ECE 146A: Analog Communication Theory and Techniques
Lab 4: Angle Modulation and Demodulation

Lab Report Due: 5:00 p.m., Tuesday, February 26, 2008
(Place in the ECE 146A Homework Box on the 3rd Floor of Harold Frank Hall or Bring to Class)

1 Objective

To goal of this lab is to implement two types of angle modulation: frequency modulation (FM) and phase modulation (PM). You will also examine different methods of demodulating these signals using a discriminator and a phase-locked loop (PLL). The modulated and demodulated signals will be analyzed via comparisons in the time and frequency domains.

2 Equipment

Matlab, Simulink, and the Communication Toolbox software are available on the ECI workstations.

3 Background and Preparation

Review the two types of modulation, FM and PM, covered in your textbook. Review the tutorial in the Communication Toolbox manual about modulation and demodulation, and read about the different Simulink blocks used for these operations.

Implement the two types of angle modulation using Simulink based on the equations given below. You may use any blocks available including those in the Communication Toolbox. Your design should have a single block from which you can choose a modulation type (for example, like the Analog Filter block where you may choose from the different filter types using a pull-down menu). Test your implementation by using different types of message signals, e.g., sinusoidal, square, and triangular waveforms.

3.1 Angle Modulation

In general, we can write

$$s(t) = A_c \cos(2\pi f_c t + 2\pi\theta(t) + \theta_c) \tag{1}$$

where A_c is the carrier amplitude, f_c is the carrier frequency, θ_c is the initial phase, and $\theta(t)$ is the modulated phase which is a function of the message signal $m(t)$.

3.2 Frequency Modulation

For FM, the modulated phase is given by

$$\theta(t) = k_f \int_0^t m(\tau)d\tau \tag{2}$$

where k_f is the frequency sensitivity. Substituting this expression into (1) yields

$$s_{FM}(t) = A_c \cos(2\pi f_c t + 2\pi k_f \int_o^t m(\tau)d\tau + \theta_c). \tag{3}$$

3.3 Phase Modulation

For PM, the modulated phase is

$$\theta(t) = k_p m(t) \tag{4}$$

where k_p is the phase sensitivity. Substituting this expression into (1) yields

$$s_{PM}(t) = A_c \cos(2\pi f_c t + 2\pi k_p m(t) + \theta_c). \tag{5}$$

4 Procedure

For the following experiments, you should be able to view the signals simultaneously in the time and frequency domains.

4.1 Sinusoidal Modulation

Generate FM and PM waveforms using a sinusoidal message signal. Set the modulation frequencies, signal amplitudes, and sensitivity constants (k_f and k_p) such that for both cases (FM and PM) you generate narrowband and wideband signals.

(1) What criteria did you use to determine whether the FM and PM signals were wideband or narrowband? What parameters did you choose?

Next, verify the quasi-steady-state FM spectrum by generating a wideband FM signal and observing its magnitude spectrum. (Note that the magnitude spectrum is the square root of the power spectrum.)

(2) Print a plot of the resulting spectrum and specify the modulation index β that you decided to use. Explain why the spectrum does not look exactly like that predicted by the theory.

4.2 Triangular-Wave Modulation

Create a triangular waveform and use it as the message signal for FM and PM.

(3) How do the spectra of the FM and PM signals differ? Interpret your results.

Recall for FM that $\theta(t) = k_f \int_0^t m(\tau)d\tau$. This quantity is the maximum instantaneous phase deviation for a general message signal $m(t)$.

(4) When $m(t)$ is a triangular waveform, what can you say about the instantaneous phase deviation? Express $\theta(t)$ above as a function of the waveform amplitude.

4.3 Noise Modulation

Select Gaussian and then uniform noise signals for the message signal and examine the quasi-steady-state FM spectrum by implementing wideband FM and observing its magnitude spectrum.

(5) Is the agreement with the theory any better or worse than for the sinusoidal modulation? Suggest reasons for what you observed.

