Mar Athanasius College Of Engineering, Kothamangalam
Department of Electronics and Communication

5TH SEMSTER B.TECH

ECT 305
ANALOG AND DIGITAL COMMUNICATION

L-T-P: 3-1-0
Credit : 4

Prepared By
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Course Outcome

After the completion of the course the student will be able to	
CO 1	Explain the existent analog communication systems.
CO 2	Apply the concepts of random processes to LTI systems.
CO 3	Apply waveform coding techniques in digital transmission.
CO 4	Apply GS procedure to develop digital receivers.
CO 5	Apply equalizer design to counteract ISI.
CO 6	Apply digital modulation techniques in signal transmission.

Evaluation Pattern

Mark distribution

Total Marks	CIE	ESE	ESE Duration
150	50	100	3 hours

Continuous Internal Evaluation Pattern:

Attendance : 10 marks
Continuous Assessment Test (2 numbers) : 25 marks
Assignment/Quiz/Course project : 15 marks

End Semester Examination Pattern: There will be two parts; Part A and Part B. Part A contain 10 questions with 2 questions from each module, having 3 marks for each question. Students should answer all questions. Part B contains 2 questions from each module of which student should answer any one. Each question can have maximum 2 sub-divisions and carry 14 marks.

Syllabus

1
- Analog Communication

2
- Review of Random Variables and Random Processesnull

3
- Source Coding, PCM

4
- G-S Procedure and Effects in the Channelnull

5
- Digital Modulation Schemesnull

Text Books

- “Communication Systems”, Simon Haykin, Wiley.
- “Digital Communications: Fundamentals and Applications”, Sklar, Pearson.
- “Digital Telephony”, John C. Bellamy, Wiley

Syllabus : Module-1

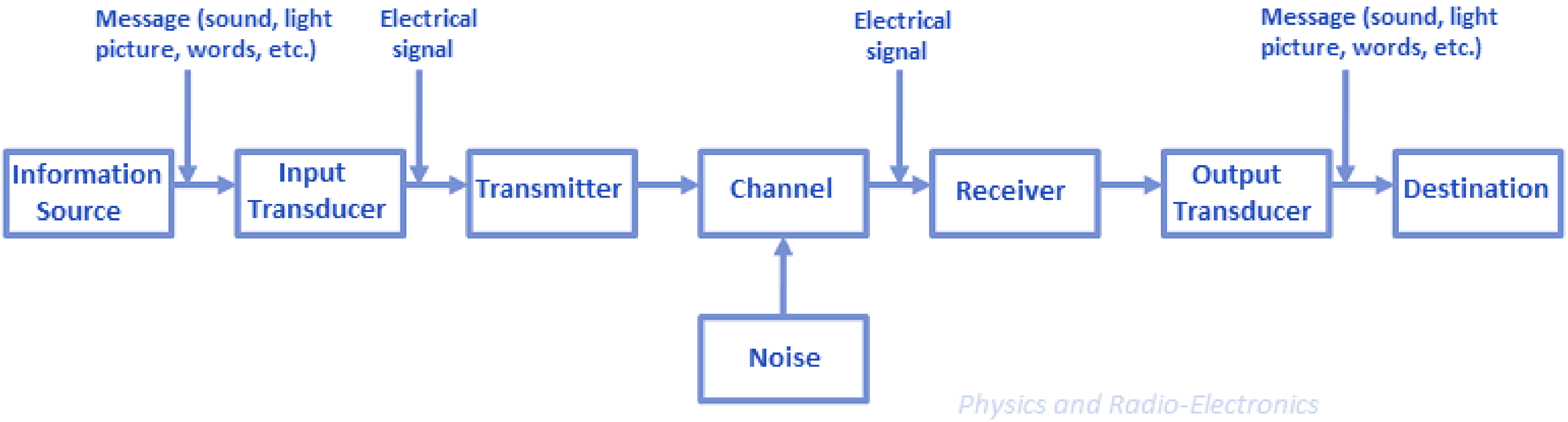
No	Topic	No. of Lectures
1	**Analog Communication**	
1.1	Block diagram of communication system, analog and digital systems , need for modulation	2
1.2	Amplitude modulation, model and spectrum and index of modulation	2
1.3	DSB-SC and SSB modulation. SSB transmitter and receiver	2
1.4	Frequency and phase modulation. Model of FM, spectrum of FM signal	2

Communication

The Communication Process

- Communication involves the transmission of information from one point to another through a succession of processes
  - The generation of message signals
  - The description of that message signal with certain measure of precision by a set of symbols
  - The encoding of these symbols in a form that is suitable for transmission
  - The transmission of the encoded symbols to the desires destinations
  - The decoding and reproduction of the original symbols
  - The recreation of the original message signal with a definable degradation in quality

Elements of a communication system



Block Diagram of Communication System

Block Diagram of Communication Systems

- Information Source
  - Produces the information which is to be transmitted
- Input Transducer
  - A transducer is a device which converts one form of energy into another form .
  - If the information source is not electrical in nature, an input transducer converts it into a time varying electrical signals
- Transmitter
  - The function of the transmitter is to convert the information into a signal which is suitable for transmission over a given communication channel.
- Communication Channel
  - It is the medium by which electronic signal is sent from one place to another.
  - In simplest form it may be a pair of wire that carry a voice from microphone to a hand set.
  - The medium may be wireless also

Block Diagram of Communication Systems

- Noise
  - Noise is random undesirable electric energy that enter the communication system via the communication medium and it interferes with the transmitted message.
  - Sources of noise
    - From atmosphere
    - From outer space where and stars emit various kind of radiation that can interfere with communications
    - Electrical interference created by manufactured equipment eg. Thermal noise
  - Noise signals are low level, but they can often seriously interfere with the transmitted signal after being transmitted over a long distance.
  - Noise is a serious problem of electronic communication systems
- Receiver
  - Accept the transmitted message from the channel and convert it back into a form understandable by humans

Elements of a communication system

- Basic elements of communication system are
  - Transmitter
  - Channel
  - Receiver
- Transmitter and receiver located at different points in space
- Channel is a medium that connect them.
  - The transmitted signal propagates along the channel, it gets distorted due to channel imperfections
  - Addition of noise and interfering signals
  - Received signal is a corrupted version of transmitted signal.
- The receiver needs to reconstruct a recognizable form of the original message signal for a user.

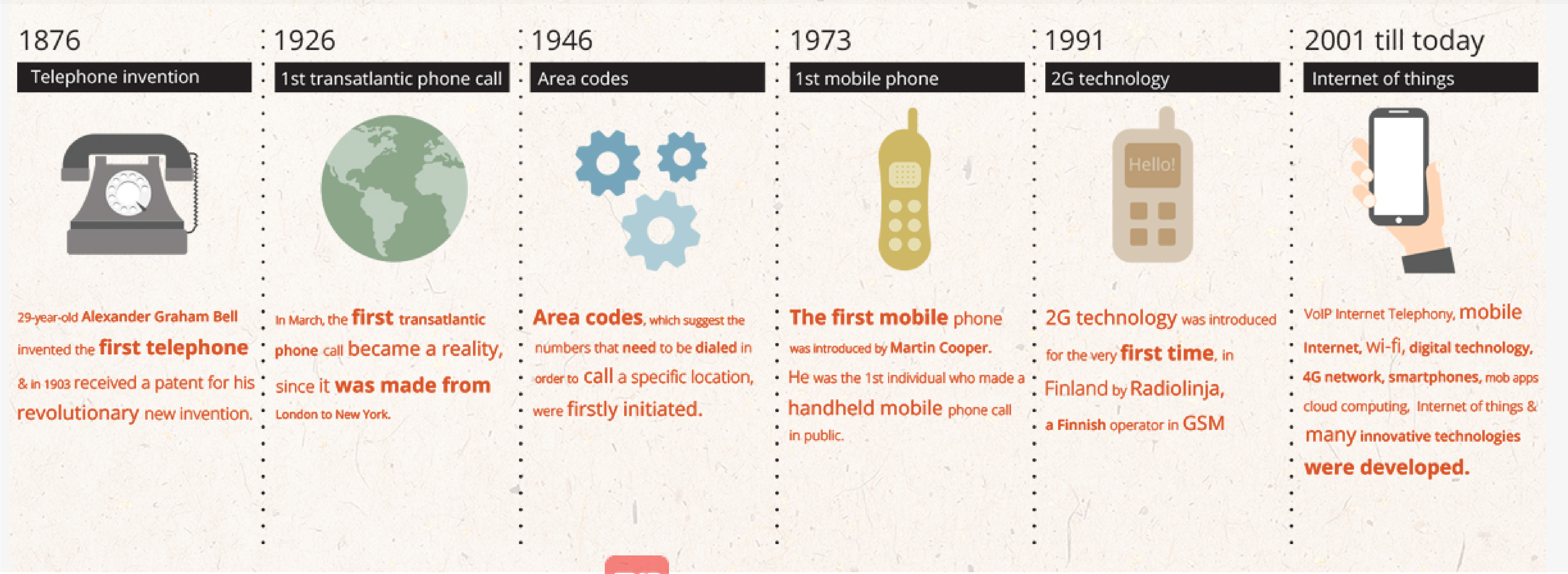
Modes of communication

- **Two modes**
- Broadcasting
    - Single powerful transmitter and numerous receivers
    - Information bearing signals flow only in one direction
    - E.g.: radio or television
- Point to point communication
    - Communication process takes place over a link between a single transmitter and receiver,
    - Bidirectional flow of information bearing signals
    - Transmitter and receiver should be present at each end of the link
    - E.g.: telephone

- Communication process is statistical in nature.

History

- https://www.fiberoptics4sale.com/blogs/wave-optics/introduction-to-communication-systems



Primary Communication Resources

- Two Primary Resources
  - Transmitted Power :
    - Average power of the transmitted signal
  - Channel Bandwidth :
    - band of frequencies allocated for the transmission of the message signal
- Two resources must be used efficiently as possible.
- Channels are power limited or band limited.
- **Noise** is the unwanted waves that tend to disturb the transmission and processing of message signals
- **Signal-to-noise ratio** : ratio of the average signal power to the average noise power both measured at the same point (in dB)

Sources of Information

- Four important sources of information
  - Speech
  - Music
  - Pictures
  - Computer data
- A signal is defined as a single valued function of time t.
- It can be
- 1-D such as speech, music or computer data
- 2-D as in case of pictures
- 3-D as in case of video

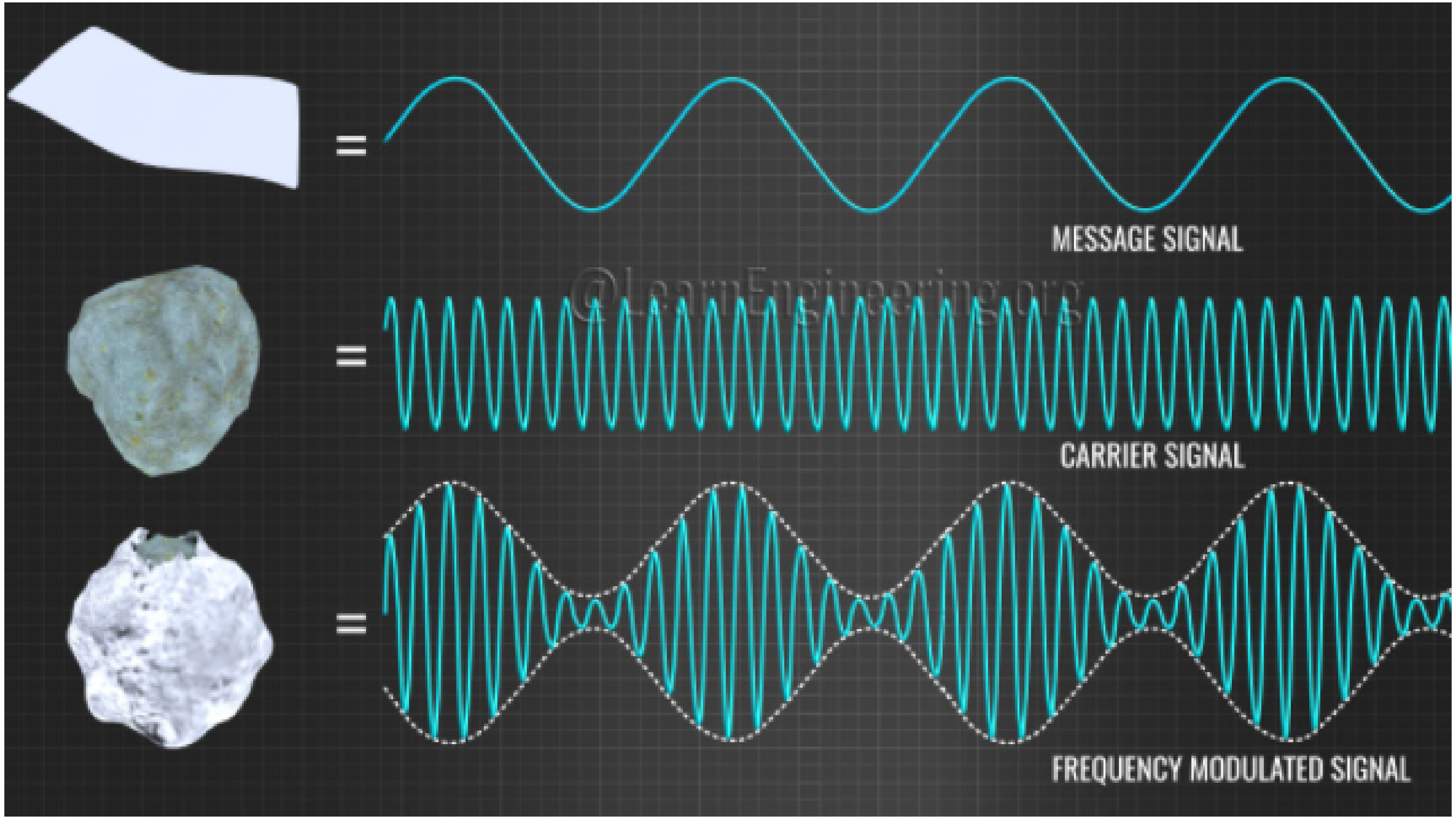
Communication Channels

- Depending on the mode of transmission used there are two groups of communication channels
- Guided Propagation
  - Telephone channels, coaxial cables and optic fibers
- Free propagation
  - wireless broadcast channels, mobile radio channels, and satellite channels

Modulation Process

- The purpose of a communication system is to deliver a message signal form an information source in recognizable form to a user destination , with the source and the user being physically separated from each other.
- Transmitter modifies the message signal into a form suitable for transmission over the channel
  - Modulation involves varying some parameter of a carrier wave in accordance with the message signal
  - Demodulation the receiver recreates the original message signal from a degraded version of the transmitted signal after propagation through the channel.
- Due to the unavoidable presence of noise and distortion in the received signal, we cannot recreate the original signal exactly.
  - The resulting degradation in overall system performance is influenced by the type of modulation scheme used.
  - Some modulation scheme are less sensitive to the effects of noise and distortion than others.

