Experiment No. 7

Angle Modulation/Frequency Modulation

Objective: To visualize the message modulating the carrier frequency using Frequency Modulation.

Pre-requests: Basics of MATLAB and fundamentals of signals & systems.

Useful References:

- Lecture Notes of the course,
- Signal processing & Linear Systems, (B. P. Lathi, ©2004, ISBN: 978-0-19-568583-1).
- Communication Systems, (Simon S. Haykin, © 2000, ISBN: 978-0-47-117869-9).

Theory :

Angle modulation is a non linear modulation operation. Angle modulation has two types of modulations; Frequency modulation (FM) and Phase modulation (PM). FM modulation can be expressed as follows:

$$m_{FM}(t) = A_c \cos\left(\omega_c t + k_f \int_{-\infty}^{t} m(\tau)d\tau\right) \qquad \text{Ex 7.1}$$

Where k_f is the frequency modulation deviation constant. Suppose that the message signal is a sinusoidal type as follows:

$$m(t) = -a \sin(\omega_m t) \qquad \text{Ex 7.2}$$

Substituting Ex 7.2 in Ex 7.1 yields

$$m_{FM}(t) = A_c \cos\big(\omega_c t + \beta_f \cos(\omega_m t)\big) \qquad \text{Ex 7.3}$$

Where $\beta_f = k_f a \omega_m$. If the message signal is not sinusoidal one, then the modulation index, β_f will take the form

$$\beta_f = \frac{k_f \max|m(t)|}{W} \qquad \text{Ex 7.4}$$

Where W is the bandwidth of the non-sinusoidal message. On the other hand, the bandwidth of the FM modulated signal can be calculated approximately using Carson's rule

$$B_T = 2(\beta_f + 1)W \qquad \text{Ex 7.5}$$

The amplitude of the modulated signal is constant, therefore, the power of the transmitted signal can be determined as

$$P_{FM} = \frac{A_c^2}{2} \qquad \text{Ex 7.6}$$

The transmitted signal $m(t)$ can be retrieved from the FM modulated signal by accomplishing a differentiation operation on the phase of the low pass equivalent signal and divide the results by the deviation constant, k_f,

$$\theta(t) = k_f \int_{-\infty}^{t} m(\tau)d\tau \xleftarrow{differentiation} k_f m(t) \xleftarrow{divide\ by\ k_f} m(t) \qquad \text{Ex 7.6}$$

Procedure: Implementing the DSB-LC modulation.

Use the following MATLAB program to implement the **FM**-modulation, write the program in your PC and run it.

```
% simulates FM Modulation
clear all; close all; clc;
Ac=1; fc=50; wc=2*pi*fc;            % Amplitude/Frequency of
carrier
Tb=0.1;                             % Bit interval time
T=1/fc/8; Fs=1/T;                   % Sampling period/frequency
Nb=Tb/T; lt=2^(nextpow2(3*Nb)); t=[1:lt]*T; % Time vector
m= ones(Nb,1)*[4,-8,-4]; m=m(:).';
```

```
m=[m, zeros(1,lt-length(m))];       % Message signal m(t)
int_m(1)=0;  T2=T/2;
for i=1:lt-1
   int_m(i+1)=int_m(i)+(m(i)+m(i+1))*T2; % Integration of m(t)
end
kF=30; % Deviation constant
m_FM=Ac*cos(wc*t+kF*int_m); % FM signal
% Demodulation/Detection
th=unwrap(angle(hilbert(m_FM)))-wc*t;
% to get the phase of low-pass equivalent
y_FM=[0 diff(th)/T/kF];  % Demodulated/Detected signal
plot_MOD(T,lt,m,m_FM,y_FM,'FM')
```

You will need this function to get the results plotted:

```
function plot_MOD(T,lt,msg,modul,demodul,How,detected,Bd,Ad)
% plots AM signals and their spectra
Fs=1/T; % Sampling Frequency/Period
t=[1:lt]*T; f =[-Fs/2: Fs/lt: Fs/2];  % Time/Freq. vector
M=fftshift(fft(msg));
M=[M M(1)]*T; % Spectrum of Message signal
Modul=fftshift(fft(modul));
Modul=[Modul Modul(1)]*T; % Spectrum of modulated signal
Y=fftshift(fft(demodul));
Y=[Y Y(1)]*T; % Spectrum of demodulated signal
subplot(421), plot(t,msg)
title('Message signal m(t)')
subplot(422), plot(f,abs(M))
title('Spectrum of message')
subplot(423), plot(t,modul)
title([How ' modulated signal'])
subplot(424), plot(f,abs(Modul))
title('Spectrum of modulated signal')
subplot(425), plot(t,demodul)
title('Demodulated signal y(t)')
subplot(426), plot(f,abs(Y))
title('Spectrum Y(f) of y(t)')
if nargin==9
  H=fftshift(fft(Bd,lt)./fft(Ad,lt));
  Hm=abs([H H(1)]); % Frequency Response of LPF
  hold on, plot(f,Hm,'r-')
end
if nargin>6
  Y_dtr=fftshift(fft(detected));
  Y_dtr=[Y_dtr Y_dtr(1)]*T; % Spectrum of detected signal
  subplot(427), plot(t,detected)
  title('Lowpass filtered output y_dtr(t)')
  subplot(428), plot(f,abs(Y_dtr))
  title('Spectrum Y_dtr of y_dtr(t)')
end
```

Perform the following steps,

1. Run the program and record all your results,
2. Change the message signal to $[44\ ,0\ ,-12$, and record all the results.
3. Change the message signal to $[0,-5,6]$, and record all the results.
4. Change the deviation constant k_f to 5 and repeat steps 1 to 3.
5. Change the deviation constant k_f to 15 and repeat steps 1 to 3.

Discussion:

1. How to calculate the power of the modulated signal?
2. From your results, estimate the bandwidth of the modulated signals.
3. What is the wideband and narrow band FM modulation types?
4. How to generate wideband FM signals? Use your class lectures.

Good Luck
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