GEBZE TECHNICAL UNIVERSITY

ELEC361 ANALOG COMMUNICATION SYSTEMS

PROJECT HOMEWORK

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MATLAB SIMULATION:

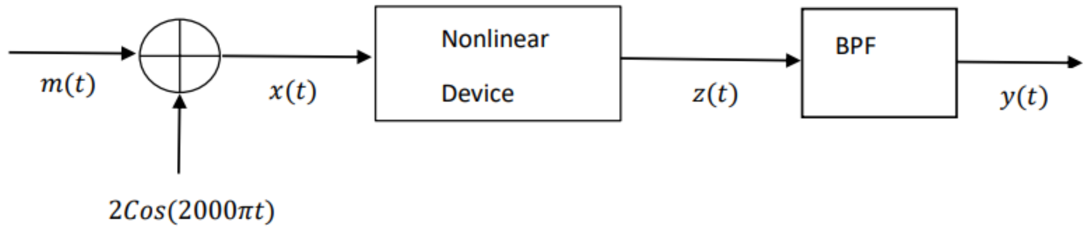


Figure 1: System Diagram

Before defining the signals in the system defined in the project, time and frequency values were separated by the sampling method. The following code block defines time and frequency sampling.

```
t0 = .1;                                        % 0.1 second variable
ts = 0.0001;                                    % sample time variable (second)
t = 0:ts:t0-ts;                                 % 0 to 0.1 sec. sampled time
fs = 1/ts;                                      % sample frequency
df = 1/t(end);                                  % sampled frequency values
```

Using time intervals defined by sampling, message signal, carrier signal, z signal and x signal on the system are defined in the code block below according to Figure 1.

```
m = 5*cos(2*pi*100.*t) + 10*cos(2*pi*200.*t);   % message signal m(t)
c = 2*cos(2*pi*1000.*t);                        % carrier signal c(t)
x = m + c;                                      % x signal -> x(t) = m(t) + c(t)
z = (x.*x) + 60.*x;                             % z signal -> z(t) = x^2(t) + 60x(t)
```

The defined signals are plotted in the following code block.

```
% PLOT m(t), c(t) ,z(t)
figure(1)

subplot(2,2,1)
plot(t,m(1:length(t)))                          % plotting m(t)
xlabel('time (s)')
ylabel('m(t)')
title('m signal')

subplot(2,2,2)
plot(t,x(1:length(t)))                          % plotting x(t)
xlabel('time (s)')
ylabel('y(t)')
title('x signal')

subplot(2,2,3)
plot(t,z(1:length(t)))                          % plotting z(t)
xlabel('time (s)')
ylabel('z(t)')
title('z signal')
```