Modulation Process- Analogy



Need for Modulation

- Increases the range of communication
- Reduces the height of antenna
- Improves the quality of reception
- Avoid mixing of signals
- Allows multiplexing of signals
- Allows bandwidth adjustments

Need for Modulation

Reduces the height of antenna

- For the effective transmission of a signal, the height h of the antenna should be comparable to the wavelength λ of the signal
  - at least the height of the antenna h should be λ / 4 in length so that the antenna can sense the variations of the signal properly.
- The low-frequency message signal has a very high value of $\boldsymbol{\lambda}$ which will require a very high antenna
  - **For example:**
  - If we have to transmit a signal of **10 kHz** then
  - **$\lambda = C / f$** and height of the antenna **$h \approx \lambda$** where **C** is the wave velocity, here **$C = 3 \times 10^8$ m/s**.
  - **$h \approx \lambda = (3 \times 10^8) / 4*(10 \times 10^3)$**
  - **h = 7.5 km.**
- Hence, we need to modulate the message signal over the high-frequency carrier signal so that we can have a practical value for the height ***h*** of the antenna

Need for Modulation

Avoids mixing of signals

- If the baseband sound signals are transmitted without using the modulation by more than one transmitter, then all the signals will be in the same frequency range i.e. 0 to 20 kHz .
- Therefore, all the signals get mixed together and a receiver can not separate them from each other .
- Hence, if each baseband sound signal is used to modulate a different carrier then they will occupy different slots in the frequency domain (different channels).
- Thus, modulation avoids mixing of signals .

Need for Modulation

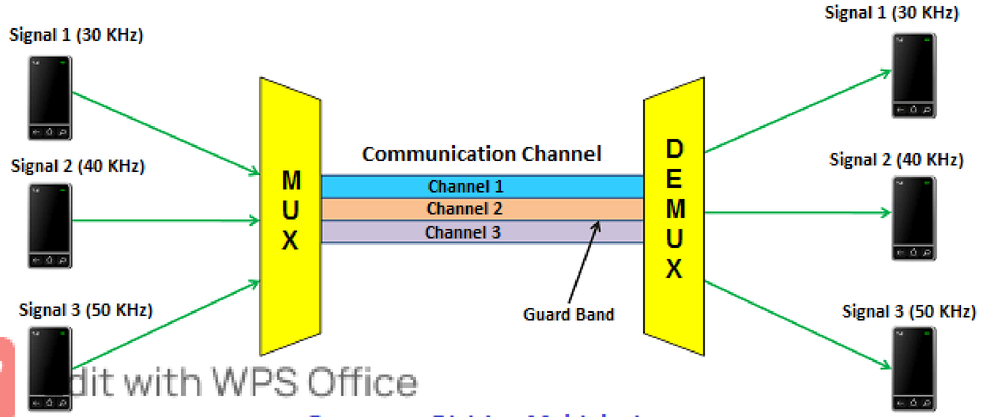
Increase the Range of Communication

- The frequency of baseband signal is low, and the low frequency signals can not travel long distance when they are transmitted .
- They get heavily attenuated .
- The attenuation reduces with increase in frequency of the transmitted signal, and they travel longer distance .
- The modulation process increases the frequency of the signal to be transmitted .
- Therefore, it increases the range of communication.

Need for Modulation

Multiplexing is possible

- Multiplexing is a process in which two or more signals can be transmitted over the same communication channel simultaneously .
- This is possible only with modulation.
- The multiplexing allows the same channel to be used by many signals .
- Hence, many TV channels can use the same frequency range, without getting mixed with each other or different frequency signals can be transmitted at the same time .



Frequency Division Multiplexing

Need for Modulation

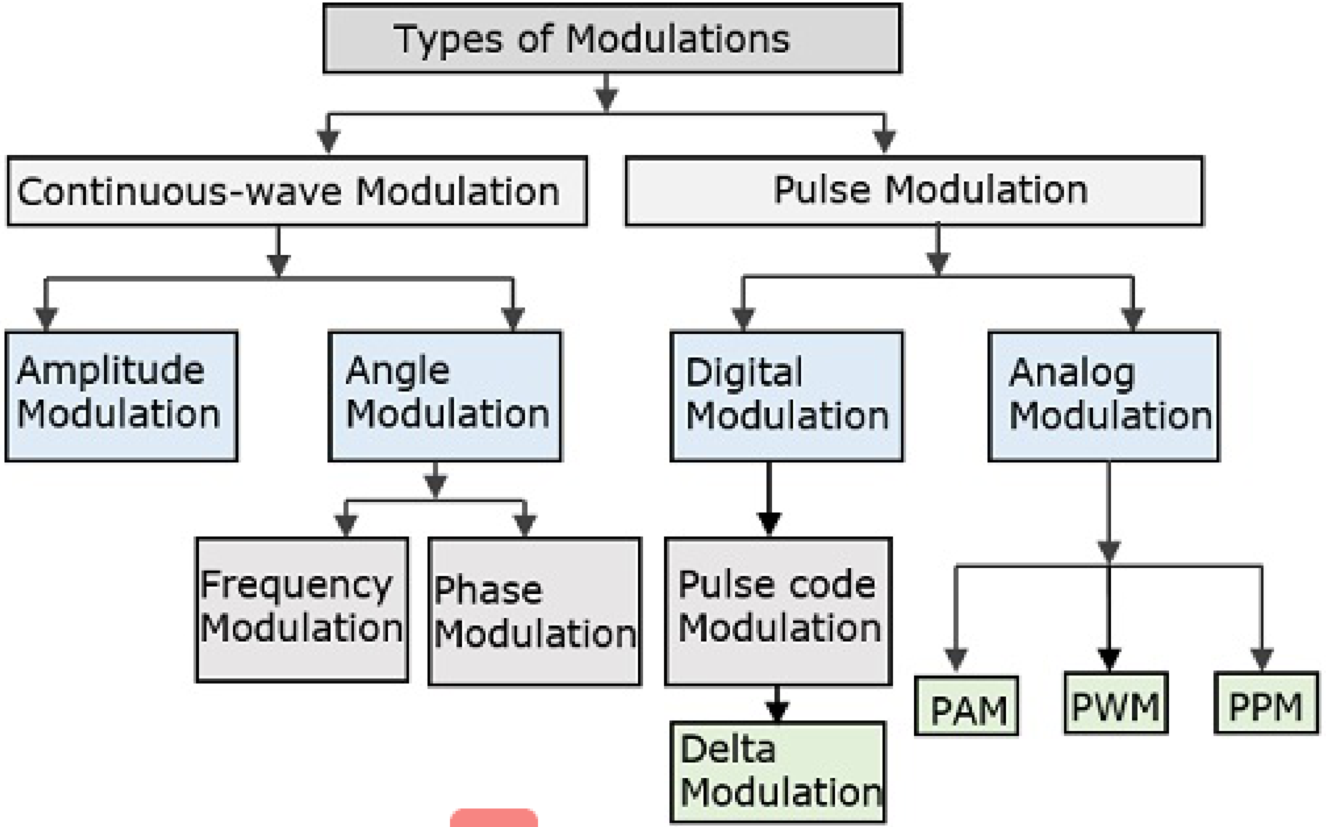
Improves Quality of Reception

- With frequency modulation (FM) and the digital communication techniques such as PCM, the effect of noise is reduced to a great extent .
- This improves quality of reception .

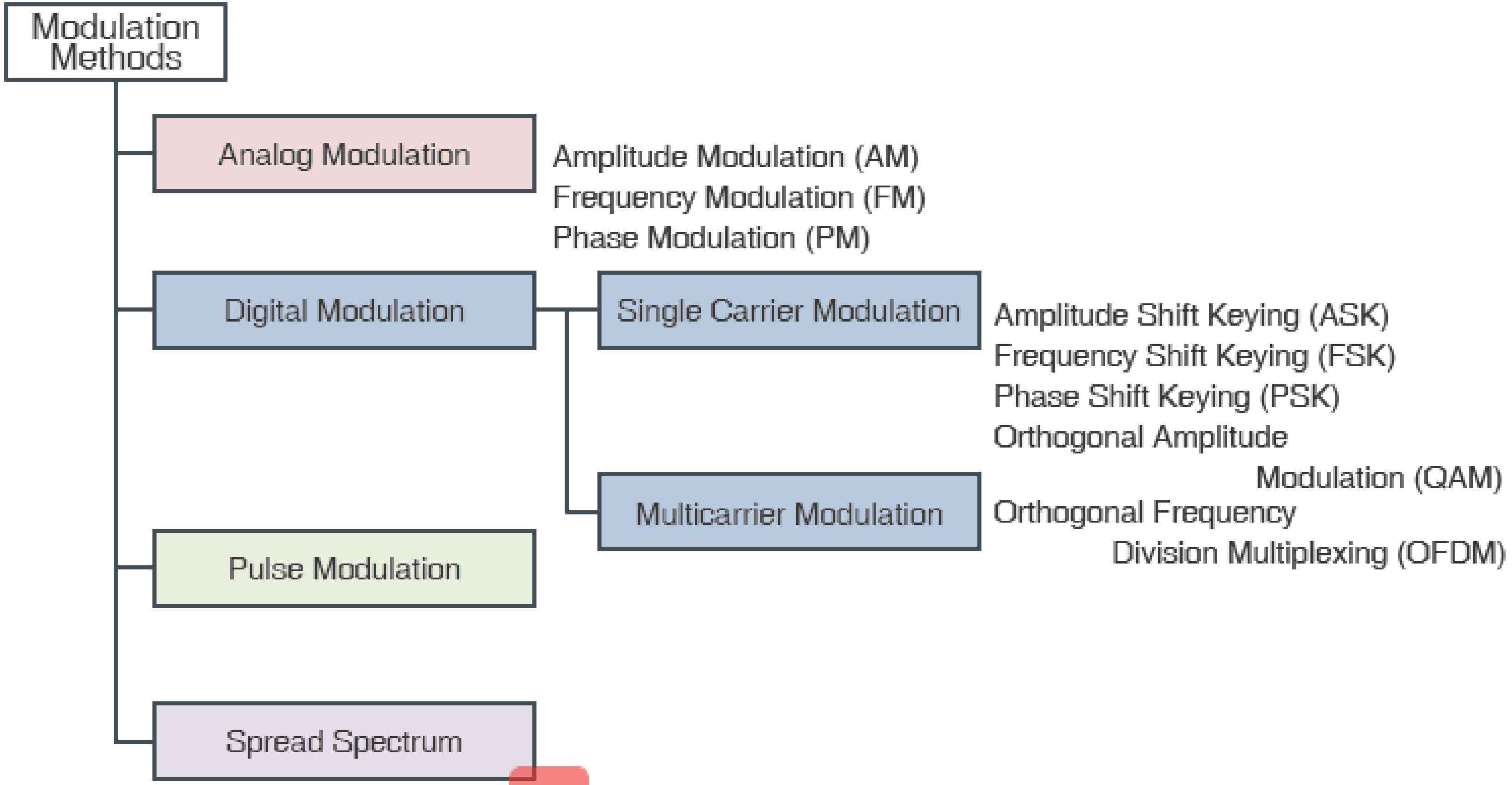
Narrow Banding of Signal

- An audio signal usually has a frequency range (20 Hz to 20 kHz), if it is directly transmitted then the ratio of highest to the lowest frequency becomes (20 kHz / 20 Hz) = 1000.
- But if this audio signal is modulated over a carrier signal of frequency 1000 kHz then the ratio of highest to the lowest frequency becomes:
- (1000 kHz + 20 kHz) / (1000 kHz + 20 Hz) ≅ 1.2
- Hence, we need modulation to convert a wideband signal into a narrow band signal.

