An Autonomous Institute
Affiliated to VTU, Belagavi,
Approved by AICTE, New Delhi,

DEPARTMENT OF MEDICAL ELECTRONICS ENGINEERING

SUBJECT CODE : 18ML42

SUBJECT NAME: PRINCIPLES OF COMMUNICATION SYSTEMS

LECTURE PRESENTATION UNIT– 2

FACULTY : Dr. D. K. RAVISH, Assoc. Prof, Dept. of ML

.

Module Structure

Module 2

- FREQUENCY MODULATION: Basic Concepts, Frequency Modulation, Spectrum Analysis Of sinusoidal FM wave, NBFM, WBFM, Constant Average power, Transmission bandwidth of FM waves, Generation of FM waves, Direct FM, demodulation of FM waves, frequency discriminator, ZCD.

TEXT BOOK

"Communication Systems", Simon Haykins & Moher, 5th Edition, John Willey, India Pvt. Ltd, 2010, ISBN 978 – 81 – 265 – 2151 – 7.

COURSE OUTCOMES

After studying this course, students will be able to:

- Analyze and compute performance of AM and FM modulation in the presence of noise at the receiver.
- Analyze and compute performance of digital formatting processes with quantization noise.
- Multiplex digitally formatted signals at Transmitter and demultiplex the signals and reconstruct digitally formatted signals at the receiver.
- Design/Demonstrate the use of digital formatting in Multiplexers, Vocoders and Video transmission.

Bridge material(Bessel function)

Bessel function, also called **Cylinder Function**, any of a set of mathematical functions systematically derived around 1817 by the German astronomer Friedrich Wilhelm Bessel during an investigation of solutions of one of Kepler's equations of planetary motion.

$$x^2\frac{d^2y}{dx^2} + x\frac{dy}{dx} + (x^2 - n^2)y = 0,$$

which is called Bessel's equation. For integral values of *n*, the Bessel functions are

Bridge material (Bessel functions)

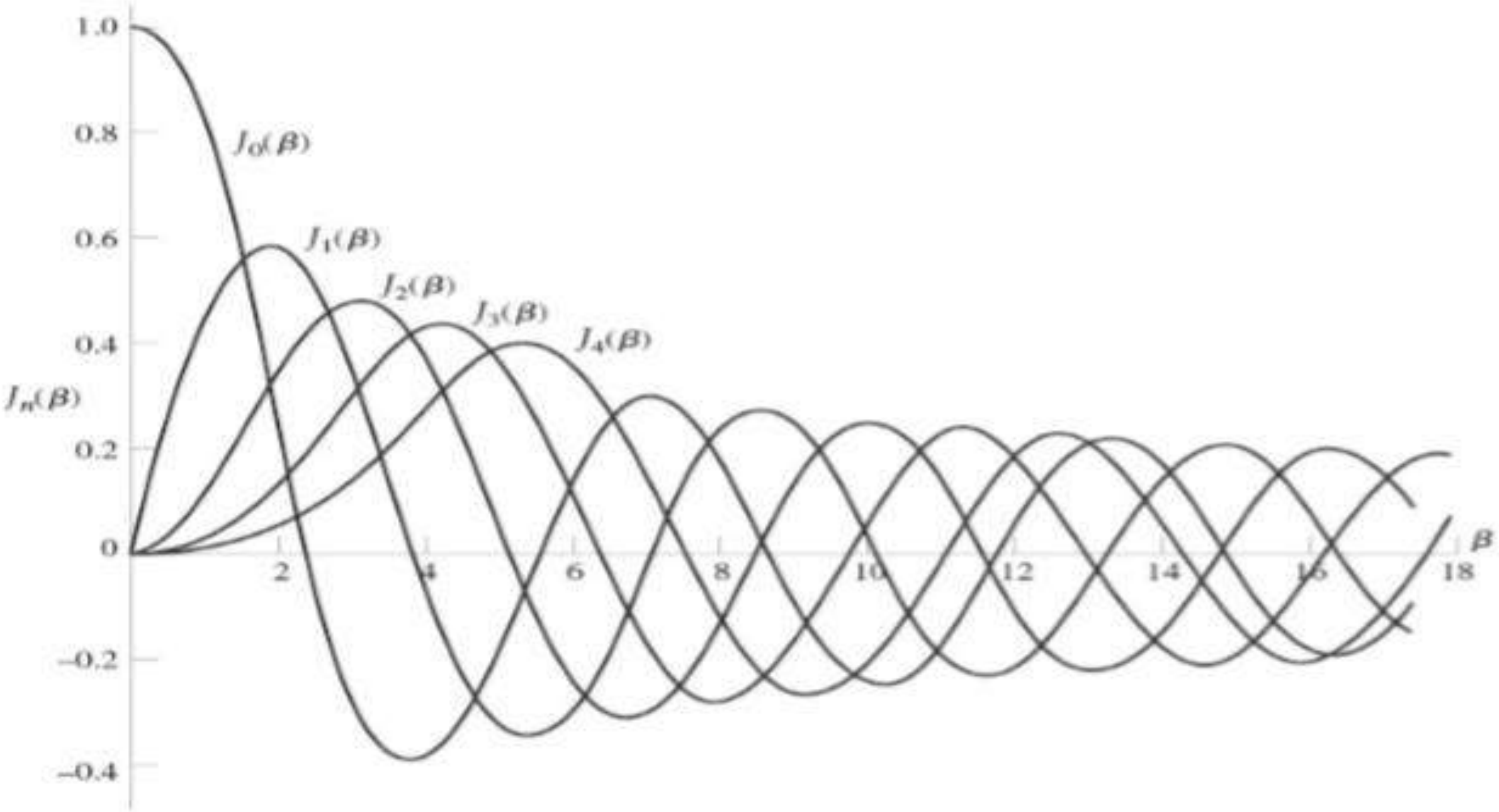


FIGURE 4.6 Plots of the Bessel function of the first kind, $J_n(\beta)$, for varying order n.

ANGLE MODULATION: Basic definitions

- The other type of modulation in continuous-wave modulation is **Angle Modulation**. Angle Modulation is the process in which the frequency or the phase of the carrier signal varies according to the message signal.

- The standard equation of the angle modulated wave is

$$s(t) = A_c \cos\theta_i(t)$$

- Where,

Ac ---- is the amplitude of the modulated wave, which is the same as the amplitude of the carrier signal

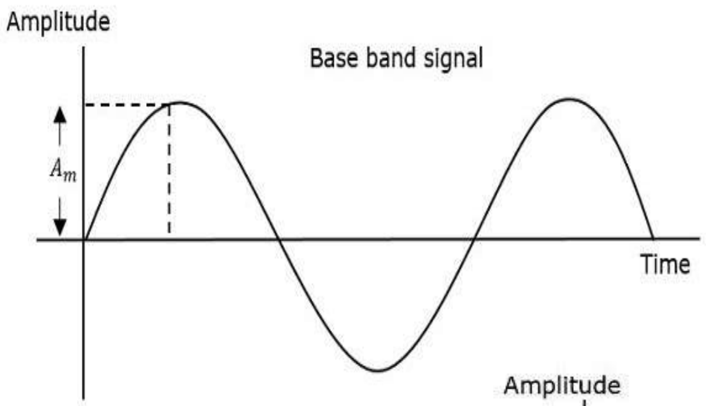
θi(t)----is the angle of the modulated wave

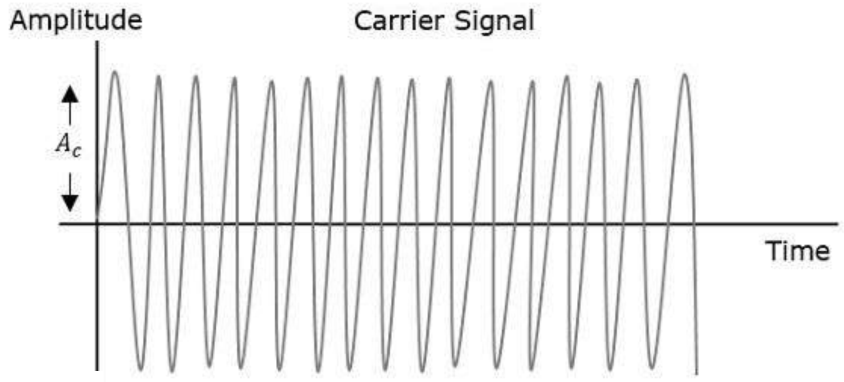
ANGLE MODULATION: Basic definitions

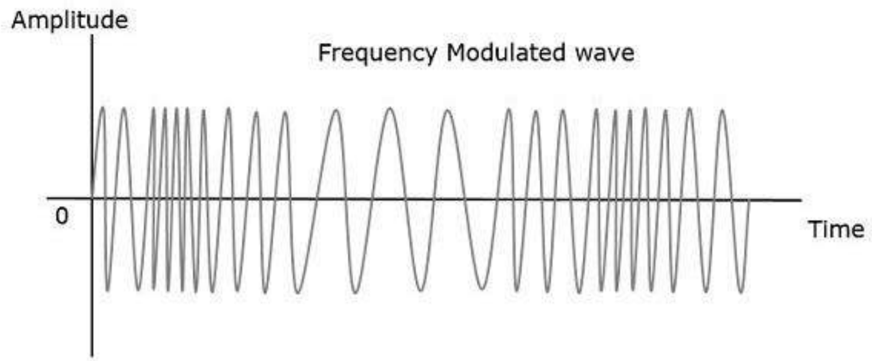
- Angle modulation is further divided into frequency modulation and phase modulation.
- **Frequency Modulation** is the process of varying the frequency of the carrier signal linearly with the message signal.
- **Phase Modulation** is the process of varying the phase of the carrier signal linearly with the message signal.