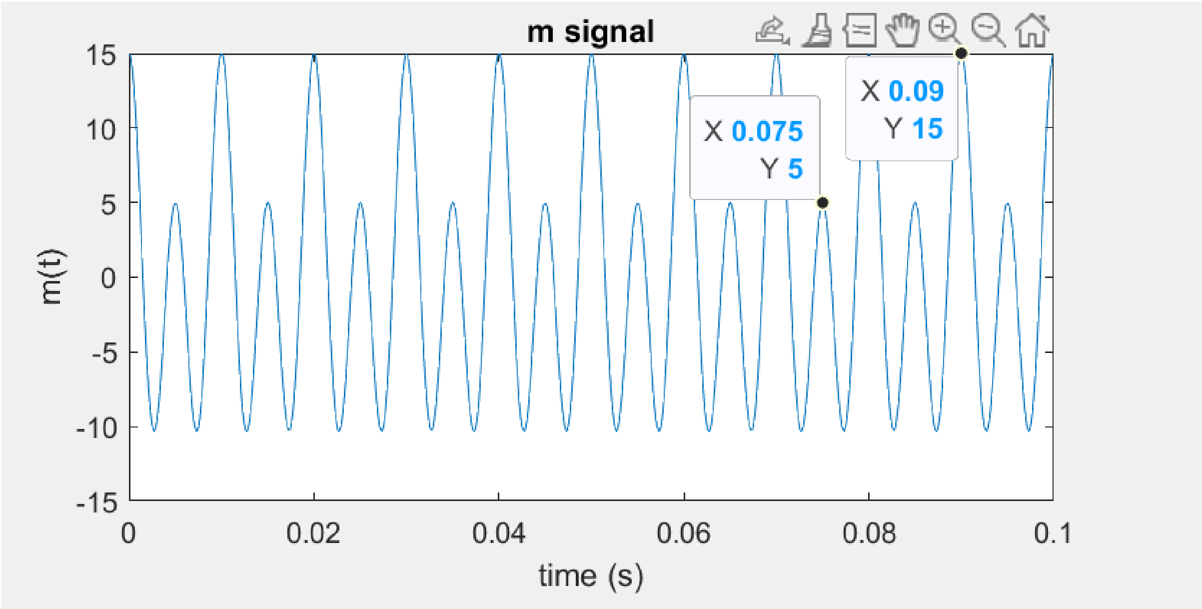


Figure 2: m(t) signal plot result

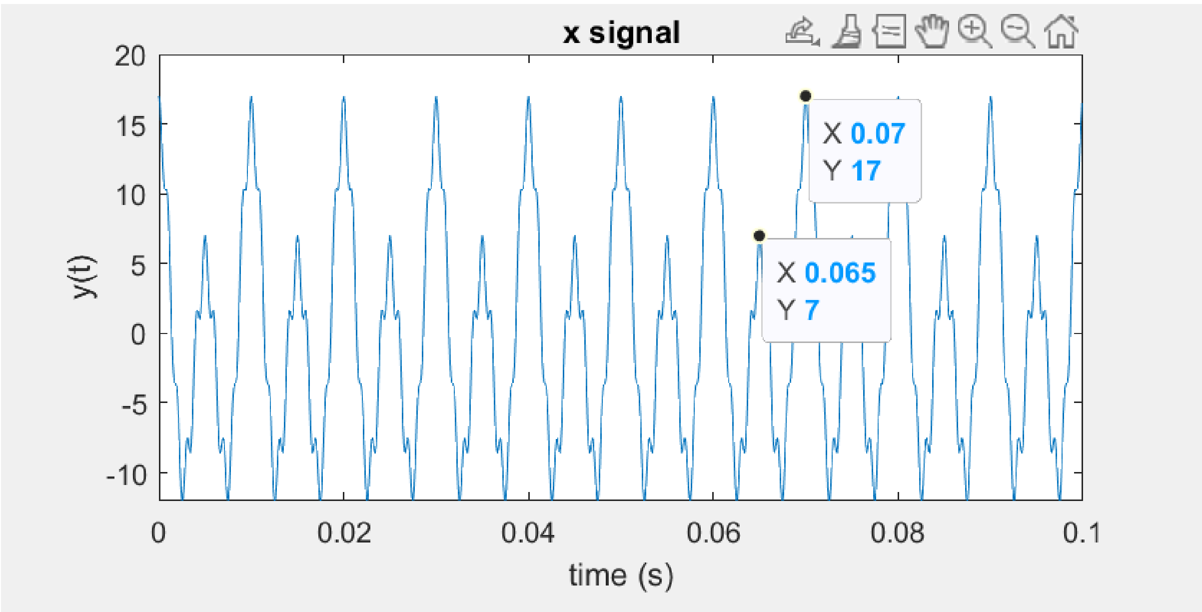


Figure 3 : m(t) signal plot result

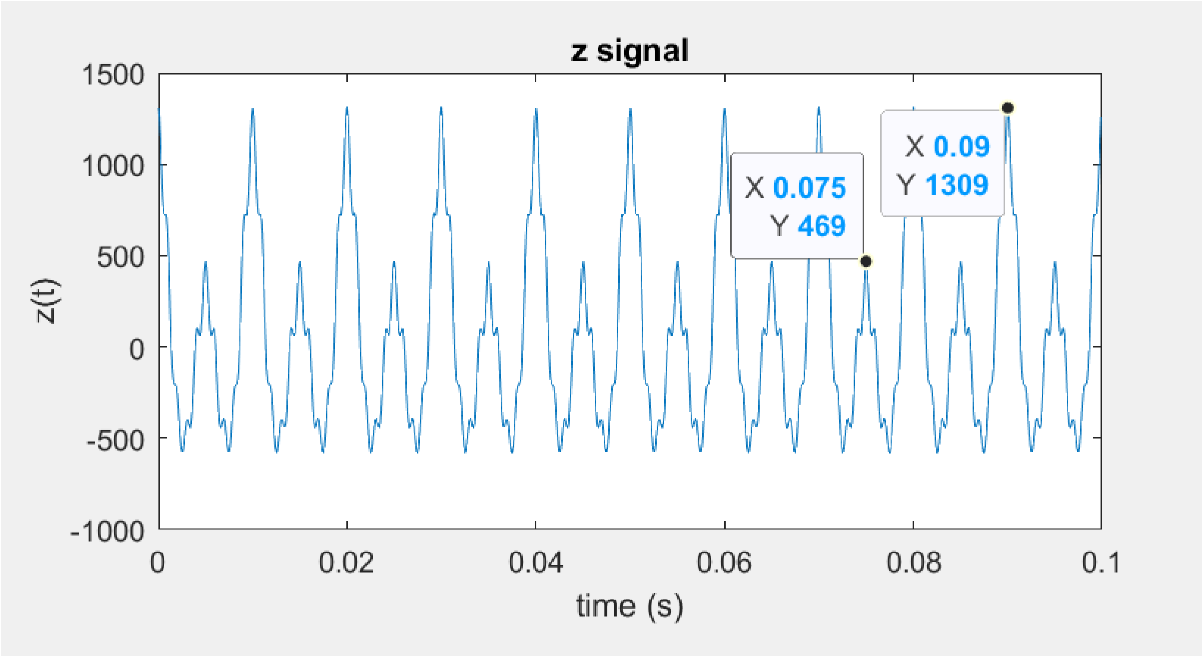


Figure 4: z(t) signal plot result

Fourier transform using ‘ fft ’ function to obtain the spectra of the signals has been taken in the code line given below.

```
M = fft(m);                                       % Fourier Transform m(t) -> M(f)
X = fft(x);                                       % Fourier Transform x(t) -> X(f)
Z = fft(z);                                       % Fourier Transform z(t) -> Z(f)
```

The ‘ fftshift ’ function was used to bring the Fourier transform to the real frequency of the received signals. The amplitude values are divided by the length of the signal itself in order to be accurate.

```
shifted_M = abs(fftshift(M)/length(M));          % M(f) value shifted real frequency value
shifted_X = abs(fftshift(X)/length(X));          % X(f) value shifted real frequency value
shifted_Z = abs(fftshift(Z)/length(Z));          % Z(f) value shifted real frequency value
```

The functions whose Forier transform was taken are plotted with the code block below.

```
% PLOT M(f), C(f) ,Z(f) ,Y(f)
figure(2)

subplot(2,2,1)
plot(f,shifted_M)                                 %plotting M(f)
xlabel('frequency (hz)')
ylabel('M(f)')
title('M spectral')

subplot(2,2,2)
plot(f,shifted_X)
xlabel('frequency (hz)')                          %plotting X(f)
ylabel('X(f)')
title('X spectral')
```

```
subplot(2,2,3)
plot(f,shifted_Z)                                  %plotting Z(f)
xlabel('frequency (hz)')
ylabel('Z(f)')
title('Z spectral')
```

All Fourier Graphs are symmetric.

