ECE 146A: Analog Communication Theory and Techniques
Lab 5: Angle Modulation and Demodulation – Hardware

Lab Report Due: 5:00 p.m., Thursday, March 13, 2008
(Place in the ECE 146A Homework Box on the 3rd Floor of Harold Frank Hall or Bring to Class)

1 Objective

The goal of this lab is to investigate the properties and characteristics of a frequency modulated (FM) signal and its spectrum. You will implement the FM modulator and demodulator using the MC14046 phase-locked loop (PLL) integrated circuit (IC).

2 Laboratory Room

Engineering I, Room 5162. Note that you will work in groups of two students, but each student must submit a separate lab report. Due to time constraints, your report will be relatively brief compared to those of previous labs.

3 Equipment

Along with an oscilloscope, a digital multimeter (DMM), a function generator, and a power supply, you will need the following equipment:

1. MC14046 PLL.
2. Various resistors, capacitors, and diodes.
3. Breadboard.
4. Cables: BNC to IC clips (3 each), banana cable for DC power supply (3 each), DMM test leads (1 each).
5. Needle nose pliers and wire cutters.
6. Wire.
7. Card key for room 5162.

Most of these items can be purchased as a lab kit from the Electronics Shop on the first floor of Engineering I.

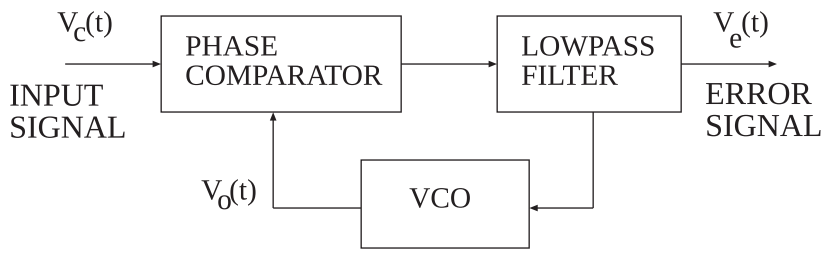

Figure 1: Block diagram of the PLL components.

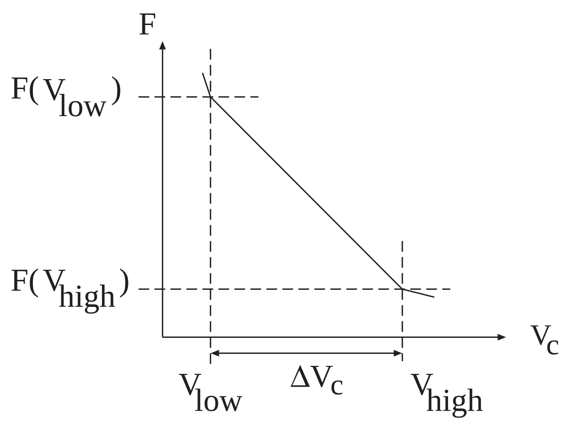

Figure 2: Voltage/frequency characteristic of a VCO.

4 Background

4.1 Phase-Locked Loop

A phase-locked loop (PLL) is basically an electronic feedback system that provides frequency selective tuning and filtering without the need for coils or inductors. It consists of three basic functional blocks:

- Phase comparator.
- Lowpass filter.
- Voltage-controlled oscillator.

Figure 1 shows a block diagram of a PLL. Observe that the phase comparator output signal is computed as the phase difference between the input signal $V_c(t)$ and the output of the voltage-controlled oscillator (VCO) $V_o(t)$. This signal is then filtered by a lowpass filter (LPF) to produce the error signal $V_e(t)$, which is needed by the VCO to generate the output frequency. As the error voltage increases, the VCO output frequency also increases.