Classification of Modulation Process



Classification of Modulation Process



Pulse Modulation

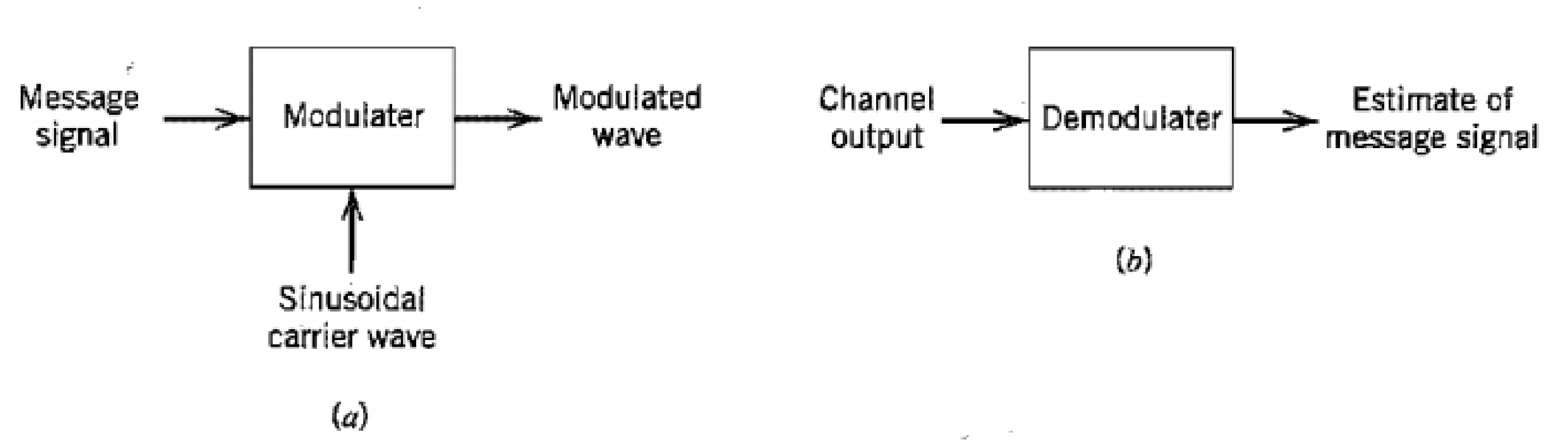
- Carrier consists of a periodic sequence of rectangular pulses.
- In analog pulse modulation, the amplitude, duration or positon of a pulse is varied in accordance with the sample values of the message signal
  - Pulse Amplitude Modulation (PAM)
  - Pulse Duration Modulation (PDM)
  - Pulse Position Modulation (PPM)
- Digital form of pulse modulation is Pulse Code Modulation (PCM)
- Starts out with PAM, then amplitude of each modulated pulse is quantized or rounded off to the nearest value in a prescribed set of discrete amplitude levels and coded into binary symbols.

Analog Communication / Continuous Wave Modulation

- The information bearing signals is referred as baseband signals- band of frequencies representing the original signals as delivered by a source of information.
- The proper use of the communication channel requires a shift of the range of baseband frequencies into other frequency range suitable for transmission and a corresponding shift back to the original frequency ranger after reception.
- A shift of the range of frequencies in a signal is accomplished by using modulation.
- The process by which some characteristics of a carrier wave is varied in accordance with a modulating wave (signal)
- Carrier is a sinusoidal wave.
- Baseband signal is referred to as modulating wave and the result of the modulation process is referred as modulated wave

Analog Communication

- Modulation is performed at the transmitting end and at the receiving end of the system we perform demodulation to obtain the original baseband signal back.
- Since at the receiver we obtain signal as well as the added channel noise, we need to choose a suitable type of modulation



Types of CW modulation

- Amplitude Modulation
  - In amplitude modulation , the amplitude of the sinusoidal wave is varied in accordance with the baseband signal.
- Angle Modulation
  - The angle of the sinusoidal carrier is carried in accordance with the baseband signal.

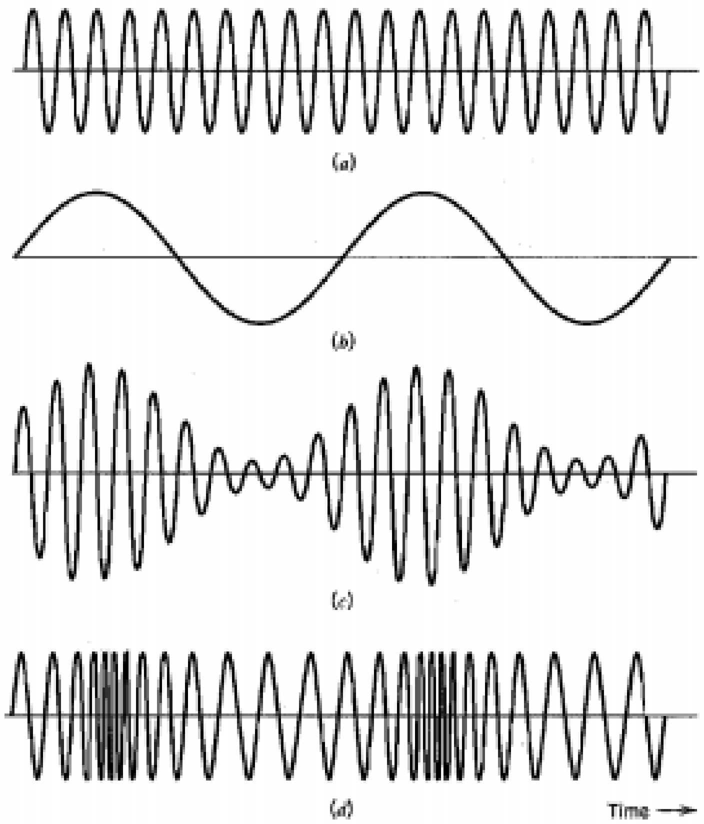


FIGURE 2.2 Illustrating AM and FM signals produced by a single tone. (a) Carrier wave. (b) Sinusoidal modulating signal. (c) Amplitude-modulated signal. (d) Frequency-modulated signal.

Continuous wave modulation (Analog Modulation)

- A sinusoidal wave is used as a carrier

CW Modulation

- **Amplitude** — Amplitude of the carrier varied in accordance with the amplitude of the message signal
- **Frequency** — Frequency of the carrier varied in accordance with the amplitude of the message signal
- **Phase** — Phase of the carrier varied in accordance with the amplitude of the message signal

Amplitude Modulation

- Consider a sinusoidal carrier wave $c(t)$ defined by
- $c(t) = A_c \cos(2\pi f_c t)$
  - A_c is the carrier amplitude
  - f_c is the carrier frequency
- Assuming the phase of the carrier wave is zero.
- Let $m(t)$ be the base band signal that carries the specification of the message.
- Amplitude modulation (AM) is the process in which the amplitude of the carrier wave $c(t)$ is varied about a mean value , linearly with the base band signal $m(t)$
- An amplitude modulated (AM) wave may be described as a function of time as
- $s(t) = A_c[1 + k_a\, m(t\,)] \cos(2\pi f_c t)$
- k_a is a constant called amplitude sensitivity of the modulator responsible for the generation of the modulated signal $s(t)$, k_a is measures in $volt^{-1}$

Amplitude Modulation

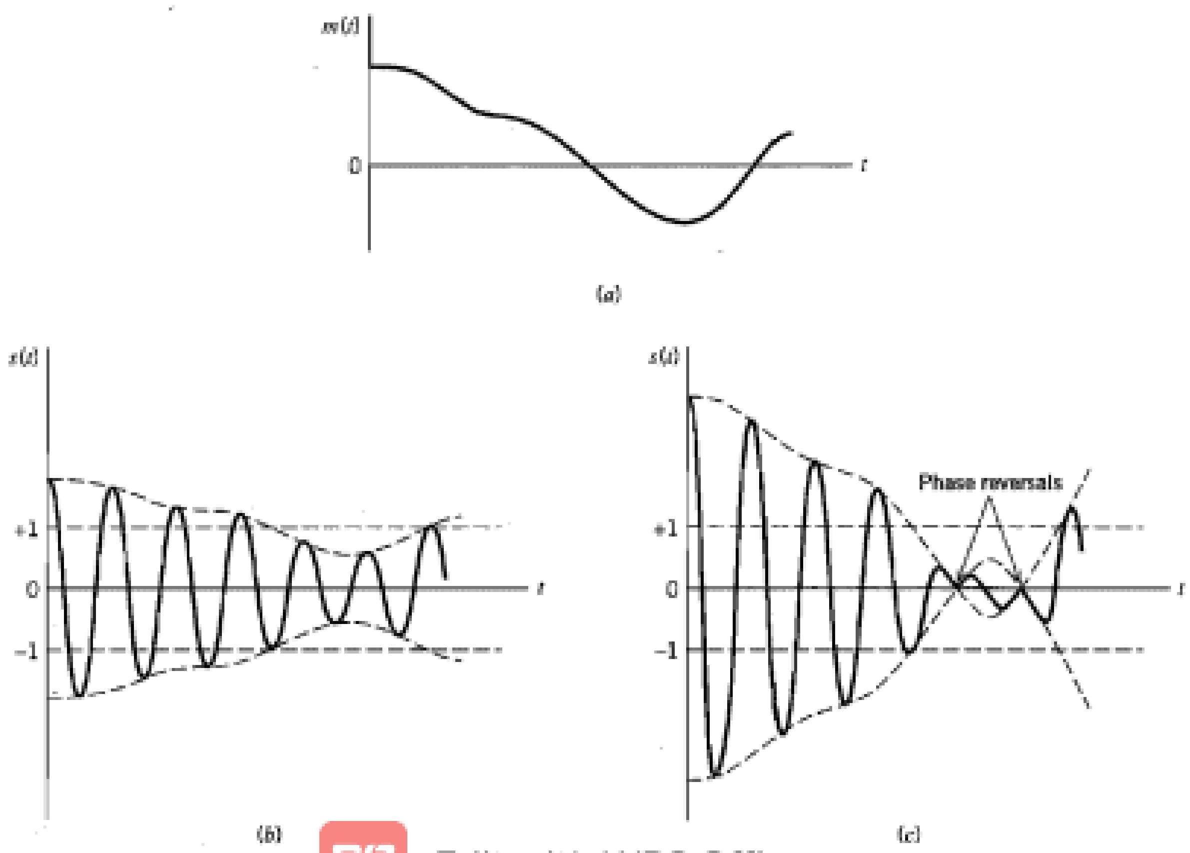


FIGURE 2.3 Illustrating the amplitude modulation process. (*a*) Baseband signal $m(t)$. (*b*) AM wave for $|k_a m(t)| < 1$ for all t. (*c*) AM wave for $|k_a m(t)| > 1$ for some t.

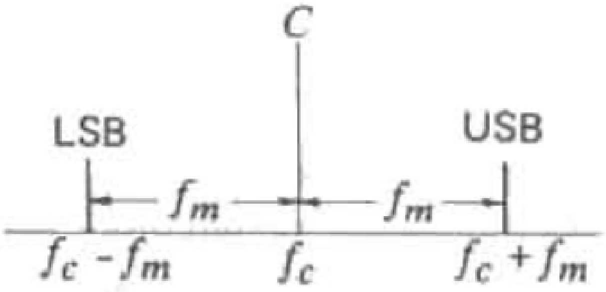
Amplitude Modulation

- $v_c = V_c \sin \omega_c\, t$
- $v_m = V_c \sin \omega_m\, t$
- $A = V_c + v_m = V_c + V_m \sin \omega_m\, t = V_c(1 + m \sin \omega_m\, t)$
- The instantaneous voltage of the resulting amplitude modulated wave is
- $v = A \sin \theta = A\ \sin \omega_m\, t = V_c(1 + m \sin \omega_m\, t) \sin \omega_c\, t$
- The above expression can be expanded by the means of trigonometrical relation
- $\sin x\ \sin y = 1/2[\cos(x - y) - \cos(x + y)]$
- We get
- $v = V_c \sin \omega_c\, t + \frac{mV_c}{2} \cos(\omega_c - \omega_m)\, t - \frac{mV_c}{2} \cos(\omega_c + \omega_m)\, t$
- m is called modulation index $m = \frac{V_m}{V_c}$

Amplitude Modulation

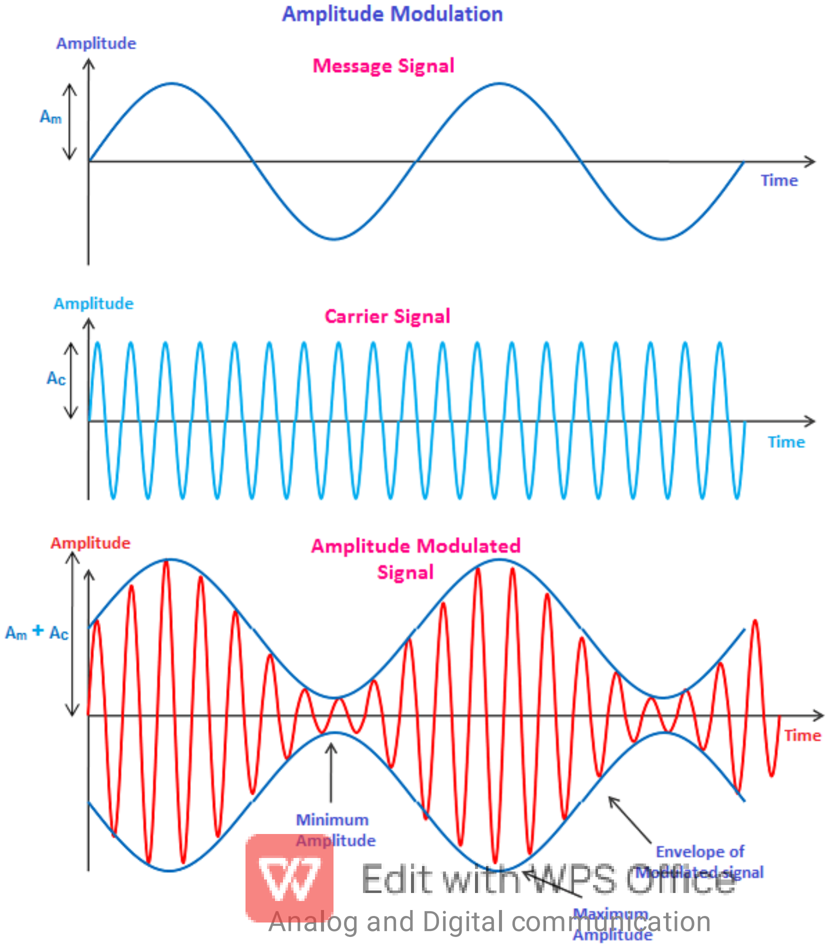
2. The carrier frequency f_c is much greater than the highest frequency component W of the message signal $m(t)$ i.e. $f_c \gg W$
   - W is the message bandwidth. If this equation is not satisfies an envelope cannot be visualized satisfactorily.