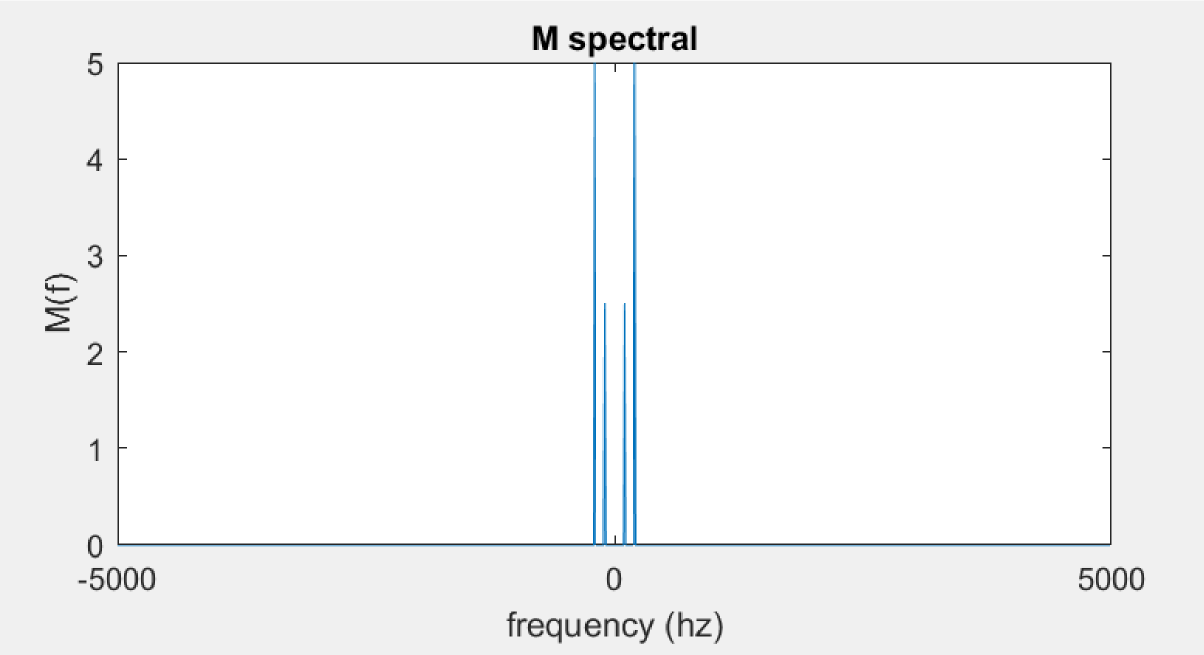


Figure 5: m(t) Fourier Transform Graph

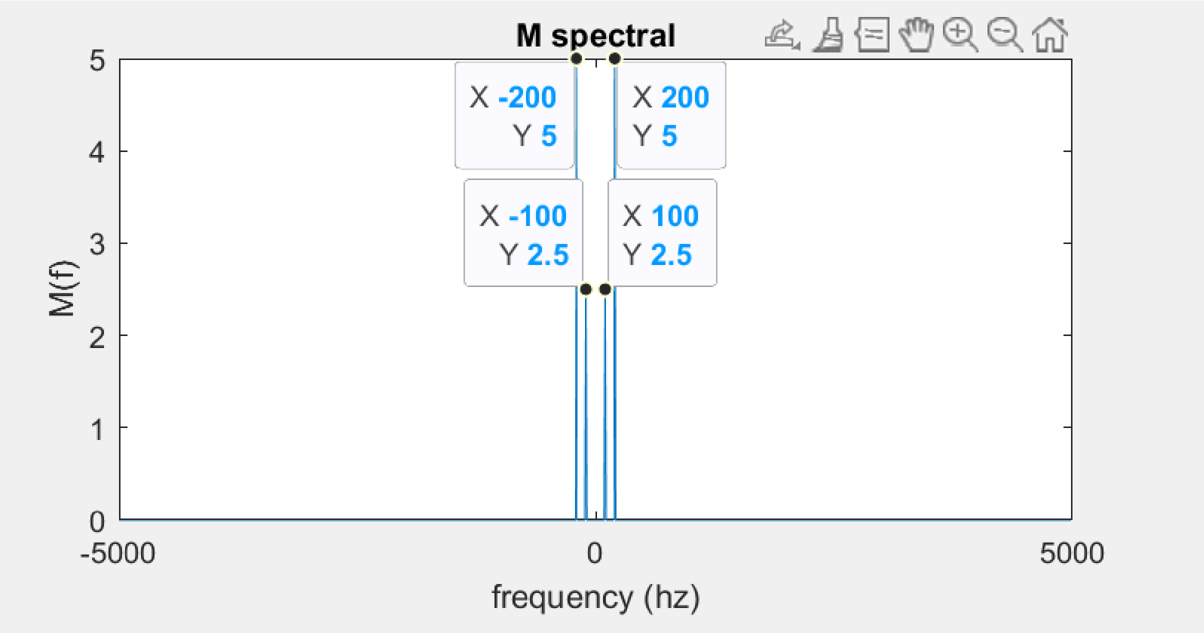


Figure 6: m(t) Fourier Transform Graph with values

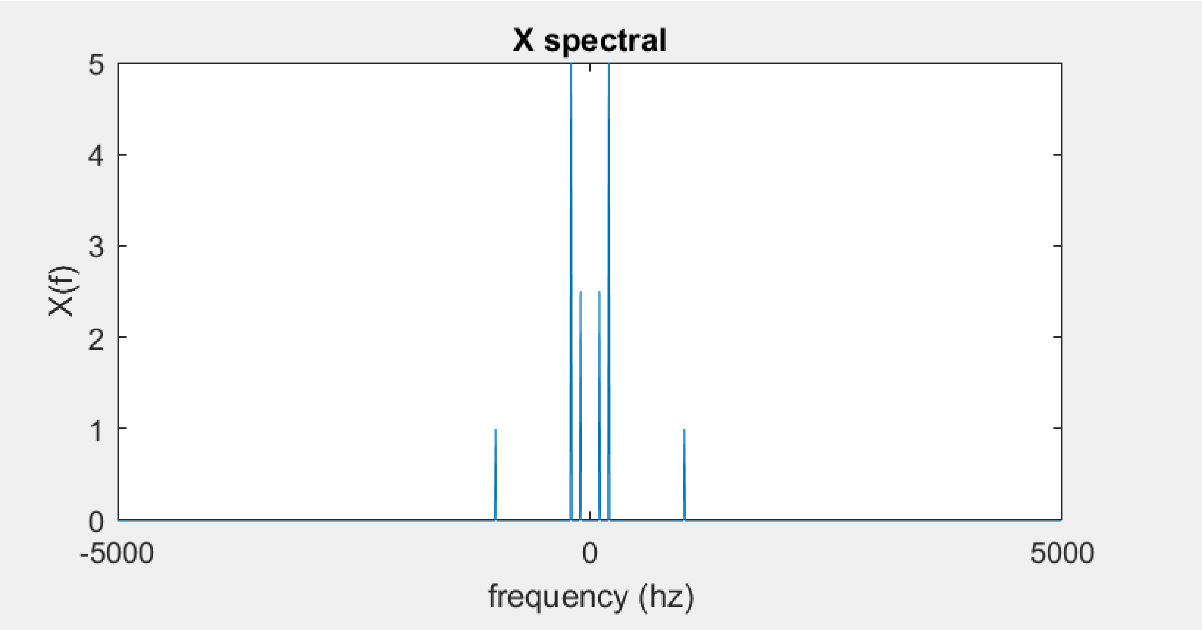


Figure 7: x(t) Fourier Transform Graph

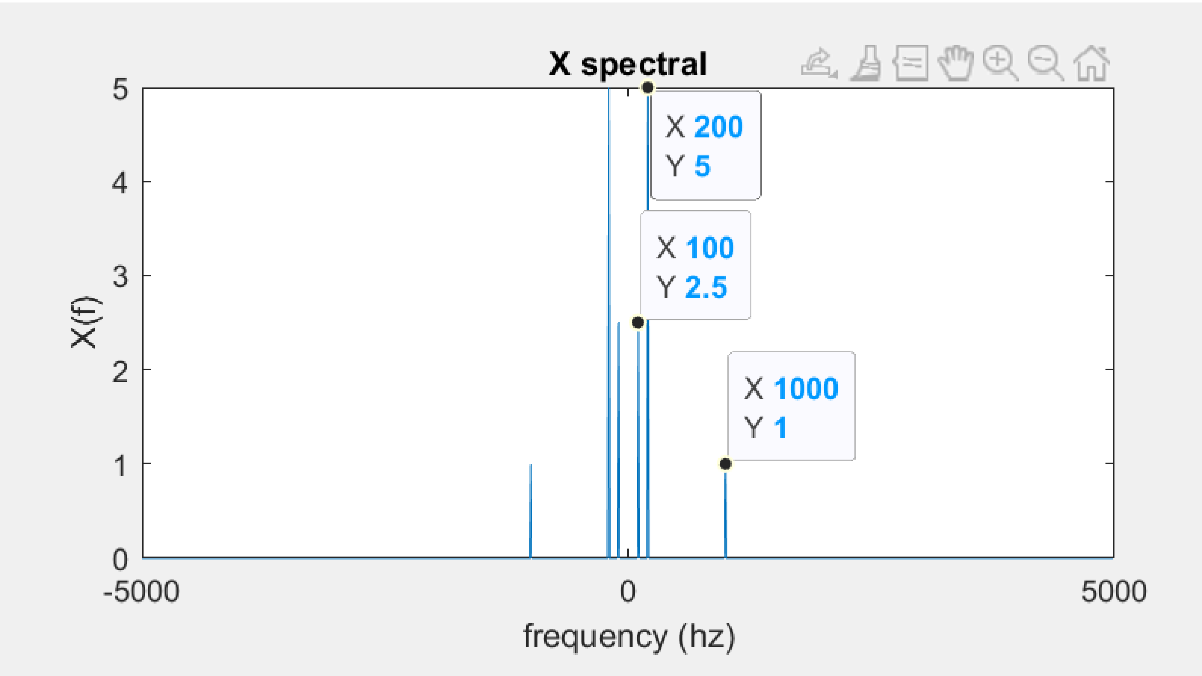


Figure 8: x(t) Fourier Transform Graph with values

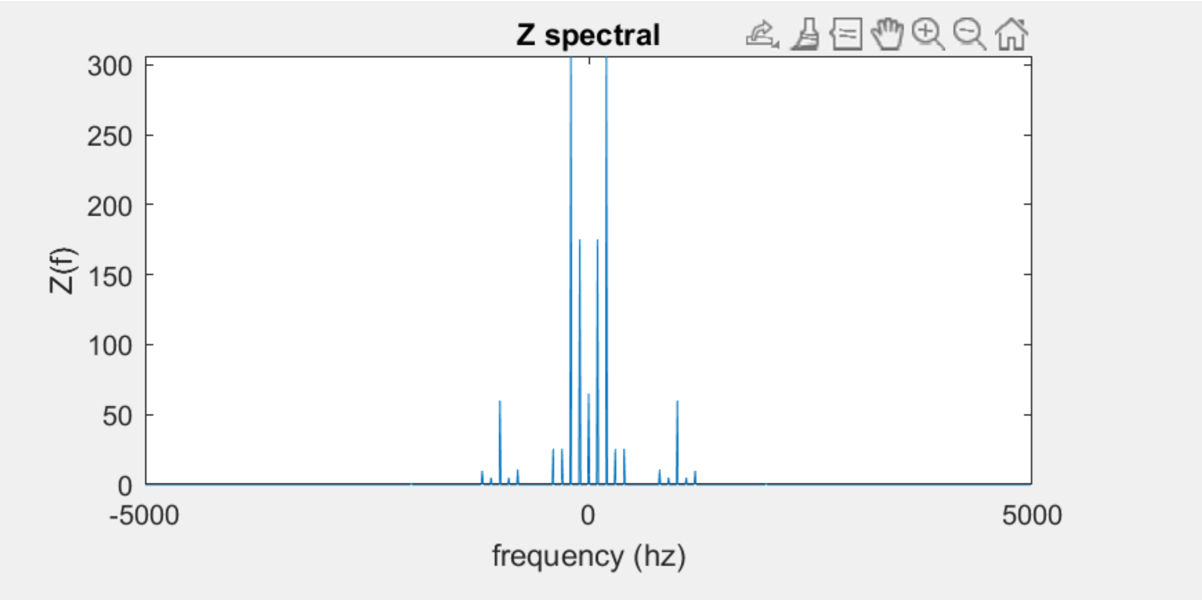


Figure 9: z(t) Fourier Transform Graph

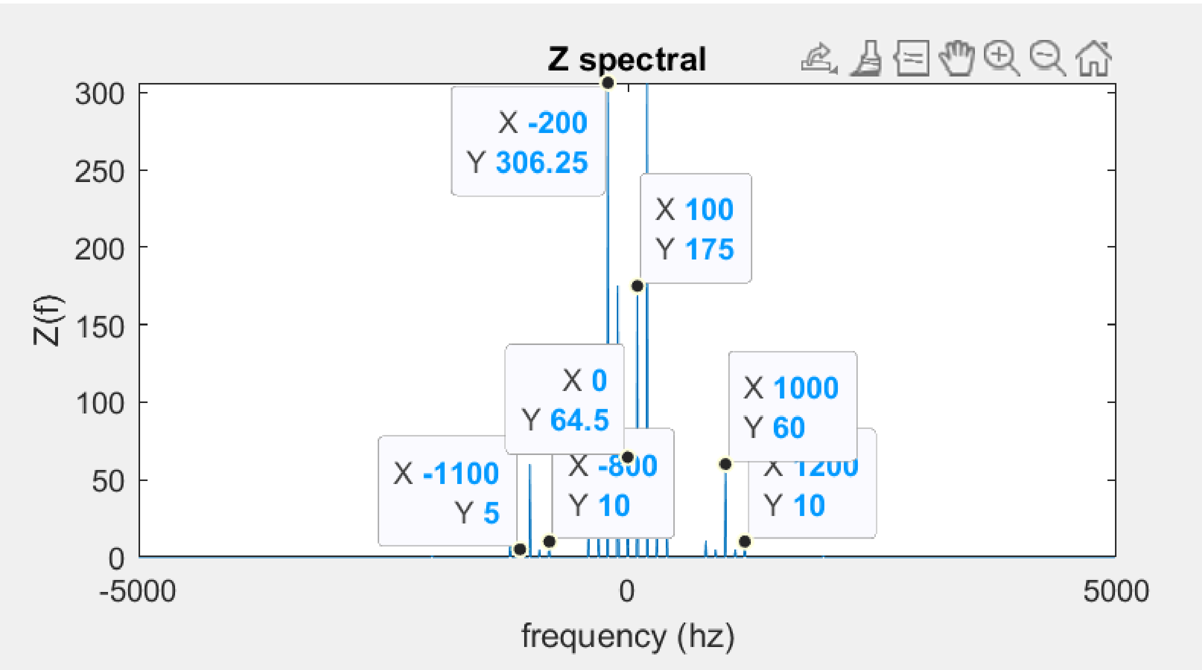


Figure 10: z(t) Fourier Transform Graph with values

The z signal we found was filtered with a bandpass filter. The center frequency is set to 1000 Hz, the bandwidth is 400 Hz and the gain is 1. Calculations and filter properties are defined in the code below.

```
% Band Pass Filter Settings
gain = 1;                                        % gain value
bandwidth = 400;                                 % bandwidth value (hz)
center_Frequency = 1000;                         % center frequency value (hz)

%BPF frequency limit calculations
freq_Low_BPF = center_Frequency-(bandwidth/2);   %band pass filter low frequency (hz)
freq_High_BPF = center_Frequency+(bandwidth/2);  %band pass filter high frequency (hz)
```

To apply the bandpass filter, a vector with the same length as the vector obtained in the Fourier transform of the z signal was created by using the 'ones' function. Every value of the created vector is zero. The reason why it is 0 is to multiply the frequency values that do not pass through the band pass by 0. The calculation of the pass values in the vector is found by subtracting the end points of the band pass filter from the ratio of the sampling values. A bandpass filter has been applied in the code block below.

