ELP311

Communication Engineering Laboratory

Experiment 4
FM Demodulation using MATLAB

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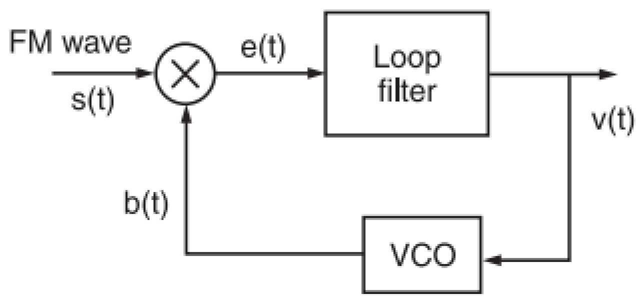
Objective

The aim of this experiment is to simulate and understand the demodulation of an FM signal using PLL.

Theory

The block diagram of PLL is shown below:



The operation of a PLL is like any other feedback system where the feedback signal tends to follow the input signal. If the signal fed back is not equal to the input signal, the error signal will change the value of the feedback signal until it is equal to the input signal. The difference signal between $s(t)$ and $b(t)$ is called error signal. A PLL operates on a similar principle except for the fact that the quantity feedback is not the amplitude, but a generalized phase $\varphi(t)$.

The error signal $e(t)$ is utilized to adjust the VCO frequency in such a way that the instantaneous phase angle comes close to the angle of the incoming signal $s(t)$.

At this point, the two signals $s(t)$ and $b(t)$ are synchronized and the PLL is locked to the incoming signal $s(t)$.

Here, we have assumed that the VCO is adjusted initially so that when the control voltage comes to zero, the following two conditions are satisfied:

i. The frequency of the VCO is precisely set at the unmodulated carrier frequency, f_c
ii. The VCO output has a 90° phase-shift w.r.t. the unmodulated carrier wave.

MATLAB code

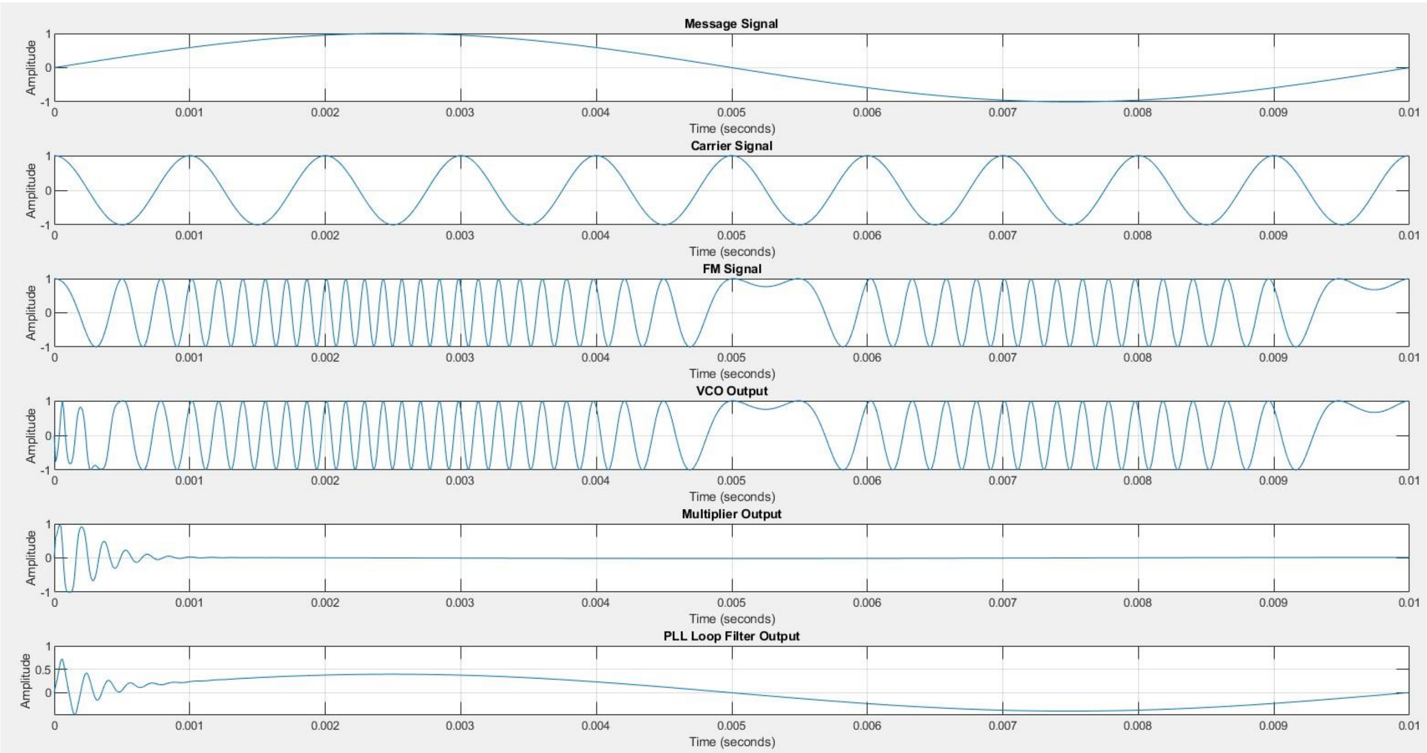
In this experiment, we first create an FM signal and then implement a phase-locked loop to demodulate the signal. Demodulation is performed for different values of initial phase of the VCO ($\varphi_2(1) = 10, 30, 50$).

```
close all;

fc=1000;   % Carrier frequency
fs=100000; % Sample frequency
N=5000;    % Number of samples

Ts=1/fs;
t=(0:Ts:N*Ts-Ts);

% Create the message signal
fm=100;             % Modulating frequency
msg=sin(2*pi*fm*t);
kf=.0628;           % Modulation index

% Create the real and imaginary parts of a CW modulated carrier to be tracked.
% Modulated carrier (better to write it as complex exponential)
modulated=exp(1i*(2*pi*fc*t+2*pi*kf*cumsum(msg)));
% Unmodulated carrier  (better to write it as complex exponential)
carrier=exp(1i*(2*pi*fc*t));

% Initilize PLL Loop
phi_2(1)=10;
e(1)=0;
mul(1)=0;
vco(1)=0;

% Define Loop Filter parameters (Sets damping)
kp=0.15;    % Proportional constant
ki=0.1;     % Integrator constant

% PLL implementation
for n=2:length(modulated)

    vco(n) = conj(exp(1i * ((2 * pi * n * fc / fs) + phi_2(n - 1))));
    mul(n) = imag(modulated(n) * vco(n));
    e(n) = e(n - 1) + (kp * mul(n)) + (ki * (mul(n) - mul(n - 1)));
    phi_2(n) = phi_2(n - 1) + e(n);

end

% Plot waveforms
startplot = 1;
endplot = 1000;
% message signal
```

