AEROSPACE COMMUNICATION SYSTEMS

PROJECT 1

ZEWAILCITY OF SCIENCES AND TECHNOLOGY

Amplitude Modulation

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❶ | PART A: DSB-LC USING MATLAB.

Requirements

1. In this part, you are required to generate a DSB-LC signal as follows:
2. Generate the message signal $m_1(t)$ shown in Fig. 1, and plot it.
3. Generate the modulated signal $s(t)$ using a carrier wave of 1 Volt amplitude and 10 kHz frequency, $K_a = 0.5$.

$$s(t) = A_c[1 + K_a m_1(t)]\cos(2\pi f_c t)$$

4. Plot the output signal $s(t)$ and comment on it.
5. Repeat the previous steps for $K_a = 1.0$ and $K_a = 2.0$.
   Comment on the plots you obtain.

Codes.

```
%% ============================= clear ==================================%%

clear;
close all;
clc;

%% ================ generate message and carrier signals =============== %%

Fs = 1000;                                 % sampling frequency.
dt = 1/Fs;                                 % sample period.
t = 0:dt:1-dt;                             % time interval
fc = 100;                                  % carrier frequency in 10^2 Hz
m_t = sawtooth((4*pi*t)+pi,0);             % message signal
c_t = 1*cos(2*pi*fc*t);                    % carrier signal.

%% ============================ Modulation  ============================ %%

Ka1 = 0.5;                                 % modulation index == 0.5 ==
Ka2 = 1;                                   % modulation index == 1.0 ==
Ka3 = 2;                                   % modulation index == 1.0 ==

s1_t = (1 + (Ka1.*m_t)).*c_t;              % modulated signal
```

```
s2_t = (1 + (Ka2.*m_t)).*c_t;            % modulated signal
s3_t = (1 + (Ka3.*m_t)).*c_t;            % modulated signal

%% ============================ Exports  ============================ %%

Message = [t' ,m_t'];
Carrier = [t', c_t'];



%% ============================== plots  ================================== %%

figure(1)

% plot message signal.
subplot(2,1,1)
plot(t,m_t,"LineWidth",2);
ylim([-1.1 1.1])
xlabel('Time(ms)')
ylabel('Amplitude(V)')
title('Message Signal')
grid on

% plot carrier signal.
subplot(2,1,2)
plot(t*10,c_t,"LineWidth",2);
xlim([0 1])
xlabel('Time(ms)')
ylabel('Amplitude(V)')
title('carrier Signal')
grid on


figure(2)

% plot modulated signal with Ka = 0.5.
subplot(3,1,1)
plot(t,s1_t,Color=[0 0.6 0]);
xlabel('Time(s)')
ylabel('Amplitude(V)')
title('Modulated Signal with Ka = 0.5')
grid on

% plot modulated signal with Ka = 1.0.
subplot(3,1,2)
plot(t,s2_t,Color=[0 0.6 0]);
xlabel('Time(s)')
ylabel('Amplitude(V)')
title('Modulated Signal with Ka = 1.0')
grid on

% plot modulated signal with Ka = 2.0.
subplot(3,1,3)
plot(t,s3_t,Color=[1 0 0]);
xlabel('Time(s)')
ylabel('Amplitude(V)')
title('Modulated Signal with Ka = 2.0')
grid on


figure(3)
```

```
% plot frequancy spectrum of the message signal.
M_s = fft(m_t);
M_Shifted = fftshift(M_s);
f = -Fs/2:1:Fs/2-1;
subplot(2,1,1)
plot(f/10,abs(M_Shifted)/Fs);
title('Message Freq. spectrum')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on

% plot frequancy spectrum of the carrier signal.
C_s = fft(c_t);
C_Shifted = fftshift(C_s);
subplot(2,1,2)
plot(f/10,abs(C_Shifted)/Fs);
title('Carrier Freq. spectrum')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on


figure(4)

% plot frequancy spectrum of the modulated signal with Ka = 0.5.
S1_s = fft(s1_t);
S1_Shifted = fftshift(S1_s);
subplot(3,1,1)
plot(f/10,abs(S1_Shifted)/Fs);
title('Freq. Spectrum of Modulated Signal with Ka = 0.5')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on


% plot frequancy spectrum of the modulated signal with Ka = 1.0.
S2_s = fft(s2_t);
S2_Shifted = fftshift(S2_s);
subplot(3,1,2)
plot(f/10,abs(S2_Shifted)/Fs);
title('Freq. Spectrum of Modulated Signal with Ka = 1.0')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on

% plot frequancy spectrum of the modulated signal with Ka = 2.0.
S3_s = fft(s3_t);
S3_Shifted = fftshift(S3_s);
subplot(3,1,3)
plot(f/10,abs(S3_Shifted)/Fs,Color=[1 0 0]);
title('Freq. Spectrum of Modulated Signal with Ka = 2.0')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on

%% =============================== LPF  ================================ %%

figure(5)
```

```
% passing the signal modulated with Ka = 0.5 through LPF.
n = 5;
Wn = 2*fc/Fs;
pos_envelop1 = abs(s1_t);
[b,a] = butter(n,Wn);
filtered_signal1 = filter(b,a,pos_envelop1);
filtered_signal_s1 = fft(filtered_signal1);
filtered_signal_Shifted1 = fftshift(filtered_signal_s1);

subplot(3,1,1)
plot(f/10,abs(filtered_signal_Shifted1)/Fs);
title('Freq. Spectrum of Demodulated Signal with Ka = 0.5')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on


% passing the signal modulated with Ka = 1.0 through LPF.
n = 5;
Wn = 2*fc/Fs;
pos_envelop2 = abs(s2_t);
[b,a] = butter(n,Wn);
filtered_signal2 = filter(b,a,pos_envelop2);
filtered_signal_s2 = fft(filtered_signal2);
filtered_signal_Shifted2 = fftshift(filtered_signal_s2);

subplot(3,1,2)
plot(f/10,abs(filtered_signal_Shifted2)/Fs);
title('Freq. Spectrum of Demodulated Signal with Ka = 1.0')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on


% passing the signal modulated with Ka = 2.0 through LPF.
n = 5;
Wn = 2*fc/Fs;
pos_envelop3 = abs(s3_t);
[b,a] = butter(n,Wn);
filtered_signal3 = filter(b,a,pos_envelop3);
filtered_signal_s3 = fft(filtered_signal3);
filtered_signal_Shifted3 = fftshift(filtered_signal_s3);

subplot(3,1,3)
plot(f/10,abs(filtered_signal_Shifted3)/Fs,Color=[1 0 0]);
title('Freq. Spectrum of Demodulated Signal with Ka = 2.0')
xlabel('Frequency (kHz)')
ylabel('Magnitude')
grid on




figure(6)

subplot(2,3,1)
plot(t,pos_envelop1);
xlabel('Time(ms)')
ylabel('Amplitude(V)')
title('Envelope of Modulated Signal with Ka = 0.5')
```

```
grid on
subplot(2,3,4)
plot(t,filtered_signal1)
xlabel('Time(s)')
ylabel('Amplitude(v)')
title('Demodulated Signal with Ka = 0.5')
grid on

subplot(2,3,2)
plot(t,pos_envelop2);
xlabel('Time(ms)')
ylabel('Amplitude(V)')
title('Envelope of Modulated Signal with Ka = 1.0')

grid on
subplot(2,3,5)
plot(t,filtered_signal2)
xlabel('Time(s)')
ylabel('Amplitude(v)')
title('Demodulated Signal with Ka = 1.0')
grid on

subplot(2,3,3)
plot(t,pos_envelop3,Color=[1 0 0]);
xlabel('Time(ms)')
ylabel('Amplitude(V)')
title('Envelope of Modulated Signal with Ka = 2.0')

grid on
subplot(2,3,6)
plot(t,filtered_signal3,Color=[1 0 0])
xlabel('Time(s)')
ylabel('Amplitude(v)')
title('Demodulated Signal with Ka = 2.0')
grid on
```

Results.