```
L = length(m);                                  % Length of Message signal
f = fs/length(M)*(-length(M)/2:length(M)/2-1);  % sampled all frequency values
r_df = round(df);                               % for getting integer value

% create equal size of Z(f) vector list with zeros
Y = zeros(1,L);

% positive frequency side for BPF
Y(freq_Low_BPF/r_df:freq_High_BPF/r_df+1) = Z(freq_Low_BPF/r_df:freq_High_BPF/r_df+1)*
gain;

% negative frequency side for BPF
Y((fs/r_df)-(freq_High_BPF/r_df):(fs/r_df)-(freq_Low_BPF/r_df)+1) =
Z((fs/r_df)-(freq_High_BPF/r_df):(fs/r_df)-(freq_Low_BPF/r_df)+1) * gain;

% WARNING: Vector list is not 0 to 1000. it is 1 to 1000, so we must add 1
% last limit to get spectrum values.
```

Real frequency values were obtained by using the resulting filtered Y(f) function ‘fftshift’ with function. Amplitude values were obtained by dividing by the length of the function. The filtered spectrum function ter Fourier transform was taken using the ‘ ifft ’ function.

```
shifted_Y = abs(fftshift(Y)/length(Y));       % Z(f) value shifted real frequency value
y = ifft(Y);                                  % inverse fourier transform
```

The graphs of the y(t) and Y(f) functions were obtained with the following lines of code. Graph is symmetric.

```
subplot(2,2,4)
plot(t,y(1:length(t)))                        % plotting y(t)
xlabel('time (s)')
ylabel('y(t)')
title('y signal')

subplot(2,2,4)
plot(f,shifted_Y)                             % plotting Y(f)
xlabel('frequency (hz)')
ylabel('Y(f)')
title('Y spectral')
```

