Fundamentals of Frequency Modulation

1-Basic Principles of Frequency Modulation

A sine wave carrier can be modified for the purpose of transmitting information from one place to another by varying its frequency. This is known as frequency modulation (FM).

In FM, the carrier amplitude remains constant and the carrier frequency is changed by the modulating signal. As the amplitude of the information signal varies, the carrier frequency shifts proportionately. As the modulating signal amplitude increases, the carrier frequency increases. With no modulation the carrier is at its normal center or resting frequency. Frequency deviation (fd) is the amount of change in carrier frequency produced by the modulating signal. The frequency deviation rate is how many times per second the carrier frequency deviates above or below its center frequency. The frequency of the modulating signal determines the frequency deviation rate.

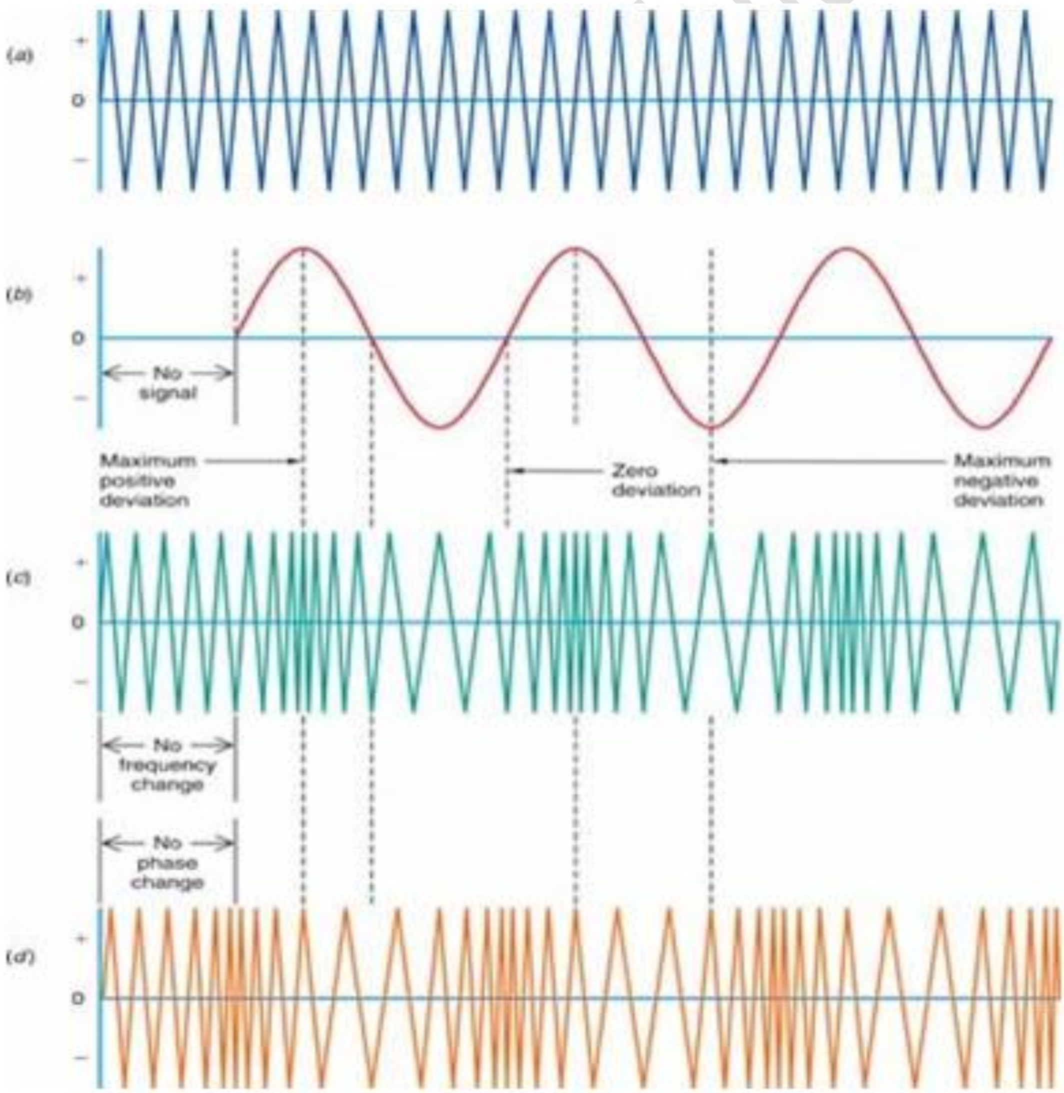


Figure 1: FM and PM (a) Carrier. (b) Modulating signal. (c) FM (d) PM

2- Principles of Phase Modulation

When the amount of phase shift of a constant frequency carrier is varied in accordance with a modulating signal, the resulting output is a phase modulation (PM) signal. Phase modulators produce a phase shift which is a time separation between two sine waves of the same frequency. The greater the amplitude of the modulating signal, the greater the phase shift. The maximum frequency deviation produced by a phase modulator occurs during the time that the modulating signal is changing at its most rapid rate.