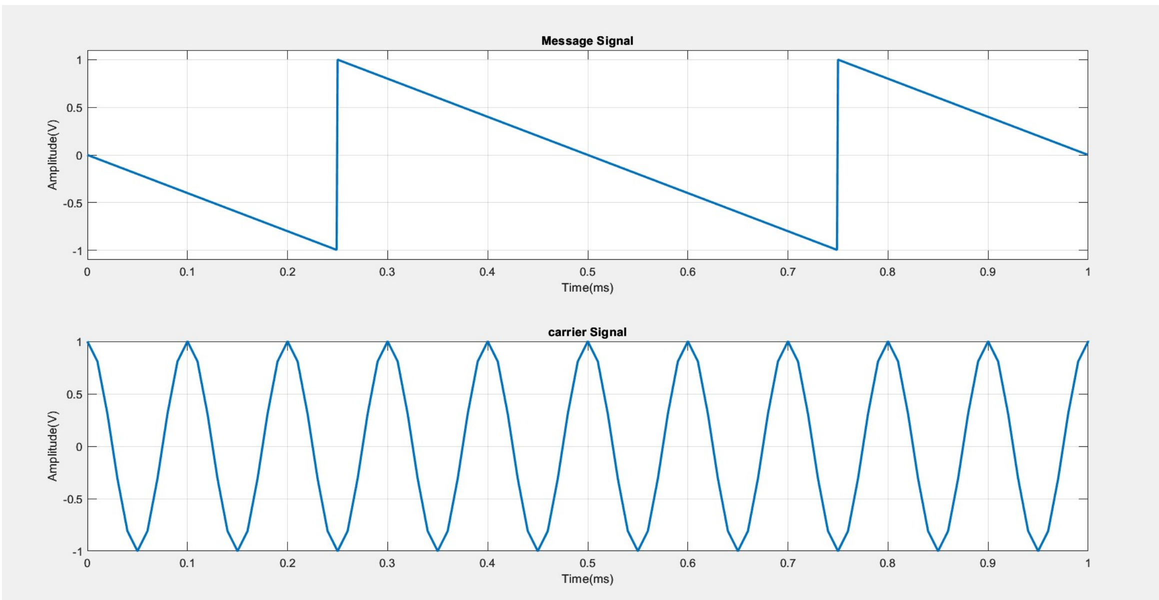

Fig.1.1 | Message and Carrier signals

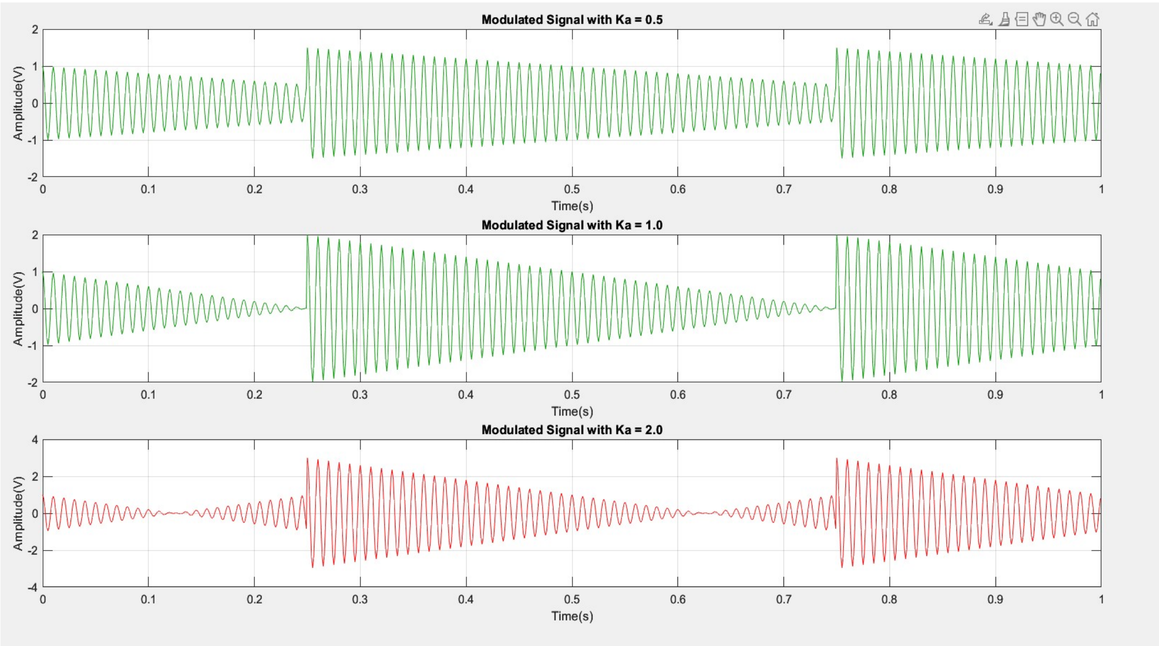

Fig.1.2| Modulated signals with K_a = 0.5, 1.0, 2.0 respectively.

❁ Discussion of the Plots and results.

- It is to be noted that the envelope after modulation represents the original sawtooth signal in the first two plots with K_a = 0.5 and 1.0, where in the third plot with $K_a = 2.0$, the signal is over modulated resulting in distortion due to zero crossings in the modulated signal, which makes the envelope not to represent the original sawtooth signal.

- Also, it is to be noted that the value of K_a = 1.0 that represents best efficiency Because it uses minimum power to modulate the signal.

$$\mu = \frac{A_m}{A_c} = K_a A_m$$

- According to this equation of power efficiency:

$$\eta = \frac{\mu}{\mu^2 + 1}$$

Therefore, the maximum power efficiency is at K_a = 1.0, and Efficiency of 33%.

❷ | PART B: DSB-LC USING SIMULINK..

Requirements

In this part, it is required to use Simulink in conjunction with the MATLAB workspace. Repeat Part A using Simulink.

- Use simin block to use the message signal defined in your workspace.
- Use a multi-input scope to show the message signal and the modulated signal on the same graph.