- $v = V_c \sin \omega_c t + \frac{mV_c}{2} \cos(\omega_c - \omega_m) t - \frac{mV_c}{2} \cos(\omega_c + \omega_m) t$



- Consider the equation. It has three terms.
  - First term represents the unmodulated carrier
  - The two additional terms are the two side bands.
  - The frequency of the lower sideband (LSB) is $f_c - f_m$ and the frequency of the upper sideband (USB) $f_c + f_m$.

Amplitude Modulation



Amplitude Modulation

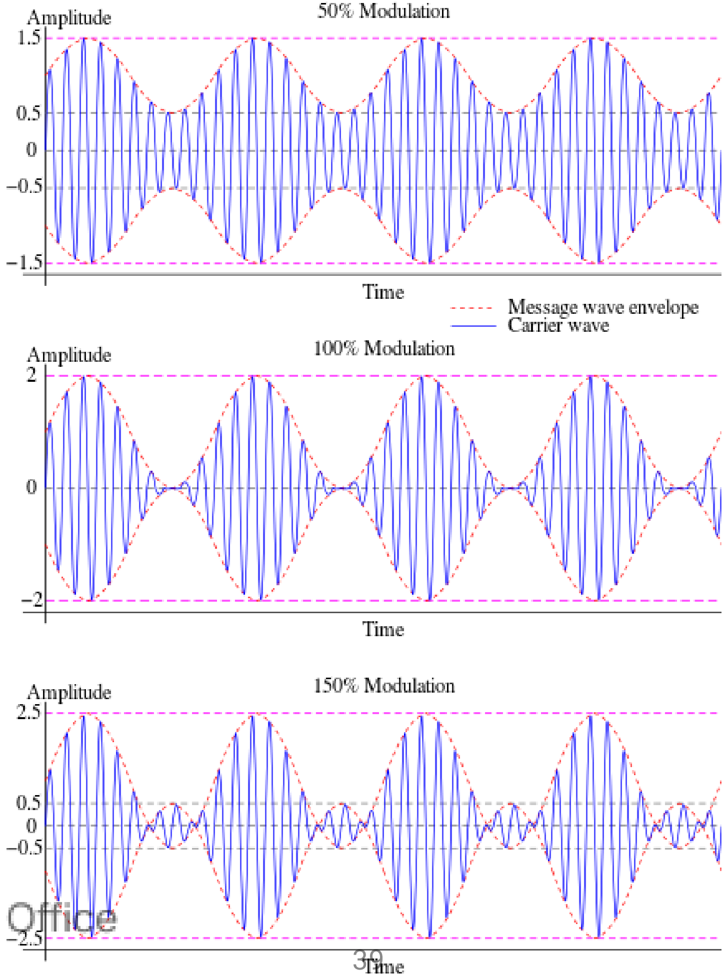
- We observe that the envelope of $s(t)$ has essentially the same shape as the baseband signal $m(t)$ provide that

1. The amplitude of $k_a\, m(t)$ is always less than unity

- $|\, k_a\, m(t)| < 1\; for\; all\; t$
- This condition ensures that the function $1 +\; k_a\, m(t)$ is always positive .
- The modulation index is a number lying between 0 and 1
- It is often expressed as percentage and called the percentage modualtion
- For a perfect modulation, the value of modulation index should be 1, which implies the percentage of modulation should be 100%.
- For instance, if this value is less than 1, i.e., the modulation index is 0.5, then the modulated output would look like the following figure. It is called as **Under-modulation**. Such a wave is called as an **under-modulated wave**.

Amplitude Modulation

- If the value of the modulation index is greater than 1, i.e., 1.5 or so, then the wave will be an **over-modulated wave**..
- As the value of the modulation index increases, the carrier experiences a 180 degree phase reversal, which causes additional sidebands and hence, the wave gets distorted.
- Such an over-modulated wave causes interference, which cannot be eliminated.



Amplitude Modulation

- Thus bandwidth requirement of the amplitude modulation is twice the frequency of the modulating signal.
- Suppose that the baseband signal $m(t)$ is bandlimited to the interval $-W \le f \le W$

$$S(f) = \frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)] + \frac{k_a A_c}{2}[M(f - f_c) + M(f + f_c)]$$

- The shape of the spectrum is as shown
- The spectrum of the amplitude modulated signal for the case $f_c > W$

as shown in Figure 2.4*b* for the case when $f_c > W$. This spectrum consists of two delta functions weighted by the factor $A_c/2$ and occurring at $\pm f_c$, and two versions of the baseband spectrum translated in frequency by $\pm f_c$ and scaled in amplitude by $k_a A_c/2$.

Amplitude Modulation

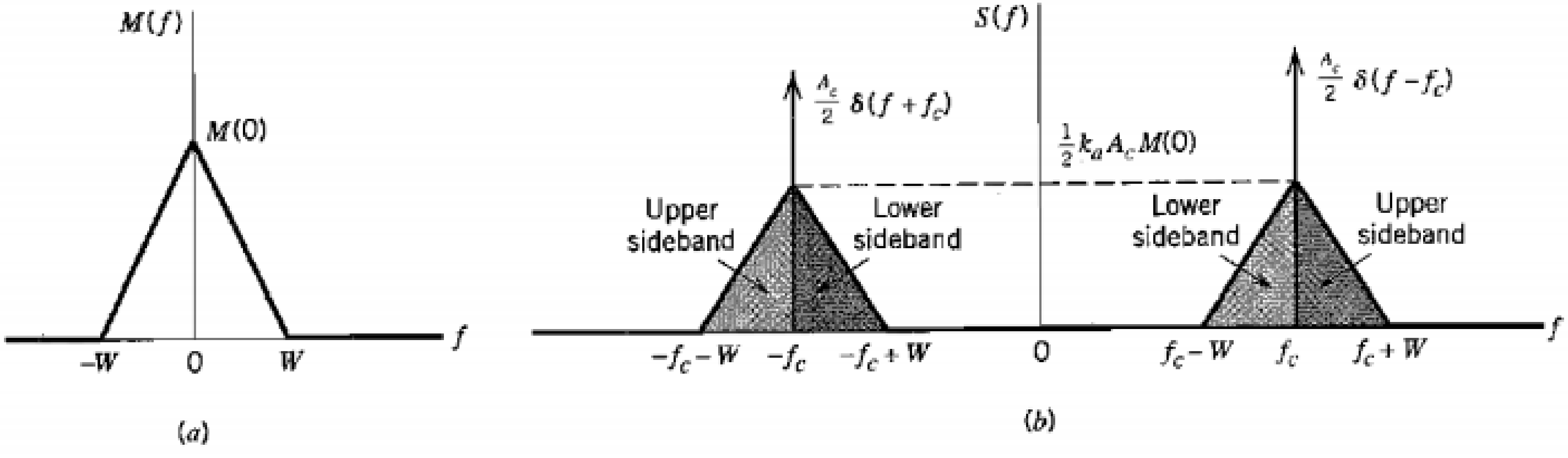


FIGURE 2.4 (a) Spectrum of baseband signal. (b) Spectrum of AM wave.

Amplitude Modulation

1. As a result of the modulation process, the spectrum of the message signal $m(t)$ for negative frequencies extending from $-W$ to 0 becomes completely visible for positive (i.e., measurable) frequencies, provided that the carrier frequency satisfies the condition $f_c > W$; herein lies the importance of the idea of "negative" frequencies.
2. For positive frequencies, the portion of the spectrum of an AM wave lying above the carrier frequency f_c is referred to as the *upper sideband*, whereas the symmetric portion below f_c is referred to as the *lower sideband*. For negative frequencies, the upper sideband is represented by the portion of the spectrum below $-f_c$ and the lower sideband by the portion above $-f_c$. The condition $f_c > W$ ensures that the sidebands do not overlap.
3. For positive frequencies, the highest frequency component of the AM wave equals $f_c + W$, and the lowest frequency component equals $f_c - W$. The difference between these two frequencies defines the *transmission bandwidth* B_T for an AM wave, which is exactly twice the message bandwidth W, that is,

$$B_T = 2W \tag{2.6}$$

Representation of AM

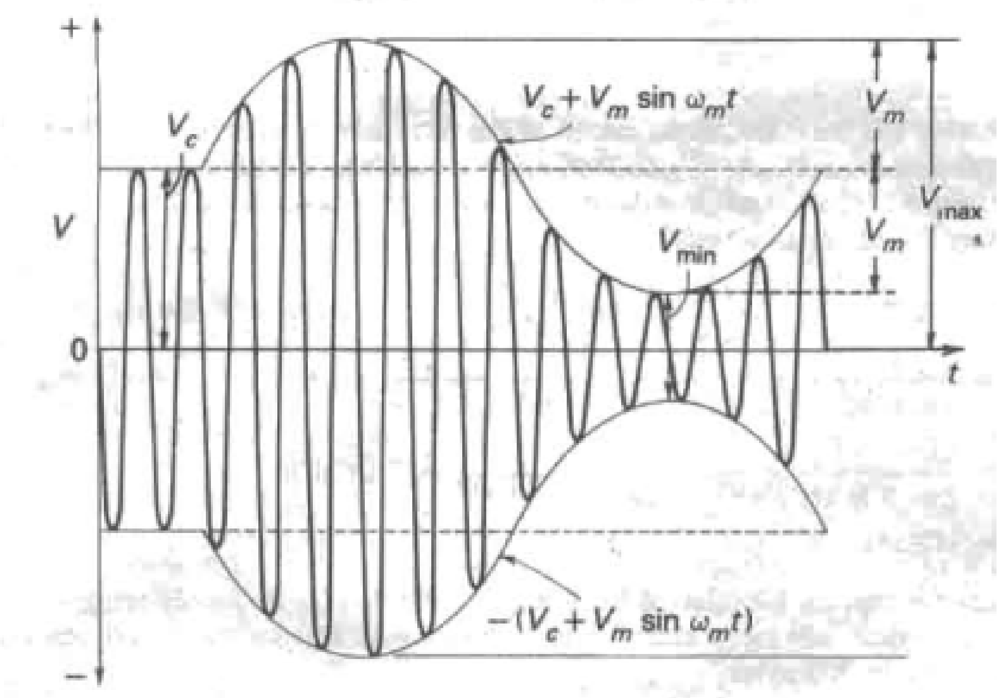


FIGURE 3-3 Amplitude-modulated wave.

Amplitude Modulation

- One cycle of modulated wave is as shown.
- The top envelop of the AM wave is given by the relation $A = V_c + V_m \sin \omega_m t.$
- The maximum negative amplitude or bottom envelope is given by $-A = -(V_c + V_m \sin \omega_m t)$
- The modulated wave extends between these two limiting envelopes and has a repetition rate equal to the unmodulated carrier frequency.

$$V_m = \frac{V_{max} - V_{min}}{2}$$

and

$$V_c = V_{max} - V_m = V_{max} - \frac{V_{max} - V_{min}}{2}$$

$$= \frac{V_{max} + V_{min}}{2}$$

$$m = \frac{V_m}{V_c} = \frac{(V_{max} - V_{min})/2}{(V_{max} + V_{min})/2}$$

$$= \frac{V_{max} + V_{min}}{V_{max} + V_{min}}$$

Power Relations in the AM wave

- It has been shown that the carrier component of the modulated wave has the same amplitude as the unmodulated carrier.
- i.e. the amplitude of the carrier is unchanged energy is either added or subtracted
- The modulated wave contains extra energy in the two sideband components.
- Therefore the modulated wave contains more power than the carrier had before modulation took place.
- Since the amplitude of the sidebands depends om the modulation index m so the total power of the modulated wave will depend on the modulation index also

Power Relations in the AM wave

The total power in the modulated wave will be

$$P_t = \frac{V_{carr}^2}{R} + \frac{V_{LSB}^2}{R} + \frac{V_{USB}^2}{R} \text{ (rms)} \tag{3-11}$$

where all three voltages are (rms) values ($\sqrt{2}$ converted to peak), and R is the resistance, (e.g., antenna resistance), in which the power is dissipated. The first term of Equation (3-11) is the unmodulated carrier power and is given by

$$P_c = \frac{V_{carr}^2}{R} = \frac{(V_c/\sqrt{2})^2}{R}$$

$$= \frac{V_c^2}{2R} \tag{3-12}$$

Power Relations in the AM wave

Similarly,

$$P_{LSB} = P_{USB} = \frac{V_{SB}^2}{R} = \left(\frac{mV_c/2}{\sqrt{2}}\right)^2 \div R = \frac{m^2V_c{}^2}{8R}$$

$$= \frac{m^2}{4}\frac{V_c^2}{2R}, \qquad (3\text{-}13)$$

Substituting Equations (3-12) and (3-13) into (3-11), we have

$$P_t = \frac{V_c^2}{2R} + \frac{m^2}{4}\frac{V_c^2}{2R} + \frac{m^2}{4}\frac{V_c^2}{2R} = P_c + \frac{m^2}{4}P_c + \frac{m^2}{4}P_c$$

$$\frac{P_t}{P_c} = 1 + \frac{m^2}{2} \qquad (3\text{-}14)$$

Current Calculations

- In AM it is generally more convenient to measure the AM transmitter current than the power.
- Let Ic be the rms value of the current and It be the rms value of the total or modulated current and Let R be the antenna resistance

$$\frac{P_t}{P_c} = \frac{I_t^2 R}{I_c^2 R} = \left(\frac{I_t}{I_c}\right)^2 = 1 + \frac{m^2}{2}$$

$$\frac{I_t}{I_c} = \sqrt{1 + \frac{m^2}{2}} \quad \text{or} \quad I_t = I_c \sqrt{1 + \frac{m^2}{2}}$$