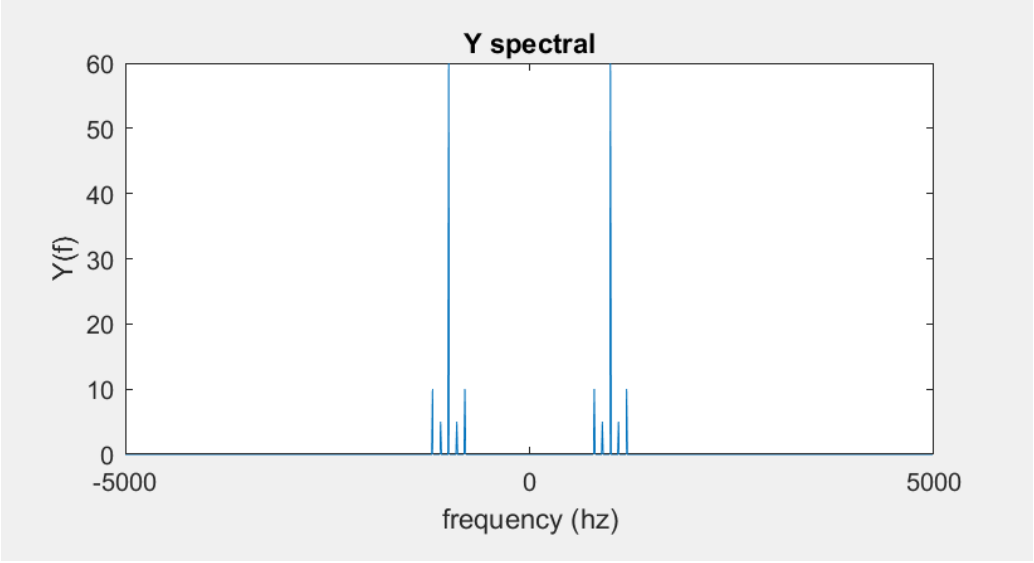


Figure 11: Y(f) spectral graph

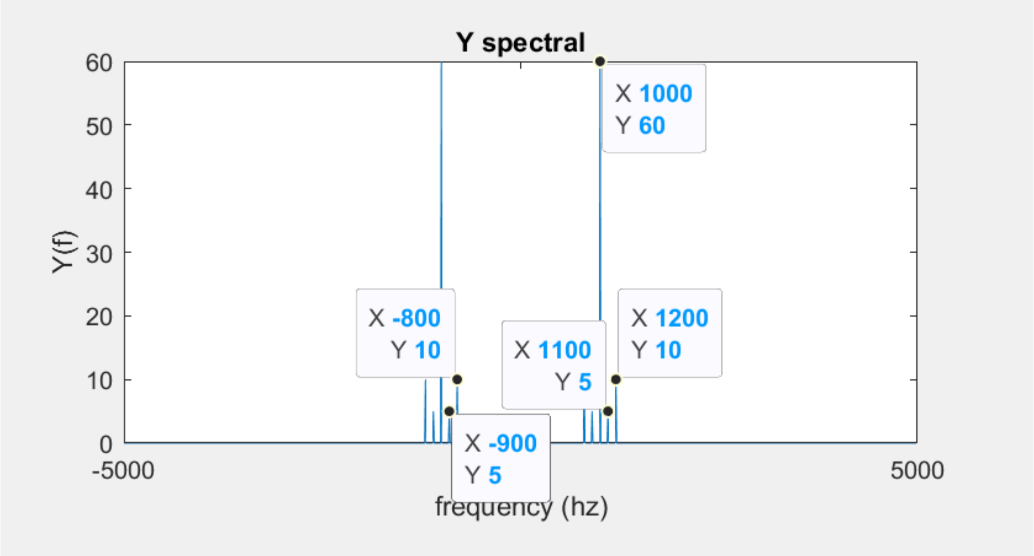


Figure 12: Y(f) spectral graph with values

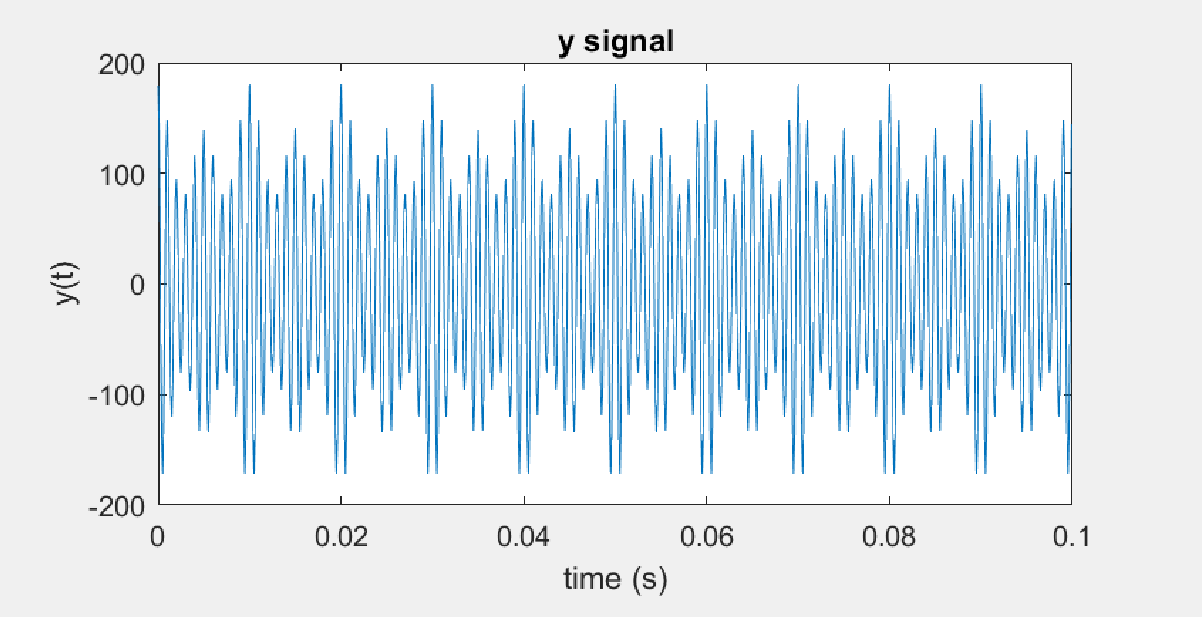


Figure 13: y(t) signal graph

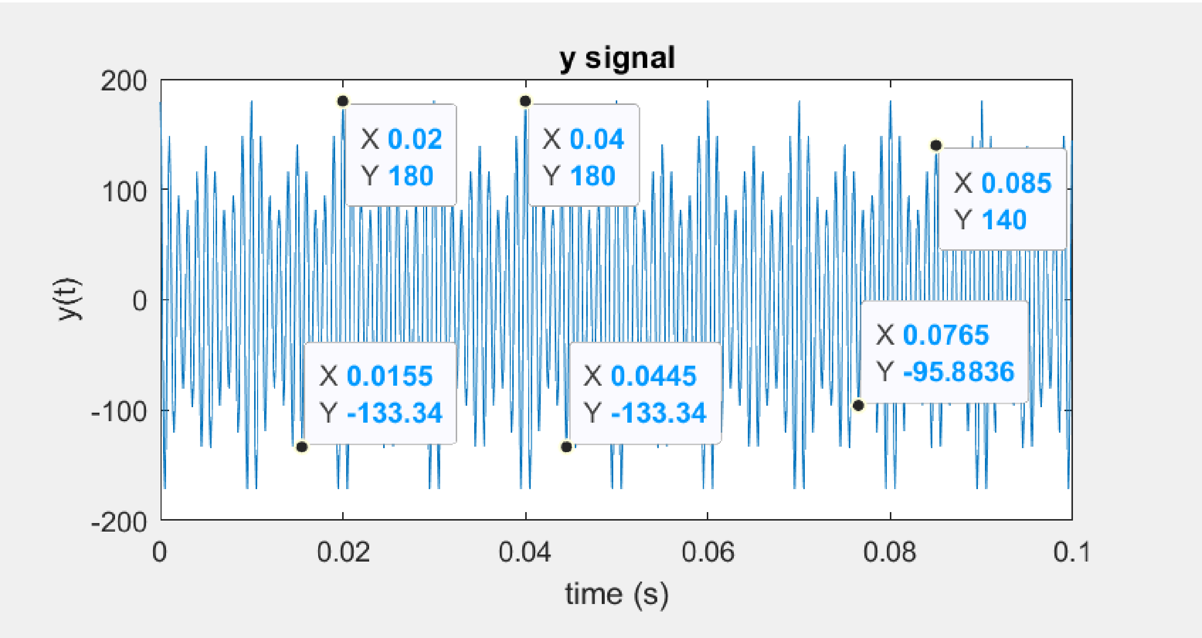


Figure 14: y(t) signal graph with values

The 'envelope' function was used to find the envelope function of the y(t) signal. The lower and upper functions of the envelope were found by writing the code block below.

```
env = envelope(real(y));                                % envelope y(t)
%WARNING: Input must be real, so we used that real function.

figure(3)
[up,lo] = envelope(real(y),100,'analytic');
hold on
plot(t,up,'-',t,lo,'--')                                % plotting envelope
hold off
```

