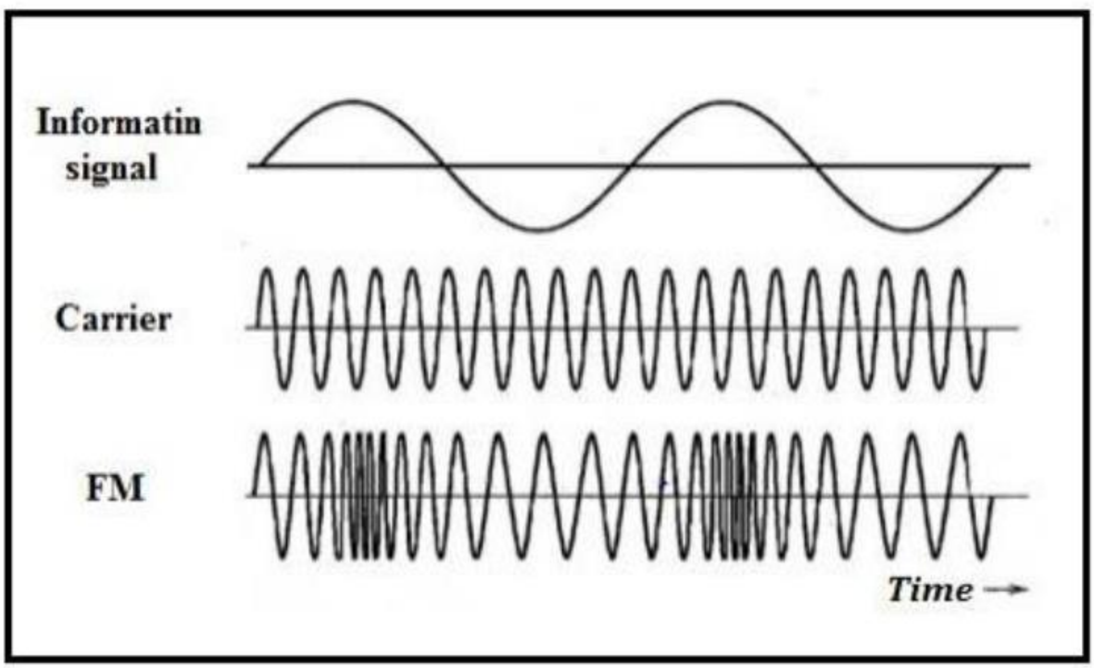
Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Syatems
Lecturer: Prof. Dr. Bayan Mahdi Sabbar & Dr. Mayasah Razzaq Ab
Lecture:5

Lecture 5

Frequency Modulation (FM)

5.1 Introduction

In FM the frequency of the carrier is varied in accordance with the instantaneous value of modulating signal. Here amplitude and phase is kept constant. To generate a frequency modulated signal, the frequency of the radio carrier is changed in line with the amplitude of the incoming audio signal. The frequency of the carrier is made to increase as the voltage in the information signal increases and to decrease in frequency as it reduces.



When the audio signal is modulated onto the radio frequency carrier, the new radio frequency signal moves up and down in frequency. The amount by which the signal

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moves up and down is important. It is known as the deviation and is normally quoted as the number of kilohertz deviation. As an example, the signal may have a deviation of plus and minus 3 kHz. In this case the carrier is made to move up and down by 3 kHz. We can write an FM wave in the form:

$$e_{FM}(t) = E_c \cos(w_c t + \beta \sin(w_m t))$$

5.2 Modulation index

As in other modulation systems, the modulation index indicates by how much the modulated variable varies around its unmodulated level. It relates to variations in the carrier frequency. The modulation index of FM is defined as:

$$\beta = \frac{\text{Peak frequency deviation}}{\text{modulating frequency}}$$

$$\beta = \frac{\Delta f}{f_m}$$

5.3 Common Applications

Frequency modulation (FM) is most commonly used for radio and television broadcast. The FM band is divided between a variety of

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purposes. Analog television channels 0 through 72 utilize bandwidths between 54 MHz and 825 MHz. In addition, the FM band also includes FM radio, which operates from 88 MHz to 108 MHz. Each radio station utilizes a 38 kHz frequency band to broadcast audio.