Frequency Modulation

- **Frequency Modulation (FM)**, the frequency of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal.
- Hence, in frequency modulation, the amplitude and the phase of the carrier signal remains constant.







Mathematical Representation

- The equation for instantaneous frequency f_i in FM modulation is

$$f_i = f_c + k_f m(t)$$

- Where,

f_c is the carrier frequency

k_t is the frequency sensitivity

$m(t)$ is the message signal

- We know the relationship between angular frequency ω_i and angle $\theta_i(t)$ as

Mathematical Representation

$$\omega_i = \frac{d\theta_i(t)}{dt}$$

$$\Rightarrow 2\pi f_i = \frac{d\theta_i(t)}{dt}$$

$$\Rightarrow \theta_i(t) = 2\pi \int f_i \, dt$$

Substitute, f_i value in the above equation.

$$\theta_i(t) = 2\pi \int (f_c + k_f m(t))\, dt$$

$$\Rightarrow \theta_i(t) = 2\pi f_c t + 2\pi k_f \int m(t)\, dt$$

Substitute, $\theta_i(t)$ value in the standard equation of angle modulated wave.

Mathematical Representation

$$s(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int m(t)\, dt\right)$$

- This is the **equation of FM wave**.

- If the modulating signal is

$$m(t) = A_m \cos(2\pi f_m t)$$

- then the equation of FM wave will be

Mathematical Representation

$$s(t) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t))$$

Where,

$$\beta = \textit{modulation index} = \frac{\Delta f}{f_m} = \frac{k_f A_m}{f_m}$$

- The difference between FM modulated frequency (instantaneous frequency) and normal carrier frequency is termed as **Frequency Deviation**. It is denoted by Δf which is equal to the product of kf and Am
- FM can be divided into **Narrowband FM** and **Wideband FM** based on the values of modulation index β
- https://www.youtube.com/watch?v=yGkV8ou1AeQ

Narrowband FM

Following are the features of Narrowband FM.

- This frequency modulation has a small bandwidth when compared to wideband FM.
- The modulation index β is small, i.e., less than 1.
- Its spectrum consists of the carrier, the upper sideband and the lower sideband.
- This is used in mobile communications such as police wireless, ambulances, taxicabs, etc.

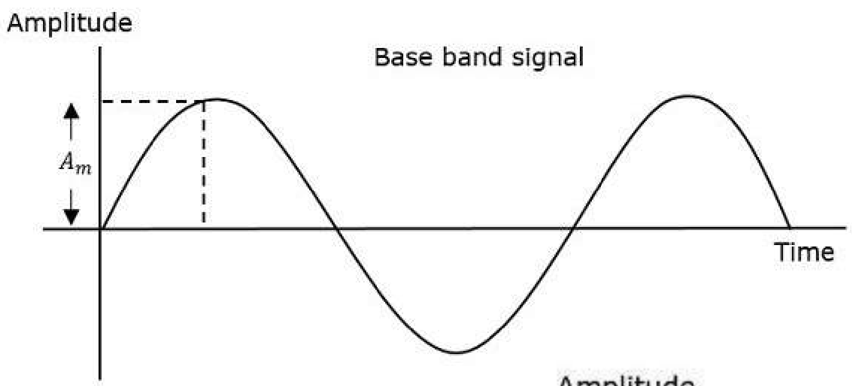
Wideband FM

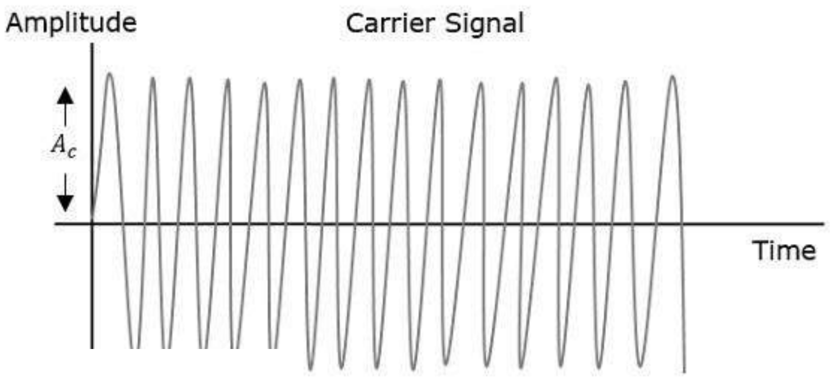
Following are the features of Wideband FM.

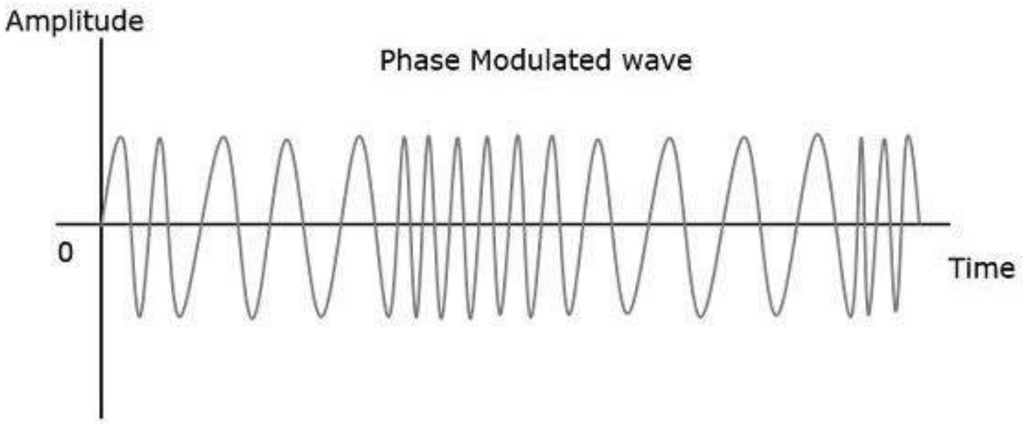
- This frequency modulation has infinite bandwidth.
- The modulation index β is large, i.e., higher than 1.
- Its spectrum consists of a carrier and infinite number of sidebands, which are located around it.
- This is used in entertainment, broadcasting applications such as FM radio, TV, etc.

Phase Modulation

- **Phase Modulation (PM)**, the phase of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal.
- So, in phase modulation, the amplitude and the frequency of the carrier signal remains constant.







Mathematical Representation

- The equation for instantaneous phase φi in phase modulation is

$$\phi_i = k_p m(t)$$

Where,

- k_p is the phase sensitivity
- $m(t)$ is the message signal

- The standard equation of angle modulated wave is

$$s(t) = A_c \cos(2\pi f_c t + \phi_i)$$

Mathematical Representation

Substitute, ϕ_i value in the above equation.

$$s(t) = A_c \cos(2\pi f_c t + k_p m(t))$$

This is the **equation of PM wave**.

If the modulating signal, $m(t) = A_m \cos(2\pi f_m t)$, then the equation of PM wave will be

$$s(t) = A_c \cos(2\pi f_c t + \beta \cos(2\pi f_m t))$$

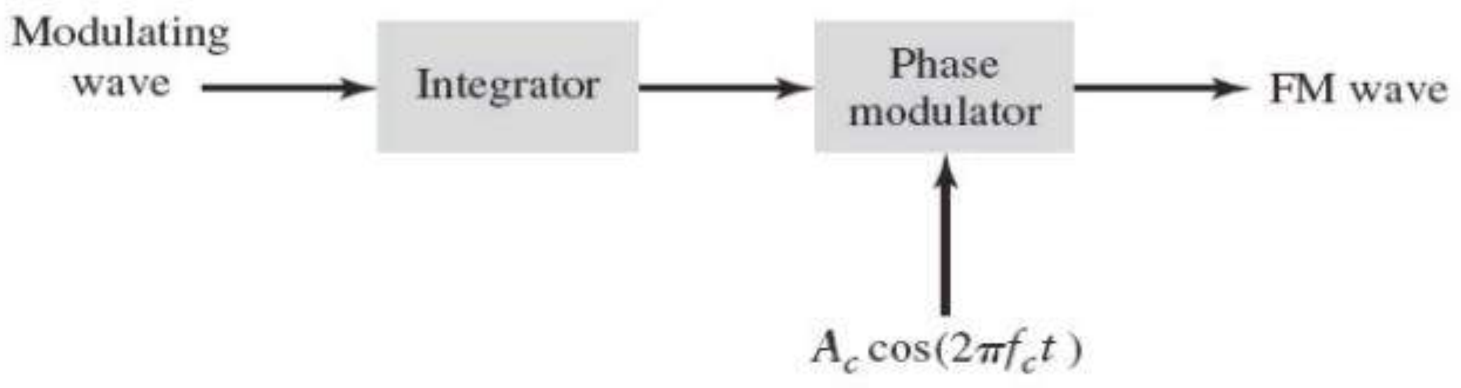
Where,

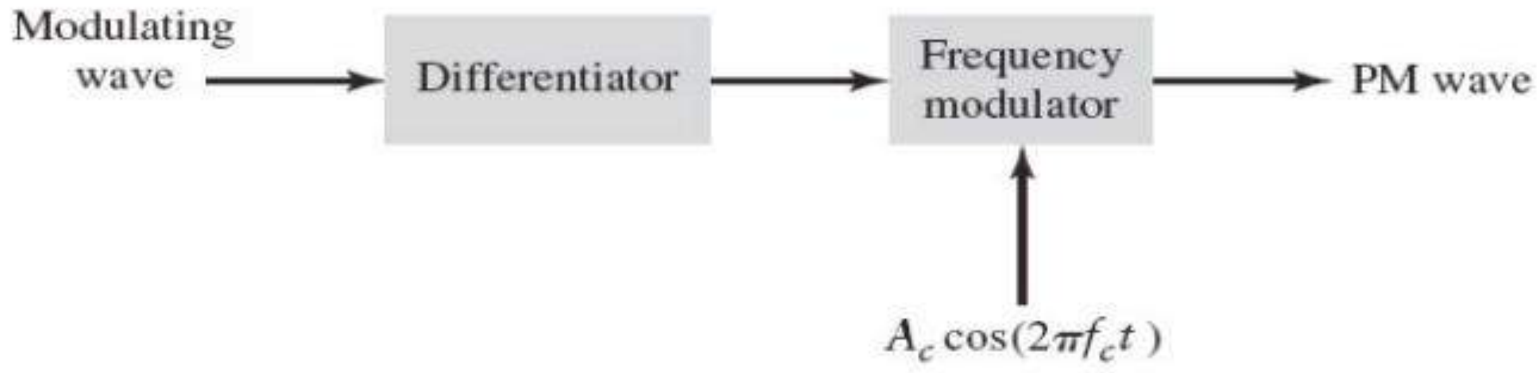
- β = ***modulation index*** = $\Delta\phi = k_p A_m$
- $\Delta\phi$ is phase deviation