4.4 Narrowband FM (NBFM)

The transmitted signal for NBFM can be represented by

$$s_{NBFM}(t) = A_c A_m m(t)\cos(2\pi f_c t) + A_c \sin(2\pi f_c t). \tag{6}$$

Using a square-wave message signal, set A_m to a small value, and let $A_c = 1$, $f_c = 1$ kHz, and the modulating frequency be 100 Hz. Compare the magnitude of the spectrum with that for conventional amplitude modulation (AM). Adjust A_m so that the spectra of AM and NBFM are very similar.

(6) Explain why it is possible for NBFM and AM to have similar spectra.

4.5 Demodulation

Next you will examine two methods of demodulating FM signals, first using a discriminator and then using a phase-locked loop (PLL).

4.5.1 Demodulation Using a Discriminator

A discriminator is a differentiator (or an approximation thereof) followed by an envelope detector. Starting with the FM signal in (3), the output of a differentiator can be written as

$$\frac{ds_{FM}(t)}{dt} = -2\pi A_c(f_c + k_f m(t))\sin(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau + \theta_c). \tag{7}$$

If the instantaneous frequency of the sine term is much greater than the modulating frequency f_m (assuming a sinusoidal message) or the one-sided bandwidth of an arbitrary message $m(t)$, then the output of the differentiator will appear like an AM signal (but with a variable-frequency carrier). Thus, $m(t)$ can be recovered by an envelope detector (which ignores minor variations in the carrier frequency).

Construct a discriminator circuit and make sure that $m(t)$, $s_{FM}(t)$, and the output of the envelope detector can all be viewed simultaneously in the time and frequency domains. Test the performance of your design by generating FM signals using sinusoidal and triangular waveforms for $m(t)$.

(7) Modulate a 1 kHz carrier with a 20 Hz and then a 200 Hz triangular waveform. Do you see any significant differences in the demodulated waveforms for the two frequencies? Explain.

Using the previously implemented sinusoidal modulation, add white noise to $s_{FM}(t)$ that is bandlimited to twice the frequency of the carrier. Set the power level such that the noise is 20 dB above the carrier signal power. Verify that the power spectrum of the combined (noisy) signal approximates that of white noise. Note that because of the low signal-to-noise ratio (SNR) of -20 dB, the discriminator is largely "detecting" the noise.

(8) Display the power spectrum of the discriminator output. Can you still see the spectrum of the original signal within that of the noise?

(9) Is the noise spectrum at the discriminator output still white? Explain.

(10) Examine the spectrum of the discriminator output before and after the low-pass filter and comment on what you observe.

4.5.2 Demodulation Using a PLL

A PLL demodulates an FM signal using feedback to force a voltage-controlled oscillator (VCO) to remain in phase with the carrier of the incoming signal. The message signal $m(t)$ is recovered as the control input of the VCO.

Design a PLL using a VCO that is essentially the frequency modulator covered previously. The phase comparison is accomplished by using a multiplier followed by a low-pass filter. Use a simple first-order low-pass filter with one real pole.

(11) Test your PLL demodulator on a sinusoidally modulated FM signal. Note that it will take several hundred samples before the output will stabilize. This time period is referred to as the capture phase during which the PLL acquires (locks onto) the carrier. Suggest reasons why this capture phase occurs.

(12) Adjust the initial parameters until the demodulated sinusoidal message (after capture) best resembles the input. Which parameter values result in good demodulation?

(13) You will probably see some ripples on the demodulated signal. Explain their origin.

(14)-(16) Repeat items **(11)-(13)** using a triangular waveform for the message signal $m(t)$.

5 Lab Report

- Answer all questions and print out the most useful plots to support your answers.
- Include printouts of the various modulation and demodulation schemes, with all Matlab and Simulink models that you designed.
- Write a paragraph about any questions or confusions that you may have experienced with this lab.