Experiment 8

Frequency Modulation and Demodulation

Objectives :

By the end of this experiment, the student should be able to:

1. Demonstrate the modulation of FM.
2. Examine the factors affecting the shape of the spectrum and the bandwidth of FM signals.
3. Distinguish between different types of FM Signal
4. Implement the phase locked loop (PLL) for FM demodulation.
5. Implement frequency discriminator method for demodulating FM.

***Introduction*:**

Frequency modulation (FM) is a process in which the carrier frequency is varied by the amplitude of the modulating signal. The FM signal can be expressed by the following equation:

$$S(t)= A_c \cos[\, 2\pi f_c t + 2\pi k_f \int_0^t m(\tau).\, d\tau \,] \quad \ldots\ldots (2)$$

If $m(t) = A_m \cos(\, 2\pi f_m t)$
then :

$$S(t) = A_c \cos[\, 2\pi f_c t + \frac{k_f . A_m}{f_m} \sin(\, 2\pi f_m t)\,] \quad \ldots\ldots (3)$$

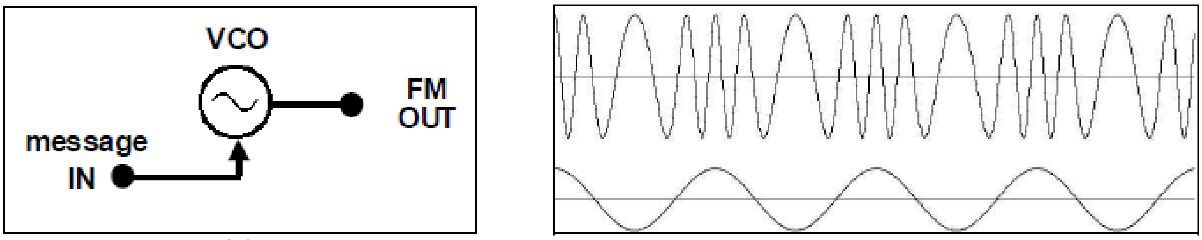
$$= A_c \cos[\, 2\pi f_c t + \beta \sin(\, 2\pi f_m t)\,] \quad \ldots\ldots (4)$$

Where:
A_m: is the message signal amplitude.
f_m: is the message signal frequency.
A_c : is the carrier signal amplitude.
f_c : is the carrier signal frequency.
k_f **:** is the deviation sensitivity.
Δf : is the frequency deviation and it is equal to $k_f . A_m$.
β : is the FM modulation index and it is equal to $\frac{\Delta f}{f_m}$.

FM Generation:
A simple and direct method of generating an FM signal is by the use of a voltage controlled oscillator -VCO. The frequency of such an oscillator can be varied by the magnitude of an input (control) voltage. The block diagram of VCO-FM generator is shown in Figure 2(a).

For the VCO to work as a frequency modulator, it has to manifest a linear relation between the magnitude of the input signal and the output oscillation. Large signal amplitude may take the system out of its linear range of operation. Therefore a careful design of the deviation sensitivity of the

VCO is required to ensure linear operation over the full range of input signal amplitudes.



(a) (b)

Figure .1 FM by VCO (a), and Resulting Output (b).

Spectral analysis:

1. ***FM Bandwidth***

In theory FM modulated signal will have an infinite number of sidebands and hence an **infinite bandwidth** but in practice all significant sideband energy (98% or more) is concentrated within the transmission bandwidth B_T defined by Carson's rule.

$$B_T = 2\Delta f + 2f_m \quad \text{.........(2)}$$

$$= 2f_m(1+\beta) \quad \text{.........(3)}$$

$$= 2\Delta f\left(1+\frac{1}{\beta}\right) \quad \text{.........(4)}$$

There are a few interesting points of summary relative to frequency modulation bandwidth:

- The bandwidth of a frequency modulated signal varies with both deviation and modulating frequency.
- Increasing modulating frequency reduces modulation index - it reduces the number of sidebands with significant amplitude and hence the bandwidth.
- Increasing modulating frequency increases the frequency separation between sidebands.
- The frequency modulation bandwidth increases with modulation frequency but it is not directly proportional to it

2. ***Bessel functions:***

For the case of a carrier modulated by a single sine wave, the resulting frequency spectrum can be calculated using Bessel functions of the first kind, as a function of the sideband number and the modulation index. The carrier and sideband amplitudes are illustrated for different modulation indices of FM signals. For particular values of the modulation index, the carrier amplitude becomes zero and all the signal power is in the sidebands.Since the sidebands are on both sides of the carrier, their count is doubled, and then multiplied by the modulating frequency to find the bandwidth. For example, 3 kHz deviation modulated by a 2.2 kHz audio tone produces a modulation index of 1.36. Examining the table 1 shows this modulation index will produce three sidebands. These three sidebands, when doubled, gives us (6 * 2.2 kHz) or a 13.2 kHz required bandwidth.