5.4 The spectrum of FM

Any signal that is modulated produces sidebands. In the case of an amplitude modulated signal they are easy to determine, but for frequency modulation is not quite easy. They are dependent upon the not only the deviation, but also the level of deviation, i.e. the modulation index β. The total spectrum is an infinite series of discrete spectral components expressed by a complex formula using Bessel functions of the first kind

Based on Bessel function, it can be shown that $s(t)$ has the series expansion:

$$s(t) = E_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos[(w_c + n w_m)t]$$

Where $Jn(\beta)$ is the n-th order Bessel function of the first kind. These functions can be computed by the series:

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$$J_n(\beta) = \sum_{m=0}^{\infty} (-1)^m \frac{(\frac{1}{2}\beta)^{n+2m}}{m!\,(n+m)!}$$

A short listing of Bessel function of first kind of order n and discrete value of argument β is shown in Table 5.1, and graph of the function is shown in Figure 5.1. Note that for very small β value $J0(\beta)$ approach unity, while $J1(\beta)$ to $Jn(\beta)$ approach zero.

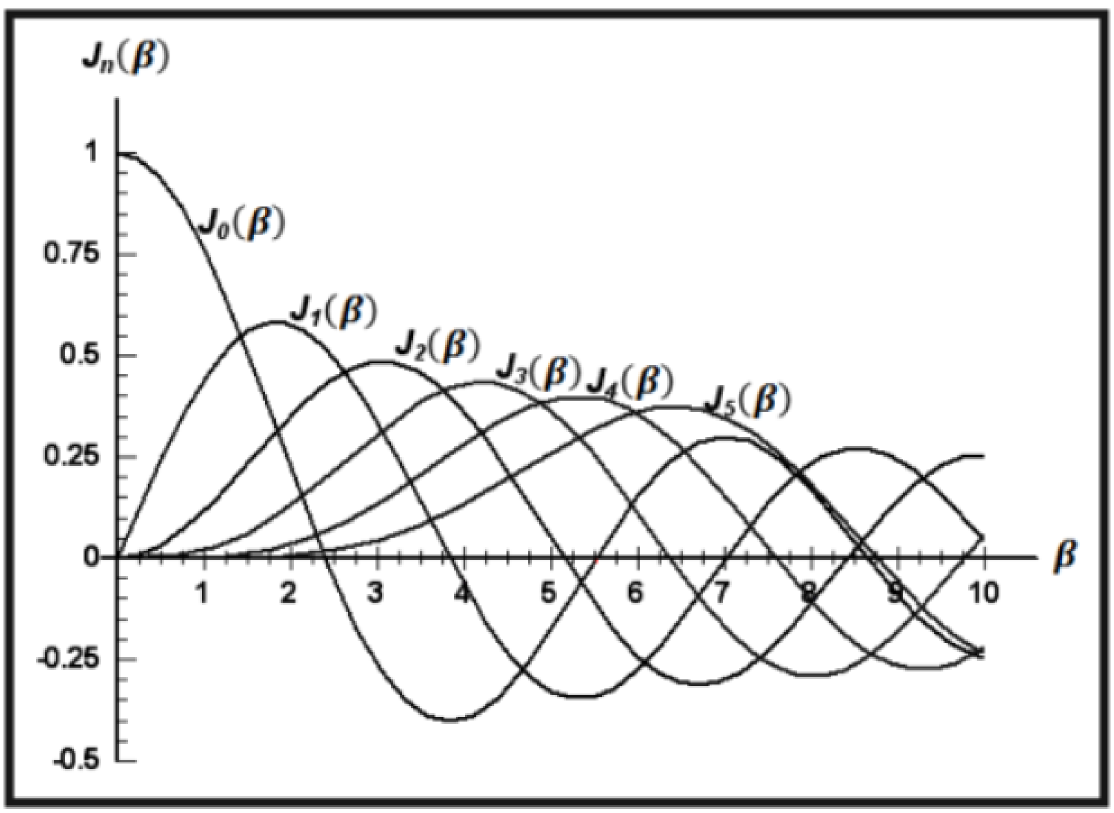

Figure 5.1: Bessel function of kind 1 and of order 1 to 10.