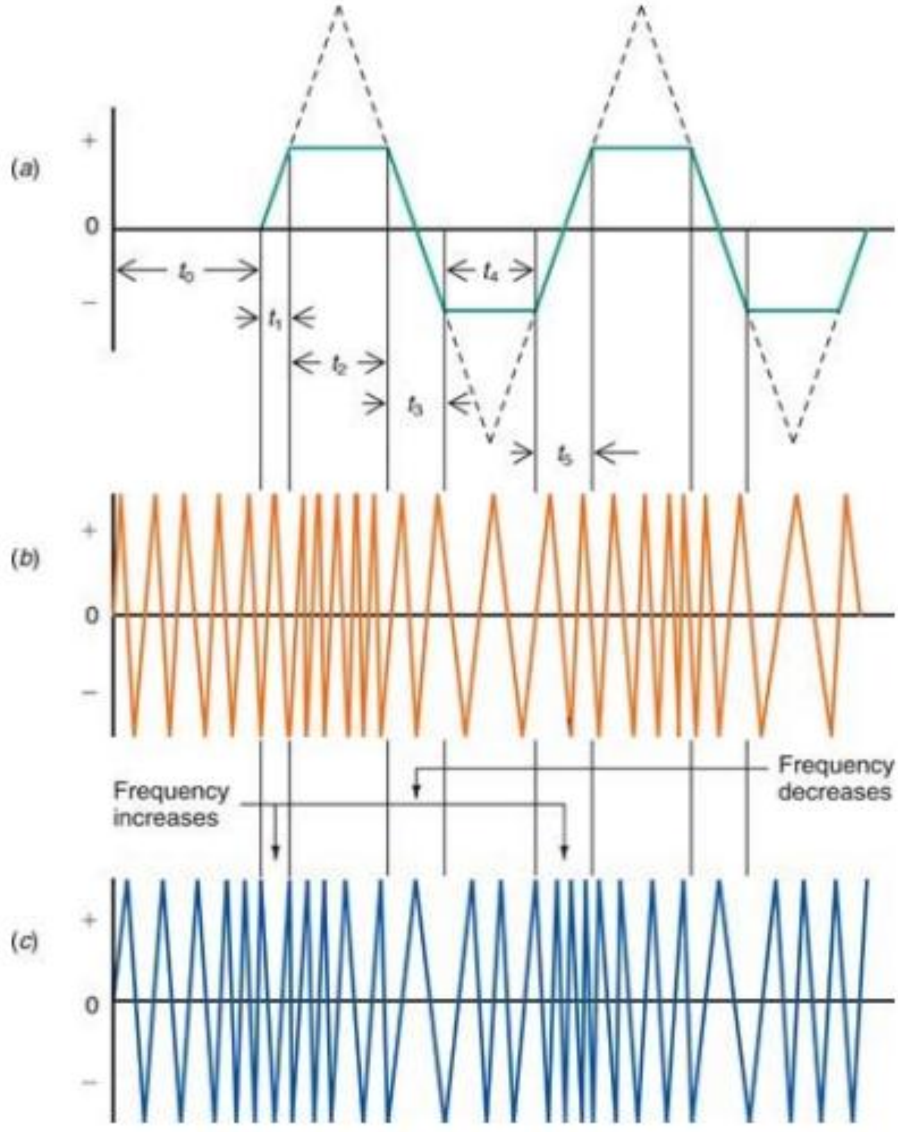


Figure 2: A frequency shift occurs in PM only when the modulating signal amplitude varies. (a) Modulating signal. (b) FM signal. (c) PM signal.

Relationship between the Modulating Signal and Carrier Deviation FM and in PM, the frequency deviation is directly proportional to the amplitude of the modulating signal. In PM, the maximum amount of leading or lagging phase shift occurs at the peak amplitudes of the modulating signal. In PM the carrier deviation is proportional to both the modulating frequency and the amplitude.

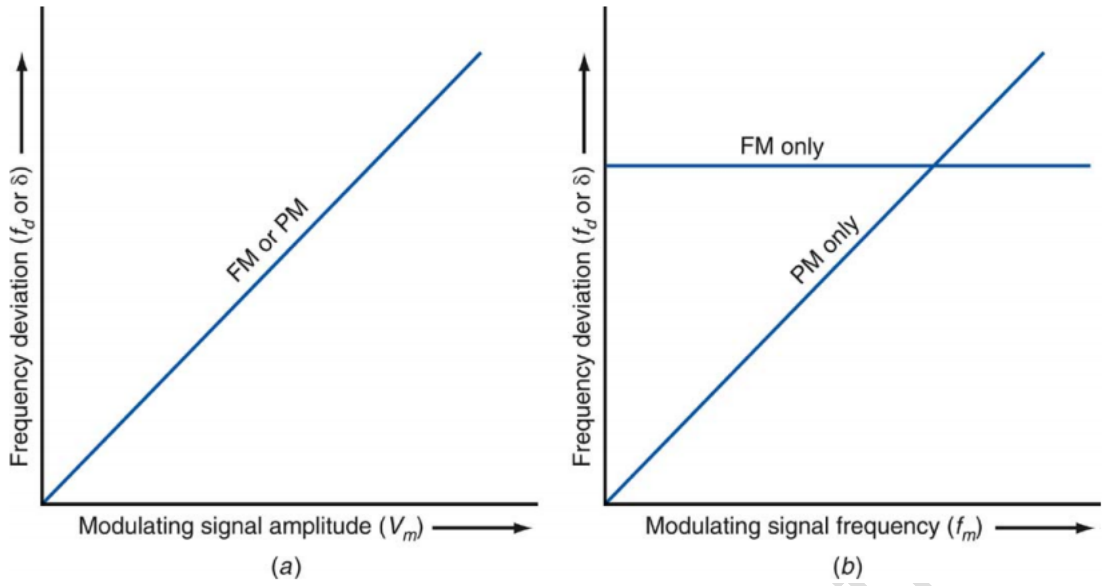


Figure 3: Frequency deviation as a function of (a) modulating signal amplitude and (b) modulating signal frequency.