Model

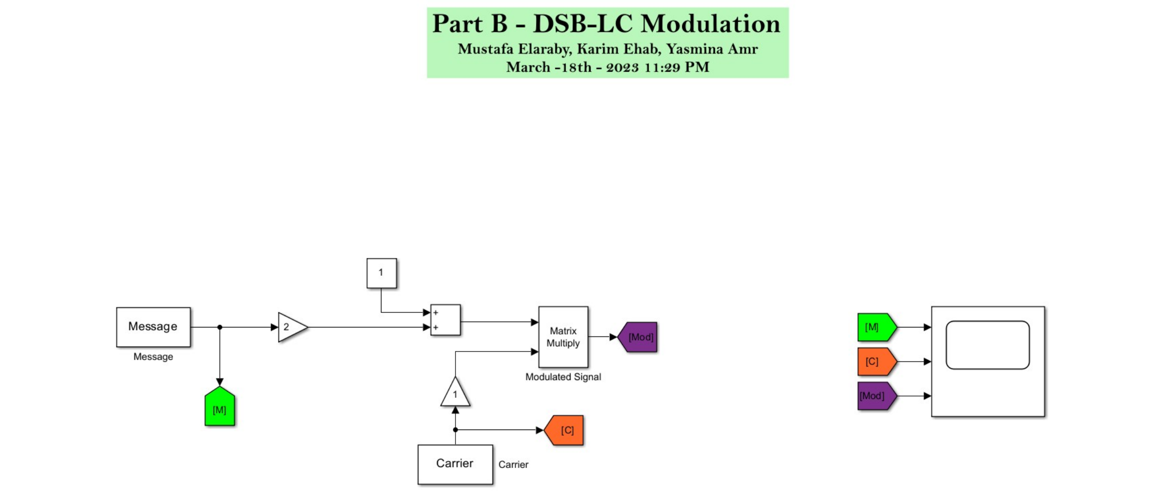

Fig.2.1| Simulink Model of AM DSB-LC.

Model Parameters.

#	Block	Parameter	Value
1.	Simin	Data	Message
	Message	Sample time	1/fs
2.	Simin	Data	Carrier
	Carrier	Sample time	1/fs
3.	Gain	Gain	0.5, 1.0, 2.0
	K_a	Multiplication	Element-wise
4.	Gain	Gain	1
	A_c	Multiplication	Element-wise
5.	Adder	-	-
6.	Constant	Value	1
7.	Matrix Multiply	Number of inputs	2
		Multiplication	Matrix(*)

❁ Results.

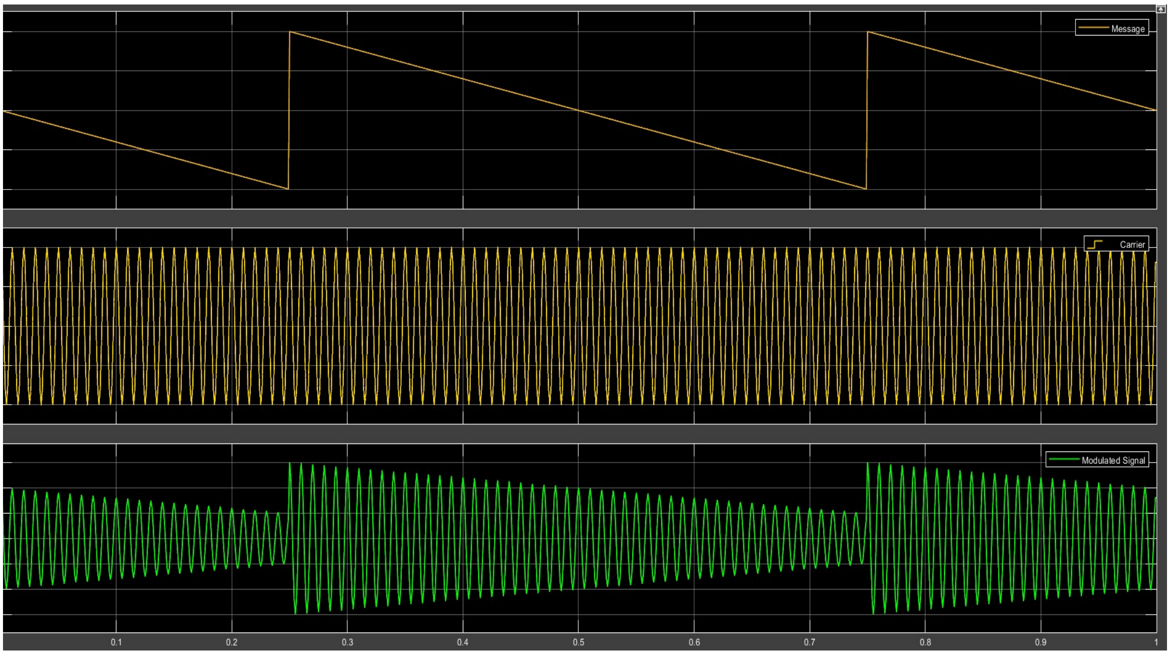

Fig.2.2| Modulated signals with $K_a = 0.5$.

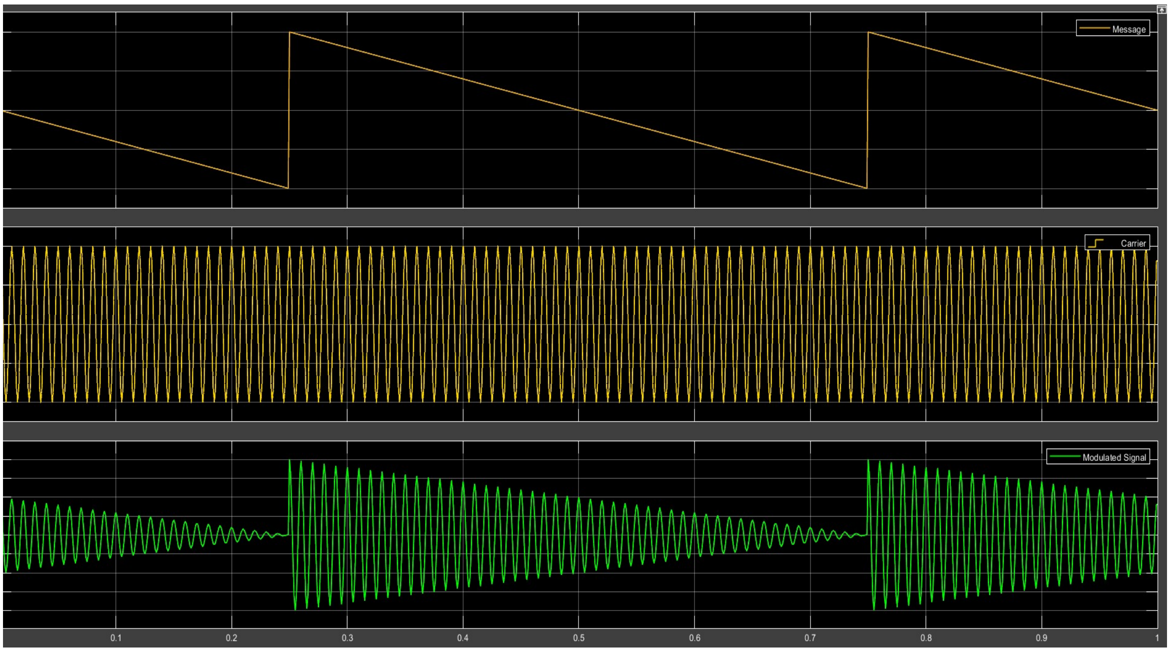

Fig.2.3| Modulated signals with $K_a = 1.0$.