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Modulation Index	Sideband										
	carrier	1	2	3	4	5	6	7	8	9	10
0.00	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						
2.41	0	0.52	0.43	0.20	0.06	0.02					
2.5	- 0.05	0.50	0.45	0.22	0.07	0.02	0.01				
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	0.05	0.02		
5.53	0	- 0.34	- 0.13	0.25	0.40	0.32	0.19	0.09	0.03	0.01	
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

Figure 5.2 shows frequency spectrum which refers to FM signal in frequency domain which can be seen on the spectrum analyzer

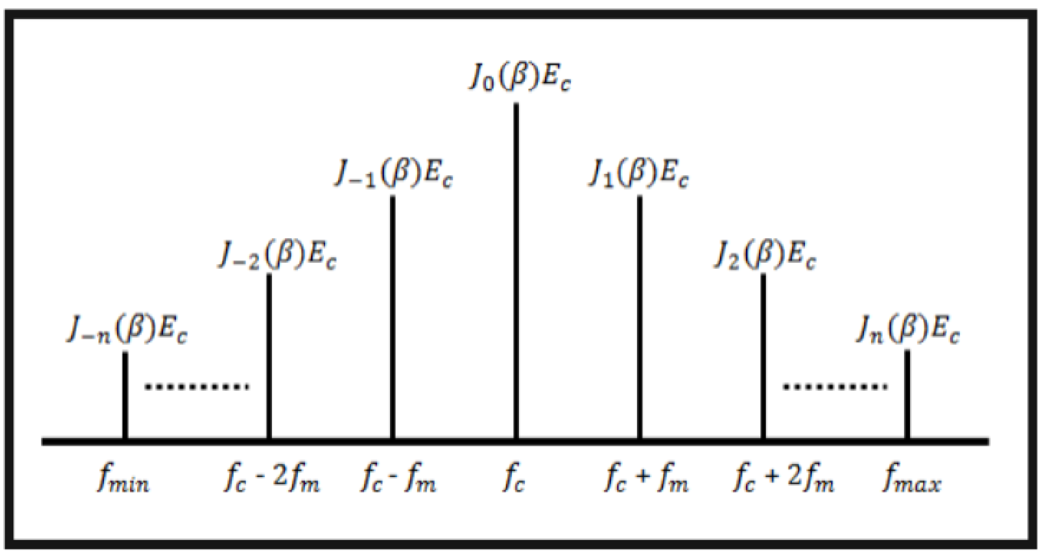

Figure 5.2: Frequency spectrum of FM signal

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Important notes:

• FM wave contains an infinite number of sidebands thus suggesting an infinite bandwidth requirement for transmission or reception. The sidebands are at $(fc \pm fm)$, $(fc \pm 2fm)$, $(fc \pm 3fm) \cdots \cdots$

• The number of sideband components are decided by modulation index value (β).

• The amplitude of sidebands depends on the value of coefficient $Jn(\beta)$ as given in the Bessel table 6.1.

• The sidebands are symmetry at fc Each two sidebands at a similar distance to fc will have the same amplitude. $Jn(\beta)$ with negative value shows phase difference of 180°.

5.5 Narrowband FM (NBFM) and Wideband FM (WBFM)

An FM signal produced with low modulation index ($\boldsymbol{\beta \ll 1}$ **or** $\boldsymbol{\Delta f \ll fm}$) , is called a narrow band FM signal. However, for most purposes we can ignore the high-order Bessel function contributions and represent its spectrum with the approximation:

$$s(t) = E_C\, j_0(\beta)\, \cos(w_c t) + E_C\, j_1(\beta) \cos((w_c + w_m)t) - E_C\, j_{-1}(\beta) \cos((w_c - w_m)t)$$

The narrowband FM is similar to AM in that it has sideband components at ($fc \pm fm$),hence it requires a transmission bandwidth of $2fm$. Its spectrum differs from AM in the two sideband components, by the fact that they are 180 degrees out of phase”. However, an FM signal with high modulation index ($\boldsymbol{\beta \gg 1}$ **or** $\boldsymbol{\Delta f \gg fm}$) , is called wideband FM and its bandwidth is approximately $2\Delta f$.

Combining the results of WBFM with that of NBFM leads to Carson’s Rule, that the minimum practical bandwidth required to transmit an FM signal will be

$$\boldsymbol{BW = 2(f_m + \Delta f)}$$

5.6 Bandwidth

A bandwidth gives the frequency spectrum required for transmission. FM bandwidth depends on modulation index $\boldsymbol{\beta}$. It can be said that the higher the modulation index, the greater required system bandwidth. FM signal bandwidth can be calculated using the equations below:

Carson Law: $\mathrm{BW} = 2(\beta + 1) f_m$

Bessel Law: $\mathrm{BW} = 2\mathrm{n} f_m$

5.7 Power of FM signal

The total power in the infinite spectrum is:

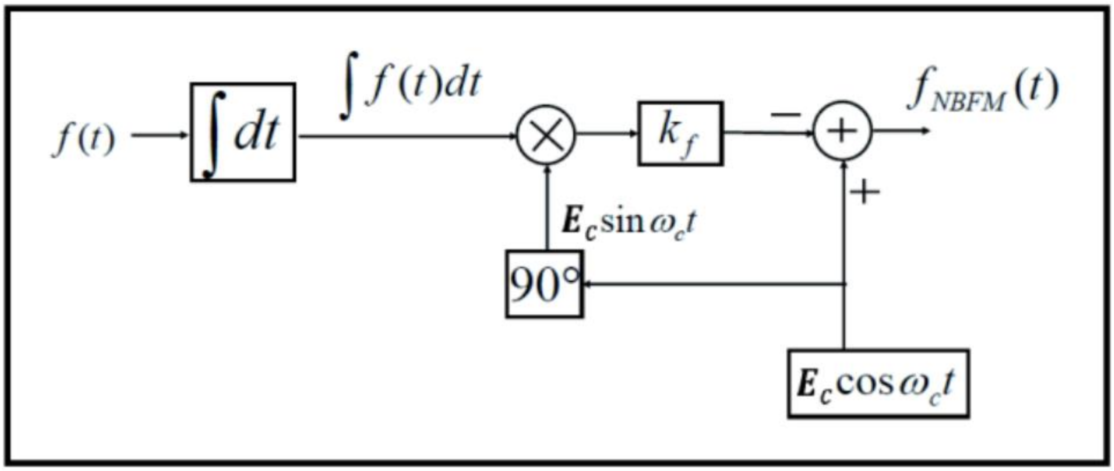
$$P_t = \frac{{E_c}^2}{2R} \sum_{n=-\infty}^{\infty} \left(J_n(\beta)\right)^2 = \frac{{E_c}^2}{2R}$$

Hence, the carrier power is:

$$P_c = \frac{{E_c}^2}{2R} \left(J_0(\beta)\right)^2$$

5.8. Generation of NBFM

Narrowband FM, like DSB-LC, is an example of linear modulation. It is possible to generate NBFM signal by using phase shifter and balance modulator as shown in figure 5.3



5.9. Generation of WBFM

One method of generating wideband FM signals is to first produce a narrowband FM signal and then use frequency multiplication to increase the modulation index to the desired range of values. This is known as the indirect method of generating wideband FM signals. A second method, known as direct method, is to vary the carrier frequency directly with the modulating signal.

1- Indirect Method

This method is called as Indirect Method because we are generating a wide band FM wave indirectly. This means, first we will generate NBFM wave and then with the help of frequency multipliers we will get WBFM wave. The block diagram of generation of WBFM wave is shown in the following figure.

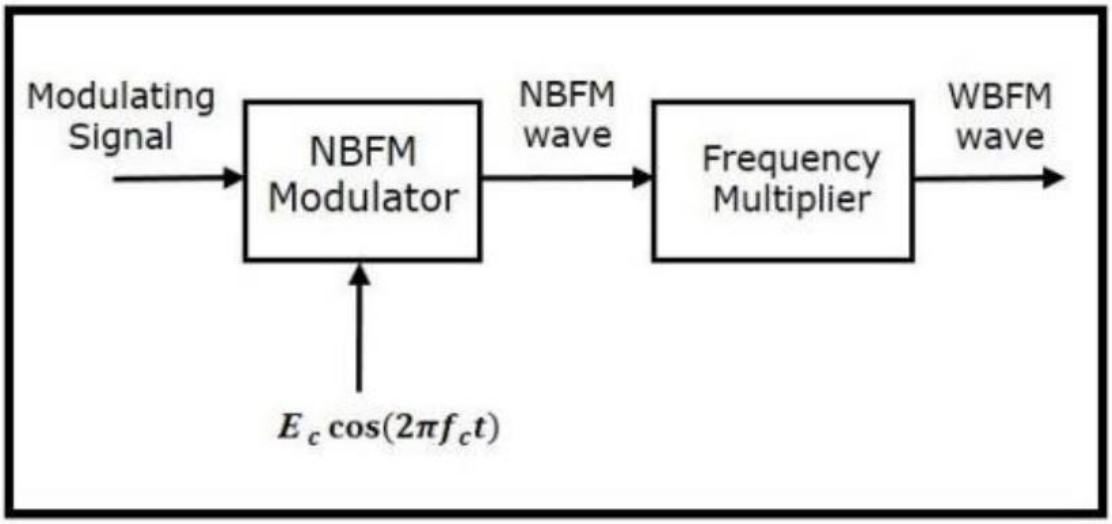


Figure 5.4: Indirect method for WBFM Generation

This block diagram contains mainly two stages. In the first stage, the NBFM wave will be generated using NBFM modulator. We have seen the block diagram of NBFM modulator at the previous section. We know that the modulation index of NBFM wave is less than one. Hence, in order to get the required modulation index (greater than one) of FM wave, choose the frequency multiplier value properly. Frequency multiplier is a nonlinear device, which produces an output signal whose frequency is 'n' times the input signal frequency. Where, 'n' is the multiplication factor.