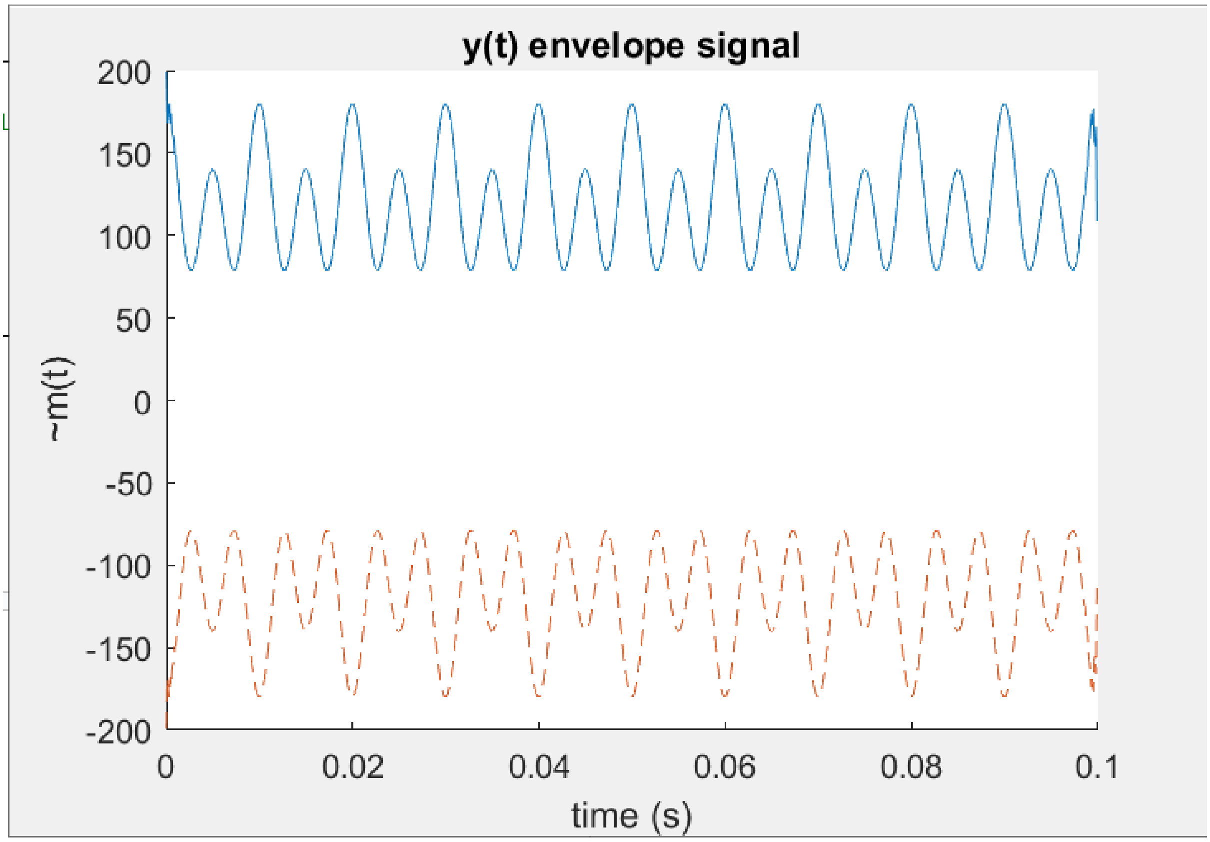


Figure 15: y(t) upper and lower envelope graph

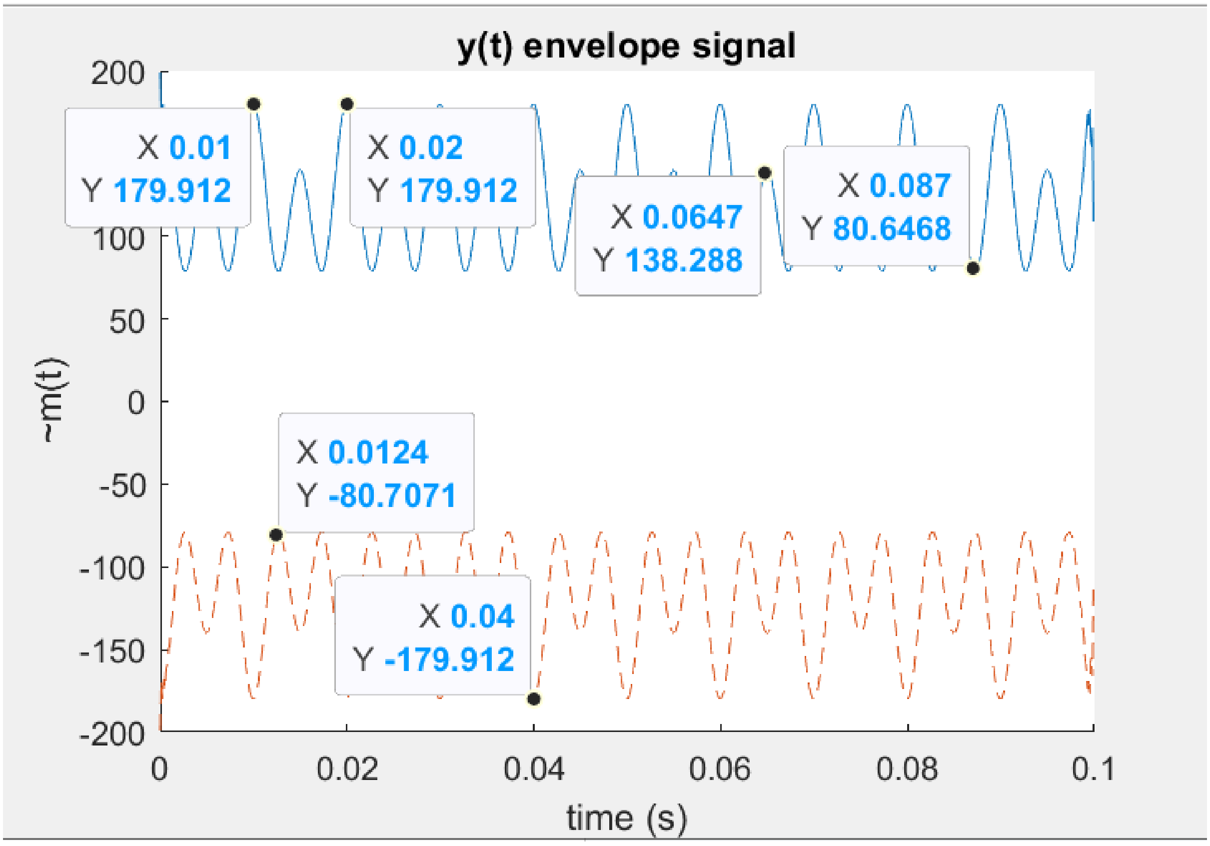


Figure 16: y(t) upper and lower envelope graph with values

The envelope function was taken into Fourier transform and its graph was obtained in the code block below.

```
%envelope fourier transform
ft_env = fft(env);

%  envelope func. shifted real frequency value
shifted_ft_env = abs(fftshift(ft_env)/length(ft_env));

subplot(2,1,2)
plot(f,shifted_ft_env)                                      % plotting ~M(f)
xlabel('frequency (hz)')
ylabel('~M(f)')
title('~M spectral')
```