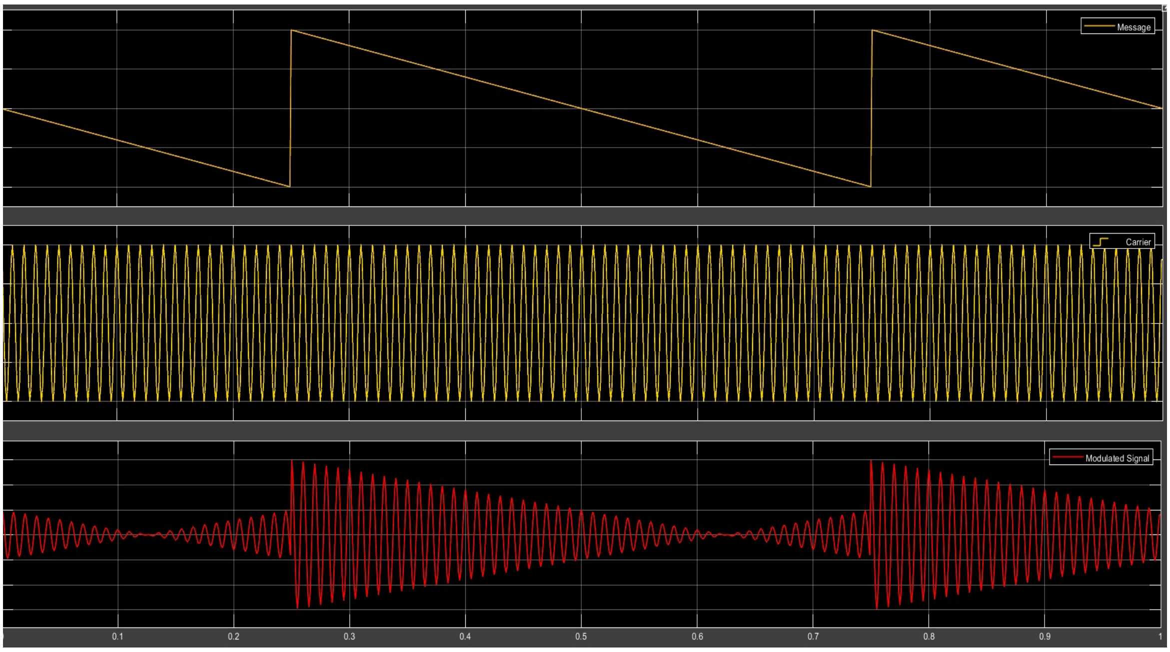

Fig.2.4| Modulated signals with $K_a = 2.0$.

The Results of Simulink is the same as that of the matlab code, waiting for the the toolbox to assure the results more.

❸ | PART C: DSB-LC USING SIMULINK TOOLBOXES.

❁ Requirements

Using the DSB AM Modulator block from the Communications toolbox in Simulink, verify your findings from Part B.

❁ Model

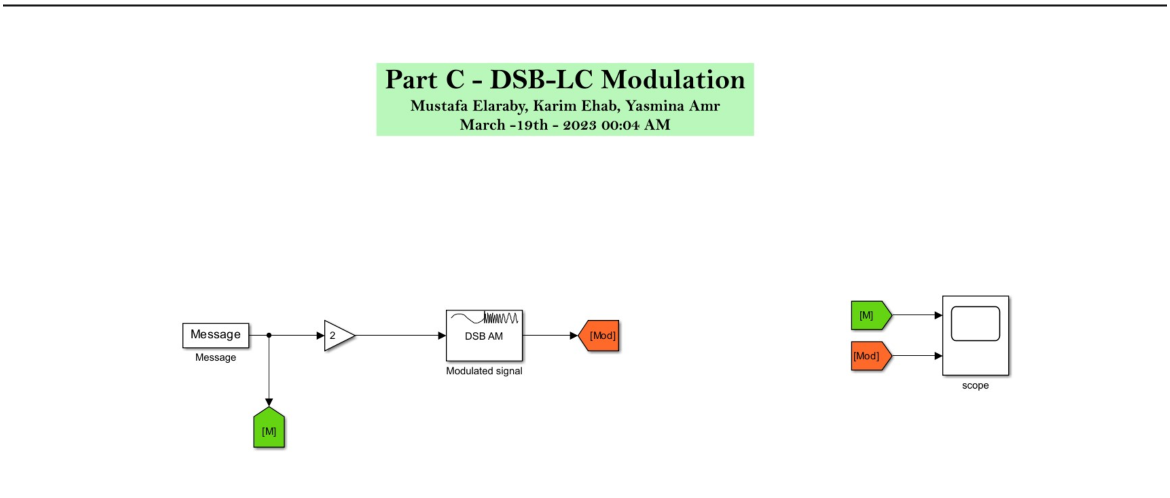

Fig.3.1| Simulink Model of AM DSB-LC using Toolbox.

Model Parameters.

#	Block	Parameter	Value
1.	Simin Message	Data	Message
		Sample time	1/fs
2.	Gain K_a	Gain	0.5, 1.0, 2.0
		Multiplication	Element-wise
3.	DSB AM Modulator	Input signal offset	1
		Carrier frequency	10,000
		Initial phase	0

Results.

