Lab Assignment - 9
The Phase-Locked Loop (PLL)

April 13, 2016

In this lab, we will study the design and simulation of phase-locked loops (PLL).

In coherent demodulation, we require a local replica of the carrier at the transmitter. A phase-locked loop helps in generating a local carrier of the same frequency and phase as those of the transmitter carrier. The PLL acquires the frequency and phase of an incoming carrier and tracks any changes in them. In this lab, we will develop a PLL, observe how it acquires the frequency of an incoming carrier and then track it.

A PLL has three basic components:

- Phase Detector
- Voltage-Controlled Oscillator (VCO)
- Loop Filter

We say that the PLL is locked when the output of the VCO has the same frequency as that of the incoming carrier and the phase is $\pi/2$ apart.

The following questions are of our interest when designing or anlayzing a PLL.

1. How much of the deviation Δf in incoming carrier can the PLL capture in its VCO output when started from an unlocked state? This is called the capture range.

2. How much of the deviation Δf in incoming carrier can the PLL track when it is in the locked state. This is called the lock range.

In this lab, you are allowed to use for loops. You will take one sample of the incoming carrier, multiply it by the sample of the VCO and then pass the output through the filter. The output of the filter will be used to generate a single sample of the VCO output that will be used to multiply by the next sample of the incoming carrier. In summary, your processing will be sample-by-sample in a loop until all the samples are traversed. The basic skeleton of the code is as follows:

```
% Lab Assignment 9
% Phase-Locked Loop
% -------------------------------------------------------------------------
% Author:

close all;clear all;clc;

% Initialize all the following variables here.
% Fs = Sampling frequency, samples per second
% Fc = VCO free-running frequency, Hz
% df = The deviation in the incoming carrier frequency, Hz
% F0 = Cut-off frequency of the loop filter, Hz
% K_vco = VCO sensitivity, rad/volts
% sim_end = Simulation end time in seconds.

Fs = 20e3;
F0 = 1;
Fc = 2e3;
df = 10;
K_vco = 2*pi*15e1;
sim_end = 2;

% Generate the time axis

% Generate the incoming carrier

% Declare empty vectors to store the output of the loop filter, error
% detector and vco output.
len_y = length(y);
error_detector = zeros(1, len_y);
loop_filter = zeros(1, len_y);
vco_output = zeros(1, len_y);

% Initialize VCO angle to zero
vco_angle = 0;
T = 1/Fs;

% Declare the loop filter
[b, a] = butter(1, F0/(Fs/2));
z = zeros(max(length(a), length(b))-1,1);

% Simulate the PLL loop iterations
for i=1:len_y,
    % Calculate the output of the VCO using current vco_angle

    % Calculate the output of the error detector using one sample of the
    % incoming carrier and one sample of the VCO output

    % Calculate the loop filter's output. Note that the variable Z contains
    % the final state of the filter after a sample is passed through it.
    [loop_filter(i), z] = filter(b, a, error_detector(i), z);

    % Update the VCO angle based on the output from the loop filter. The
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    % output of the loop filter adds to the free-running frequency of the
    % VCO after multiplication by K_vco. To convert this frequency to VCO
    % angle, you can integrate the frequency term to get the VCO angle. The
    % integration can be thought of as a cumulative sum of the updated
    % frequency.


    % Limit the VCO angle to -2*pi and 2*pi. When the value of VCO angle is
    % higher than 2*pi subtract 2*pi and when the value of the VCO angle is
    % lower than -2*pi add 2*pi.

end

% Plot error detector output
% Plot a scaled version of the loop filter's output, i.e.,
% loop_filter*K_vco/(2*pi).
% Plot last five cycles of incoming carrier and the VCO output overlayed on
% each other
```

Laboratory Tasks

Task 1: Complete the skeleton code for a fully functional PLL, and plot the scaled version of the loop filter's output. How this value relates to the frequency deviation Δf of the incoming carrier?

Task 2: Find the capture range of the PLL by increasing the frequency of the input signal from the free running frequency in steps of 2 Hz until the PLL is unable to lock onto the signal.

Task 3: Repeat Task 2, but this time decrease the frequency deviation in steps of 2 Hz until the PLL is unable to lock onto the signal.

Task 4: Based on Task 2 and 3, calculate the capture range of the PLL. Compare the observed capture range with the range calculated using the formula $\frac{\sqrt{2\pi f_0 K_{VCO}}}{\pi}$.

Task 5: How the loop filter output changes with increasing and decreasing the loop filter bandwidth? Explain.

Task 6: How the loop filter output changes with increasing and decreasing K_{VCO}. Explain.