The basic operation of the PLL can briefly be explained as follows. With no input signal applied to the system, the error voltage $V_e(t)$ is equal to zero, and the VCO operates at a predetermined "free running" frequency f_o. When an input signal with a frequency f_c not equal to f_o is applied to the system, the phase comparator produces a nonzero error voltage, which makes the VCO output frequency approach f_c. Thus, the feedback loop causes the VCO to synchronize in frequency (i.e.,

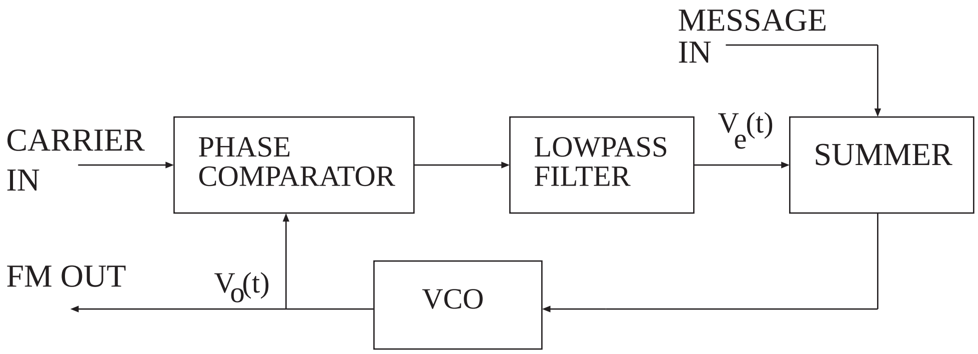

Figure 3: FM modulation using a PLL.

become locked) with the incoming signal. Once in lock, the VCO output frequency is essentially identical to that of the input signal. Figure 2 shows a typical voltage/frequency characteristic for a VCO.

A PLL circuit can be used to create an FM signal. The input to the phase comparator is the carrier signal, and assuming that the carrier frequency is within the capture range of the PLL, the VCO output frequency will be equal to the carrier frequency. Now, if the VCO control voltage is the sum of the message waveform and the loop error voltage, then the VCO output frequency will vary about the carrier frequency according to the message. Thus, the VCO output is the desired FM signal. A block diagram of a PLL frequency modulator is shown in Figure 3.

4.2 Frequency Modulation

Frequency modulation (FM) is a form of angle modulation where the message signal $m(t)$ is used to vary the carrier frequency. Review the material on FM covered in Lab 4 and discussed in your textbook. An implementation based on the MC14046 IC is shown in Figure 4. Review details of the MC14046 IC by studying the data sheet on the course web site.

4.3 Frequency Demodulation

A PLL may also be used to demodulate an FM signal. The quiescent frequency (i.e., with no input signal) of the VCO is adjusted to the frequency of the unmodulated carrier. Assuming that the instantaneous frequency of the FM signal remains within the lock range of the PLL, the VCO output frequency will equal the frequency of the FM input. This in turn means that the error signal, which is the VCO input, corresponds to a reconstructed version of the message that created the FM signal. A block diagram of an FM demodulator based on a PLL is shown in Figure 5, and an implementation using the MC14046 IC is shown in Figure 6.

5 Preparation

- Review the theory of FM, PLLs, and VCOs in your textbook and the Matlab Communication Toolbox manual.
- Read the data sheet on the MC14046 IC.
- Answer the following questions:
  1. Why don't we choose a carrier frequency f_c higher than 100 kHz in this lab.