Converting PM into FM

In order to make PM compatible with FM, the deviation produced by frequency variations in the modulating signal must be compensated for. This compensation can be accomplished by passing the intelligence signal through a low-pass RC network. This RC low-pass filter is called a frequency correcting network, pre-distorter, or 1/f filter and causes the higher modulating frequencies to be attenuated. The FM produced by a phase modulator is called indirect FM.

Modulation Index and Sidebands

Any modulation process produces sidebands. When a constant-frequency sine wave modulates a carrier, two side frequencies are produced. Side frequencies are the sum and difference of the carrier and modulating frequency. The bandwidth of an FM signal is usually much wider than that of an AM signal with the same modulating signal.

Modulation Index

The ratio of the frequency deviation to the modulating frequency is known as the modulation index (mf). In most communication systems using FM, maximum limits are put on both the frequency deviation and the modulating frequency. In standard FM, the maximum permitted frequency deviation is 75 kHz and the maximum permitted modulating frequency is 15 kHz. The modulation index for standard FM is therefore 5.

Bessel Functions

Narrowband FM (NBFM) is any FM system in which the modulation index is less than $\pi/2 = 1.57$, or $mf < \pi/2$. NBFM is widely used in communication.

Modulation Index	Carrier	ide ands airs															
		1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
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	—	—	—	—	—	—	—	—	—	—	—	—
2.5	−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	0.05	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	0.03	—	—	—	—	—
9.0	−0.09	0.24	0.14	−0.18	−0.27	−0.06	0.20	0.33	0.30	0.21	0.12	0.06	0.03	0.01	—	—	—
10.0	−0.25	0.04	0.25	0.06	−0.22	−0.23	−0.01	0.22	0.31	0.29	0.20	0.12	0.06	0.03	0.01	—	—
12.0	−0.05	−0.22	−0.08	0.20	0.18	−0.07	−0.24	−0.17	0.05	0.23	0.30	0.27	0.20	0.12	0.07	0.03	0.01
15.0	−0.01	0.21	0.04	0.19	−0.12	0.13	0.21	0.03	−0.17	−0.22	−0.09	0.10	0.24	0.28	0.25	0.18	0.12

Figure 4: Carrier and sideband amplitudes for different modulation indexes of FM signals based on the Bessel functions.

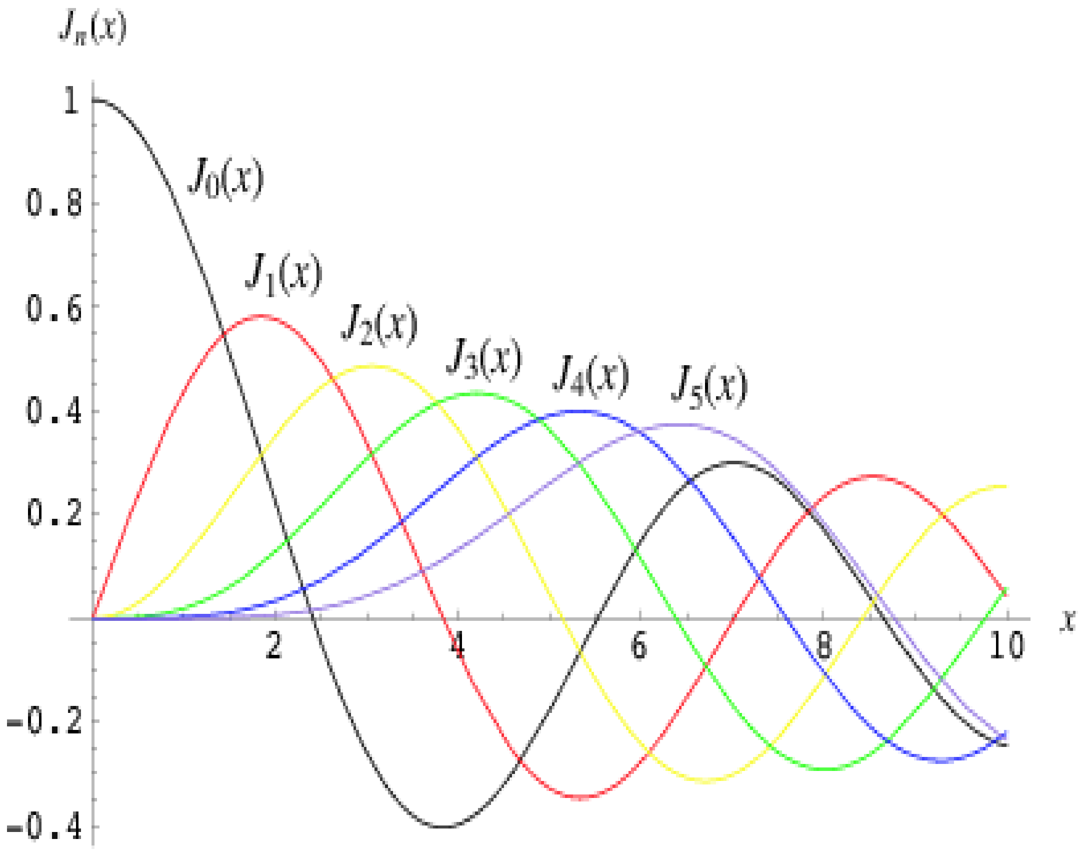


Figure 5: Plot of the Bessel function data from Fig 4.