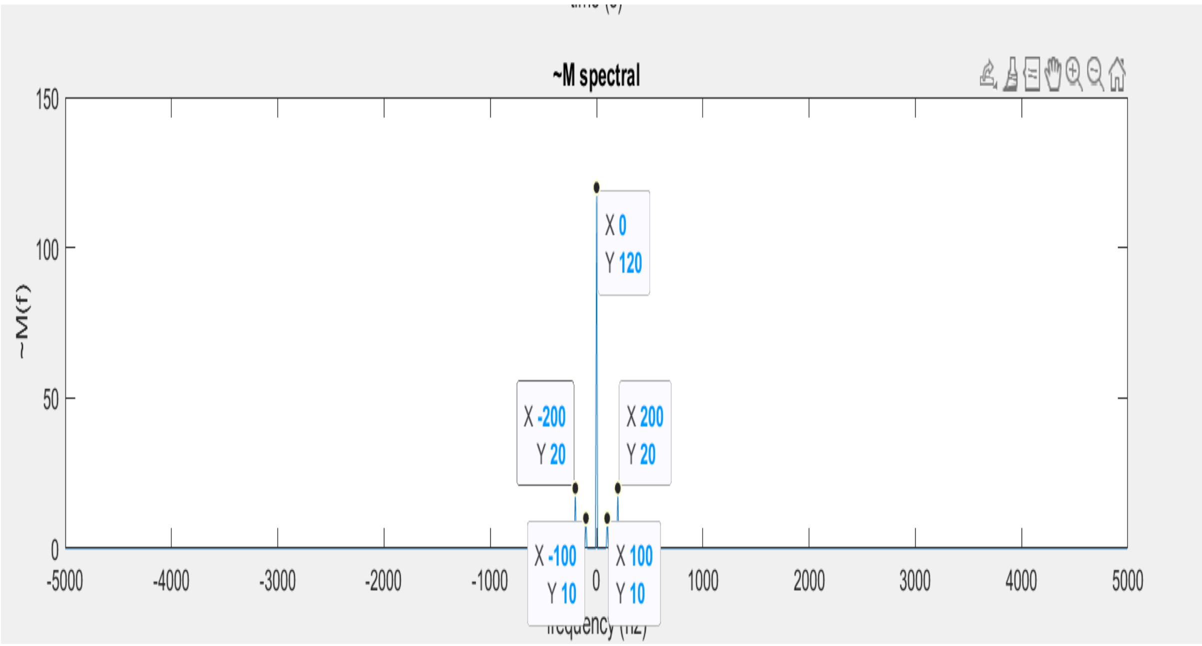


Figure 17: ~m(t) Spectral Graph

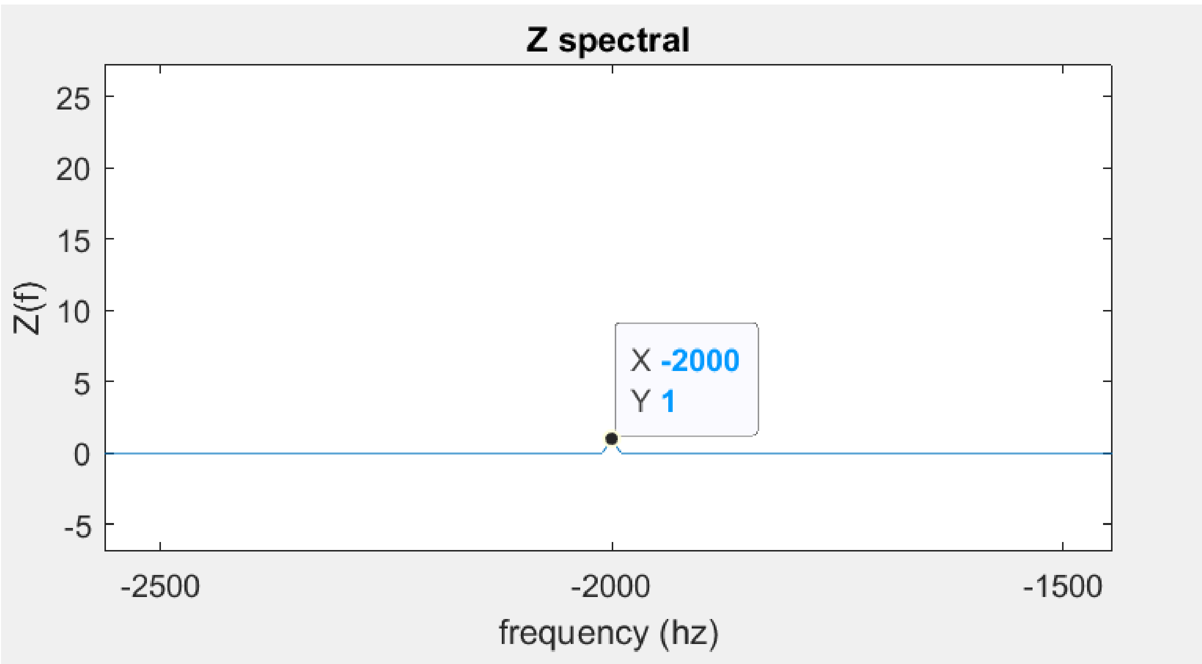


Figure 18: Z(f) 2000 hz Dirac

ANALYTIC SOLUTIONS AND COMPARE SIMULATION :

$m(t) = 5\cos(2\pi 100t) + 10\cos(2\pi 200t)$
$c(t) = 2\cos(2\pi 1000t)$
$x(t) = m(t) + c(t) = 5\cos(2\pi 100t) + 10\cos(2\pi 200t) + 2\cos(2\pi 1000t)$

$z(t) = 60x(t) + x^2(t)$

$= 300\cos(2\pi 100t) + 600\cos(2\pi 200t) + 120\cos(2\pi 1000t) + 25\cos^2(2\pi 100t)$

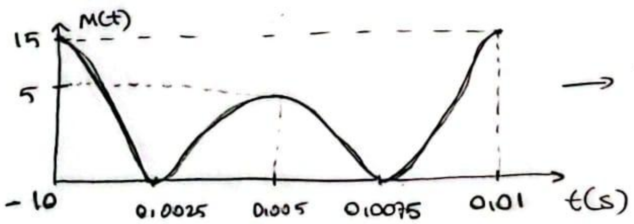
$+ 100\cos^2(2\pi 200t) + 4\cos^2(2\pi 1000t) + 1100\cos(2\pi 100t)\cos(2\pi 200t)$

$+ 20\cos(2\pi 100t)\cos(2\pi 1000t) + 40\cos(2\pi 200t)\cos(2\pi 1000t)$

All signal function find in time domain. ($x(t), y(t), z(t)$)
Analysis $x(t)$, $y(t)$ and $z(t)$ time graph.

$$m(t) = \underbrace{5\cos(2\pi 100t)}_{\substack{\text{max} = 5 \\ \text{period} = 0{,}01s}} + \underbrace{10\cos(2\pi 200t)}_{\substack{\text{max} = 10 \\ \text{period} = 0{,}005s}}$$

max = 15
period = 0,01
second 0,005 → −5 + 10 = 5
second 0,0025 → 0 − 10 = −10 → Min value



→ Figure 2 same

The m(t) signal is periodic. Figure 2 and the graph of x(t) analytical solution look the same. Figure 2 is plotted 0 to 0,1 second. Values are same with analytical solution.

When the signal x(t) was examined, the carrier signal ($2\cos(2\pi 1000t)$) was added. Since it is difficult to draw graph, so analyse again m(t) for x(t) values. The maximum value of m(t) signal is 15, carrier signal maximum value is 2, so x(t) maximum value is 17, because the frequency values are multiples of themselves. Minimum value is −12.

x(t) max. → 17
x(t) min. → −12

Figure 3. is the same our analytic solution.