2- Direct Method

This method is called as the Direct Method because we are generating a wide band FM wave directly. In this method, Voltage Controlled Oscillator (VCO) is used to generate WBFM.VCO produces an output signal, whose frequency is proportional to the input signal voltage. This is similar to the definition of FM wave. The block diagram of the generation of WBFM wave is shown in the following figur**e.**

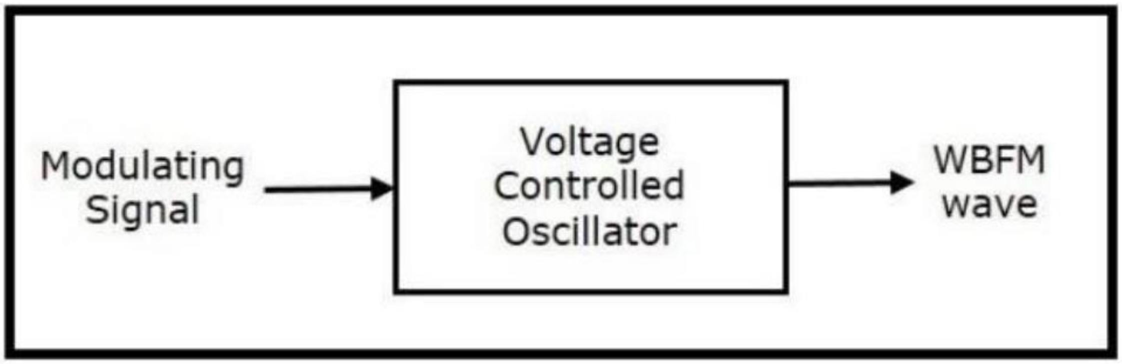


Figure 5.5: Direct method for WBFM Generation.

5.10 Demodulation of FM

The most popular method for FM demodulation is the Phase Locked Loop (PLL). The working of a PLL FM demodulator is very easy to understand. The input FM signal and the output of the VCO are applied to the phase detector circuit. The output of the phase detector is filtered using a low pass filter, the amplifier and then used for controlling the VCO. When there is no carrier modulation and the input FM signal is in the center of the pass band (i.e. carrier wave only) the VCO's tune line voltage will be at the center position. When deviation in carrier frequency occurs (that means modulation occurs) the VCO frequency follows the input signal in order to keep the loop in lock. As a result the tune line voltage to the VCO varies and this variation is proportional to the modulation done to the FM

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carrier wave. This voltage variation is filtered and amplified in order to get the demodulated signal.

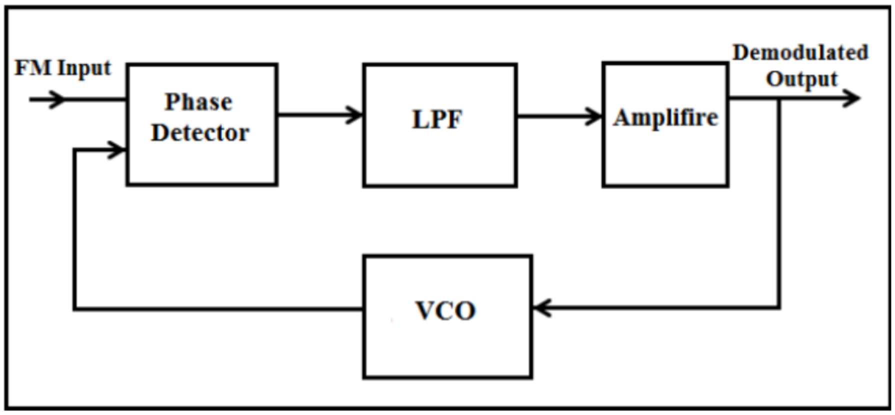

Figure 5.6: PLL FM demodulator circuit.

Example: A 10 MHz carrier is frequency modulated by a pure signal tone of frequency 8 kHz. The frequency deviation is 32 KHz. Calculate the bandwidth of the resulting FM waveform.

Solution:

$BW = 2(fm + \Delta f)$

$BW = 2(8 + 32)$

$BW = 80$ KHz