FM Signal Bandwidth

The higher the modulation index in FM, the greater the number of significant sidebands and the wider the bandwidth of the signal. When spectrum conservation is necessary, the bandwidth of an FM signal can be restricted by putting an upper limit on the modulation index.

Example: If the highest modulating frequency is 3 kHz and the maximum deviation is 6 kHz, what is the modulation index & the band width?

mf = 6 kHz/3 kHz = 2

BW = 2 N fm   Where N is the number of significant* sidebands

BW = 2(3 kHz) (4) = 24 kHz

*Significant sidebands are those that have an amplitude of greater than 1% (.01) in the Bessel table.

Noise-Suppression Effects of FM

Noise is interference generated by lightning, motors, automotive ignition systems, and power line switching that produces transient signals. Noise is typically narrow spikes of voltage with high frequencies. Noise (voltage spikes) add to a signal and interfere with it. Some noise completely obliterates signal information.

FM signals have a constant modulated carrier amplitude. FM receivers contain limiter circuits that deliberately restrict the amplitude of the received signal. Any amplitude variations occurring on the FM signal are effectively clipped by limiter circuits. This amplitude clipping does not affect the information content of the FM signal, since it is contained solely within the frequency variations of the carrier.

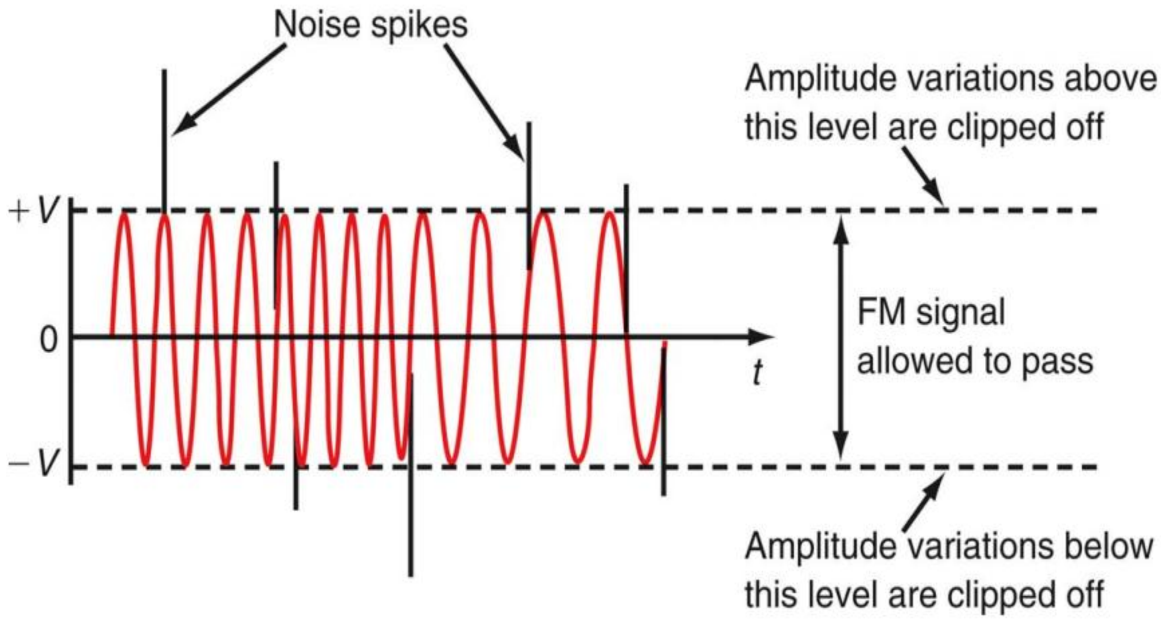
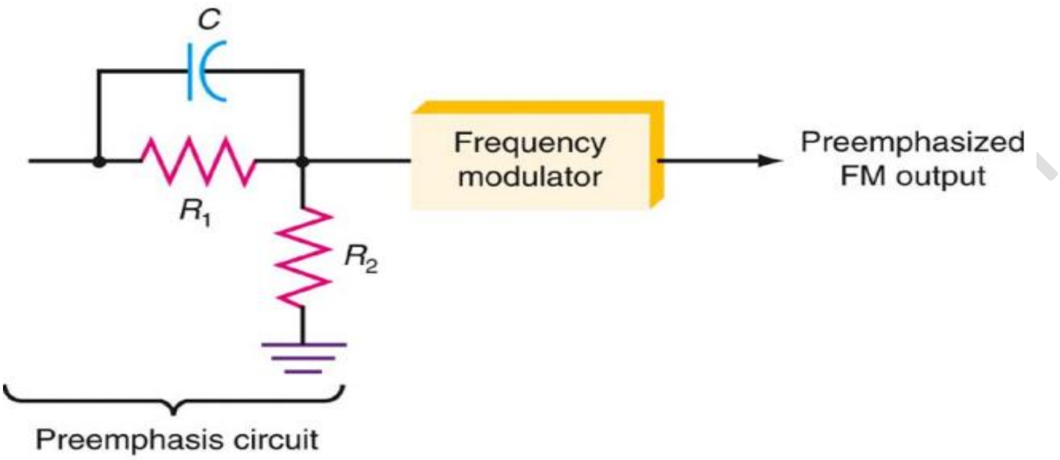


Figure 6: An FM signal with noise.