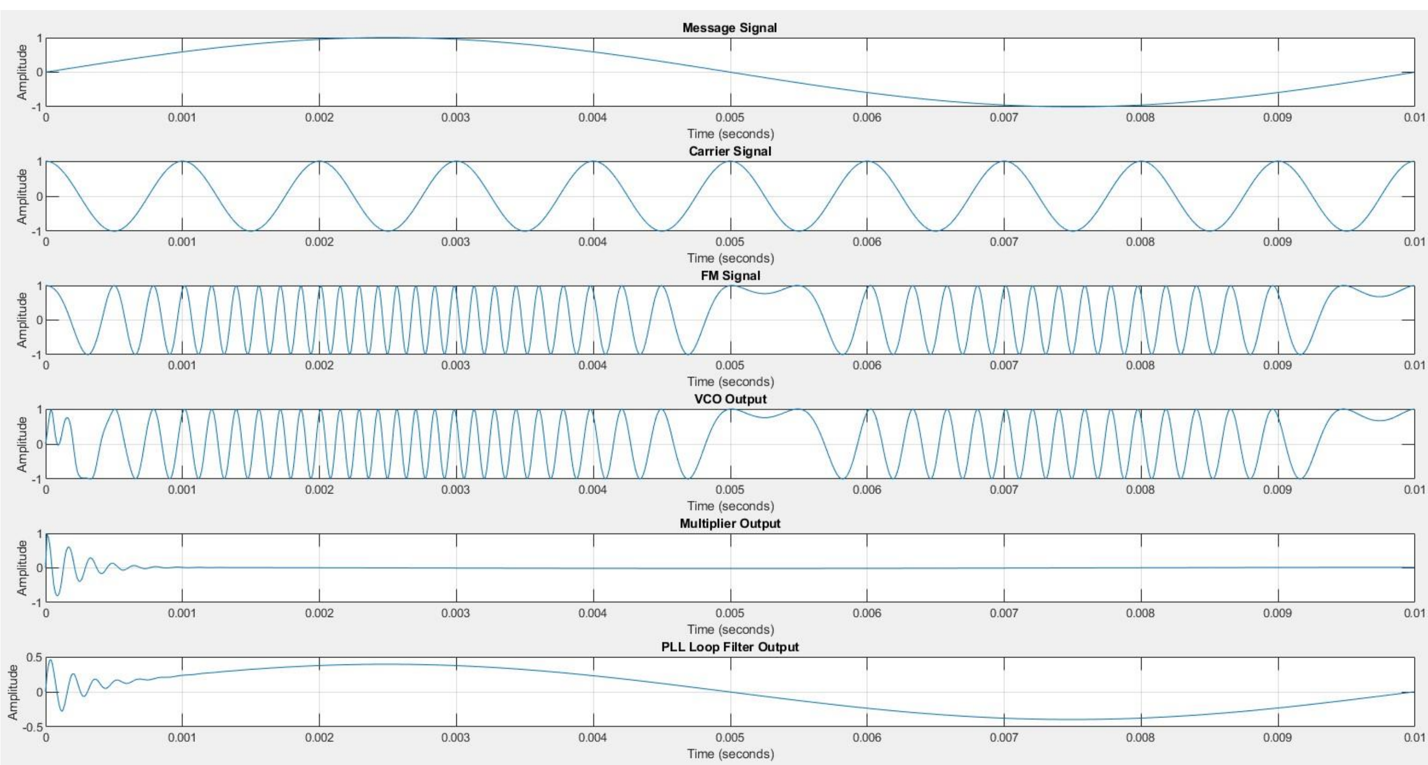
```
figure(1);
subplot(6,1,1);
plot(t(startplot:endplot), msg(startplot:endplot));
title('Message Signal');
xlabel('Time (seconds)');
ylabel('Amplitude');
grid;

% carrier signal
figure(1);
subplot(6,1,2);
plot(t(startplot:endplot), real(carrier(startplot:endplot)));
title('Carrier Signal');
xlabel('Time (seconds)');
ylabel('Amplitude');
grid;

% FM signal
figure(1);
subplot(6,1,3);
plot(t(startplot:endplot), real(modulated(startplot:endplot)));
title('FM Signal');
xlabel('Time (seconds)');
ylabel('Amplitude');
grid;

% VCO output
figure(1);
subplot(6,1,4);
plot(t(startplot:endplot), real(vco(startplot:endplot)));
title('VCO Output');
xlabel('Time (seconds)');
ylabel('Amplitude');
grid;

% multiplier output
figure(1);
subplot(6,1,5);
plot(t(startplot:endplot), real(mul(startplot:endplot)));
title('Multiplier Output');
xlabel('Time (seconds)');
ylabel('Amplitude');
grid;

% filter output
figure(1);
subplot(6,1,6);
plot(t(startplot:endplot), real(e(startplot:endplot)));
title('PLL Loop Filter Output');
xlabel('Time (seconds)');
ylabel('Amplitude');
grid;
```