Relationship between PM and FM

- An FM wave can be generated by first integrating the message signal m(t) with respect to time t and thus using the resulting signal as the input to a phase modulation.
- A PM wave can be generated by first differentiating m(t) with respect to time t and then using the resulting signal as the input to a frequency modulator.
- We may deduce the properties of phase modulation from those frequency modulation and vice versa.

Relationship between PM and FM

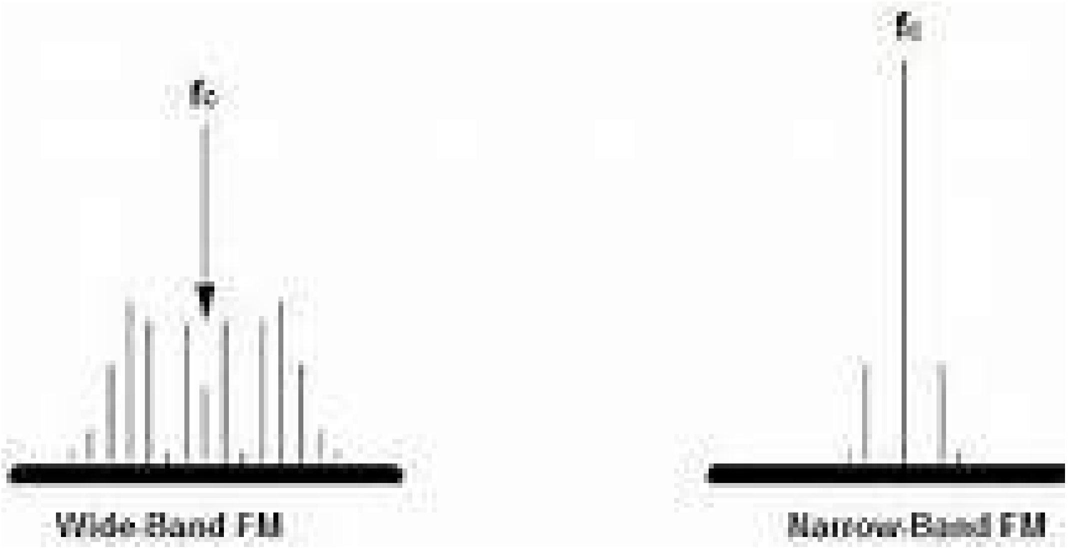




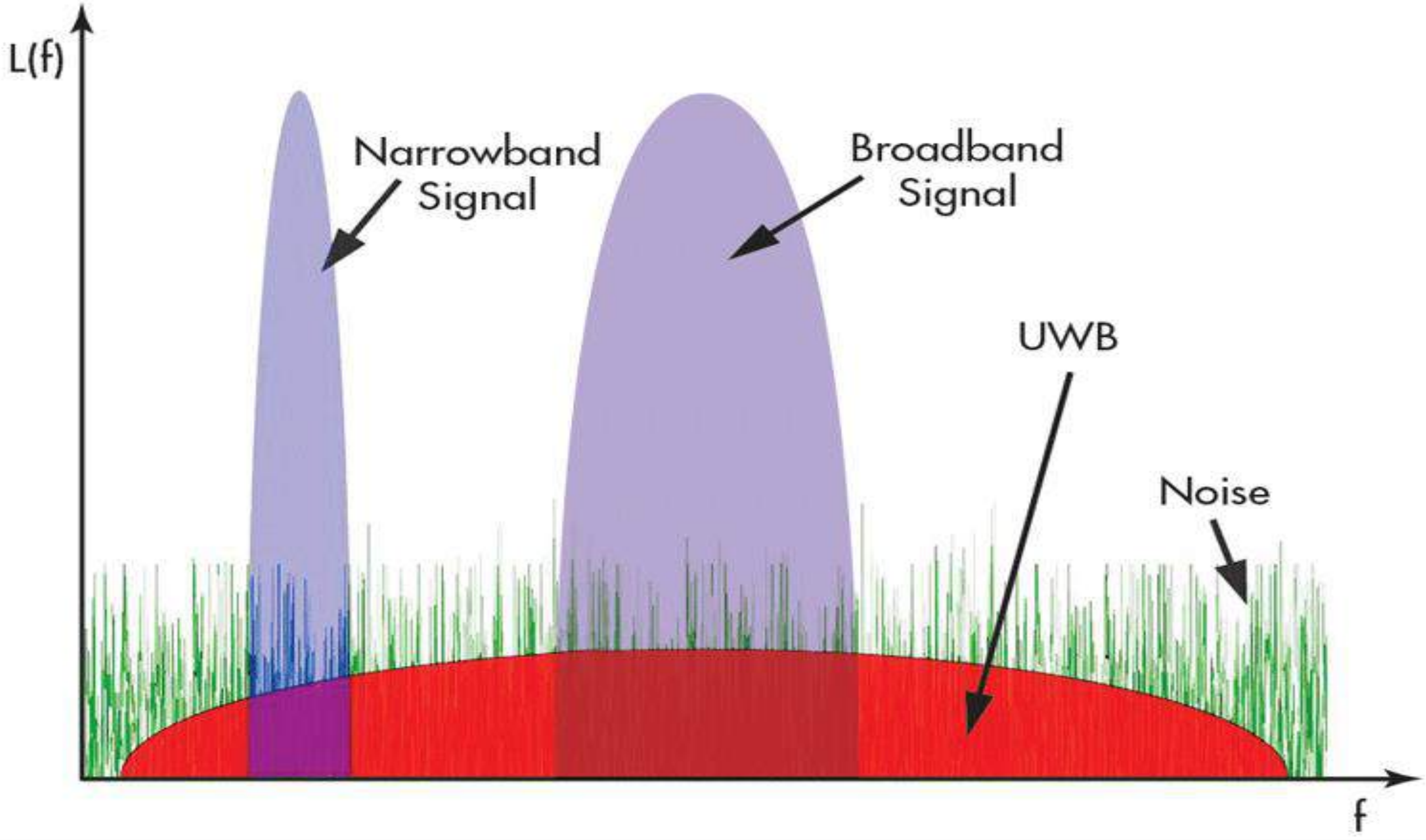
FM

1. Narrowband FM

1. Wideband FM



Frequency modulation



Narrow-Band Frequency Modulation

- FM wave is a nonlinear function of the modulating wave.
- This property makes the spectral analysis of the FM wave a much more difficult task than that of the corresponding AM wave.
- Frequency modulation can be classified as narrowband if the change in the carrier frequency is about the same as the signal frequency, or as wideband if the change in the carrier frequency is much higher (modulation index > 1) than the signal frequency.

Narrow-Band Frequency Modulation

- Narrow-Band FM means that the message signal has narrow bandwidth.
- Consider the single-tone wave as a message signal, which is extremely narrow banded:

$$m(t) = A_m \cos(2\pi f_m t)$$

- Instantaneous frequency

$$\begin{aligned} f_i(t) &= f_c + k_f A_m \cos(2\pi f_m t) \\ &= f_c + \Delta f \cos(2\pi f_m t) \end{aligned}$$

$$\Delta f = k_f A_m$$

Phase

$$\begin{aligned} \theta_i(t) &= 2\pi \int_0^t f_i(\tau)\, d\tau = 2\pi \left[f_c t + \frac{\Delta f}{2\pi f_m} \sin(2\pi f_m t) \right] \\ &= 2\pi f_c t + \frac{\Delta f}{f_m} \sin(2\pi f_m t) \end{aligned}$$

Narrow-Band Frequency Modulation

- Phase deviation of the FM wave $\beta = \dfrac{\Delta f}{f_m}$
- Modulation index of the FM wave: f_m
- Then, FM wave is