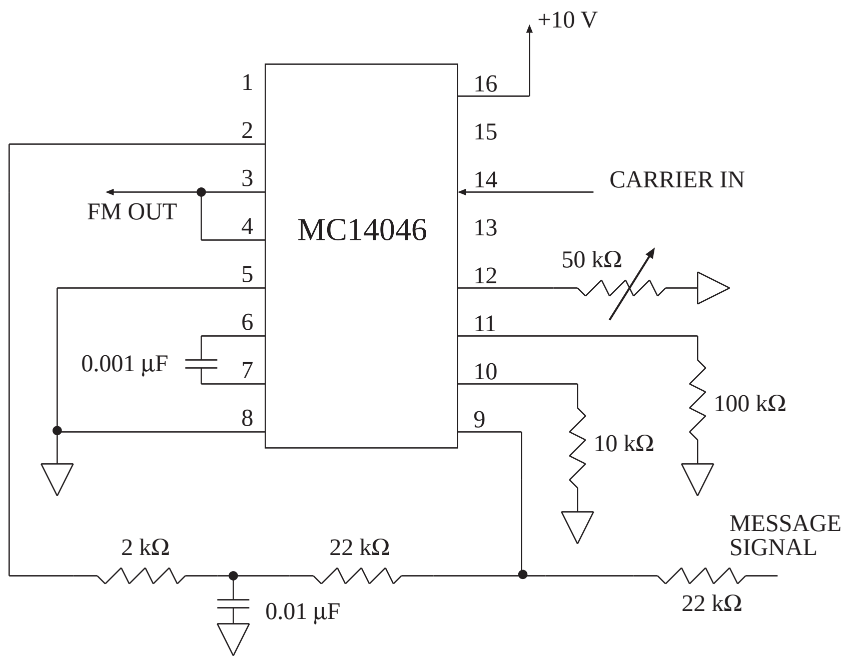

Figure 4: FM modulator circuit based on the MC14046.

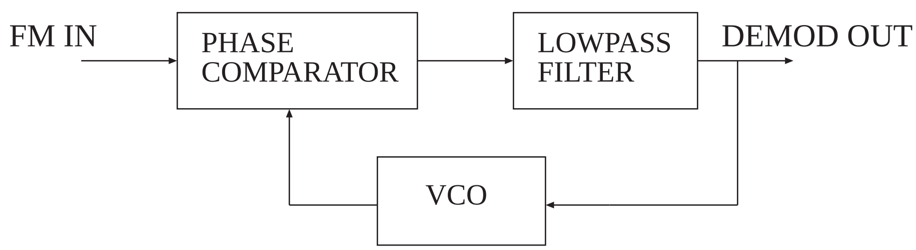

Figure 5: Block diagram of an FM demodulator.

2. What are the similarities and differences between FM modulation and FM demodulation using a PLL?
3. Give mathematical expressions that describe what occurs in (a) FM, (b) the VCO, and (c) the PLL.

6 Procedure

The carrier is a 100 kHz square wave with 10 V peak-to-peak and +5 V DC bias. The message signal $m(t)$ is a 1 kHz sine wave with 5 V peak-to-peak. Proceed through the following steps to design and implement the FM modulator and demodulator.

(a) Adjust the free-running frequency (pin 4) to 100 kHz by varying the 50 kΩ potentiometer. Construct the circuit in Figure 7 to adjust the free-running frequency.

(b) Construct the circuit shown in Figure 4 to implement the FM modulator.

(c) Fine tune the carrier frequency until a stable (but probably imperfect sine wave) is produced at pin 9, assuming that the modulator input is the sine-wave message.

(d) Connect the output FM signal to the input of the FM demodulator. If the waveform is unstable and not like a sine wave, fine tune the carrier frequency until a stable sine wave is produced at pin 9 of the FM demodulator. When this occurs, your modulator and demodulator are working properly.

(e) Print out the spectra of the message signal, the FM signal, and the demodulated FM signal for a few different values of the modulation index β (small, medium, and large) by varying the message frequency and its amplitude. When you observe and record the waveforms, use the same time scale in all instances. You should also record the selected modulation parameters. (Note that plotting on the oscilloscope may take some time, so do these as time permits.)

1. Can you observe any changes in the waveform and spectrum when varying the signal parameters?
2. For each set of parameter values, estimate how many sidebands need to be retained in order to have a reasonably accurate approximation of the waveform.
3. What is the corresponding bandwidth of the FM signal? How do the measured results compare to your estimates? Explain any discrepancies.

(f) Compare the PLL input signal with the VCO output. Can you see that these two signals are locked? Display the two signals simultaneously on the oscilloscope and record them on the same plot.

(g) Repeat the above procedures for a 1 kHz square-wave message signal using the same 100 kHz sine-wave carrier signal. Answer the same questions for this modified case.

7 Lab Report

Use a brief version of the standard lab report and include the following items.