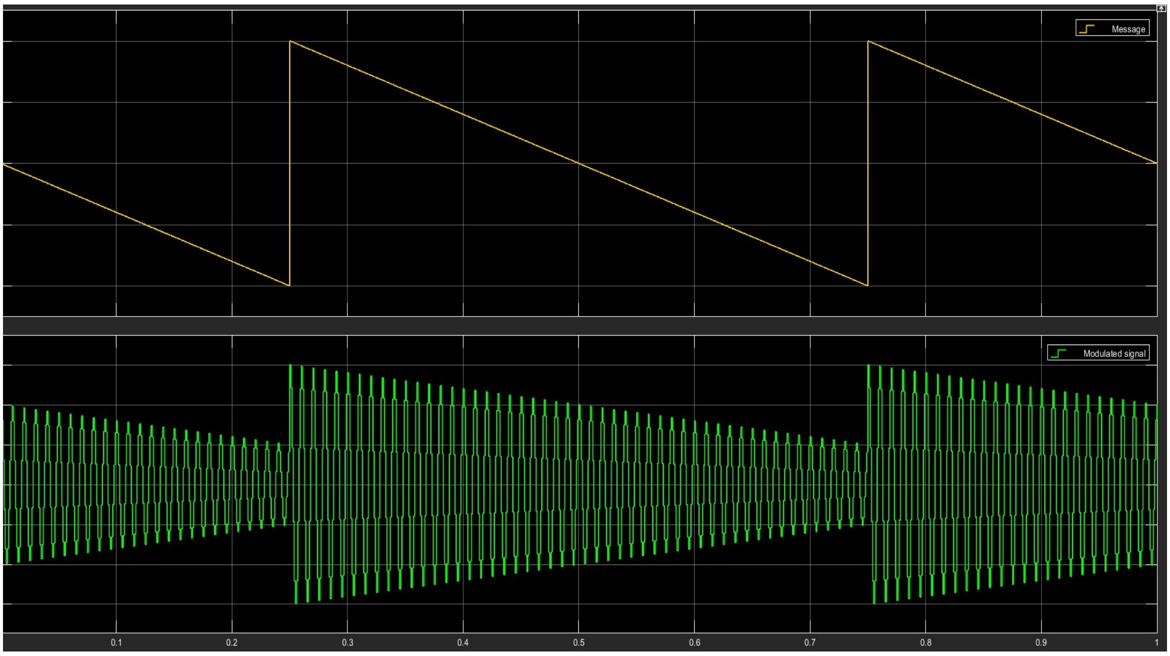

Fig.3.2| Modulated signals with $K_a = 0.5$.

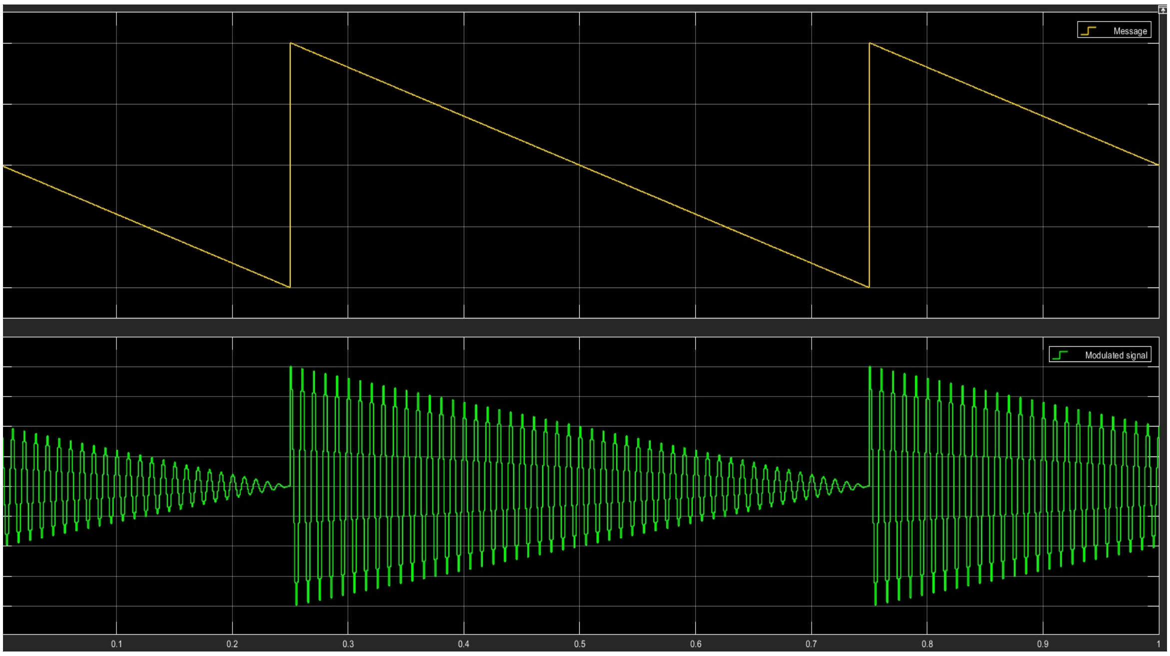

Fig.3.3| Modulated signals with $K_a = 1.0$.

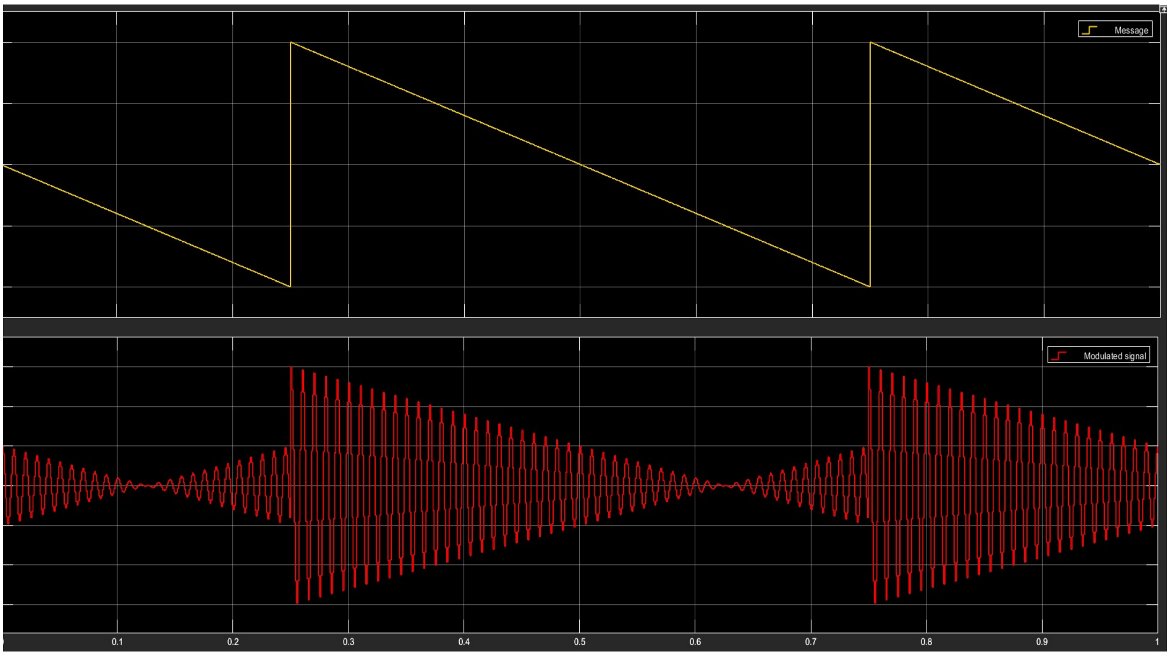

Fig.3.4| Modulated signals with $K_a = 2.0$.

The Results of Simulink toolbox is the same as that of the previous results assuring the accuracy and correctness of it.

❹ | PART D: SSB USING MATLAB..

Requirements

In this part, it is required to generate a SSB signal as follows:

1) Generate the message signal $m_2(t)$ where $B = 1kHz$ and plot it.

$$m_2(t) = sinc(Bt)$$

2) Generate the modulated signal $s_2(t)$ using the SSB modulator where the carrier wave has 1 Volt amplitude and $10kHz$ frequency.
3) Plot the USB output.
4) Plot the LSB output.
5) Plot the spectrum of the modulated signal in both cases.
6) Implement a suitable demodulator to extract m2(t) from s2(t).
7) Investigate the output of the previous steps if the generator carrier wasn't perfectly synchronized as in the following cases
   - Local carrier frequency at the receiver is f1 = fc + 0.1B.
   - Local carrier frequency at the receiver is f1 = fc − 0.1B.
8) Comment on the plots you obtain.