$z(t)$ signal is $60x(t) + x^2(t)$. Drawing $z(t)$ signal is hard, but we can find minimum and maximum values.

$$\max\{z(t)\} = 60 \times \max\{x(t)\} + [\max\{x(t)\}^2]$$

$\max\{x(t)\} = 17$, so;

$$\max\{z(t)\} = 1309$$

The same method was applied to find the minimum value

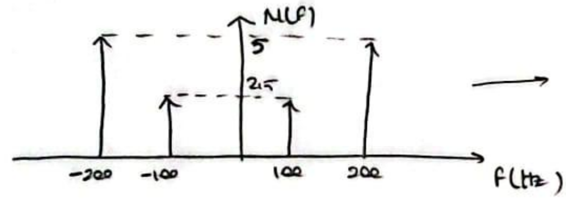
$\min\{x(t)\} = -12 \longrightarrow \min\{z(t)\} = -576$

Figure 4 has same minimum and maximum value.

Fourier Transform and Spectral Graph;

$$m(t) \xrightarrow{F} M(f), \quad x(t) \xrightarrow{F} X(f)$$

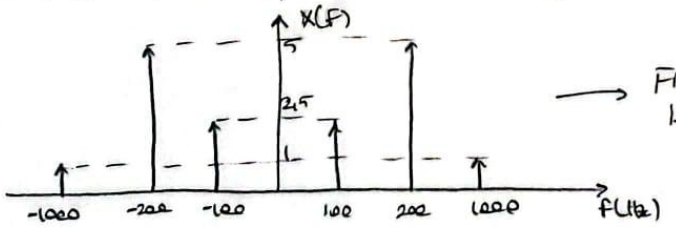
$$M(f) = 2.5(\delta(f-100) + \delta(f+100)) + 5(\delta(f-200) + \delta(f+200))$$



$\longrightarrow$ Figure 5-6 is same

$$X(f) = M(f) + \delta(f-1000) + \delta(f+1000)$$

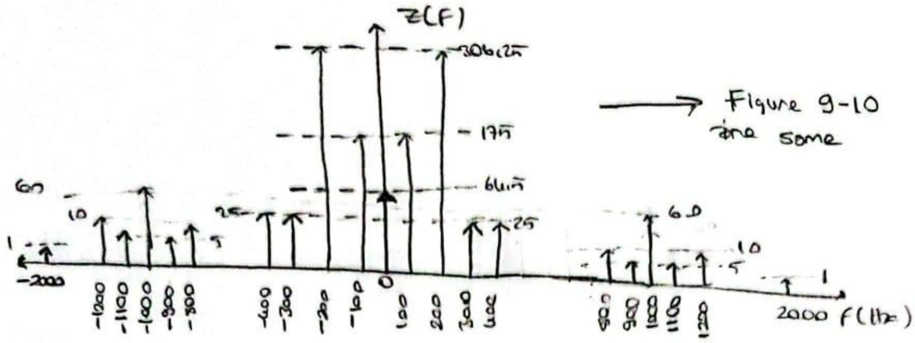
$$= 2.5(\delta(f+100) + \delta(f-100)) + 5(\delta(f+200) + \delta(f-200)) + \delta(f+1000) + \delta(f-1000)$$



$\longrightarrow$ Figure 7-8 is same

$$z(t) \xrightarrow{F} Z(f)$$

$$Z(f) = 150(\delta(f-100) + \delta(f+100)) + 300(\delta(f-200) + \delta(f+200))$$
$$+ 60(\delta(f-1000) + \delta(f+1000)) + \frac{25}{2}\delta(f) + \frac{25}{4}(\delta(f-200) + \delta(f+200))$$
$$+ 50\delta(f) + 25(\delta(f-200) + \delta(f+200)) + 2\delta(f) + \delta(f-2000) + \delta(f+2000)$$
$$+ 25(\delta(f-100) + \delta(f+100) + \delta(f-300) + \delta(f+300))$$
$$+ 5(\delta(f-900) + \delta(f+900) + \delta(f-1100) + \delta(f+1100))$$
$$+ 10(\delta(f-800) + \delta(f+800) + \delta(f-1200) + \delta(f+1200))$$



→ Figure 9-10 are same

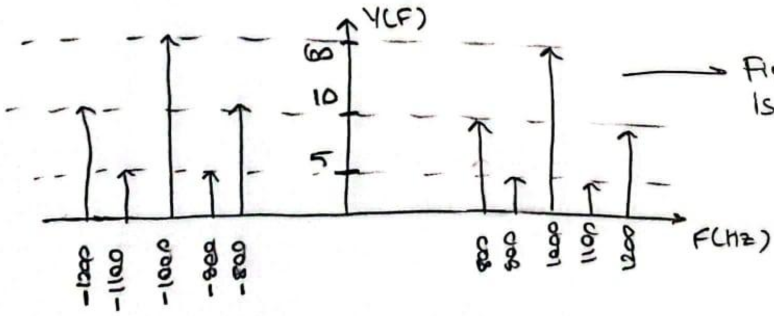
Note: In Figure 9-10, 2000 Hz dirac disappear. In Figure 18 you can see 2000 Hz dirac Z(f) Function.

$$z(t) \longrightarrow \boxed{\begin{array}{c}\text{Bandpass Filter}\\ f_c = 1000\,\text{hz}\\ BW = 400\,\text{Hz}\end{array}} \xrightarrow{y(t)}$$

$$Y(f) = 60\big(\delta(f-1000) + \delta(f+1000)\big)$$
$$+\, 5\big(\delta(f-900) + \delta(f+900) + \delta(f+1100) + \delta(f-1100)\big)$$
$$+\, 10\big(\delta(f-800) + \delta(f+800) + \delta(f-1200) + \delta(f+1200)\big)$$

$$Y(f) \xrightarrow{F^{-1}} y(t)$$

$$y(t) = 120\cos(2\pi 1000t) + 20\cos(2\pi 1000t)\cos(2\pi 100t)$$
$$+\, 40\cos(2\pi 1000t)\cos(2\pi 200t)$$



→ Figure 11-12 is same

$\max\{y(t)\} = 180$ → Figure 14 $\max\{y(t)\} = 180$

if we accept cosinus is 1.

Figure 14 and our analytic solution are same. Their spectral are same too.

Envelope Signal ($\sim m(t)$) ;

The envelope signal result is given in figure 15. The spectral graph this signal is found in figure 16. If we find $\sim N(f)$ function in figure 16 and take the inverse Fourier transform, we can obtain $\sim m(t)$ signal.

Figure 16 spectral $\longrightarrow \sim N(f)$

$$\sim N(f) = 120\delta(f) + 20\left(\delta(f-200)+\delta(f+200)\right) + 10\left(\delta(f-100)+\delta(f+100)\right)$$

$$\sim N(f) \xrightarrow{F^{-1}} \sim m(t)$$

$$\sim m(t) = 40\cos(2\pi 200t) + 20\cos(2\pi 100t) + 120$$

Figure 15 and $\sim m(t)$ function are same.

Compare $\sim m(t)$ and $m(t)$

$$m(t) = 10\cos(2\pi 200t) + 5\cos(2\pi 100t)$$

$$\sim m(t) = \underbrace{40\cos(2\pi 200t) + 20\cos(2\pi 100t)}_{4m(t)} + \underbrace{120}_{DC\ value}$$

The $\sim m(t)$ function resulting from demodulation is similar to the message signal ($m(t)$). Since the message signal is carried with the larger carrier signal, there is a high amplitude Dirac in the the spectral graph (figure 16) of the demodulated signal. This dirac bring us the DC value. This can be solved by placing a capacitance at the output of the demodulation system to get rid of the DC value.

$$\boxed{\underbrace{\sim m(t) = 4m(t)}_{\text{if we get rid of DC value}}}$$

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Project Homework

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