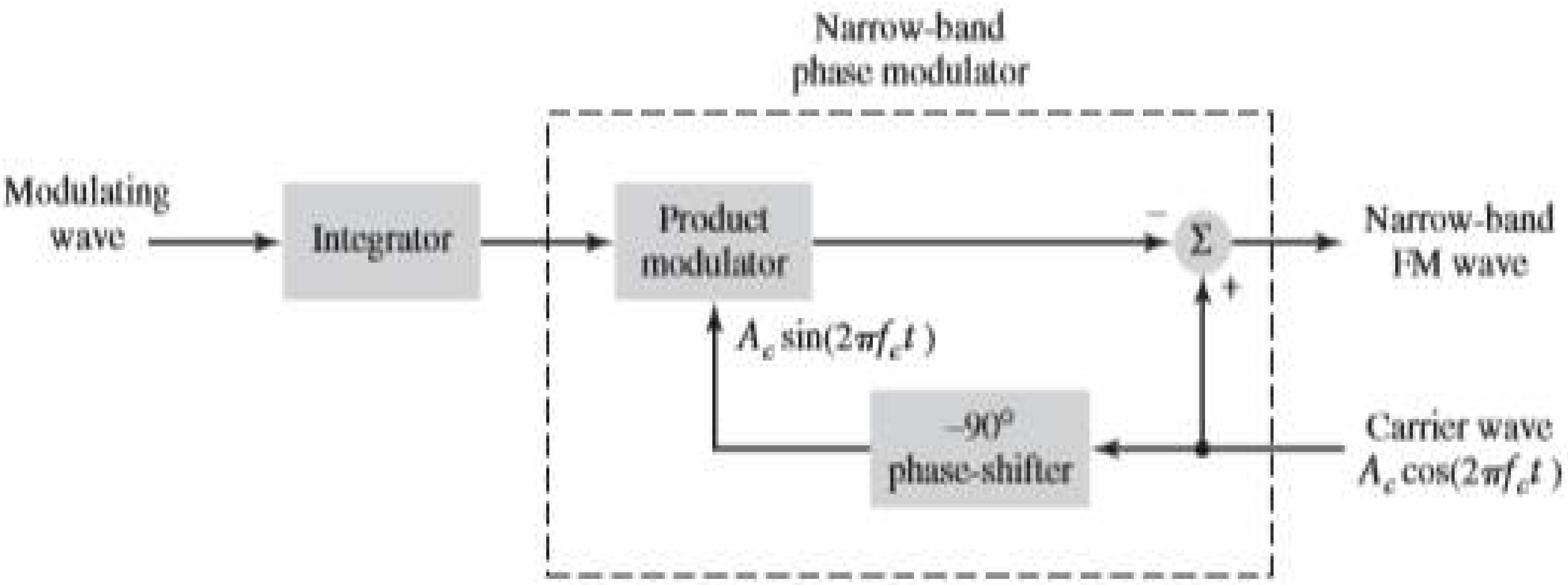
$$s(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$$

- For small f_m

$$\cos[\beta(2\pi f_m t)] \approx 1, \qquad \sin[\beta \sin(2\pi f_m t)] \approx \beta \sin(2\pi f_m t)$$

$$s(t) \approx A_c \cos(2\pi f_c t) - \beta A_c \sin(2\pi f_c t) \sin(2\pi f_m t)$$

Block diagram of an indirect method for generating a narrow-band FM wave



Wide-Band Frequency Modulation

- Wideband FM (WBFM) is used at the expense of greater spectrum usage.
- The term WBFM is used in applications where the modulation index is equal to or larger than 1.
  - Spectral analysis of the wide-band FM wave

$$s(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$$

or

$$s(t) = \Re\left[A_c \exp[j2\pi f_c t + j\beta \sin(2\pi f_m t)]\right] = \Re[\tilde{s}(t) \exp(j2\pi f_c t)]$$

where $\tilde{s}(t) = A_c \exp\left[j\beta \sin(2\pi f_m t)\right]$ is called "complex envelope".

Note that the complex envelope is a periodic function of time with a fundamental frequency f_m which means

$$\tilde{s}(t) = \tilde{s}(t + kT_m) = \tilde{s}(t + \frac{k}{f_m})$$

where $T_m = 1/f_m$

Wide-Band Frequency Modulation

- Then we can rewrite

$$\begin{aligned}\tilde{s}(t) &= \tilde{s}(t + k/f_m) \\ &= A_c \exp[j\beta \sin(2\pi f_m (t + k/f_m))] \\ &= A_c \exp[j\beta \sin(2\pi f_m t + 2k\pi)] \\ &= A_c \exp[j\beta \sin(2\pi f_m t)]\end{aligned}$$

- Fourier series form

$$\tilde{s}(t) = \sum_{n=-\infty}^{\infty} c_n \exp(j2\pi n f_m t)$$

where

$$\begin{aligned}c_n &= f_m \int_{-1/(2f_m)}^{1/(2f_m)} \tilde{s}(t) \exp(-j2\pi n f_m t)\, dt \\ &= f_m A_c \int_{-1/(2f_m)}^{1/(2f_m)} \exp[j\beta \sin(2\pi f_m t) - j2\pi n f_m t]\, dt\end{aligned}$$

Wide-Band Frequency Modulation

- Define the new variable: $x = 2\pi f_m t$

  Then we can rewrite

$$c_n = \frac{A_c}{2\pi} \int_{-\pi}^{\pi} \exp[j(\beta \sin x - nx)]\, dx$$

- nth order Bessel function of the first kind and argument β

$$J_n(\beta) = \frac{1}{2\pi} \int_{-\pi}^{\pi} \exp[j(\beta \sin x - nx)]\, dx$$

- Accordingly

$$c_n = A_c J_n(\beta)$$

  which gives

$$\tilde{s}(t) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \exp(j2\pi n f_m t)$$

Wide-Band Frequency Modulation

- Then the FM wave can be written as

$$\begin{aligned} s(t) &= \Re[\tilde{s}(t)\exp(j2\pi f_c t)] \\ &= \Re\left[A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\exp[j2\pi n(f_c + f_m)t]\right] \\ &= A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\cos[2\pi(f_c + nf_m)t] \end{aligned}$$

- Fourier transform

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

which shows that the spectrum consists of an infinite number of delta functions spaced at $f = f_c \pm nf_m$ for $n = 0, +1, +2, \ldots$

Wide-Band Frequency Modulation

Properties of Single-Tone FM for Arbitrary Modulation Index β

1. For different values of n

$$\begin{aligned} J_n(\beta) &= J_{-n}(\beta), && \text{for } n \text{ even} \\ J_n(\beta) &= -J_{-n}(\beta), && \text{for } n \text{ odd} \end{aligned}$$

2. For small value of β

$$\begin{aligned} J_0(\beta) &\approx 1, \\ J_1(\beta) &\approx \frac{\beta}{2} \\ J_n(\beta) &\approx 0, \quad n > 2 \end{aligned}$$

6. The equality holds exactly for arbitrary β

$$\sum_{n=-\infty}^{\infty} J_n^2(\beta) = 1$$

Bessel functions

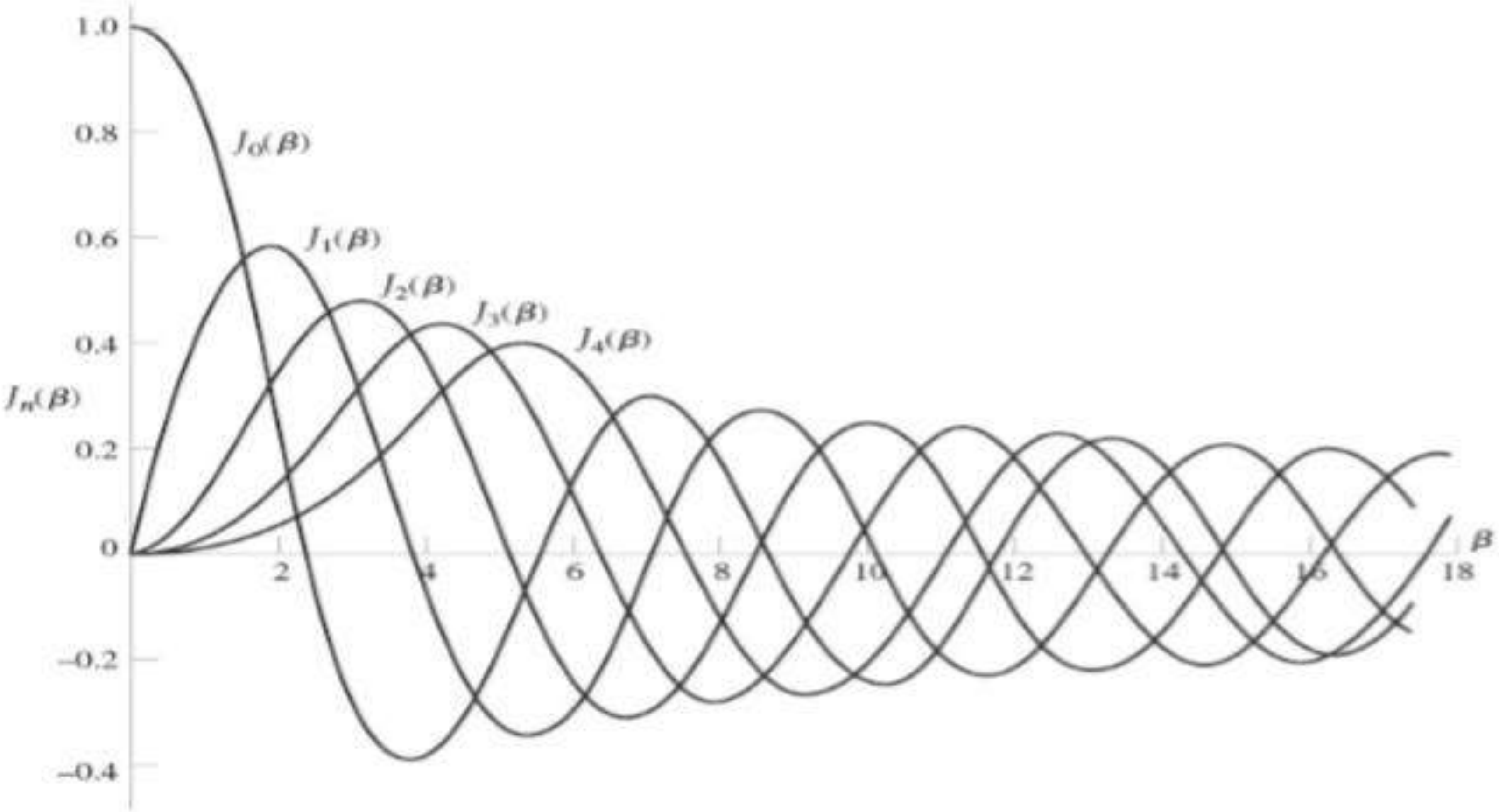
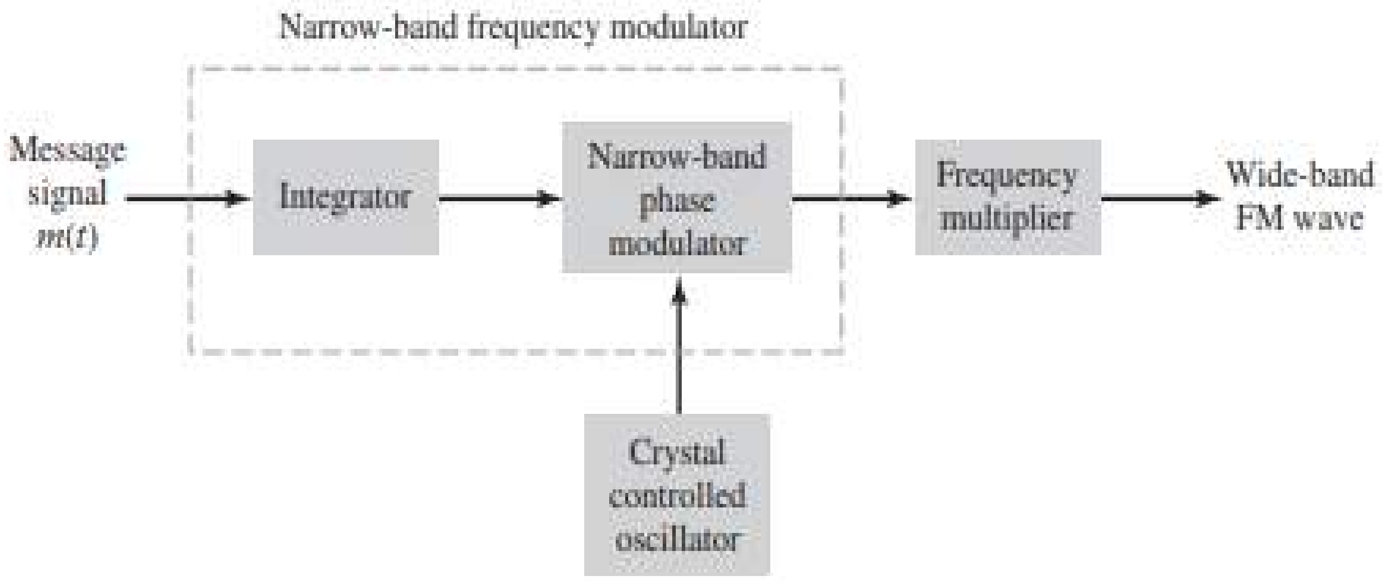