- Two plots from the oscilloscope showing the modulated and demodulated signals, and a couple of plots showing the spectrum magnitudes from the oscilloscope.
- Answers to all questions.
- Circuit designs: specifications, design considerations, schematic drawings, and parts list.
- Testing results: debugging and circuit tune-up, spectrum plots, and time-domain waveforms.
- Write a paragraph about any questions or confusions that you may have experienced with this lab.

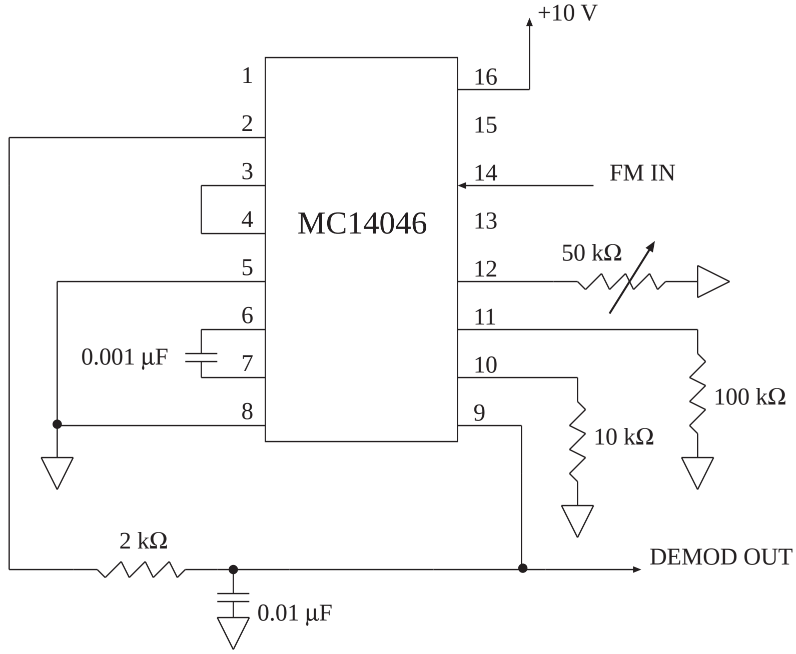

Figure 6: FM demodulator circuit based on the MC14046 IC.

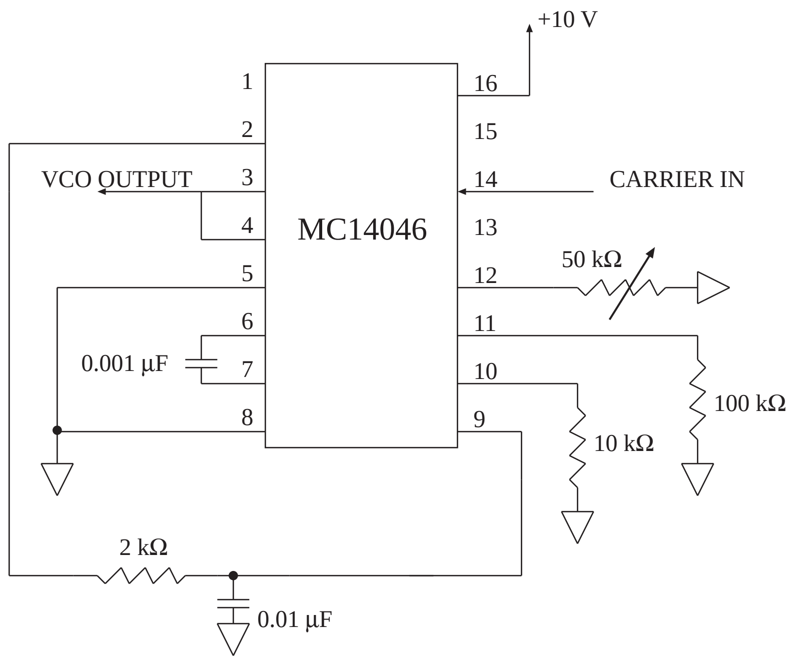

Figure 7: PLL circuit for adjusting the free-running frequency.