Plots

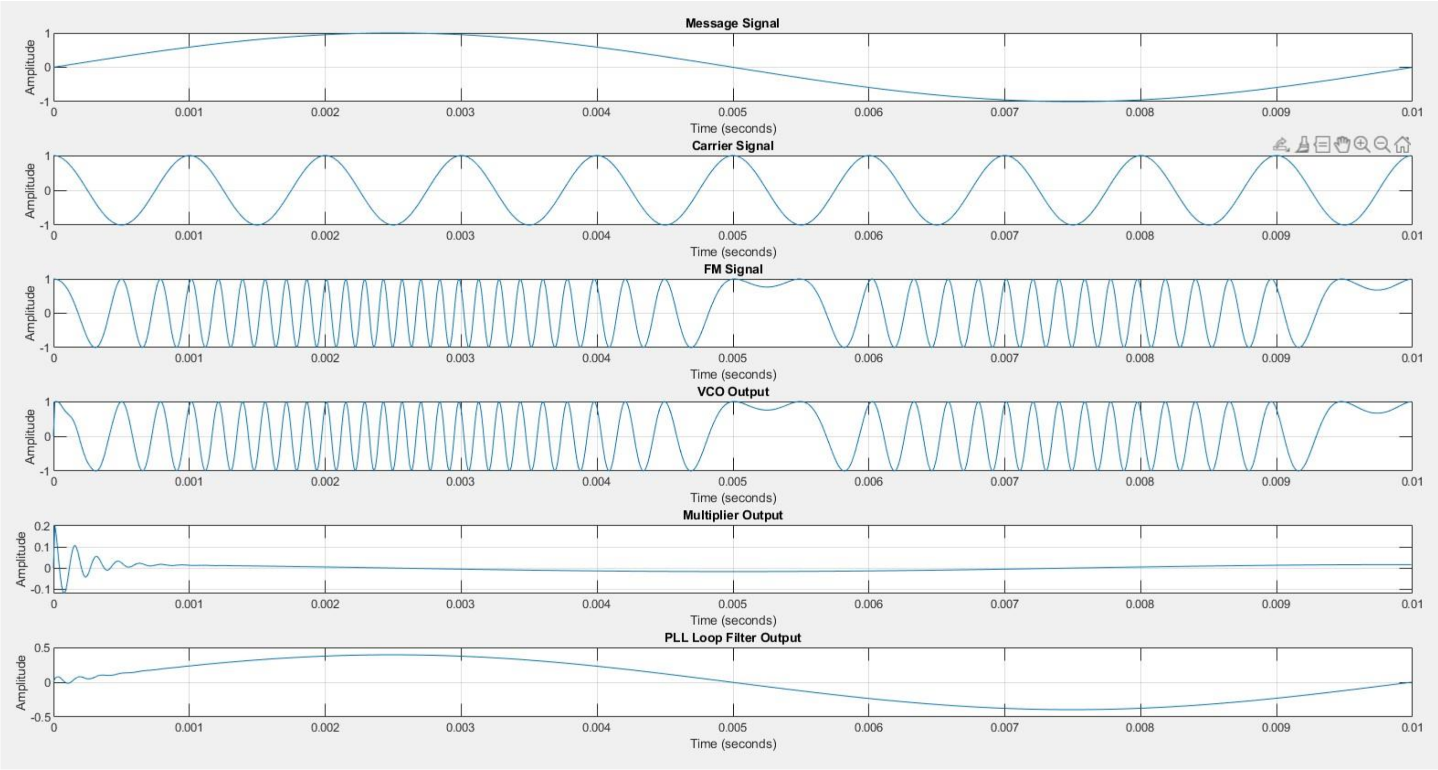
1. $\varphi_2(1) = 10$



2. $\varphi_2(1) = 30$



3. $\varphi_2(1) = 50$



Tutorial Questions

1. **What is the BW requirement for FM signal?**
   According to Carson's rule, the bandwidth of an FM signal is given as

$$BW = 2(\beta + 1)f_m$$

   Here, β denotes modulation index and f_m denotes the message signal frequency.

2. **What is impact of message signal amplitude on Bandwidth of FM signal?**
   Modulation index, $\beta \propto a$, where a denotes the amplitude of the message signal. Therefore, the bandwidth of the FM signal increases as the amplitude of the message signal increases.

3. **As compared to amplitude modulation, the channel bandwidth is less in FM. True or False? Comment.**
   False. The bandwidth of an AM signal is twice the frequency of the message signal whereas the bandwidth of an FM signal can be inferred from Carson's rule.

4. **As compared to Amplitude modulation, transmitted power is less in FM. True/False? Comment.**
   False. FM based signal transmission consumes more power than an equivalent AM based signal transmission. In an AM signal, there is wastage of power as a major part of the power carried by the carrier wave does not contain the information whereas there is no wastage of power in an FM signal.

5. **What is frequency swing of an FM signal?**
The frequency swing of an FM signal is the maximum deviation of instantaneous modulated signal frequency from its mean. Mathematically, it is given by

$$\Delta f = \beta f_m$$

Here, β denotes modulation index and f_m denotes the message signal frequency.

6. **Why is FM called voltage to frequency conversion process?**
FM is called voltage to frequency conversion process because the message signal initially has the units of voltage and through FM it is converted to frequency variations of the modulated signal.

7. **What are the various demodulation methods for FM signal? Why PLL is preferred method?**
Following are some of the demodulation methods of FM signal:

   i. Frequency Discrimination Using Slope Detector