FIGURE 4.6 Plots of the Bessel function of the first kind, $J_n(\beta)$, for varying order n.

Generation of FM Waves

- DIRECT METHOD



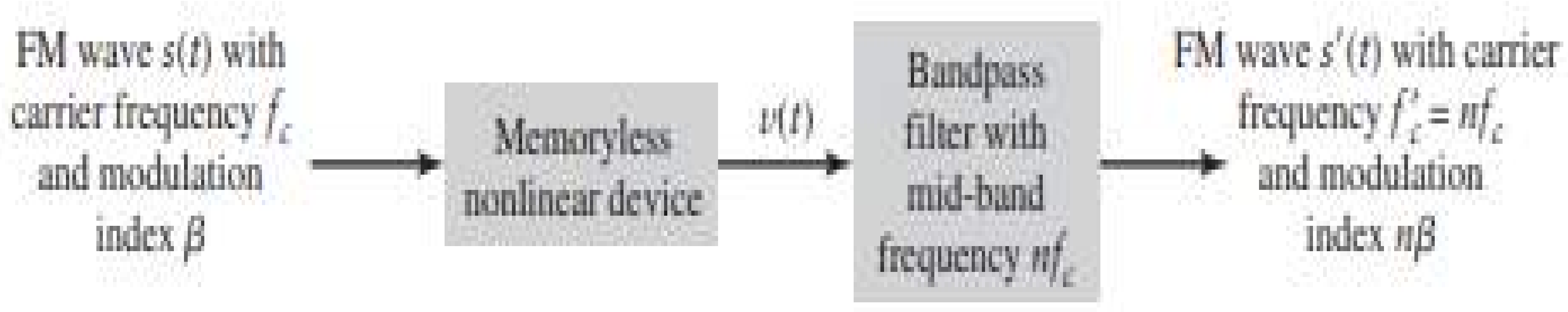
DIRECT METHOD

- The direct method uses a sinusoidal oscillator, with one of the reactive elements (e.g., capacitive element) in the tank circuit of the oscillator being directly controllable by the message signal.
- In conceptual terms, the direct method is therefore straightforward to implement.
- Moreover, it is capable of providing large frequency deviations.
- However, a serious limitation of the direct method is the tendency for the carrier frequency to drift, which is usually unacceptable for commercial radio applications.
- To overcome this limitation, frequency stabilization of the FM generator is required, which is realized through the use of feedback around the oscillator.

INDIRECT METHOD: ARMSTRONG MODULATOR

- In the indirect method, on the other hand, the message signal is first used to produce a narrow-band FM, which is followed by frequency multiplication to increase the frequency deviation to the desired level.
- In this second method, the carrier-frequency stability problem is alleviated by using a highly stable oscillator (e.g., crystal oscillator) in the narrowband FM generation; this modulation scheme is called the Armstrong wide-band frequency modulator, in recognition of its inventor

Block diagram of frequency multiplier.



INDIRECT METHOD: ARMSTRONG MODULATOR

- A frequency multiplier consists of a memoryless nonlinear device followed by a bandpass filter.
- The implication of the nonlinear device being memoryless is that it has no energy-storage elements. The input–output relation of such a device may be expressed in the general form

$$v(t) = a_1 s(t) + a_1 s^2(t) + \cdots + a_n s^n(t)$$

- where a1,a2,a3……..a N are coefficients determined by the operating point of the device, and n is the highest order of nonlinearity. In other words, the memoryless nonlinear device is an nth power-law device. The input is an FM wave defined by

INDIRECT METHOD: ARMSTRONG MODULATOR

$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau\right]$$

where the instantaneous frequency is

$$f_i(t) = f_c + k_f m(t)$$

It suffices to say that after bandpass filtering of the nonlinear device's output we have a new FM wave defined by

$$s'(t) = A_c \cos\left[2\pi f_c' t + 2\pi k_f' \int_0^t m(\tau)\, d\tau\right]$$

whose instantaneous frequency is

$$f_i'(t) = nf_c + nk_f m(t)$$

Demodulation of FM Signals

- Frequency demodulation is the process by means of which the original message signal is recovered from an incoming FM wave.
- In other words, frequency demodulation is the inverse of frequency modulation.
- With the frequency modulator being a device that produces an output signal whose instantaneous frequency varies linearly with the amplitude of the input message signal, it follows that for frequency demodulation we need a device whose output amplitude is sensitive to variations in the instantaneous frequency of the input FM wave in a linear manner too.

FM Demodulator Classification

- Coherent & Non-coherent
- A coherent detector has two inputs—one for a reference signal, such as the synchronized oscillator signal, and one for the modulated signal that is to be demodulated.
- A noncoherent detector has only one input, namely, the modulated signal port.
- Example: The envelope detector is an example of a noncoherent detector.
- Demodulator Classification
- – Frequency Discrimination
- Noncoherent demodulator
- FM----AM---ED----m(t)
- --Phase Shift Discrimination
- Noncoherent demodulator
- FM-----PM----m(t)
- – Phase-Locked Loop (PLL) Detector
- Coherent demodulator
- Superior performance; complex and expensive

FREQUENCY DISCRIMINATOR

- FM signal is given by

$$s(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau\right)$$

- We can motivate the formulation of a receiver for doing this recovery by noting that if we take the derivative with respect to time, then we obtain

$$\frac{ds(t)}{dt} = -2\pi A_c[f_c + k_f m(t)] \sin\left(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau\right)$$

