ES442 Lab 6
Frequency Modulation and Demodulation

Objective
1. Build simple FM demodulator by using frequency discriminator
2. Build simple envelope detector for FM demodulation
3. Using MATLAB m-file and simulink to implement FM modulation and demodulation.

Part List
1uF capacitor (2); 10.0Kohm resistor, 1.0Kohm resistor, Power supply with +/-5V, Scope and frequency analyzer, FM signal Generator.

Estimated Time
About 90 minutes.

Introduction
Frequency modulation is a form of modulation, which represents information as variations in the instantaneous frequency of a carrier wave. In analog applications, the carrier frequency is varied in direct proportion to changes in the amplitude of an input signal. This is shown in Fig. 1.

The FM-modulated signal has its instantaneous frequency that varies linearly with the amplitude of the message signal. Now we can get the FM-modulation by the following:

\[ \varphi(t) = \cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau\right) \]

where \( k_f \) is the sensitivity factor, and represents the frequency deviation rate as a result of message amplitude change. The instantaneous frequency is:

\[ \omega_i = 2\pi f_c + 2\pi k_f m(t) \]
The maximum deviation of Fc (which represents the max. shift away from Fc in one direction) is:

\[ \Delta f = k_f m(t)_{\text{max}} \]

Note that The FM-modulation is implemented by controlling the instantaneous frequency of a voltage-controlled oscillator(VCO). The amplitude of the input signal controls the oscillation frequency of the VCO output signal. In the FM demodulation what we need to recover is the variation of the instantaneous frequency of the carrier, either above or below the center frequency. The detecting device must be constructed so that its output amplitude will vary linearly according to the instantaneous freq. of the incoming signal. One approach to perform demodulation, is using frequency discrimination:

In this method we differentiate the FM signal to get an AM signal, then we use an envelope detector. The following figure how how to implement such a demodulator:

In this case, the output of the differentiator will be an AM modulated signal. The AM modulated signal can be demodulated using an envelope detector. For more information about the envelope detector refer to AM modulation lab.

See the following animation to see how the differentiator operates:
https://www.youtube.com/watch?v=ZtC2r09e9mQ

The differentiator generates an output signal proportional to the first derivative of the input with respect to time. The transfer function of this circuit is \( v_o = -RC(dv_i/dt) \). Obviously, a constant input (regardless of its magnitude) generates a zero output signal.

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1 Read the following for more information: http://www.electronics-tutorials.ws/opamp/opamp_7.html
Procedures

A-Frequency Demodulation with using Frequency Discriminator
In this section we are going to build a simple FM demodulator.

1. Use the signal generator to generate an FM signal with the message signal being sine signal. The carrier frequency 400Hz, message signal frequency 10Hz, and frequency deviation 100Hz. (Carrier Amp: 1Vpp; output: 50 Ohm).
2. Capture the FM signal using the Scope. Make sure the signal goes through at least four periods in the captured signal.
3. Measure the maximum frequency and minimum frequency by using cursors (DO NOT USE “QUICK MEASURE”). Take a snapshot of the FM modulated signal.
4. Use the spectrum analyzer to observe the frequency spectrum of the FM signal. Record your observation.
5. Answer the following questions:
   a. What is the maximum peak frequency deviation?
   b. What is the modulation index?
   c. What is the modulating signal frequency?
   d. Calculate the frequency deviation sensitivity for this FM signal.
   e. What will be the time representation for the FM signal?
6. Build the circuit below on your prototype board. Make sure all the connections are properly made. Be careful with the +/- voltages powering up the op-amp. Disable the power supply until you have fully checked the circuit. Connect your FM modulated signal to the input of the circuit below. Pay attention to the pin outs of the OP-Amp and the polarity of capacitors and the diode.
7. Answer the following questions:
   a. In the circuit above identify the differentiator and the envelope detector functional blocks.
   b. Calculate the RC time constant of the envelope detector for this circuit. What center frequency can handle? What is the modulating signal?
   c. Write the time domain expression for the differentiator in terms of its input.
   d. What is the frequency domain expression for the differentiator in terms of its input? See the Introduction.

8. Measure the signal at the output of the differentiator. Take a snapshot of the signal. How does it look like? How does it look like? What type of a signal is this?

9. Calculate the modulating index of the output of the differentiator.

10. Measure the signal at the output of the envelope detector. Take a snapshot of the signal. How does it look like? What is the frequency of this signal?

11. Change the modulating signal on the FM signal generator. What happens to the output of the ED?

12. Change the modulating signal to a square waveform and observe the output of the demodulator.

13. Change the modulating signal back to a sinusoidal waveform. For what range of frequencies the output of the ED is non-distorted?

14. Change the carrier frequency back to 400 Hz.

15. For what range of modulating signal frequencies the output of the ED is non-distorted?

16. Assuming we use a slope detector in place of the differentiator, draw the circuit diagram. Show all the components. Make sure you use a schematic capture program to sketch your circuit. You will not receive a grade if you use Paintbrush or Visio.
**B- Analytical Mode of a Discriminator Demodulator**

In this section we like to establish an analytical model for the Frequency Discriminator we used in the lab. Assume the input signal is

\[ v_{in}(t) = A_i \sin[\omega_0 t + \theta(t)] \]

Find the mathematical expression for the output of the DC Blocker module.

**C- Modeling Discriminator Using Matlab**

In this section we like to use Matlab to generate an FM signal and model the frequency discriminator, similar to the circuit we completed in the lab. Carefully, review the Matlab code given in Appendix A below. Use the input parameters you used in the lab.

1- Using the provided Matlab code, plot the FM modulated signal and the modulating signal.
2- Show the frequency spectrum of the FM modulated signal. Is it consistent with what you saw on the scope?
3- Plot the output of the Envelop Detector for different values of R. What happen to the signal? What is the best choice of RC? Note that in our case we used C= 1uF.
Appendix A:

```matlab
% Plot the frequency modulated signal
fc=100;
fm=5;
ts=1/(10*fc);
fs=(1/ts);
kf=2; % Frequency deviation sensitivity
wc=2*pi*fc;
t=0:ts:2;
m=Sin(2*pi*fm*t);
y=cos(wc*t+([kf*2*pi+cumsum(m)].*ts));
figure(1)
subplot(211)
title('Input signal')
subplot(212)
plot[t,m]
% Plot the frequency response
mf=fftshift(fft(m))*ts;
delta=fs/length(mf);
f=-fs/2:delta:fs/2-delta;
figure(2)
subplot(211)
plot(f,abs(mf))
title('Magnitude spectrum of input signal')
subplot(212)
plot(f,abs(a))
title('Magnitude spectrum of the fm')
```

Frequency Representation of FM Signal

```matlab
% Plot the output of the differentiator
E=diff(y)/ts;
figure(3)
plot(E)
title('The differentiation of fm ')

% Plot of the output signal from the envelope detector:
% For different values of R
vout(1)=E(1);
tl=(0:length(E)-1)*ts;
R=10^-5,10^-4,10^-3,10^-2)*3.2, % Different values of R
c=10^-6;
for n=1:4
  for i =2:length(E)
    if E(i)>vout(i-1)
      vout(i)=vout(i-1);
    else
      vout(i)=vout(i-1).*exp(-ts/(R(n)*c));
    end
  end
figure(4)
subplot(4,1,n)
plot(tl,vout,tl,E)
title('The AM signal and envelope signal')
end
```

Differentiator | Envelope Detector