Pre-emphasis

Noise can interfere with an FM signal and particularly with the high-frequency components of the modulating signal. Noise is primarily sharp spikes of energy and contains a lot of harmonics and other high-frequency components. To overcome high-frequency noise, a technique known as pre-emphasis is used. A simple high-pass filter can serve as a transmitter's pre-emphasis circuit. Pre-emphasis provides more amplification of only high frequency components.

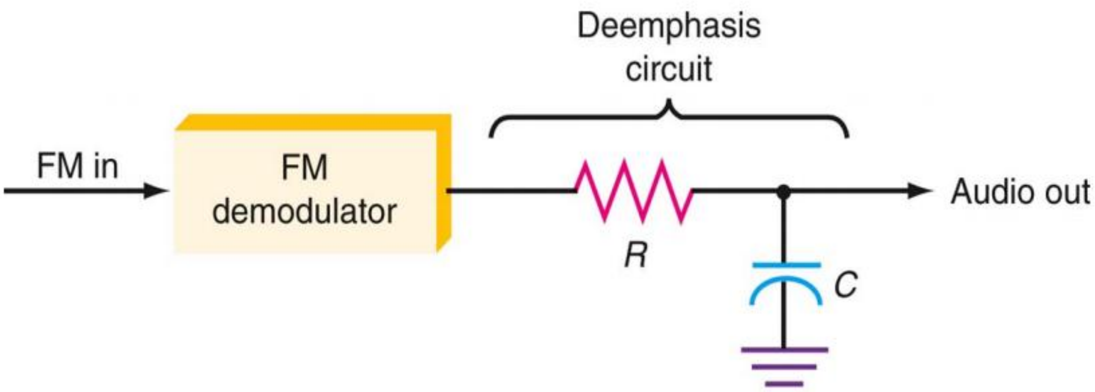


$$f_u = \frac{R_1 + R_2}{2\pi R_1 R_2 C}$$

(*a*)

Figure 7: Pre-emphasis circuit.

De-emphasis is A simple low-pass filter can operate as a de-emphasis circuit in a receiver. A de-emphasis circuit returns the frequency response to its normal flat level. The combined effect of pre-emphasis and de-emphasis is to increase the signal-to-noise ratio for the high frequency components during transmission so that they will be stronger and not masked by noise.



$$f_L = \frac{1}{2\pi RC}$$

(*c*)

Figure 8: De-emphasis circuit.

As both PM and FM have constant amplitude Ac, the average power of a PM or FM signal is, $Pav = \frac{Ac^2}{2}$ regardless of the value of K_f or K_p .

Generation of FM

We had earlier identified two different categories of FM, namely, NBFM and WBFM. We shall now present the schemes for their generation.

Narrowband FM

One of the principal applications of NBFM is in the (indirect) generation of WBFM as explained later on in this section. we have,

$$s(t) \simeq A_c\left[\cos(\omega_c t) - c_f\, m_I(t)\sin(\omega_c t)\right]$$

The system shown in Fig. 9 can be used to generate the NBFM signal. Applying m (t) directly to the balanced modulator, results in NBPM.

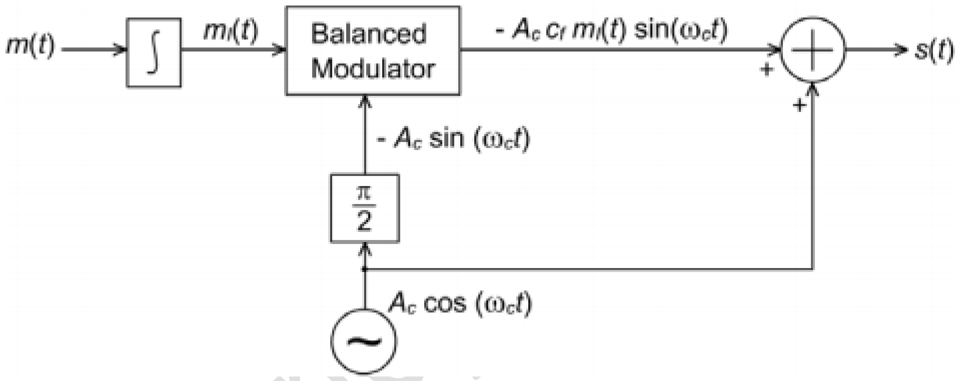


Fig. 9: Generation of NBFM signal

WBFM: Indirect and direct methods

There are two distinct methods of generating WBFM signals: a) Direct FM b) Indirect FM. Details on their generation are as follows.

a) Indirect FM (Armstrong's method)

In this method - attributed to Armstrong - first a narrowband FM signal is generated. This is then converted to WBFM by using frequency multiplication. This is shown schematically in Fig 10.