- differentiation corresponds to a linear transfer function in the frequency domain

$$\frac{d}{dt} \rightleftharpoons j2\pi f$$

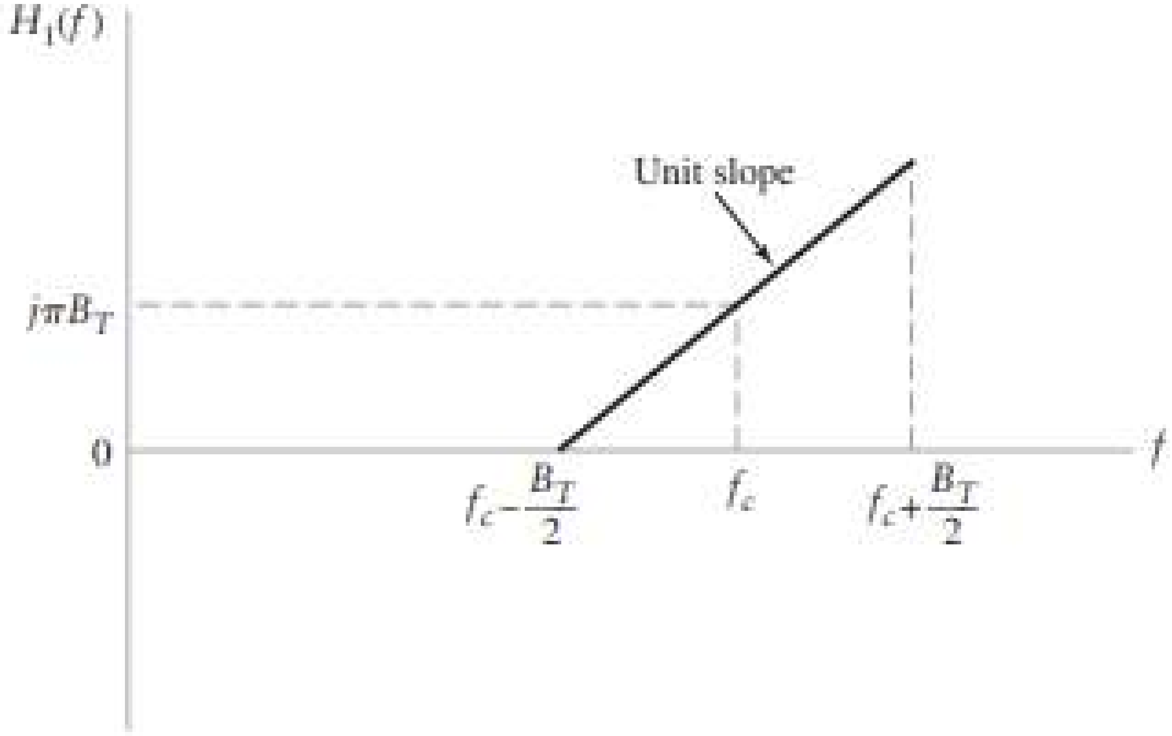
FREQUENCY DISCRIMINATOR

- A typical transfer characteristic that satisfies this requirement is described by

$$H_1(f) = \begin{cases} j2\pi[f - (f_c - B_T/2)], & f_c - (B_T/2) \le |f| \le f_c + (B_T/2) \\ 0, & \text{otherwise} \end{cases}$$

- The transfer characteristic of this so-called slope circuit is given below for positive frequencies.
- A practical slope circuit would have a nonunity gain associated with the slope; but, to simplify matters, we assume that it has unity gain without loss of generality.
- The circuit is also not required to have zero response outside the transmission bandwidth, provided that the circuit is preceded by a band-pass filter centered on with bandwidth f BT.

Frequency response of an ideal slope circuit



FREQUENCY DISCRIMINATOR

- It is simplest to proceed with a complex baseband representation of the signal processing performed by the discriminator.
- The complex envelope of the FM signal S(t) is

$$\tilde{s}(t) = A_c \exp\left(j2\pi k_f \int_0^t m(\tau)\, d\tau \right)$$

- For complex baseband filter

$$\tilde{H}_1(f) = \begin{cases} j2\pi[f + (B_T/2)], & -B_T/2 \leq f \leq B_T/2 \\ 0, & \text{otherwise} \end{cases}$$

FREQUENCY DISCRIMINATOR

$$\tilde{S}_1(f) = \frac{1}{2}\tilde{H}_1(f)\tilde{S}(f)$$

$$= \begin{cases} j\pi\left(f + \frac{1}{2}B_T\right)\tilde{S}(f), & -\frac{1}{2}B_T \le f \le \frac{1}{2}B_T \\ 0, & \text{elsewhere} \end{cases}$$

$$\frac{d}{dt}\tilde{s}(t) \rightleftharpoons j2\pi f\tilde{S}(f)$$

$$\tilde{s}_1(t) = \frac{1}{2}\frac{d}{dt}\tilde{s}(t) + \frac{1}{2}j\pi B_T\tilde{s}(t)$$

$$\tilde{s}_1(t) = \frac{1}{2}j\pi A_c B_T\left[1 + \left(\frac{2k_f}{B_T}\right)m(t)\right]\exp\left(j2\pi k_f\int_0^t m(\tau)\,d\tau\right)$$

FREQUENCY DISCRIMINATOR

$$s_1(t) = \mathbf{Re}[\tilde{s}_1(t)\exp(j2\pi f_c t)]$$
$$= \frac{1}{2}\pi A_c B_T\left[1 + \left(\frac{2k_f}{B_T}\right)m(t)\right]\cos\left(2\pi f_c t + 2\pi k_f\int_0^t m(\tau)\,d\tau + \frac{\pi}{2}\right)$$

$$\left(\frac{2k_f}{B_T}\right)|m(t)|_{\max} < 1, \qquad \text{for all } t$$

$$v_1(t) = \frac{1}{2}\pi A_c B_T\left[1 + \left(\frac{2k_f}{B_T}\right)m(t)\right]$$

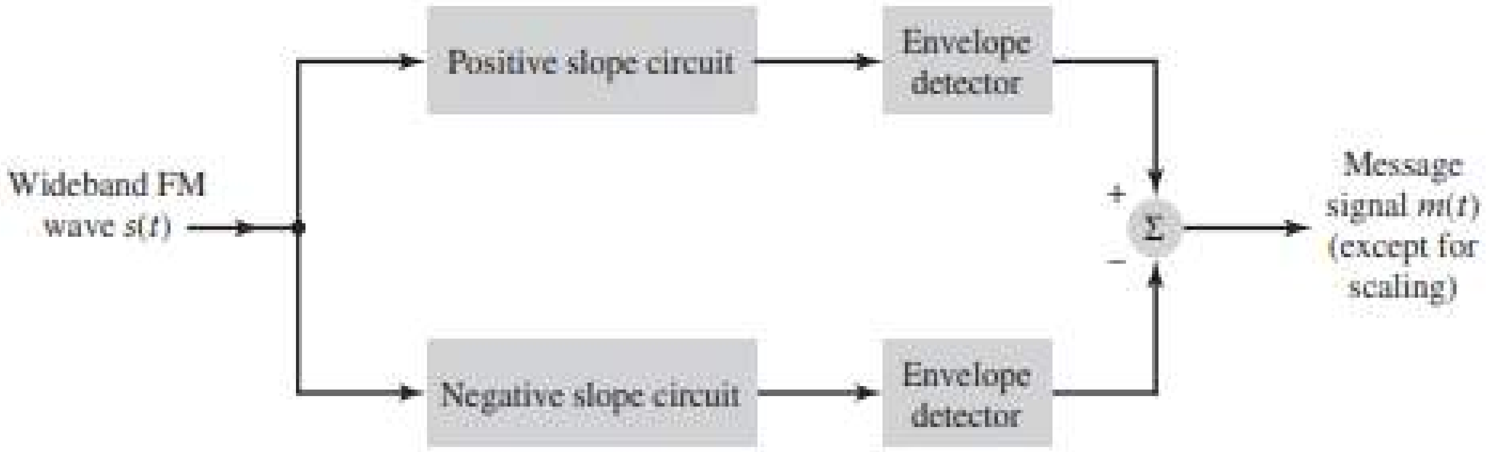
$$v_2(t) = \frac{1}{2}\pi A_c B_T\left[1 - \left(\frac{2k_f}{B_T}\right)m(t)\right]$$

https://www.youtube.com/watch?v=2tDStlT9pO4

Block diagram of balanced frequency discriminator.

$$v(t) = v_1(t) - v_2(t)$$
$$= cm(t)$$

where c is a constant.