Modulation by several sine waves

- In practice, modulation of a carrier by several sine waves simultaneously is the rule rather than the exception

1. Let V_1, V_2, V_3, etc., be the simultaneous modulation voltages. Then the total modulating voltage V_t will be equal to the square root of the sum of the squares of the individual voltages; that is,

$$V_t = \sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots}$$

Dividing both sides by V_c, we get

$$\frac{V_t}{V_c} = \frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots}}{V_c}$$

$$= \sqrt{\frac{V_1^2}{V_c^2} + \frac{V_2^2}{V_c^2} + \frac{V_3^2}{V_c^2} + \cdots}$$

that is,

$$m_t = \sqrt{m_1^2 + m_2^2 + m_3^2 + \cdots} \tag{3-17}$$

Modulation by several sine waves

2. Equation (3-14) may be rewritten to emphasize that the total power in an AM wave consists of carrier power and sideband power. This yields

$$P_t = P_c\left(1 + \frac{m^2}{2}\right) = P_c + \frac{P_c m^2}{2} = P_c + P_{SB}$$

where P_{SB} is the total sideband power and is given by

$$P_{SB} = \frac{P_c m^2}{2} \qquad (3\text{-}18)$$

If several sine waves simultaneously modulate the carrier, the carrier power will be unaffected, but the total sideband power will now be the sum of the individual sideband powers. We have

$$P_{SB_T} = P_{SB_1} + P_{SB_2} + P_{SB_3} + \cdots$$

Substitution gives

$$\frac{P_c m_t^2}{2} = \frac{P_c m_1^2}{2} + \frac{P_c m_2^2}{2} + \frac{P_c m_3^2}{2} + \cdots$$

$$m_t^2 = m_1^2 + m_2^2 + m_3^2 + \cdots$$

If the square root of both sides is now taken, Equation (3-17) will once again be the result.

- To calculate the total modulation index, take the square root of the sum of the squares of the individual modulation indices

Power Relations in the AM wave -Questions

1. A 400 watt carrier is modulated to a depth of 75%. Calculate the total power in the modulated wave.
2. A broad cast radio transmitter radiates 10 kW when the modulation percentage is 60. How much is the carrier power?
3. A certain transmitter radiates 9 kW with the carrier unmodulated and 10.125 kW when the carrier is sinusoidally modulated. Calculate the modulation index, percent of modulation, if another wave corresponding to 40% modulation is transmitted simultaneously, determine the total radiated power.
4. The antenna current of an AM broadcast transmitter modulated to a depth of 40 % by an audio sine wave is 11 A. It increases to 12 A as a result of the simulataneous modulation by another audio sine wave. What is the modulation index due to this second wave?

Advantages of Amplitude Modulation

- AM waves can travel longer distances
- AM transmitters and receivers are less complex.
- AM receivers are very cheap as no specialized components are needed .
- Demodulation of AM can be done by using simple circuits consisting of diodes

Disadvantage of Amplitude Modulation

- An AM Modulation is not efficient in terms of its power usage.
- Power wastage happens in case of Double sideband Full carrier transmission.
- Its not efficient in terms of terms of bandwidth
- The power in the sideband is the useful power
- AM detectors are sensitive to noise hence an amplitude modulation signal is prone to high levels of noise.

Double Side band Suppressed Carrier

- From the basic equation of AM wave it is obvious that the carrier component in AM wave remains constant in amplitude and frequency.
- This means that the carrier of an AM Wave does not convey any information
- In power calculation of the AM signal the ration of total power to carrier power is given by $(1+\frac{m_a^2}{2})$
    - If $m_a = 1$ then two third of the total power is required for transmitting the carrier which does not contain any information.
    - Hence if the carrier is suppressed, only the sidebands remain and in this way a saving of two third power may be achieved at 100 % modulation.
    - This type of suppression does not affect the baseband signal in any way.
- The resulting signal obtained by suppressing the carrier from the modulated wave is called Double side band suppresses carrier system(DSSC)

Double Side band Suppressed Carrier

- Thus a DSB-SC modulation there is no carrier signal only sidebands are present.
- Again the modulated signal has information only in the sidebands.

Mathematical Expression

- Let the modulating signal

$$m(t) = A_m cos\omega\ _m t$$

- Let the carrier signal

$$c(t) = A_c cos\omega\ _c t$$

- Mathematically we can represent the equation for DSB_SC wave as the product of modulating and carrier wave.

$$s(t) = A_m cos\omega\ _m t A_c cos\omega\ _c t$$

Double Side band Suppressed Carrier

Bandwidth of DSB_SC Wave

- Consider the equation of DSBSC modulated wave

$$s(t) = A_m A_c cos\omega_m t cos\omega_c t$$

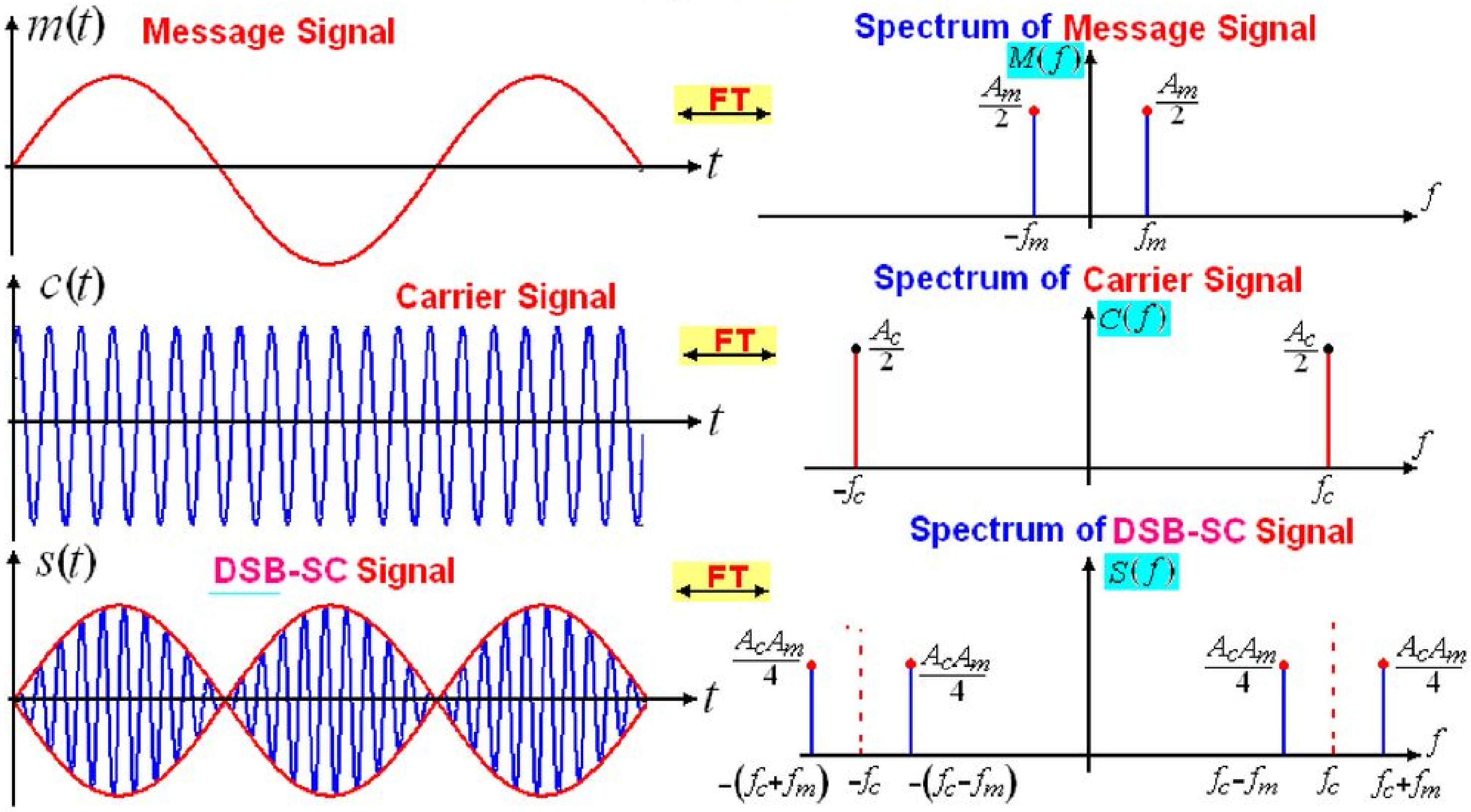
$$s(t) = \frac{A_m A_c}{2} cos(\omega_c + \omega_m)t + \frac{A_m A_c}{2} cos(\omega_c - \omega_m)t$$

- Thus DSBSC modulated wave has only 2 frequencies.
- The maximum and Minimum frequencies are $\omega_c + \omega_m$ and $\omega_c - \omega_m$
- There fore the bandwidth

$$BW = (\omega_c + \omega_m) - (\omega_c - \omega_m) = 2\omega_m$$

- There fore the BW of a DSB-SC wave is same as that of AM wave and is equal to twice the frequency of modulating signal.

Double Side band Suppressed Carrier



$s(t)$ undergoes a phase reversal whenever $m(t)$ crosses zero

Double Side band Suppressed Carrier

Note

- It is observed that the DSB-SC signal exhibits phase reversal at zero crossings, i.e. whenever the base band signal crosses zero.
    - Because of this the envelope of an DSB-SC modulated signal is different from the message signal
    - This is unlike the case of an AM wave.
- It is also clear that the impulses at missing $\pm\omega_c$ are missing which means that the carrier is suppressed in the spectrum and only two sidebands USB and LSB are left. Hence the name DSB-SC
- In the figure considering the positive side the upper sideband frequency is $(\omega_c+\omega_m)$ where as the lower side band frequency is $(\omega_c-\omega_m)$
- So the transmission of bandwidth of a DSB-SC signal is $2\omega_m$ bandwidth is same as that the AM wave.

Single Sideband Suppressed Carrier (SSB-SC)

- If two sideband carry same information ,DSB signal is redundant ie in DSB the basic information is transmitted twice
- One in each side band.
- So one of the sideband may be suppressed.
- The carrier and one side band is suppressed.
- When only one sideband is transmitted , the modulation is referred as single side band modulation.

Single Sideband Suppressed Carrier (SSB-SC)

- The AM modulated signal from a balanced modulator is given by

$$e(t) = ke_m(t)\cos\omega_c t$$

- Where
  - k is constant
  - $e_m(t)$ modulating signal $E_m\cos\omega_m t$
- Therefore

$$e(t) = kE_m\cos\omega_m t\cos\omega_c t$$

$$e(t) = \frac{kE_m}{2}cos(\omega_c + \omega_m)\mathrm{t} + \frac{kE_m}{2}cos(\omega_c - \omega_m)\mathrm{t}$$

$$e(t) = E_{max}(cos(\omega_c + \omega_m)\mathrm{t} + cos(\omega_c - \omega_m)\mathrm{t})$$

- The upper sideband frequency (USF)signal is given by

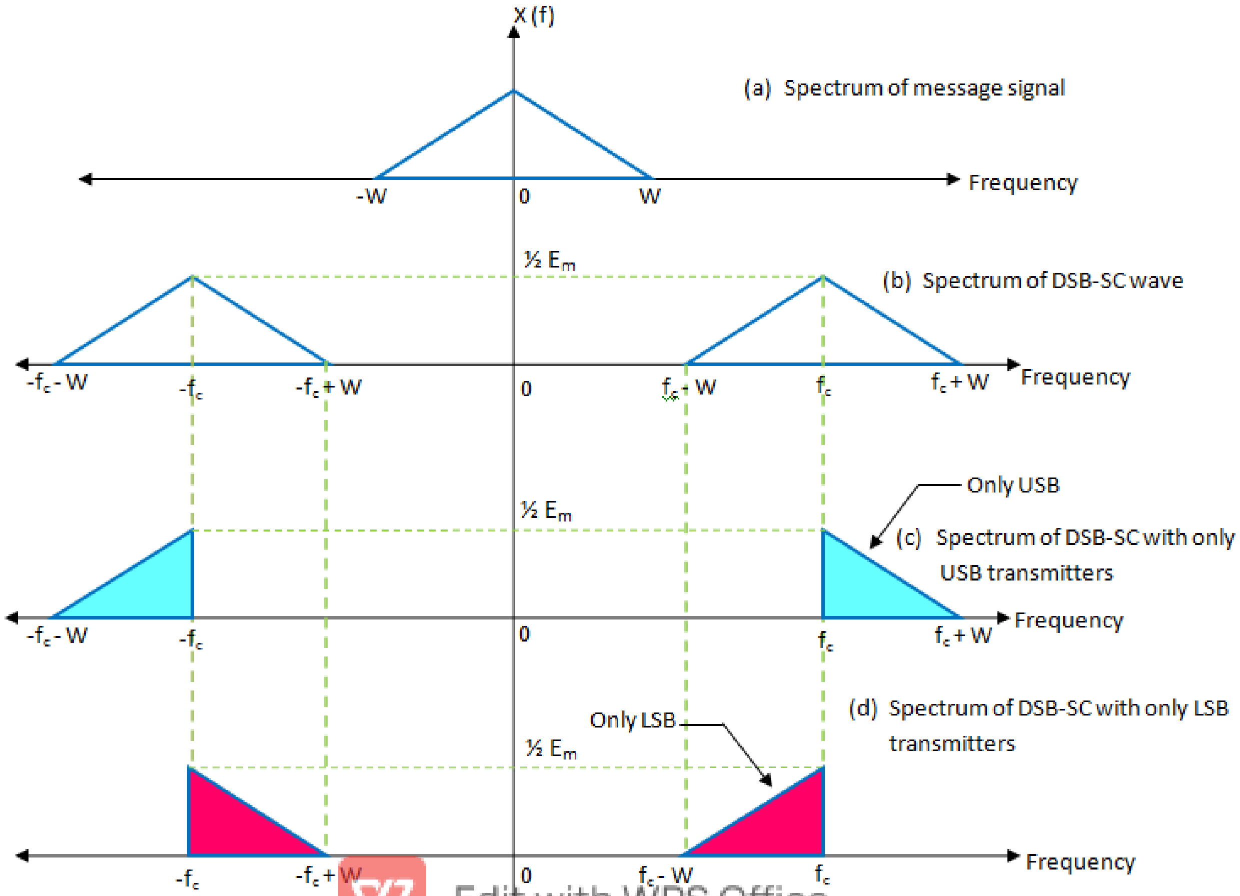
$$e_{usf} = E_m(cos(\omega_c + \omega_m)\mathrm{t}$$