$$S(f)=\frac{A_c}{2}\sum_{n=-\infty}^{\infty}J_n(\beta)\left[\delta(f-f_c-nf_m)+\delta(f+f_c+nf_m)\right]$$

Modulation index	Carrier J_0	Sidebands J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}
0.0	1.00	—	—	—	—	—	—	—	—	—	—
0.25	0.98	0.12	—	—	—	—	—	—	—	—	—
0.5	0.94	0.24	0.03	—	—	—	—	—	—	—	—
1.0	0.77	0.44	0.11	0.02	—	—	—	—	—	—	—
1.5	0.51	0.56	0.23	0.06	0.01	—	—	—	—	—	—
2.0	0.22	0.58	0.35	0.13	0.03	—	—	—	—	—	—
2.5	−0.05	0.50	0.45	0.22	0.07	0.02	—	—	—	—	—
3.0	−0.26	0.34	0.49	0.31	0.13	0.04	0.01	—	—	—	—
4.0	−0.40	−0.07	0.36	0.43	0.28	0.13	0.05	0.02	—	—	—
5.0	−0.18	−0.33	0.05	0.36	0.39	0.26	0.13	0.06	0.02	—	—
6.0	0.15	−0.28	−0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02	—
7.0	0.30	0.00	−0.30	−0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02
8.0	0.17	0.23	−0.11	−0.29	0.10	0.19	0.34	0.32	0.22	0.13	0.06

Table .1 Bessel function

3. ***FM signal types***

There are two types of FM signal :

a. Narrowband signal (NBFM):

In this type $\Delta f \ll f_m$ thus $\beta \ll 1$, and its bandwidth is approximately $2f_m$ based on Carson's rule.

b. Wideband signal (WBFM):

In this type $\Delta f \gg f_m$ thus $\beta \gg 1$, and its bandwidth is approximately $2\Delta f$ based on Carson's rule.

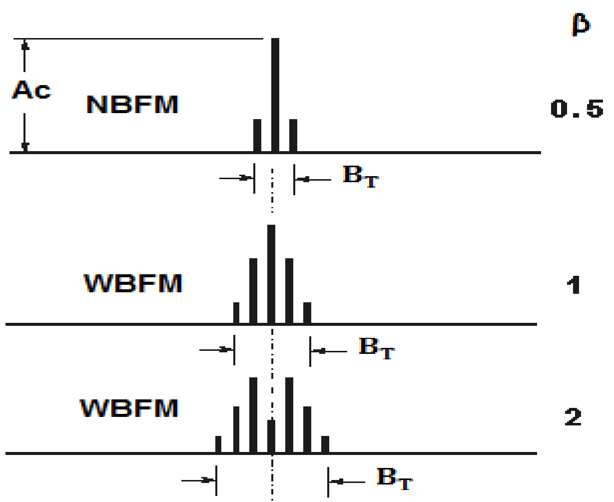


Figure.2 FM signal types

Phase Look Loop:

The block diagram of a phase locked loop (PLL) is shown in Figure 1. The principle of operation is simple. Suppose there is a non-modulated carrier at the input. If the VCO was tuned precisely to the frequency of the incoming carrier (ω_0), then the instantaneous output would be a DC voltage of magnitude depending on the phase difference between the output of the VCO and the incoming carrier. Now suppose the incoming carrier started to drift slowly in frequency, then the output voltage will vary according to the frequency variation. If the incoming carrier is frequency modulated by a message, the output of the PLL will follow the message.

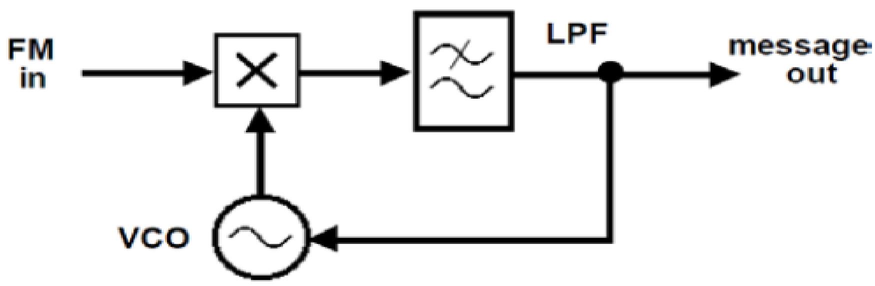


Figure.3 Phase Look Loop (PLL)

Frequency discriminator

FM can be demodulated as well by using a differentiator or a frequency discriminator. Frequency discrimination can be achieved by applying the FM signal to the linear part (transition region) of a BPF as depicted in Figure 4. The output of the discriminator is both FM and AM modulated. The message can be recovered by applying the discriminator output to an envelope detector as shown in Figure 5. The BPF of the 100 kHz channel filter module has close-to-linear pattern in the band 80-90 kHz.