   ii. Phase Discrimination Using Quadrature Detector
   iii. Phase-Locked Loop

   The PLL is the preferred method because it could easily be integrated into the radio IC by simply adding a little extra circuitry to the IC. The PLL technology eliminates the costly RF transformers. Typically, a phase locked loop FM demodulator does not require the use of an inductor, let alone a transformer.

8. **What is role of VCO and LPF in PLL based Frequency demodulation process?**
The VCO generates a feedback signal which tries to approximate the input signal.

   The multiplication of the input signal and the VCO output produces the error signal. The error signal consists of a high frequency component (sum of phases) and a low frequency component (difference of phases). The lowpass filter filters out the high frequency component, leaving only the low frequency component.

9. **Write the MATLAB script generation and detection of FM signal for multi-tone message signal.**
The MATLAB script for generation and detection of FM signal will be the same as above. However, the message signal `msg` must be defined as per the problem specification. Example of a multitone signal is shown below:

```
msg=sin(2*pi*fm1*t)+sin(2*pi*fm2*t)+sin(2*pi*fm3*t);
```

10. **How to analyze the power spectrum of FM signal using MATLAB?**
The approximate power spectral density can be plotted using MATLAB's *periodogram* function. For example, to plot the power spectral density of a signal use the following statement:

```
periodogram(x,rectwin(length(x)),length(x),fs); % fs denotes sampling frequency
```

Observations and Conclusions

From the plots obtained, we can observe that the output of the PLL matches with the message signal. There is some jitter observed initially in each of the PLL outputs. This is because at this stage the phase of the VCO output and that of the input signal are slightly different. Once the two phases are almost same, the PLL output stabilizes and matches with the input signal.

Further, it can be observed that the initial jitter in PLL output decreases with increase in the initial phase of the VCO.