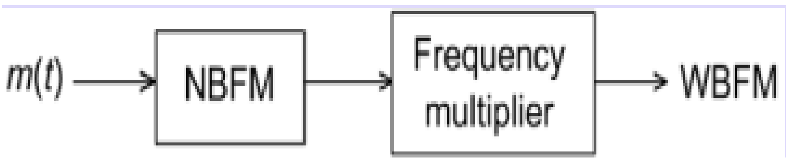


Fig. 10: Generation of WBFM (Armstrong method)

The generation of NBFM has already been described. A frequency multiplier is a nonlinear device followed by a BPF. A nonlinearity of order **n** can give rise to frequency multiplication by a factor of **n**. For simplicity, consider a square law device with output $y(t) = x^2(t)$

where x (t) is the input. An input-output relation of the type

$$y(t) = a_1 x(t) + a_2 x^2(t) + \dots a_n x^n(t)$$

Will give rise to FM output components at the frequencies fc, 2fc, ... nfc with the corresponding frequency deviations, Δf, 2Δf, ….. nΔf n where Δf is the frequency deviation of the input NBFM signal. The required WBFM signal can be obtained by a suitable BPF. If necessary, frequency multiplication can be resorted to in more than one stage. The multiplier scheme used in a commercial FM transmitter is in Fig.11.

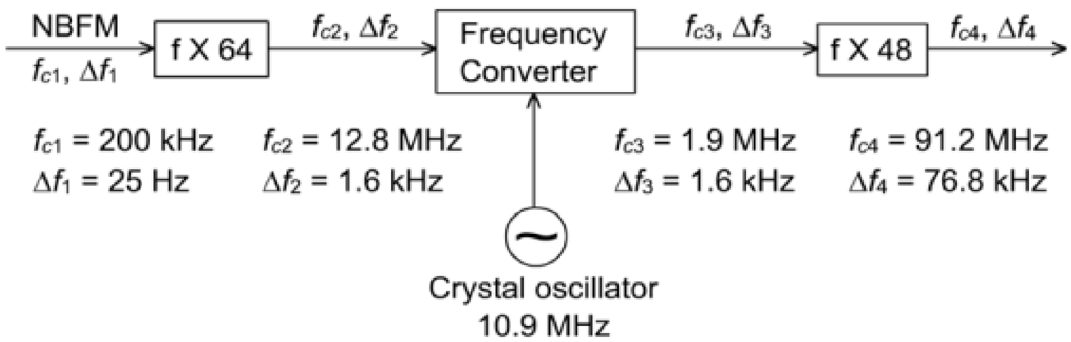


Fig.11: Multiplier chain used in typical commercial FM transmitter

Example: Armstrong's method used to generate a WBFM signal. The NBFM signal carrier frequency fc1 = 20 kHz. The required WBFM signal must have fc = 6 MHz and Δf = 10 kHz. Only frequency triples are available. However, a limitation frequency component beyond 8 MHz at their output. Is frequency conversion stage required? If so, when does it become essential? Draw the schematic block diagram of this example.

Total frequency multiplication required = $\frac{6\times10^6}{20\times10^3}$ =300

frequency triples, we have 3^5= 243 and 3^6=729. Hence a set of six multipliers is required. But these six cannot be used as a single cascade because, that would result in a carrier frequency equal to $20\times 10^3 \times 3^6$ =14.58 MHz and the last multiplier cannot produce this output. However, cascade of 5 triples can be used.

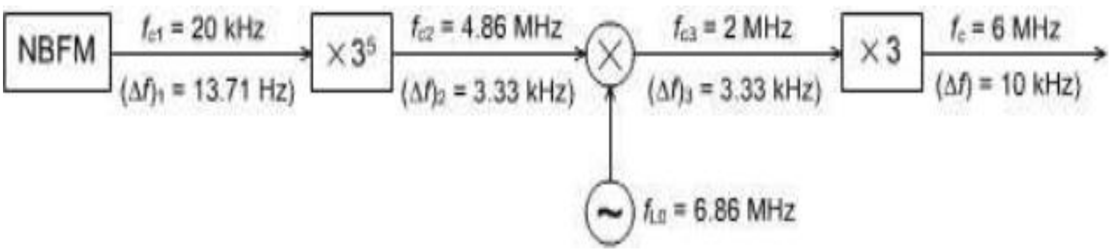


Fig 12: Generation of WBFM from NBFM of example

Exercise 5.5

In the indirect FM scheme shown in Fig. 5.17, find the values of $f_{c,i}$ and Δf_i for $i = 1, 2$ and 3. What should be the centre frequency, f_0, of the BPF. Assume that $f_{LO} > f_{c,2}$.