- The lower sideband frequency (LSF)signal is given by

$$e_{lsf} = E_m(cos(\omega_c - \omega_m)\mathrm{t}$$

- One of these sideband are removed by filtering

Single Sideband Suppressed Carrier (SSB-SC)



Single Sideband Suppressed Carrier (SSB-SC)

Advantages

- Reduction in transmission bandwidth
- Power saving : since the high power carrier and one side band are not being transmitted.
- Reduced Noise

Disadvantages

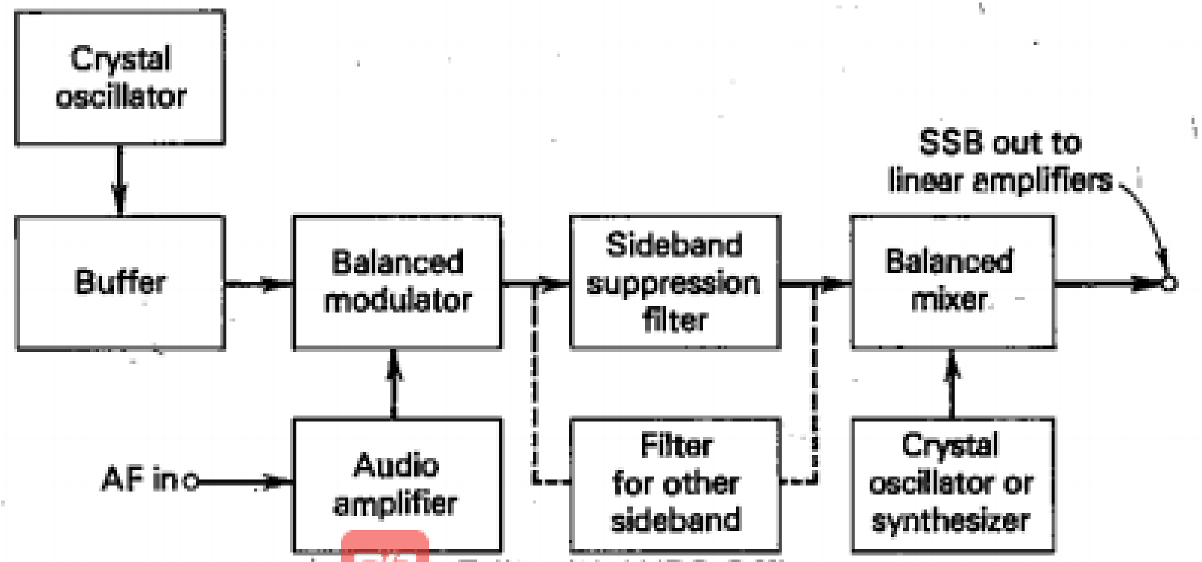
- It is expensive
- Highly complex to implement.

Generation of SSB-SC signal

- There are three practical methods to remove unwanted side band from the double sideband signal to get the single side band signal
- They are
  - Filter method (Frequency Discrimination method)
  - Phase Shift Method (Phasing Method)
  - Weaver's Method

Filter method (Frequency Discrimination method)

- After the balanced modulator , the filter is used to remove the unwanted sideband.
- This method can be used for generating the SSB modulated wave, if the message signal satisfies the following conditions.
  - The message signal should not have any low frequency content
  - The highest frequency in the system spectrum of the message signal should be smaller than carrier frequency



Filter method (Frequency Discrimination method)

- The balanced modulator is used to suppress then carrier
- Then filter suppresses one sideband signal
- The frequency of the generated single side band signal is very low .
- This frequency is boosted up to the transmitter frequency by the balanced mixer and crystal oscillator.
- The process of frequency boosting is also called up conversion.
- The sideband signal having frequency equal to the transmitter frequency is then amplified by the linear amplifier before transmission.

Advantages and Disadvantages of filter method

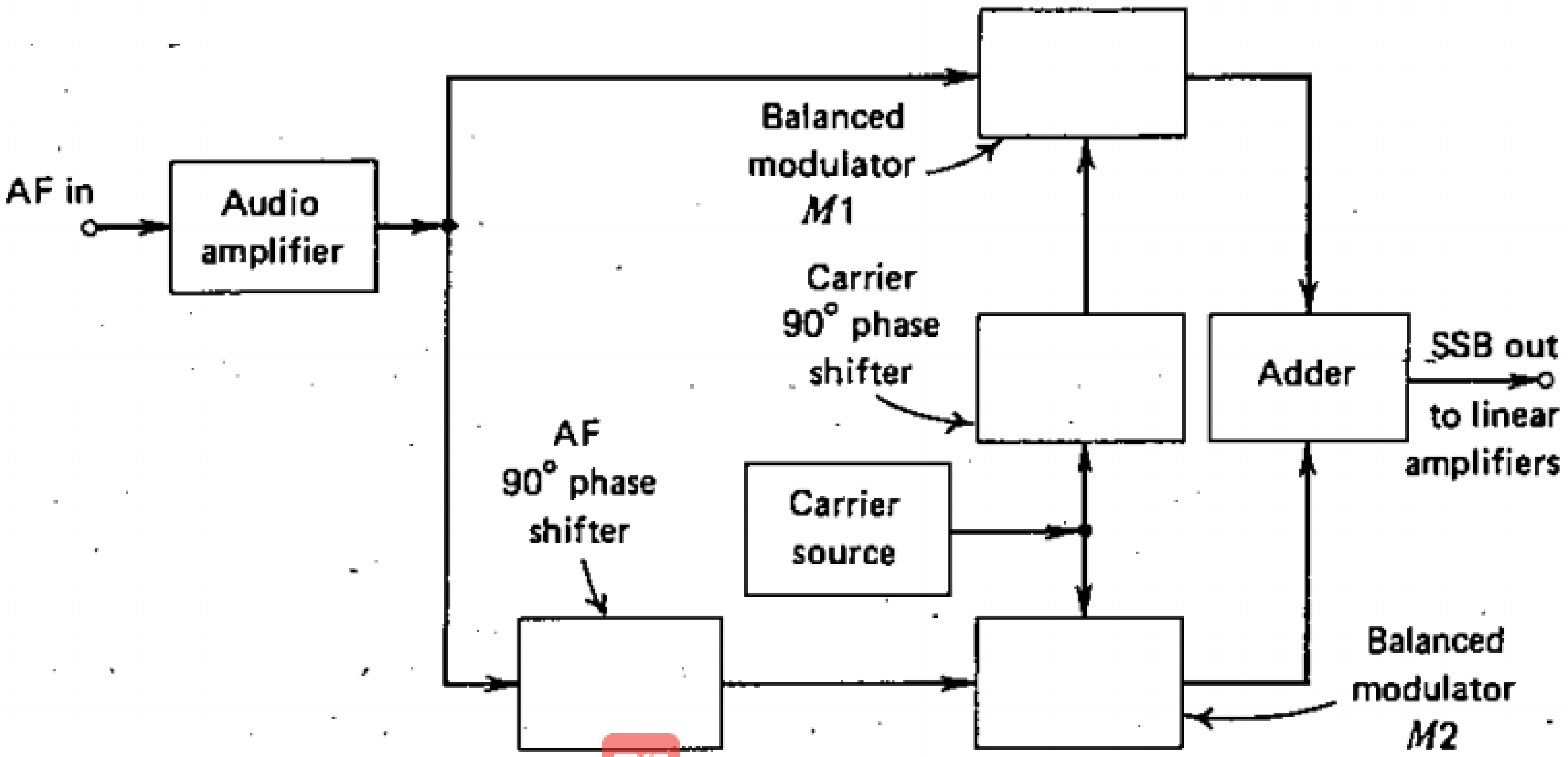
- **Advantages**
- The filter method gives a side suppression of 50 dB which is adequate
- The side band filters also help to attenuate the carrier if present in the output of balanced modulator
- Bandwidth is sufficiently flat and wide

- **Disadvantages**
- They are bulky.
- As modulation takes place at lower carrier frequency repeated mixing is required in conjunction with extremely stable oscillator to generate SSB at high radio frequencies
- At lower audio frequencies expensive filters are required.

Phase Shift Method

- The phase shift method of SSB generation uses a phase shift technique that causes one of the sideband to cancel out.
- The circuit does not have sideband filters
- The primary modulation can be done at the transmitting frequency.
- It relies on phase shifting and cancellation to eliminate the carrier and the unwanted sideband.
- This system uses two balanced modulators and two phase shifting networks.
- One of the modulators M1 receives the carrier voltage (shifted by 90 degree) and the modulating voltage where as the other M2 is fed the modulating voltage (shifted by 90 degree) and the carrier voltage.
- Both modulators produce an output consisting only one side band.

Phase Shift Method



Phase Shift Method

- Both modulators produce an output consisting only of sidebands.
- Both upper sidebands lead the input carrier voltage by 90°.
- One of the lower sidebands leads the reference voltage by 90°, and the other lags it by 90°.
- The two lower sidebands are thus out of phase, and when combined in the adder, they cancel each other.
- The upper sidebands are in phase at the adder and therefore add, giving SSB in which the lower sideband has been cancelled.

Phase Shift Method

$$v_1 = \cos[(\omega_c t + 90^\circ) - \omega_m t] - \cos[(\omega_c t + 90^\circ) + \omega_m t]$$

$$= \underbrace{\cos(\omega_c t - \omega_m t + 90^\circ)}_{\text{(LSB)}} - \underbrace{\cos(\omega_c t + \omega_m t + 90^\circ)}_{\text{(USB)}}$$

Similarly, the output of M_2 will contain

$$v_2 = \cos[\omega_c t - (\omega_m t + 90^\circ)] - \cos[\omega_c t + (\omega_m t + 90^\circ)]$$

$$= \cos(\omega_c t - \omega_m t - 90^\circ) - \cos(\omega_c t + \omega_m t + 90^\circ)$$

The output of the adder is

$$v_o = v_1 + v_2 = 2\cos(\omega_c t + \omega_m t + 90^\circ)$$

Phase Shift Method

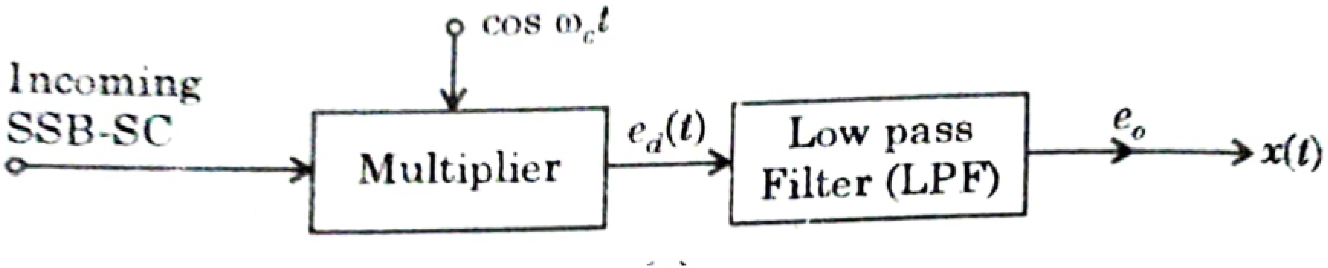
- This output is obtained by adding Equations and observing that the first term of the first equation is 180° out of phase with the first term of the second.
- We have proved that one of the sidebands in the adder is cancelled.
- The other is reinforced.
- The system as shown yields the upper sideband.
- A similar analysis shows that SSB with the lower sideband present will be obtained if both signals are fed (phase-shifted) to the one balanced modulator

Advantages and Disadvantages of Phase shift method

- **Advantage**
- Bulky filters are replaced by small filters
- Low audio frequencies are used for modulation
- It can generate SSB at any frequency
- Easy switching from one sideband to other sideband is possible
- **Disadvantage**
- The design of the 90 degree phase shifting network for the modulating signal is extremely critical.
- The requirement of complex AF phase shift network
- The output of two balanced modulators must be exactly same other wise cancellation will be incomplete

SSB Receivers

- The baseband signal $m(t)$ can be recovered from the SSB_SC signal by using the synchronous detection
- The process od synchronous detection involves the multiplication of the received SSB-SC signal with a locally generated carrier