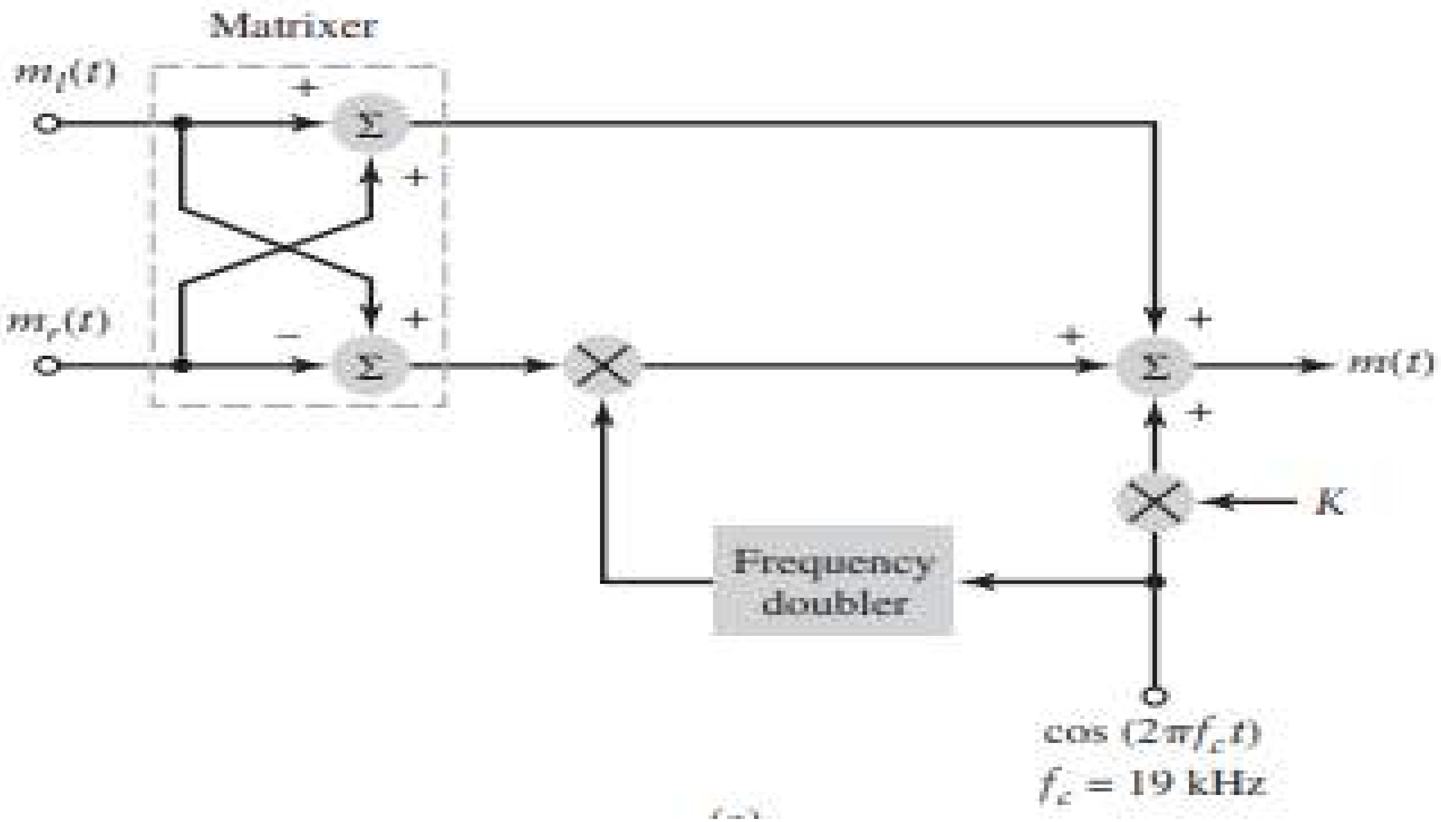
FM Stereo Multiplexing

- Stereo multiplexing is a form of frequency-division multiplexing (FDM) designed to transmit two separate signals via the same carrier.
- It is widely used in FM radio broadcasting to send two different elements of a program (e.g., two different sections of an orchestra, a vocalist and an accompanist) so as to give a spatial dimension to its perception by a listener at the receiving end.
- The specification of standards for FM stereo transmission is influenced by two factors:

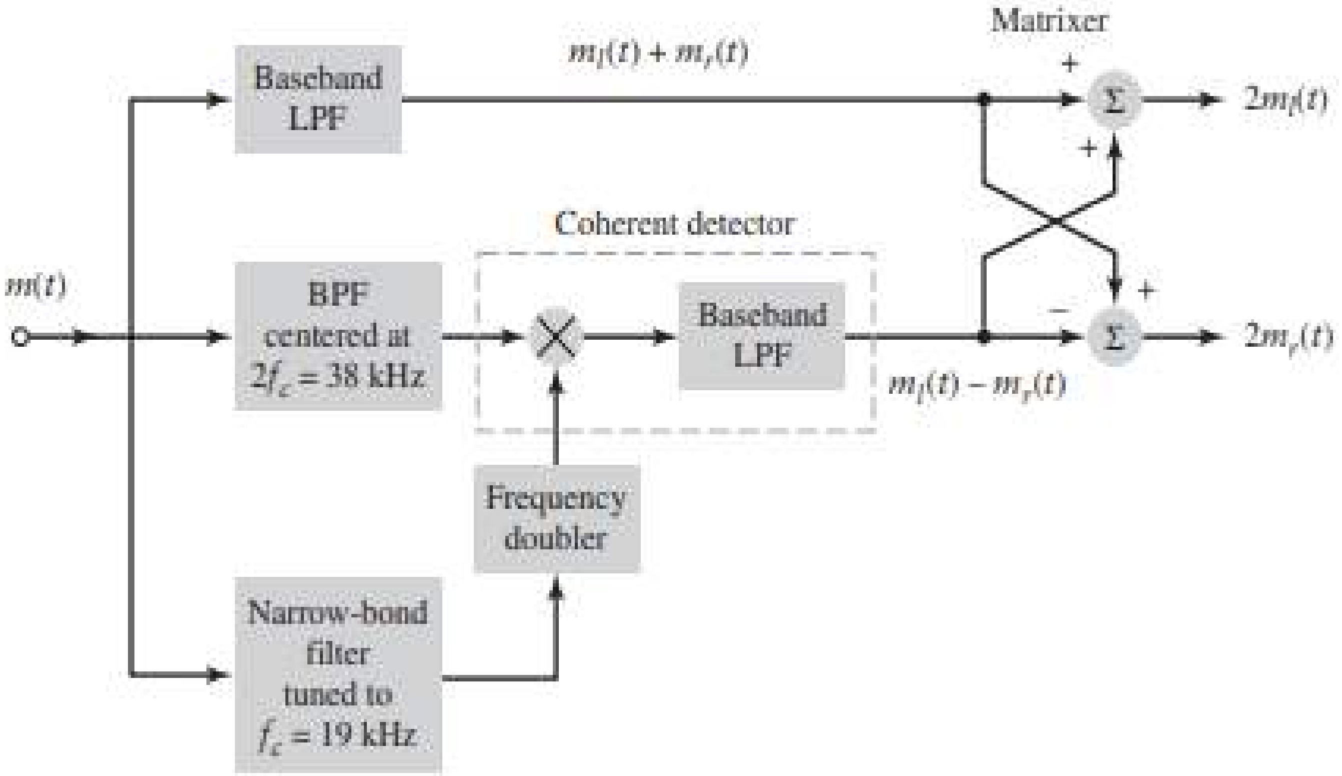
1. The transmission has to operate within the allocated FM broadcast channels.
2. It has to be compatible with monophonic radio receivers.

FM Stereo Multiplexing

- Multiplexer in transmitter of FM stereo.



Demultiplexer in receiver of FM stereo.



PHASE-LOCKED LOOP

- The phase-locked loop is a feedback system whose operation is closely linked to frequency modulation. It is commonly used for carrier synchronization, and indirect frequency demodulation. The latter application is the subject of interest here.

- Basically, the phase-locked loop consists of three major components:

1. Voltage-controlled oscillator (VCO), which performs frequency modulation on its own control signal.
2. Multiplier, which multiplies an incoming FM wave by the output of the voltage-controlled oscillator.
3. Loop filter of a low-pass kind, the function of which is to remove the high-frequency components contained in the multiplier’s output signal and thereby shape the overall frequency response of the system.

PHASE-LOCKED LOOP

- To demonstrate the operation of the phase-locked loop as a frequency demodulator, we assume that the VCO has been adjusted so that when the control signal (i.e., input) is zero, two conditions are satisfied:

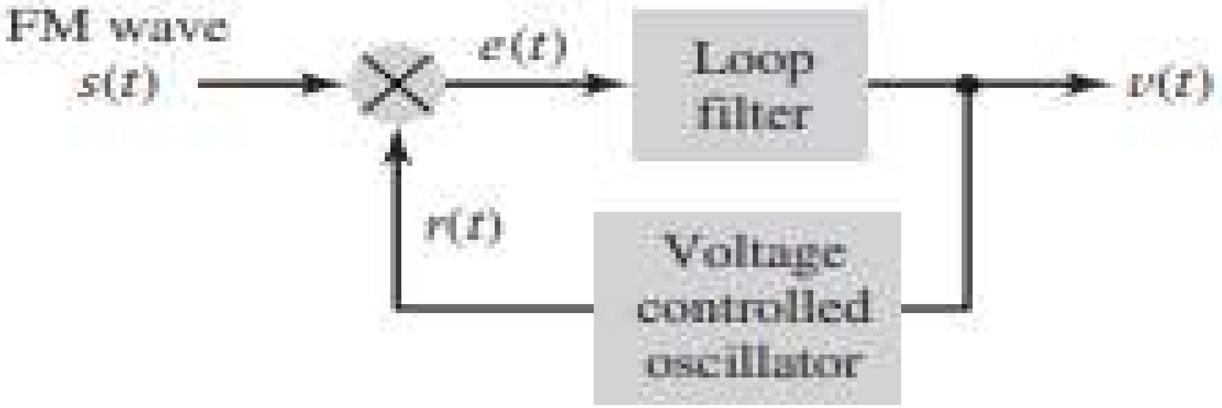
1. The frequency of the VCO is set precisely at the unmodulated carrier frequency of the incoming FM wave S(t).
2. The VCO output has a 90-degree phase-shift with respect to the unmodulated carrier wave.

https://www.youtube.com/watch?v=bJNDh46uI3w

PHASE-LOCKED LOOP

- Suppose then that the incoming FM wave is defined by

$$s(t) = A_c \sin[2\pi f_c t + \phi_1(t)]$$



PHASE-LOCKED LOOP

- where is the carrier amplitude. By definition, the angle is related to the message signal by the integral.

$$\phi_1(t) = 2\pi k_f \int_0^t m(\tau)\, d\tau$$

- The FM wave produced by the VCO as

$$\phi_2(t) = 2\pi k_v \int_0^t v(\tau)\, d\tau$$

PHASE-LOCKED LOOP

1. A high-frequency component, which is defined by the double-frequency term—namely,

$$k_m A_c A_v \sin[4\pi f_c t + \phi_1(t) + \phi_2(t)]$$

1. A low-frequency component, which is defined by the difference-frequency term— namely,

$$k_m A_c A_v \sin[\phi_1(t) - \phi_2(t)]$$

Nonlinear Effects in FM Systems

Consider a communications channel, the transfer characteristic of which is defined by the nonlinear input-output relation

$$v_o(t) = a_1 v_i(t) + a_2 v_i^2(t) + a_3 v_i^3(t)$$

$$v_i(t) = A_c \cos[2\pi f_c t + \phi(t)]$$

$$\phi(t) = 2\pi k_f \int_0^t m(\tau)\, d\tau$$

$$v_o(t) = a_1 A_c \cos[2\pi f_c t + \phi(t)] + a_2 A_c^2 \cos^2[2\pi f_c t + \phi(t)] + a_3 A_c^3 \cos^3[2\pi f_c t + \phi(t)]$$