Codes

```
%% ============================ clear =================================%%

clear;
close all;
clc;

%% ================ generate message and carrier signals =============== %%
import inverseSinc.*

B = 1000;
fc = 10000;
fs = 100000;
dt = 1 / fs;
t = -0.005:dt:0.005 - dt;
t2 = 0:dt:0.01 - dt;
m = sinc(B * t);

%% ========================== Modulation ===============================%%

USB = ssbmod(m, fc, fs, 0, "upper");
LSB = ssbmod(m, fc, fs, 0);

figure(1);

subplot(3, 1, 1)
plot(t, m, LineWidth = 1);
title('Message')
xlabel('Time(sec)')
```

```
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 1, 2)
plot(t, USB);
title('USB Modulated')
xlabel('Time(sec)')
ylabel('USB')
grid on;

subplot(3, 1, 3)
plot(t, LSB);
title('LSB Modulated')
xlabel('Time(sec)')
ylabel('LSB')
grid on;

%% ======================= Frequancy Spectrum ===========================%%

M_spectr = abs(fftshift(fft(m)));
USB_Spectr = abs(fftshift(fft(USB)));
LSB_Spectr = abs(fftshift(fft(LSB)));

f = -fs / 200:1:fs / 200 - dt;

figure(2)

subplot(3, 1, 1)
plot(f / 10, M_spectr);
title('Message Frequancy Spectrum')
xlabel('Frequancy(kHz)')
ylabel('M(f)')
grid on;

subplot(3, 1, 2)
plot(f / 10, USB_Spectr);
title('USB Modulated Frequancy Spectrum')
xlabel('Frequancy(kHz)')
ylabel('USB')
grid on;

subplot(3, 1, 3)
plot(f / 10, LSB_Spectr);
title('LSB Modulated Frequancy Spectrum')
xlabel('Frequancy(kHz)')
ylabel('LSB')
grid on;

%% ========================== Demodulation ==============================%%

% Local carrier frequency at the receiver is fc.
USB_Demod = ssbdemod(USB, fc, fs, 0);
LSB_Demod = ssbdemod(LSB, fc, fs, 0);

figure(3);

subplot(3,3, 1)
plot(t, m, LineWidth = 1);
title('Message')
xlabel('Time(sec)')
```

```
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 3, 4)
plot(t, USB_Demod, LineWidth = 1);
title('USB Demodulated with fc')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 3, 7)
plot(t, LSB_Demod, LineWidth = 1);
title('LSB demodulated with fc')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;


% Local carrier frequency at the receiver is f1 = fc + 0.1B.
f1 = fc + 0.1*B;
USB_Demod_f1 = inverseSinc(ssbdemod(USB, f1, fs, 0));
LSB_Demod_f1 = inverseSinc(ssbdemod(LSB, f1, fs, 0));




subplot(3, 3, 2)
plot(t, m, LineWidth = 1);
title('Message')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 3, 5)
plot(t, USB_Demod_f1, LineWidth = 1);
title('USB Demodulated with f1 = fc + 0.1B')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 3, 8)
plot(t, LSB_Demod_f1, LineWidth = 1);
title('LSB Demodulated with f1 = fc + 0.1B')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;


% Local carrier frequency at the receiver is f1 = fc - 0.1B.
f2 = fc - 0.1*B;
USB_Demod_f2 = inverseSinc(ssbdemod(USB, f2, fs,0));
LSB_Demod_f2 = inverseSinc((ssbdemod(LSB, f2, fs,0)));


subplot(3, 3, 3)
```

```
plot(t, m, LineWidth = 1);
title('Message')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 3, 6)
plot(t, USB_Demod_f2, LineWidth = 1);
title('USB Demodulated with f2 = fc - 0.1B')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;

subplot(3, 3, 9)
plot(t, LSB_Demod_f2, LineWidth = 1);
title('LSB Demodulated with f2 = fc - 0.1B')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;




%% =========================== Compare =================================%%

figure(4)

subplot(3,1,1)
plot(t, m, 'b', t, USB_Demod, 'r-.', t, LSB_Demod, 'g:', LineWidth = 1.5);
legend('Original Signal', 'Demodulation of Upper Sideband', 'Demodulation of
Lower Sideband');
title('Demodulation with fc')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;


subplot(3,1,2)
plot(t, m, 'b', t, USB_Demod_f1, 'r-.', t, LSB_Demod_f1, 'g:', LineWidth = 1.5);
legend('Original Signal', 'Demodulation of Upper Sideband', 'Demodulation of
Lower Sideband');
title('Demodulation with f1 = fc + 0.1B')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;


subplot(3,1,3)
plot(t, m, 'b', t, USB_Demod_f2, 'r-.', t, LSB_Demod_f2, 'g:', LineWidth = 1.5);
legend('Original Signal', 'Demodulation of Upper Sideband', 'Demodulation of
Lower Sideband');
title('Demodulation with f2 = fc - 0.1B')
xlabel('Time(sec)')
ylabel('m(t)')
ylim([-0.5 1.1])
grid on;
```

```
%% =========================== Exports ================================%%
Message = [t2' m'];
```

