Experiment
6

Frequency Modulation Using the ACB

Hardware Experimentation

Objectives

The main objectives of this experiment are:

1) To build on the introduction to FM in the previous lab (based on Matlab Simulation), and to gain a clearer understanding of its concepts using hardware experimentation with the ACB.

2) To perform FM bandwidth computations for different message waveforms.

3) To experiment with another common demodulation scheme for FM, known as Quadrature Detection.

Pre-Lab Work

1) Consider the case of FM modulation with a sinusoidal message signal (tone modulation). Give a simple validation of Carson's formula for bandwidth estimation based on the use of mathematical derivations involving *Bessel Functions* (refer to your textbook for relevant details).

2) As a preparation for the bandwidth computation in this lab, review Fourier series techniques for rectangular and triangular signals. Give the Fourier series for these signals assuming some signal period T.

Overview

Refer to your textbook and to the previous lab for a general overview and mathematical expressions of FM-modulated signals. The bulk of this hardware experiment will be based on the ACB board, where we use the VCO-LO for FM signal generation, and the Quadrature Detector for FM signal demodulation.

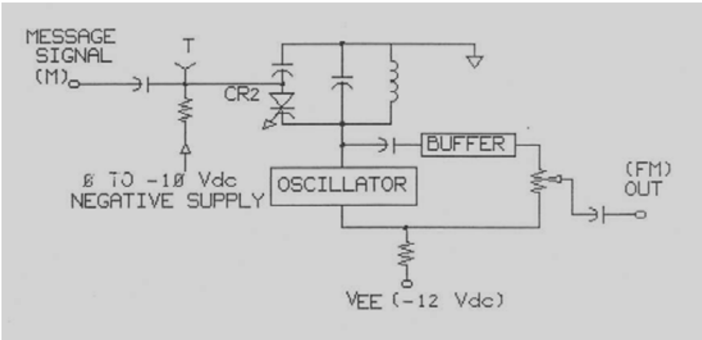
Part 1 of the work in this lab consists of FM bandwidth evaluation. A useful expression for the computation of FM bandwidth is given by Carson's rule:

$$B_T = 2(1+\beta)W$$

where W is the message signal bandwidth, while the modulation index is given by $\beta = \dfrac{k_f \max|x(t)|}{W}$.

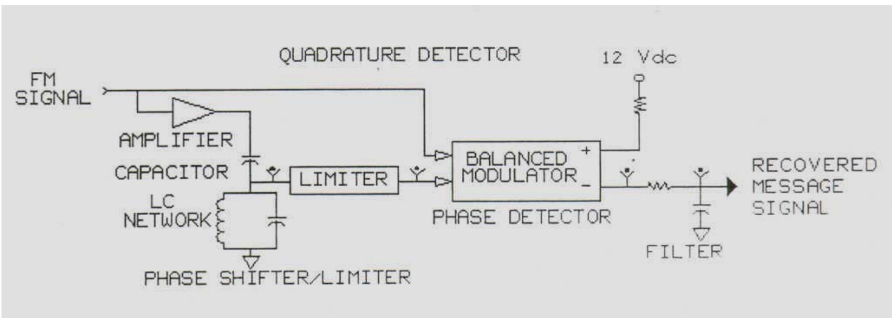
In this experiment, the FM modulator is part of the VCO-LO block. As illustrated below, the circuit essentially uses the input voltage to change the capacitance of a varactor diode that modifies the resonance frequency of an LC circuit, which in turn tunes the oscillation frequency of the VCO. You can browse through the WinFACET lab overview for more details on the circuit diagram and operation details.

Figure 1: VCO Circuit Diagram



On the other hand, the demodulator uses a circuit known as the Quadrature Detector. This is a type of FM discriminators that converts the FM carrier frequency deviation into amplitude and frequency of the original message signal. The quadrature detector circuit block on the ACB includes a Phase Shifter/Limiter, a Phase Detector, and a Filter. Its operation is described as follows. At the detector input, the received FM signal is split into two paths, with one going into the phase shifter/limiter which introduces a phase shift into the signal by ~90 degrees. The shifted signal is then clipped by the Limiter, and combined with the original FM signal. The resulting sum is applied to a balanced modulator which will work as a Phase Detector. This phase detector will produce two signals: one signal at double the carrier frequency, and another baseband signal that varies with the phase difference between the two inputs, or equivalently, with the FM signal frequency deviation. The final low-pass Filter block removes the double frequency term and output the reconstructed message signal. Refer to WinFACET software to get more details on the circuit diagram for the Quadrature Detector block.

Figure 2: FM Quadrature Detector



Lab Work

1) FM Modulation:

- For signal generation, you will be using the VCO-LO block. First, use a 2-post connector to connect the 452 kHz terminals. Notice that this produces an un-modulated carrier signal at FM Out (which may not be exactly at 452 kHz).

  Note: Use the oscilloscope to tune the <u>carrier frequency around 500 kHz</u> by adjusting the negative supply knob. This will be useful to get a good display later on.

- Select a square waveform from the external function generator, and set it to a 1 kHz frequency and 4V pk-pk amplitude. Apply this signal to terminal M of the VCO-LO block.

- Observe the modulated signal from FM Out on the oscilloscope, and sketch it. Explain intuitively why you are getting two sinusoids on the screen.

- Measure the periods and frequencies of these sinusoids. Then, estimate the FM sensitivity factor K_f (refer to the previous lab or your textbooks for exact definitions) from your measurements.

- Try changing the amplitude of the input message signal. Does the change in the FM output make sense? Explain.

- Switch now to a sinusoidal (or triangular) input signal, and observe the FM signal on the oscilloscope. Sketch and comment.

2) FM Bandwidth:

- In practice, the spectral properties of modulated signals are normally observed on a spectrum analyzer (which you don't have access to at present). In this part, you will resort to theoretical expressions (supported by lab measurements) to estimate FM signal bandwidth.

- For the 1 kHz sinusoidal signal used in Part 1, what is the bandwidth of the message signal, and what is the maximum frequency deviation of the FM modulated signal? You will need to use the K_f factor measured in Part 1,

- Use Carson's Rule and the above results to estimate the bandwidth of the FM signal modulated by the 1 kHz sinusoidal message signal.

3) FM Demodulation:

- In this part, you will be using the Quadrature Detector block on the ACB. This is another type of FM demodulators (in addition to the slope detector, PLL detector, etc, that you studied in class).

- Start WinFACET software, and go to Exercise2: Demodulation. Go through the discussion to understand the main concepts of Quadrature Detection for FM.

- Connect the FM Out signal from VCO-LO to the FM input of the Quadrature Detector block. Go through the different steps of the procedure up to Step 35 (Slide 26). Report your observations and answers to questions.

- In addition, change the signal waveform shape (from sinusoidal to rectangular and triangular) to see its impact. Comment on the results. Change also the message signal amplitude and frequency and study the impact as well.

Homework Questions

Q1. In Part 1 above, specify the expression for the instantaneous frequency of the modulated signal.

Q2. Consider two message signals, $m_1(t) = A \cos(2 \pi f_m t)$ and $m_2(t) = A \cos(4 \pi f_m t)$, with the same amplitude but m_2 having double the frequency. Would the two modulated FM signals (by m_1 and m_2) have different frequency deviations? What about their bandwidth? Explain.

Q3. Re-do the bandwidth computation of Part 2 with the triangular and rectangular signals. Note: you need to use Fourier techniques to estimate the bandwidth of the message signals (you can truncate to a few harmonics as appropriate).