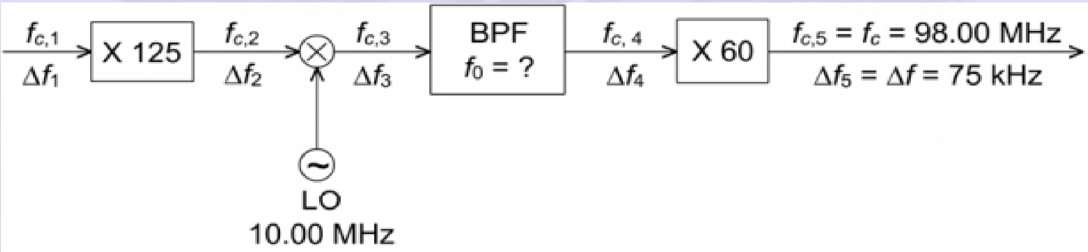


Fig. 5.17: Scheme for the Exercise 5.5

Exercise 5.6

In the indirect FM scheme shown in Fig. 5.18, find the values of the quantities with a question mark. Assume that only frequency doublers are available. It is required that $f_{LO} < f_{c,2}$.

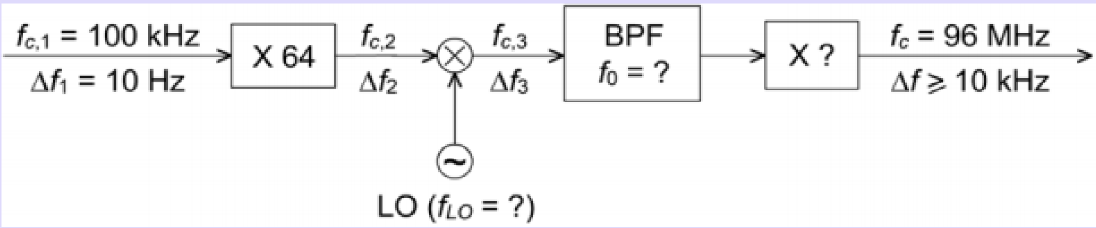


Fig. 5.18: Scheme for the Exercise 5.6

b) Direct FM

Conceptually, the direct generation of FM is quite simple and any such system can be called as a Voltage Controlled Oscillator (VCO). In a VCO, the oscillation frequency varies linearly with the control voltage. The oscillation frequency f_0 of a parallel tuned circuit with inductance L and capacitance C is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ or } \omega_0 = \frac{1}{\sqrt{LC}}$$

Let C be varied by the modulating signal m(t), as given by

$$C(t) = C_0 - k\,m(t)$$

where k is an appropriate constant.

If we assume $km(t)$ is small and slowly varying, then the output frequency ω_i of the oscillator is given by

$$\omega_i = \frac{1}{\sqrt{LC(t)}} = \frac{1}{\sqrt{L[C_0 - km(t)]}} = \frac{1}{\sqrt{LC_0}}\left[1 - \frac{k}{C_0}m(t)\right]^{-1/2}$$

Since $|(k/C_0)m(t)| \ll 1$, we can use the approximation

$$(1-z)^{-1/2} \approx 1 + \frac{1}{2}z$$

and obtain

$$\omega_i \approx \omega_c\left[1 + \frac{1}{2}\frac{k}{C_0}m(t)\right] = \omega_c + k_f m(t)$$

One of the more recent devices for obtaining electronically variable capacitance is the varactor (also called varicap, or voltacap). In very simple terms, the varactor is a junction diode. Though all junction diodes have inherent junction capacitance, varactor diodes are designed and fabricated such that the value of the junction capacitance is significant (varactors are available with nominal ratings from 0.1 to 2000 pF). Varactor diodes, when used as voltage-variable capacitors are reverse biased and the capacitance of the junction varies inversely with the applied (reverse) voltage.

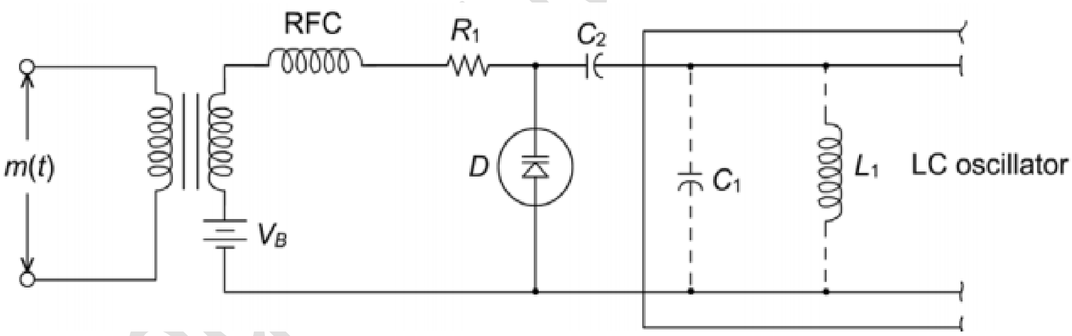
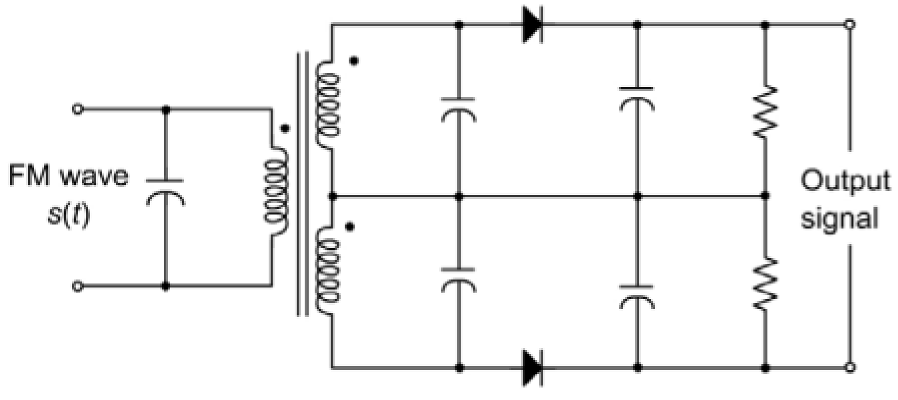


