 4;
mt1 = am1 * cos(2 * pi * fm1 * t);
mt2 = am2 * cos(2 * pi * fm2 * t);
mt3 = am3 * cos(2 * pi * fm3 * t);
mt4 = am4 * cos(2 * pi * fm4 * t);
% Carrier signals for amplitude modulation
fc1 = 100;
fc2 = 150;
fc3 = 200;
fc4 = 250;
% Modulation
st1 = am1 * cos(2 * pi * fc1 * t) .* cos(2 * pi *
fm1 * t);
st2 = am2 * cos(2 * pi * fc2 * t) .* cos(2 * pi *
fm2 * t);
st3 = am3 * cos(2 * pi * fc3 * t) .* cos(2 * pi *
fm3 * t);
st4 = am4 * cos(2 * pi * fc4 * t) .* cos(2 * pi *
fm4 * t);
% Multiplexing
st = st1 + st2 + st3 + st4;
% Demultiplexing
f_cutoff_low = 50;
f_cutoff_high = 250;
[b, a] = butter(6, [f_cutoff_low, f_cutoff_high] /
(fs / 2), 'bandpass');
rt = filtfilt(b, a, st);
% Demodulation
demt1 = rt .* cos(2 * pi * fc1 * t);
demt2 = rt .* cos(2 * pi * fc2 * t);
demt3 = rt .* cos(2 * pi * fc3 * t);
demt4 = rt .* cos(2 * pi * fc4 * t);
```



```
% Lowpass filtering
[b_lp, a_lp] = butter(6, f_cutoff_high / (fs / 2),
'low');
mt1_recovered = filtfilt(b_lp, a_lp, demt1);
mt2_recovered = filtfilt(b_lp, a_lp, demt2);
mt3_recovered = filtfilt(b_lp, a_lp, demt3);
mt4_recovered = filtfilt(b_lp, a_lp, demt4);
% Plot the results
figure;
subplot(5, 1, 1);
plot(t, mt1);
title('Message Signal 1');
xlabel('Time (s)');
ylabel('Amplitude');
subplot(5, 1, 2);
plot(t, mt2);
title('Message Signal 2');
xlabel('Time (s)');
ylabel('Amplitude');
subplot(5, 1, 3);
plot(t, mt3);
title('Message Signal 3');
xlabel('Time (s)');
ylabel('Amplitude');
subplot(5, 1, 4);
plot(t, mt4);
title('Message Signal 4');
xlabel('Time (s)');
ylabel('Amplitude');
subplot(5, 1, 5);
plot(t, mt1_recovered, t, mt2_recovered, t,
mt3_recovered, t, mt4_recovered);
legend('Recovered Signal 1', 'Recovered Signal
2', 'Recovered Signal 3', 'Recovered Signal 4');
title('Recovered Message Signals');
xlabel('Time (s)');
ylabel('Amplitude');
```

Figure 5: Amplitude Modulation and Multiplexing/Demultiplexing.

Discussion & Conclusion:

The experiment successfully implemented Frequency Division Multiplexing (FDM) using MATLAB, showcasing its versatility in system design, signal generation, and spectral analysis. MATLAB's tools allowed a comprehensive evaluation of FDM's performance, considering factors like signal-to-noise ratio and bandwidth efficiency. This hands-on experience deepened our understanding of FDM in communication systems and equipped us with practical skills for optimizing signal transmission. Overall, the experiment highlights the significance of

MATLAB in enhancing the efficiency and reliability of communication systems employing FDM.

References:

[1] W. Stallings, Data and computer communications. 2000., Accessed: Dec.16, 2023. [Online]. Available:https://www.portcity.edu.bd/files/636444710465881602_Dataandcomputercommunications.pdf [Online Copy]

[2] B. A. Forouzan, C. A. Coombs, and S. C. Fegan, Introduction to data communications and networking. McGraw-Hill Science, Engineering & Mathematics, 1998., Accessed: Dec.16, 2023. [Online]. Available: https://archive.mu.ac.in/myweb_test/syllFybscit/dcn.pdf [Online Copy]