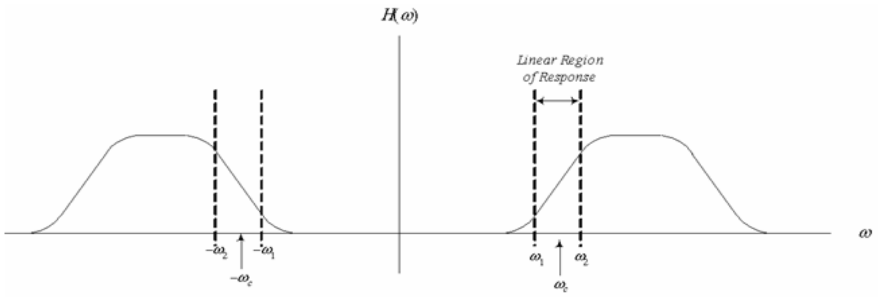


Figure .4 The BPF of the 100 kHz channel filter

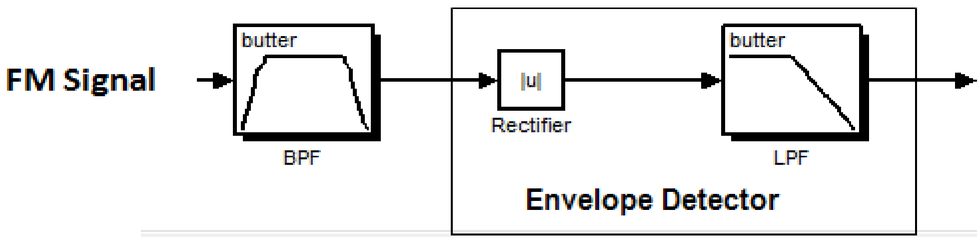


Figure .5 Frequency Discriminator

Lab Work

This experiment has tow parts. The first part studies design of the frequency deviation ratio for the modulator while the second part discuss FM generation, Spectrum analysis and bandwidth estimation.

Modules:

The following plug in modules are needed to complete the experiment:
Audio Oscillator, VCO , Multiplier, 100kHz channel filter, Utilities, Tunable LPF

Part I: Setting the Frequency Deviation

The frequency deviation is equal to the product of V_{in}, max, and Gain. Our objective is to design the Gain that yields frequency deviation of ±2 kHz.

1. Set a DC voltage of 2 V as input to VCO.
2. Set the Gain control fully anti-clockwise and the output frequency to 10 kHz.
3. Advance the Gain control until the frequency changes by 2 kHz.
4. Change to Variable DC to +2V and confirm that the deviation is about 2 kHz in the other direction. Record the measured frequency.

Part ll: Time Domain and Frequency Domain Analysis

1. Fix the message frequency from the Audio Oscillator to 1 kHz.
2. Plot the message signal, carrier signal and the modulated signal in your lab sheet.
3. Plot the spectrum of the modulated signal using PicoScope, in you lab sheet
4. Vary the message frequency and describe the impact on the spectrum of the FM signal.
5. Plot the spectrum of the FM signal at the minimum and maximum frequencies of the Audio oscillator .
6. Reset the frequency of the message to 1 kHz, and vary the deviation ratio (by varying the Gain in the VCO). Describe the effect on the spectrum of the FM signal (make sure you do not overload the VCO).
7. Plot the spectrum at the minimum value and maximum Gain setting (before overload).
8. Explain the obtained spectra in light of Carson’s Rule for bandwidth estimation.

Part III: FM Demodulation Using PLL

1. Reconstruct the FM modulator as in the previous part .
   - Let the message frequency be 1 kHz from the Audio Oscillator,
   - Let the carrier frequency be 85 kHz from VCO,
   - Let the modulator VCO gain be around 20% of the maximum value.

2. Model the PLL demodulator illustrated in Figure 3.
   - For the filter use RC LPF provided in the Utilities Module.
   - In the Multiplier module set the toggle switch to AC.
   - Set the VCO in the demodulator to 85 kHz.
   - Set the Gain control to 20% of its maximum.

.

3. Connect the output of the modulator to the input of the demodulator.
4. The PLL may or may not lock on to the incoming FM signal. Tune the Gain (and if necessary the center frequency) of the PLL-VCO until you obtain lock.
5. Examine the output of the PLL VCO and compare it with the original message.
6. Plot the message signal and recovered signal in you lab sheet.

Part IV: FM Demodulation Using Frequency Discriminator

1. Connect the FM signal to the BPF (Use the 100 kHz channel filter module, set channel select to 3).
2. Perform envelope detection by connecting the BPF output to the Rectifier in the Utilities module then connect the Rectifier output to the Tunable LPF.
3. Tune the LPF until you get the desired signal.
4. Examine the output of the frequency discriminator and compare it with the original message.
5. Plot the message and recovered signals in you lab sheet.