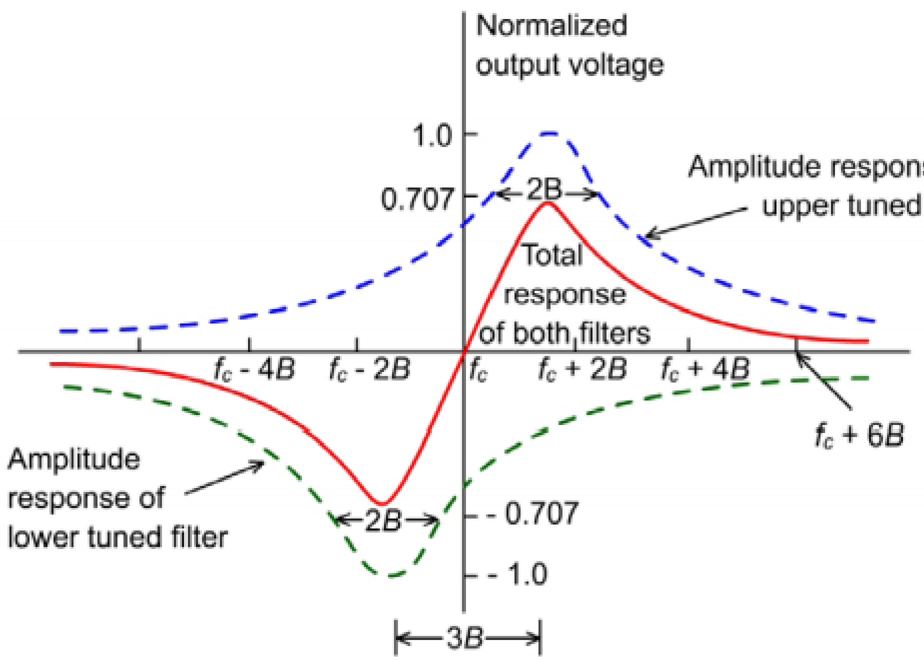
Fig.13: Direct FM generation

Demodulation of FM (Balanced slope detection):

A balanced configuration (balanced slope detection). Shown in Fig.14(a) has three tuned circuits: two on the secondary side of the input transformer and one on the primary. The resonant circuit on the primary is tuned to fc whereas the two resonant circuits on the secondary side are tuned to two different frequencies, one above fc and the other, below fc. The outputs of the tuned circuits on the secondary are envelope detected separately; the difference of the two envelope detected outputs would be proportional to m (t). The balanced configuration has linearity over a wider range (as can be seen from Fig.14(b), the width of linear frequency response is about 3B, where 2B is the width of the 3-dB bandwidth of the individual tuned circuits) and (The two resonant frequencies of the secondary are appropriately selected so that output of the discriminator is zero for f =fc).



(a)



(b)

Fig.14: Balanced slope detection (a) circuit schematic (b) response curve

Ex: For FM station if fc=90MHz and Δfc =20KHz, decide which receiver is fit to detect correctly the signal if   a- B=5KHz, b- B=15KHz, c- B=25KHz.

Frequency Modulation Versus Amplitude Modulation

Advantages of FM

FM typically offers some significant benefits over AM. FM has superior immunity to noise, made possible by clipper limiter circuits in the receiver. In FM, interfering signals on the same frequency are rejected. This is known as the capture effect. FM signals have a constant amplitude and there is no need to use linear amplifiers to increase power levels. This increases transmitter efficiency.

Disadvantages of FM

FM uses considerably more frequency spectrum space. FM has used more complex circuitry for modulation and demodulation. In the past, the circuits used for frequency modulation and demodulation involved were complex. With the proliferation of ICs, complex circuitry used in FM has all but disappeared. ICs are inexpensive and easy to use. FM and PM have become the most widely used modulation method in electronic communication today.

Ex:

The frequency multiplier is a nonlinear device followed by a bandpass filter, as shown in Fig. 4-14. Suppose that the nonlinear device is an ideal square-law device with input-output characteristics

$$e_o(t) = ae_i^2(t)$$

Find the output $y(t)$ if the input is an FM signal given by

$$e_i(t) = A\cos(\omega_c t + \beta \sin \omega_m t)$$

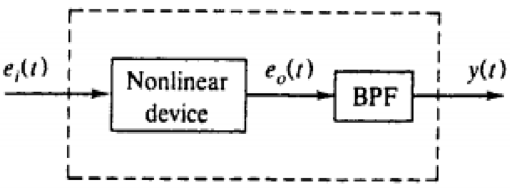


Fig. 4-14

Ans. $y(t) = A'\cos(2\omega_c t + 2\beta \sin \omega_m t)$, where $A' = \frac{1}{2}aA^2$. This result indicates that a square-law device can be used as a frequency doubler.

Knowing that $\cos^2(x) = 1/2\,[1+\cos(2x)]$

GOOD LUCK

H.S.RADHI