Nonlinear Effects in FM Systems

$$v_o(t) = \frac{1}{2} a_2 A_c^2 + \left(a_1 A_c + \frac{3}{4} a_3 A_c^3 \right) \cos[2\pi f_c t + \phi(t)]$$

$$+ \frac{1}{2} a_2 A_c^2 \cos[4\pi f_c t + 2\phi(t)]$$

$$+ \frac{1}{4} a_3 A_c^3 \cos[6\pi f_c t + 3\phi(t)]$$

$$2f_c - (2\Delta f + W) > f_c + \Delta f + W$$

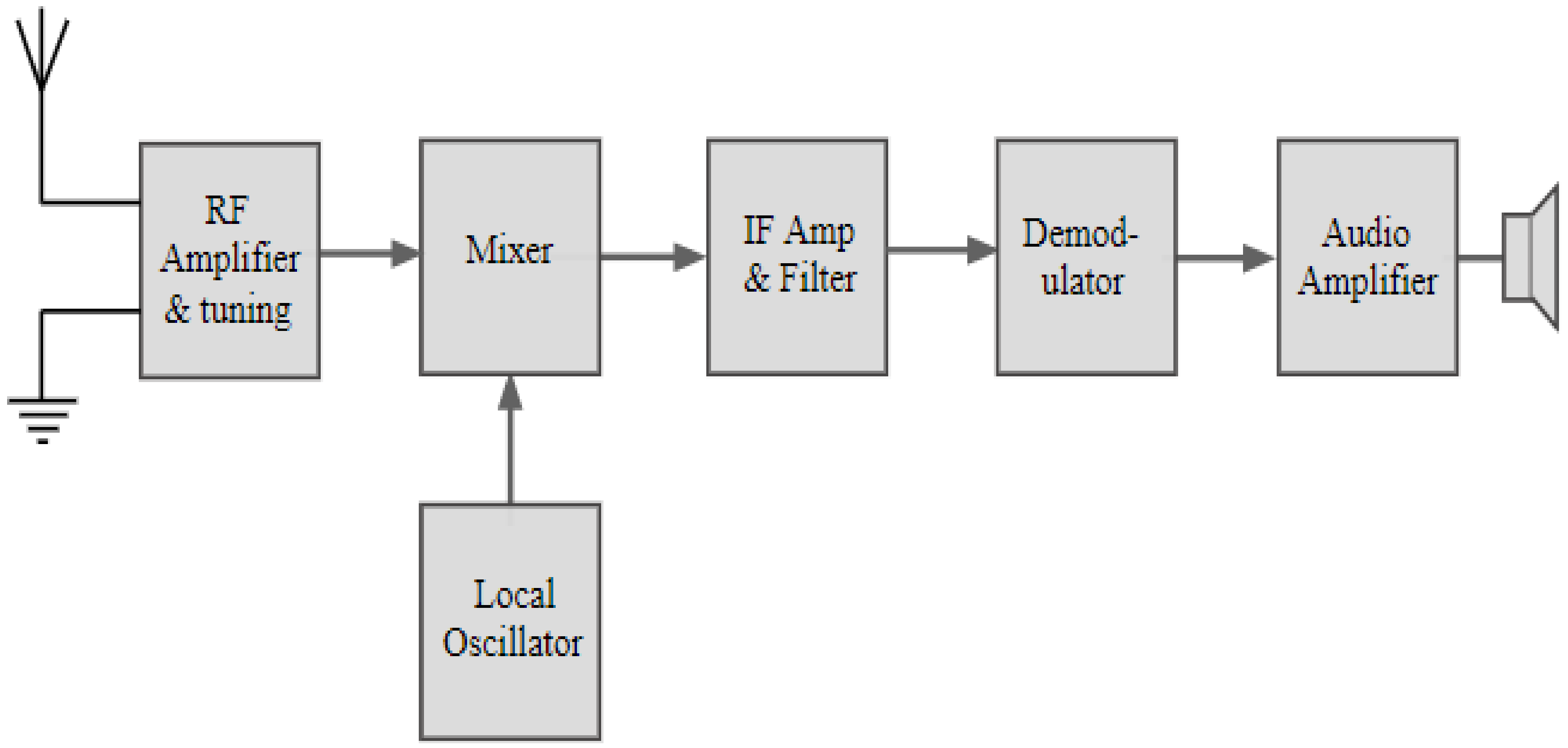
$$f_c > 3\Delta f + 2W$$

$$v_o'(t) = \left(a_1 A_c + \frac{3}{4} a_3 A_c^3 \right) \cos[2\pi f_c t + \phi(t)]$$

Superheterodyne Receiver

- The superhet radio receiver is used in many forms of radio broadcast reception, two way radio communications and the like.
- There are several different circuit blocks that make up the overall receiver, each one has its own function.
- There are some key circuit blocks within the RF design of the basic superheterodyne receiver. Although more complicated receivers can be made, the basic RF circuit design is widely used – further blocks can add improved performance or additional functionality and their operation.

Superheterodyne receiver circuit blocks



RF tuning & amplification:

- This RF stage within the overall block diagram for the receiver provides initial tuning to remove the image signal.
- It also provides some amplification.
- There are many different approaches used within the RF circuit design for this block dependent its application.
- The RF circuit design presents some challenges.
- Low cost broadcast radios may have an amplifying mixer circuit that gives some RF amplification.
- HF radios may not want too much RF gain because some of the very strong signals received could overload later stages.
- If noise performance for the receiver is important, then this stage will be designed for optimum noise performance.
- This RF amplifier circuit block will also increase the signal level so that the noise introduced by later stages is at a lower level in comparison to the wanted signal.

Local oscillator

- Early receivers used free running local oscillators.
- There was a considerable degree of RF circuit design expertise used with these oscillators in high performance superhet radios to ensure the lowest possible drift.
- High Q coils, low drift circuit configurations, heat management (because heat causes drift), etc .
- Today most receivers use one or more of a variety of forms frequency synthesizers.
- The most common approach in the RF circuit design is to use a phase locked loop approach. Single and multi-loop synthesizers are used.
- Direct digital synthesizers are also being used increasingly.
- Whatever form of synthesizer is used in the RF design, they provide much greater levels of stability and enable frequencies to be programmed digitally in a variety of ways, normally using some form of microcontroller or microprocessor system.

Mixer

- The mixer can be one of the key elements within the overall RF design of the receiver.
- Ensuring that the mixer performance matches that of the rest of the radio is particularly important.
- Both the local oscillator and incoming signal enter this block within the superheterodyne receiver.
- The wanted signal is converted to the intermediate frequency.
- In some very low cost broadcast receivers, self oscillating mixers that provide RF amplification from a single transistor may be used, these do not offer high performance.
- For a high performance radio used for two way radio communications an the like, much better performance is required.
- To achieve this mixer circuits such as balanced mixers, double balanced mixers, and the like may be seen.

IF amplifier & filter

- This superheterodyne receiver block provides the majority of gain and selectivity.
- Often comparatively little gain will be provided int he previous blocks of the RF circuit design of the radio.
- The IF stages are where the main gain is provided. Being fixed in frequency, it is much easier to achieve high levels of gain and overall performance.

Demodulator

- The superheterodyne receiver block diagram only shows one demodulator, but in reality many radio RF designs may have one or more demodulators dependent upon the type of signals being receiver.
- Even many broadcast radios will have AM and FM, but professional radios used for monitoring and two way radio communications may require a larger variety in some instances.
- Having a variety of demodulators will enable many different signal modes to be received and increase the capability of the radio.

Audio amplifier

- Once demodulated, the recovered audio is applied to an audio amplifier block to be amplified to the required level for loudspeakers or headphones.
- Alternatively the recovered modulation may be used for other applications whereupon it is processed in the required way by a specific circuit block.

Video links

- Angle modulation--https://www.youtube.com/watch?v=yGkV8ou1AeQ&t=62s
- Frequency modulation--https://www.youtube.com/watch?v=qY_yg2igDjg
- Phase locked loop---https://www.youtube.com/watch?v=bJNDh46uI3w&t=93s

UNIVERSITY QUESTIONS

1. Define Angle Modulation. State properties of angle modulated wave

2. The equation for FM wave is $S(t) = 10 \text{ Sin } [5.7*10^8 t + 5 \text{ Sin } 12*10^3 t]$, Calculate

I. Carrier frequency

II. Modulating frequency

III. Modulation index

IV. Frequency deviation

3. Derive the expression for NBFM wave.

UNIVERSITY QUESTIONS

4. Define,

I. Modulation index

II. Frequency deviation

III. Bandwidth

5. Write short note on transmission BW of FM signals

6. Describe with help of Block Diagram schemes of generating
   - FM using PM
   - PM using FM

MCQ QUESTIONS

- What is the full form of AFC?

  a) Amplitude to frequency conversion

  b) Automatic frequency conversion

  c) Automatic frequency control

  d) Audio frequency control

- Mixing is used in communication to ________

  a) raise the carrier frequency

  b) lower the carrier frequency

  c) to altered the deviation

  d) to change the carrier frequency to any required value

MCQ QUESTION

- On which factor the bandwidth required for a modulated carrier depends?

  a) baseband frequency range

  b) signal to noise ratio

  c) carrier frequency

  d) amplitude of carrier frequency

- The frequency of local oscillator _________

  a) can be either below or above the RF frequency

  b) is below the RF frequency

  c) is above the RF frequency

  d) is fixed typically at 450KHz

MCQ QUESTION

- What is the full form of IF?

  a) Intermediate Frequency

  b) Internal Frequency

  c) Indeterminate Frequency

  d) Image Frequency

- What is the full form of DTMF?

  a) Dual-Tone Multi frequency

  b) Dual Telephony Multiple Frequency

  c) Dual-Tone Minimum Frequency

  d) Digital Tone Minimum Frequency