Results

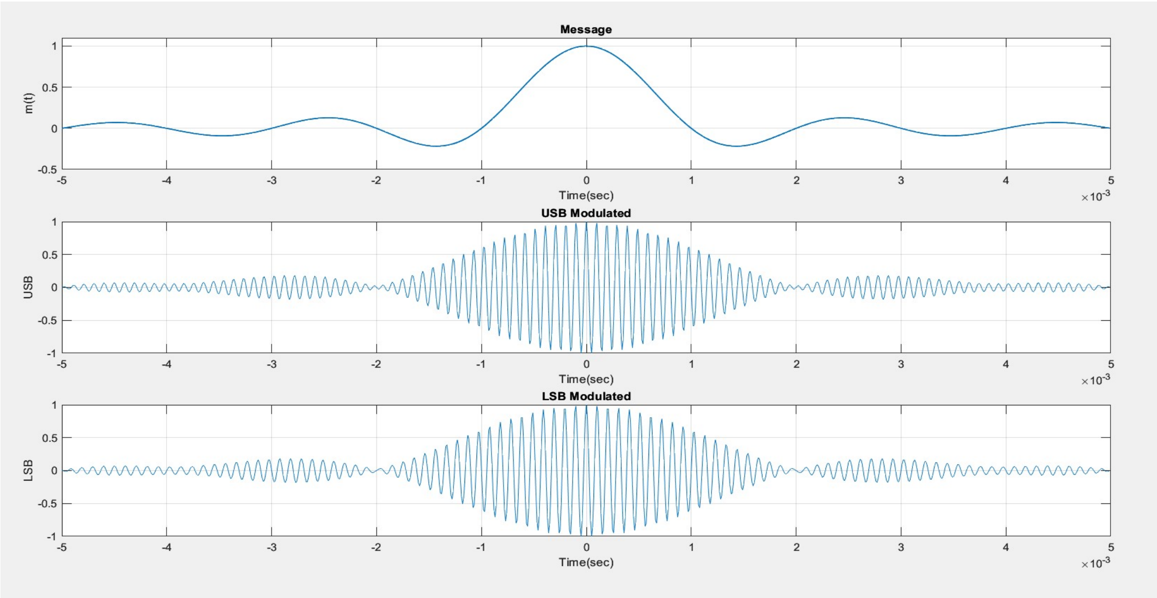

Fig..1| Message, USB and LSB

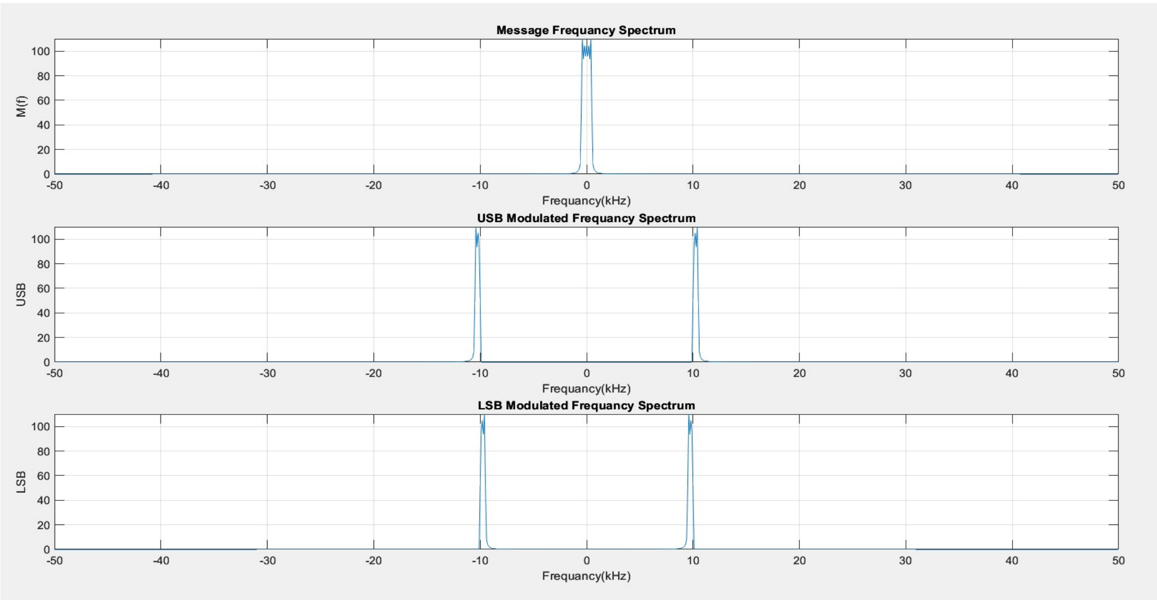

Fig.4.2| Frequency Spectrum of Message, USB and LSB

The frequency spectrum of the modulated signals is as expected two rectangles centered around 10 kHz which is the carrier signal frequency.

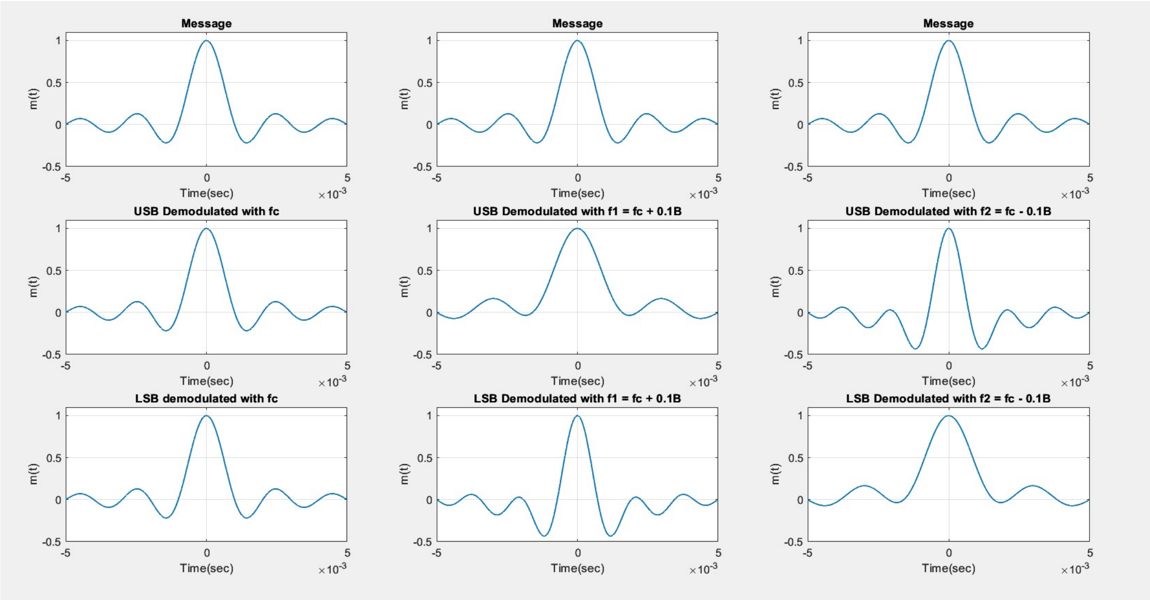

Fig.4.3| Demodulated signals with different local carrier frequency at receiver.

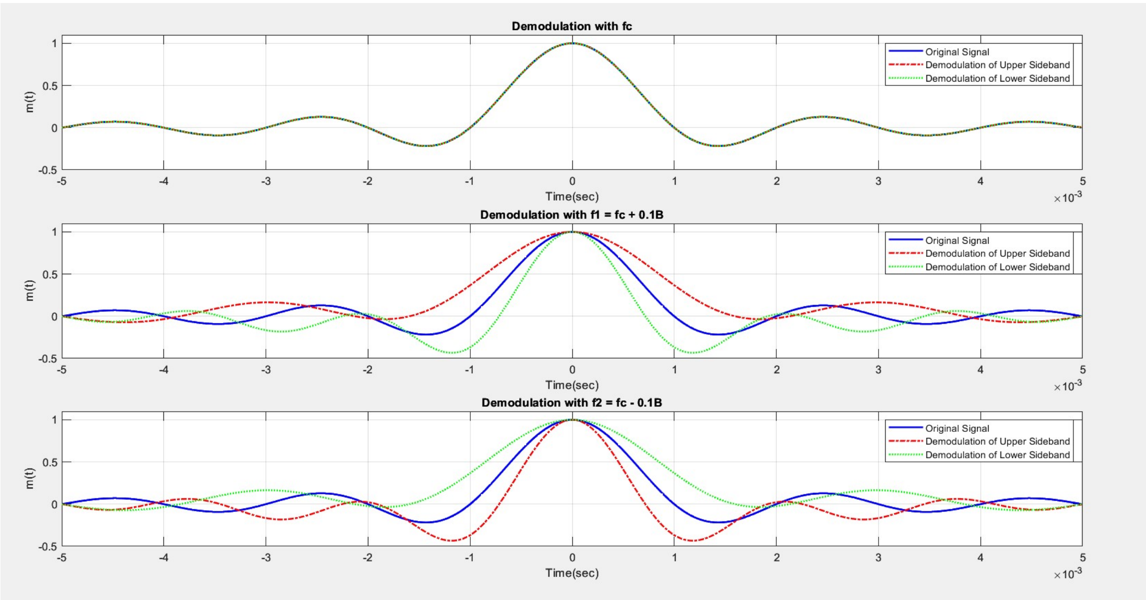

Fig.4.4| Comparison between demodulated signals with different carrier frequency.