SSB Receivers

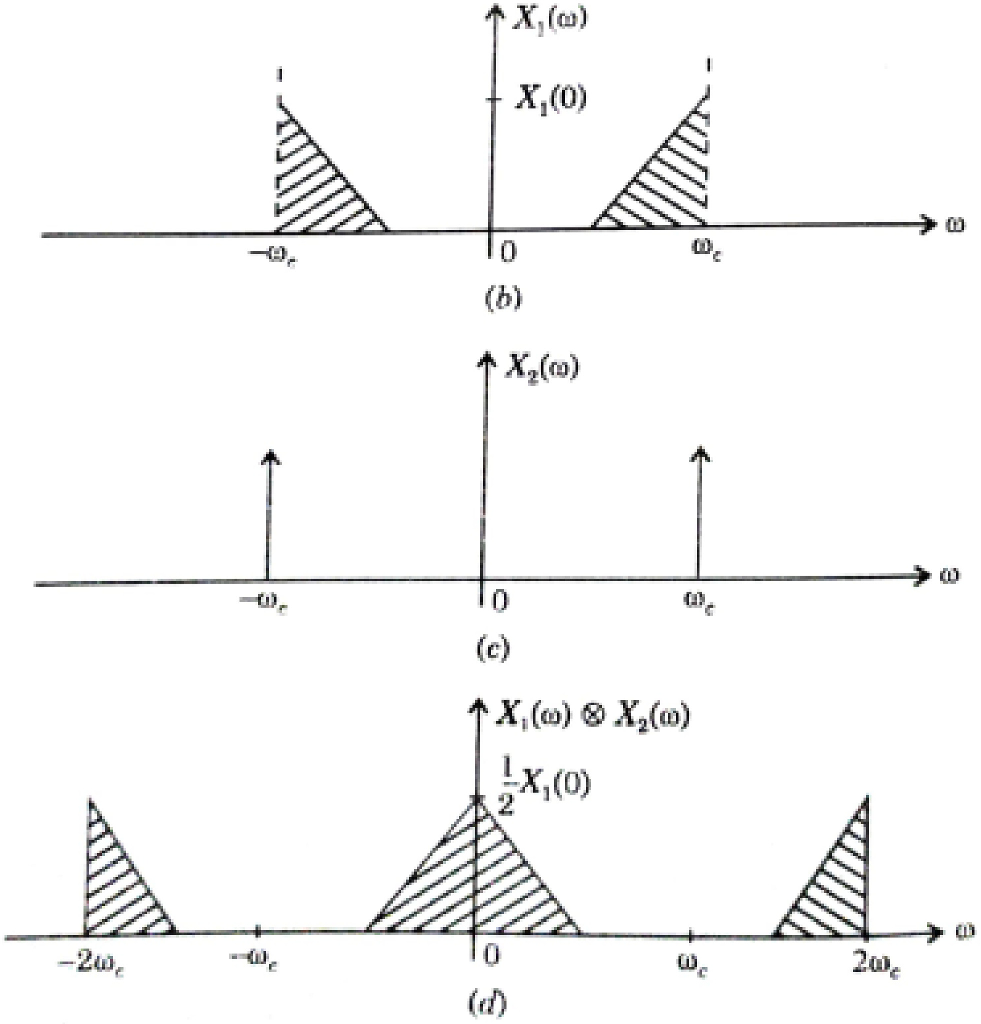


Fig. 3.37. Demodulation of SSB-SC signal
(a) Synchronous detector (b) SSB-SC (lower sideband) (c) Spectrum of cos $\omega_c t$ (locally generated carrier) (d) Convolution of figures (b) & (c).

Frequency Modulation

- Frequency modulation is a system in which the amplitude of the modulated carrier is kept constant, while its frequency and rate of change are varied-by the modulating signal.
- Phase modulation is a similar system in which the phase of the carrier is varied instead of its frequency; as in FM, the amplitude of the carrier remains constant.
- It provides better noise immunity
- Here carrier frequency deviates from fc in proportional to the amplitude of the message signal.
- Maximum deviation of 75kHz
- The shift in the carrier frequency from its resting point compared to the amplitude of the modulating voltage is called the deviation ratio

Description of Systems

- The general equation of an unmodulated wave or carrier is

$$x = A\sin(\omega t + \varphi)$$

- Where

- x is the instantaneous value of voltage
- A is the maximum amplitude
- ω is the angular velocity (rad/s)
- φ is the phase angle in rad
- ωt represents angle in rad

FM

- Frequency modulation, the amount by which the carrier frequency is varied from its unmodulated value, called the deviation, is made proportional to the instantaneous amplitude of the modulating voltage.

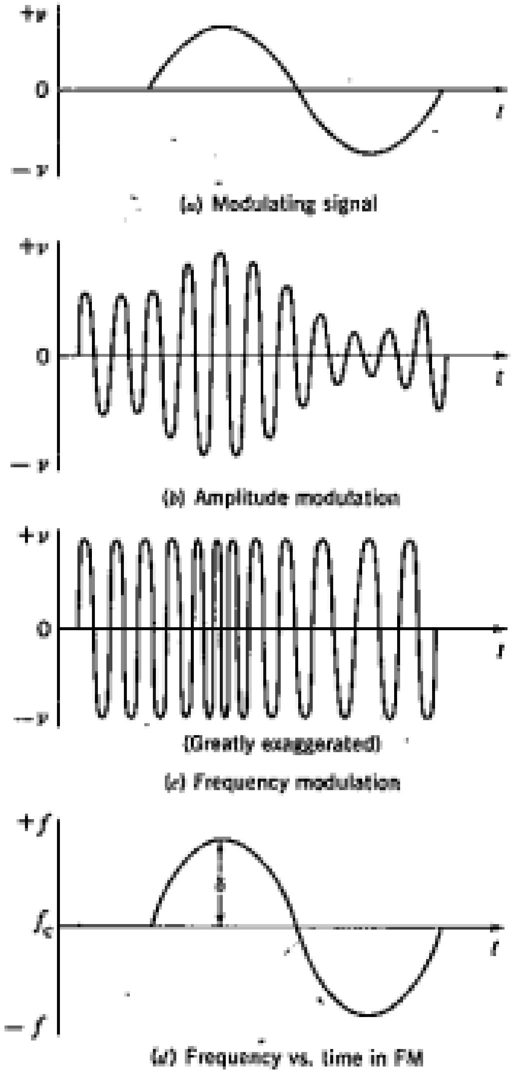
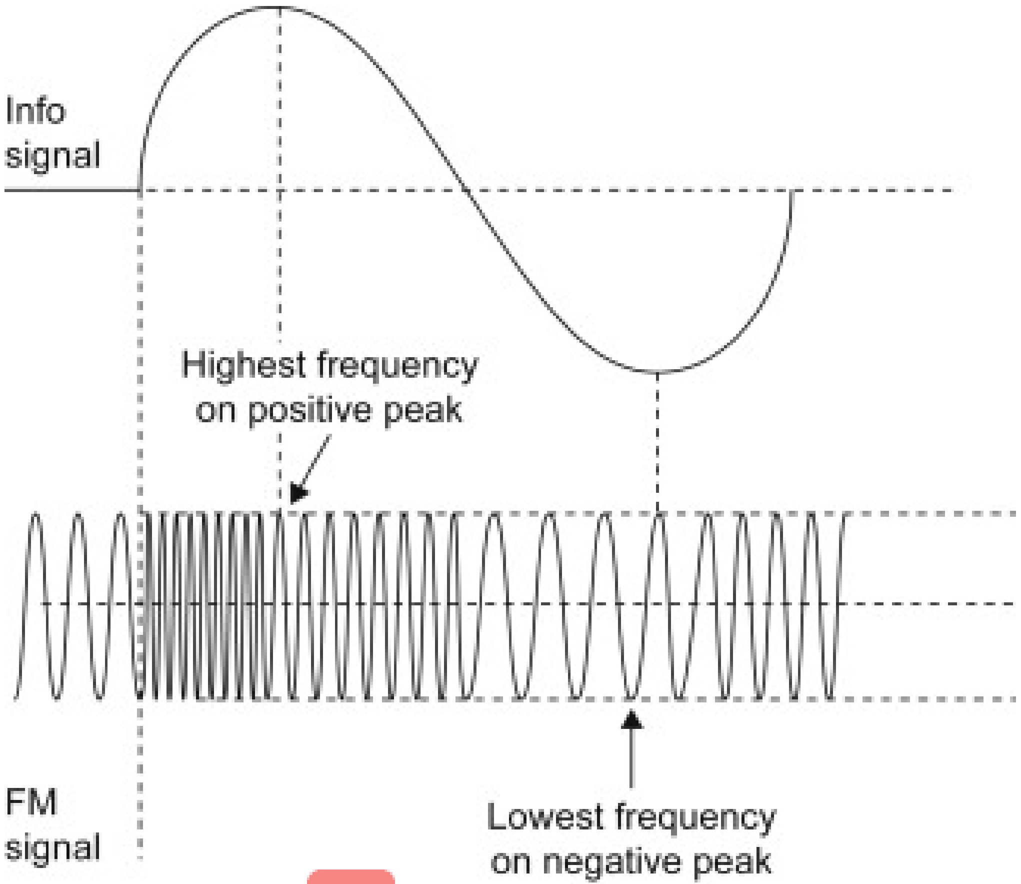


FIGURE 5-1 Basic modulation waveforms.

Frequency Modulations



Frequency Modulation

- Mathematical representation of instantaneous frequency f of the frequency modulated wave is given by

$$f = f_c(1 + kV_m \cos \omega_m t)$$

- Where
  - f_c unmodulated carrier frequency
  - k is the proportionality constant
  - $V_m \cos \omega_m t$ is the instantaneous modulating voltage
- The maximum deviation for this particular signal occur when the cosine term has a maximum value of ± 1
- So the instantaneous frequency can be written as

$$f = f_c(1 \pm kV_m)$$

- So the maximum deviation $\delta = kV_m f_c$

Frequency Modulation

- The instantaneous amplitude of FM signal will be given by

$$v = A \sin [F(\omega_c, \omega_m)] = A \sin \theta$$

where

θ is the angle traced by vector A in time t

To find θ

$$\theta = \int \omega \, dt = \int \omega_c (1 + kV_m \cos \omega_m t) \, dt = \omega_c \int (1 + kV_m \cos \omega_m t) \, dt$$

$$= \omega_c \left(t + \frac{kV_m \sin \omega_m t}{\omega_m} \right) = \omega_c t + \frac{kV_m \omega_c \sin \omega_m t}{\omega_m}$$

$$= \omega_c t + \frac{kV_m f_c \sin \omega_m t}{f_m}$$

$$= \omega_c t + \frac{\delta}{f_m} \sin \omega_m t$$

Frequency Modulation

- Substituting this equation to obtain instantaneous amplitude of the FM voltage

$$v = A \sin\left(\omega_c t + \frac{\delta}{f_m} \sin \omega_m t\right)$$

- The modulation index is for FM m_f is given by

$$m_f = \frac{\text{(maximum) frequency deviation}}{\text{modulating frequency}} = \frac{\delta}{f_m}$$

- Thus we get

$$v = A \sin (\omega_c t + m_f \sin \omega_m t)$$

- Here we get that as modulating frequency decreases and the modulating amplitude remains constant, modulation index increases.

Frequency Spectrum of FM wave

- It is difficult to analyze the frequency components in an FM signal from its equation.
- Since the equation consists of a sine of sine, the solution involves the use of Bessel Functions
- Using Bessel functions the equation maybe expanded to yield

$$
\begin{aligned}
v = A\{&J_0(m_f)\sin\omega_c t \\
&+ J_1(m_f)\,[\sin(\omega_c+\omega_m)t - \sin(\omega_c-\omega_m)t] \\
&+ J_2(m_f)\,[\sin(\omega_c+2\omega_m)t + \sin(\omega_c-2\omega_m)t] \\
&+ J_3(m_f)\,[\sin(\omega_c+3\omega_m)t - \sin(\omega_c-3\omega_m)t] \\
&+ J_4(m_f)\,[\sin(\omega_c+4\omega_m)t + \sin(\omega_c-4\omega_m)t]\cdots\}
\end{aligned}
$$