The signal demodulated with f_c is similar to the original signal as shown in fig 4.1, for the signal demodulated with $f_1 = f_c + 0.1B$, the USB is demodulated diverging out of the original signal, and the LSB id demodulated converging to itself narrower than the original message. For the signal demodulated with $f_1 = f_c - 0.1B$, the LSB is demodulated diverging out of the original signal, and the USB id demodulated converging to itself narrower than the original message.

❁ Obstacles

sometimes when I use different frequency for the receiver local carrier the demodulated signal get inverted.

Solution: I coded a function "inverseSinc.m" to check:

- If the demodulated message is inverted it returns it to it's original state.
- If not inverted it keeps it as it is.

❺ | PART E: SSB USING SIMULINK TOOLBOXES.

❁ Requirements

Using the SSB AM Modulator and SSB AM Demodulator blocks from Communications toolbox, verify your findings from Part D.

❁ Model

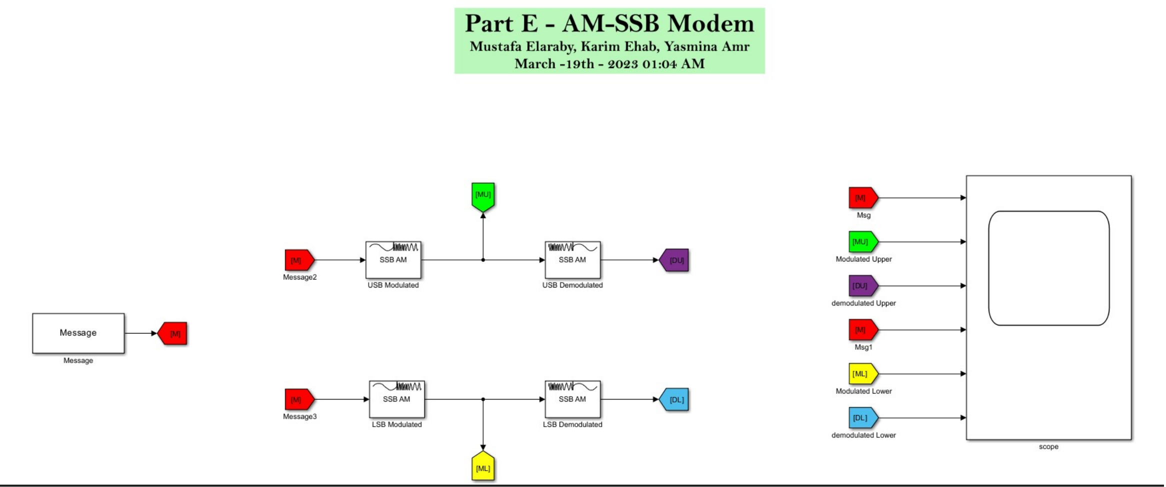

Fig.5.1| Simulink Model of AM SSB using Toolbox.

❁ Model Parameters.

#	Block	Parameter	Value
1.	Simin Message	Data	Message
		Sample time	1/fs
2.	SSB AM Modulator	Carrier frequency	10,000
		Initial phase	0
		Side Band	Upper
		Hilbert Filter Order	4

3.	SSB AM Modulator	Carrier frequency	10,000
		Initial phase	0
		Side Band	Lower
		Hilbert Filter Order	4
4.	SSB AM Demodulator	Carrier frequency	10,000
		Initial phase	0
		Low-Pass filter	Butterworth
		Filter Order	4
		Cutoff frequency	2000
5.	SSB AM Demodulator	Carrier frequency	10,000
		Initial phase	0
		Low-Pass filter	Butterworth
		Filter Order	4
		Cutoff frequency	2000

✿ Results

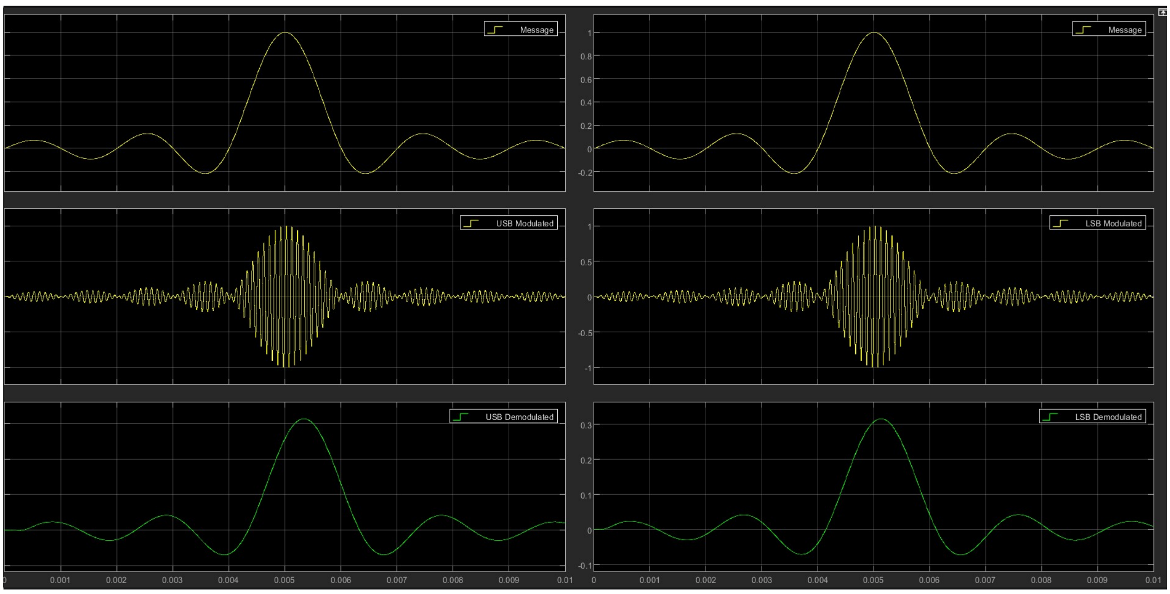

Fig.5.2| Result of AM SSB using Toolbox.

The Results of Simulink toolbox is the same as that of the previous results assuring the accuracy and correctness of it.

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