Spectrum of FM signal

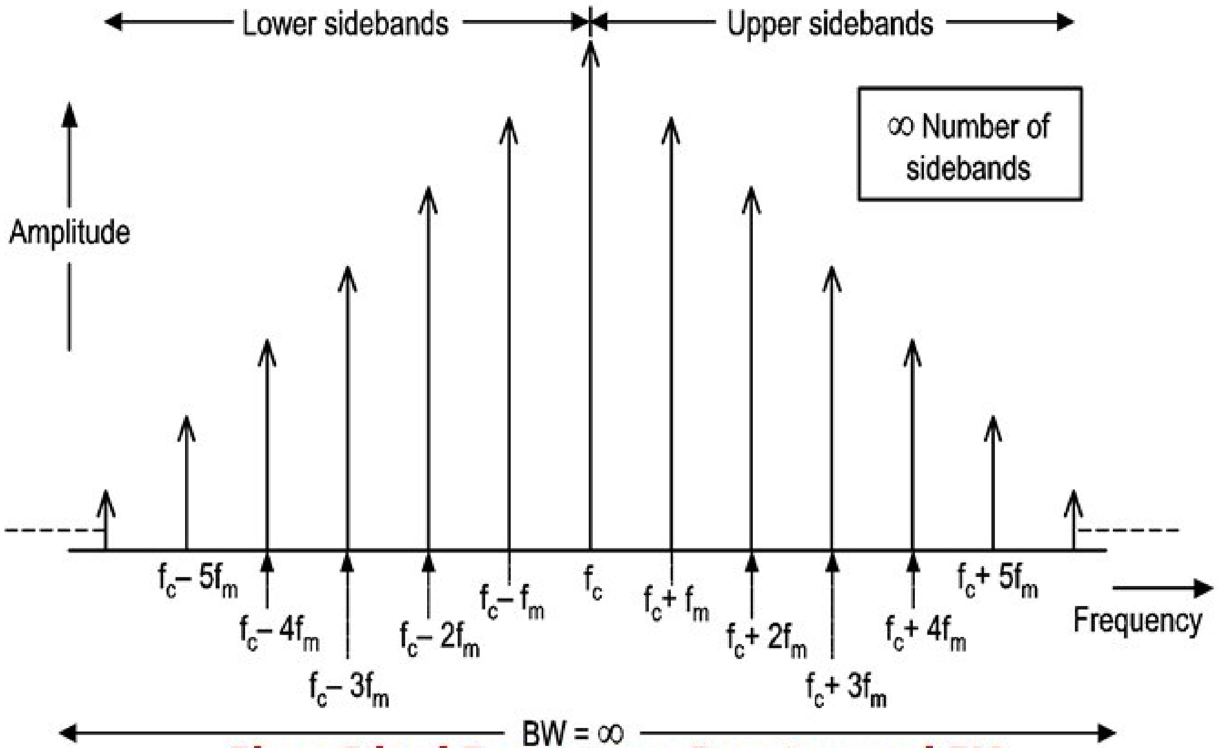


Fig. : Ideal Frequency Spectrum of FM

Frequency Spectrum of FM wave

- It can be shown that the output consists of a carrier and an apparently infinite number of pairs of sidebands.
- Each preceded by J coefficients. These are Bessel functions.
- the order denoted by the subscript
- The value of the Bessel function is given by

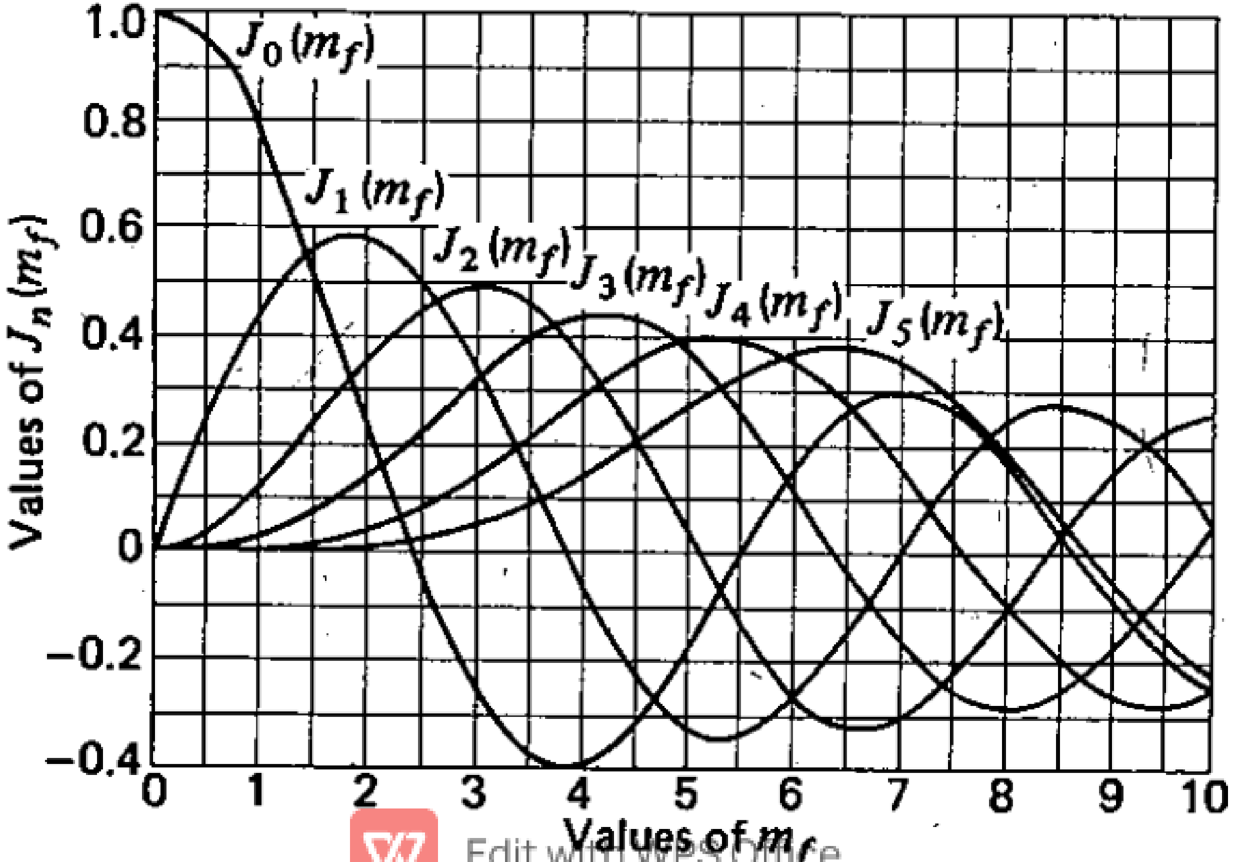
$$J_n(m_f) = \left(\frac{m_f}{2}\right)^n \left[\frac{1}{n!} - \frac{(m_f/2)^2}{1!(n+1)!} + \frac{(m_f/2)^4}{2!(n+2)!} - \frac{(m_f/2)^6}{3!(n+1)!} + \cdots\right]$$

- The value of the Bessel function is available in table format and graphical form

Table for Bessel Functions

x (m_f)	n or Order																
	J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}	J_{11}	J_{12}	J_{13}	J_{14}	J_{15}	J_{16}
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

Graphical Representation of Bessel Function



Observations

- Unlike AM, where there are only three frequencies (the carrier and the first two sidebands), FM has an infinite number of sidebands, as well as the carrier.
  - They are separated from the carrier by f_m, f_{2m}, f_{3m}.., and thus have a recurrence frequency f_m
- The J coefficients eventually decrease in value as n increases, but not in any simple manner.
  - As seen in graphical representation , the value fluctuates on either side of zero, gradually diminishing.
  - Since each J coefficient represents the amplitude of a particular pair of sidebands, these also eventually decrease, but only past a certain value of n.
  - The modulation index determines how many sideband components have significant amplitudes

Observations

- The sidebands at equal distances from fc have equal amplitudes, so that the sideband distribution is symmetrical about the carrier frequency.
    - The J coefficients occasionally have negative values, signifying a 180 degree phase change for that particular pair of sidebands.
- As m_f increases, so does the value of a particular J coefficient, such as J_{12} .
    - Bearing in mind that mf is inversely proportional to the modulating frequency, we see that the relative amplitude of distant sidebands increases when the modulation frequency is lowered.
- In FM, the total transmitted power always remains constant, but with increased depth. of modulation the required bandwidth is increased.
- The theoretical bandwidth required in FM is infinite.
    - In practice, the bandwidth used is one that has been calculated to allow for all significant amplitudes of sideband components under the most exacting conditions.

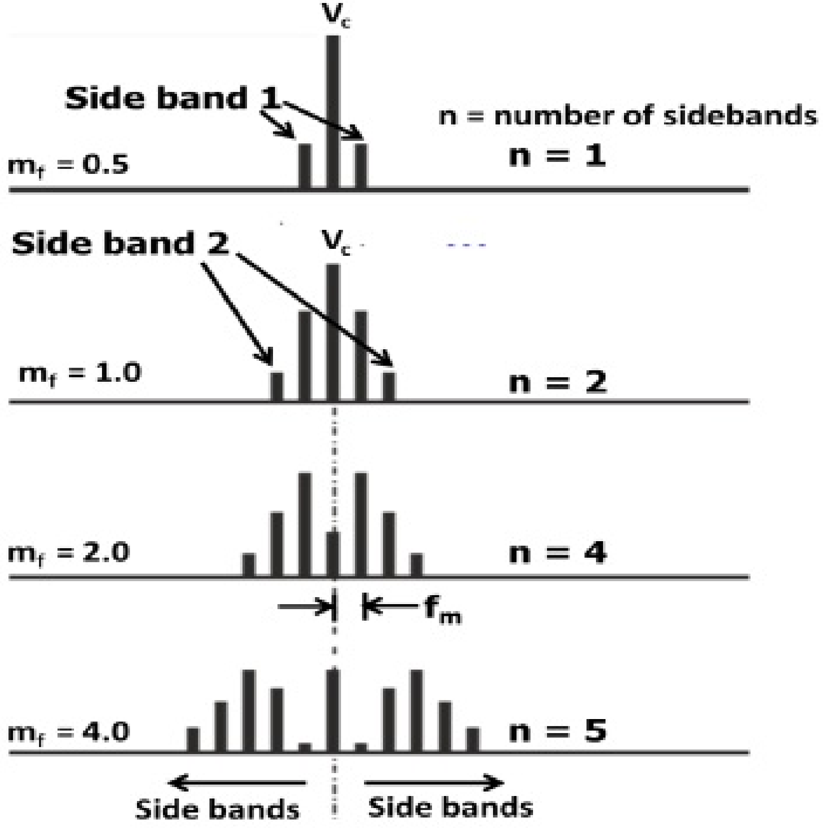
Observations

- In FM, unlike in AM, the amplitude of the carrier component does not remain constant.
  - Its J coefficient is J0, which is a Junction of m_f.
  - This is done to keep the overall amplitude of the FM wave constant would be very difficult if the amplitude of the carrier were not reduced when the amplitude of the various sidebands increased.
- It is possible for the carrier component of the FM wave to disappear completely.
  - This happens for certain values of the modulation index, called eigenvalues. The figure shows that these are approximately 2.4, 5.5, 8.6, 11.8, and so on.

Bandwidth of FM Signal

- A rule of thumb (Carson's rule) states that (as a good approximation) the bandwidth required to pass an FM wave is twice the sum of the deviation and the highest modulating frequency

$$BW = 2(\delta + f_m)$$
$$BW = 2f_m(m_f + 1)$$



Types of FM

- Depending on the value of modulation index we may distinguish two cases of frequency modulation.
- Narrowband FM
- Where m_f is small compared to one
- $\delta \ll f_m$ and $m_f = \dfrac{\delta}{f_m} \Rightarrow m_f \ll 1 \Rightarrow BW = 2f_m$
- Wideband FM
- Where m_f is small compared to one
- $\delta \gg f_m$ and $m_f = \dfrac{\delta}{f_m} \Rightarrow m_f \gg 1 \Rightarrow BW = 2\delta$

Narrowband FM

- The expression for a single tome narrow band FM is given by

$$s(t) = A\, cos\omega_c t - A\, m_f\, \sin\omega_m t\; sin\omega_c t$$

$$s(t) = A\, cos\omega_c t + \frac{1}{2} m_f\, A[cos(\omega_c + \omega_m)t \text{- } cos(\omega_c - \omega_m)t]$$

- The narrow band FM has no amplitude variation
- It has the same frequency components as AM
- Only difference us that the LSB is negative i.e. 180 degree out of phase as compared to the carrier.

Phase Modulation

- Phase modulation is that type of angle modulation in which the phase angle φ is varied linearly with the baseband or modulating signal about an unmodulated phase angle $(\omega_c t + \theta_0)$
- This means in phase modulation the instantaneous value of the phase angle is equal to the phase angle of the unmodulated carrier plus a time varying component which is proportional to the modulating signal.

$$c(t) = A\cos(\omega_c t + \theta_0)$$
$$c(t) = A\cos\varphi$$
$$\varphi = \omega_c t + \theta_0$$

Neglecting θ_0

We get

$$\varphi = \omega_c t$$

Phase Modulation

- Let the instantaneous value of phase angle be demoted by φ_i
- Therefore

$$\varphi_i = \omega_c t + \mathrm{km(t)}$$

Where k is a proportionality constant and expressed in radians/volt

- There the expression for the phase modulated wave will be

$$s(t) = A\cos\varphi_i$$

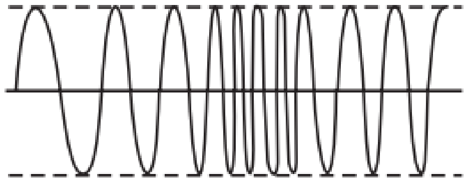
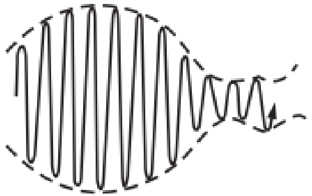
- Therefor

$$s(t) = \mathrm{A}\cos(\omega_c t + \mathrm{km(t)})$$

Comparison between AM and FM

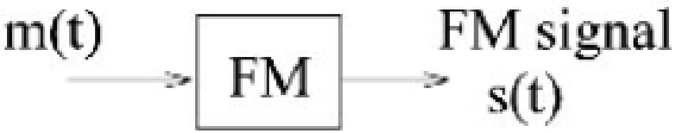
S.No.	FM	AM
1.	Amplitude of FM wave is constant. It is independent of the modulation index.	Amplitude of AM wave will change with the modulating voltage.
2.	Hence, transmitted power remains constant. It is independent of m_f.	Transmitted power is dependent on the modulation index.
3.	All the transmitted power is useful.	Carrier power and one sideband power are useless.
4.	FM receivers are immune to noise.	AM receivers are not immune to noise.
5.	It is possible to decrease noise further by increasing deviation.	This feature is absent in AM.
6.	Bandwidth = $2[\Delta f + f_m]$. The bandwidth depends on modulation index.	BW = 2 f_m. It is not dependent on the modulation index.
7.	BW is large. Hence, wide channel is required.	BW is much less than FM.

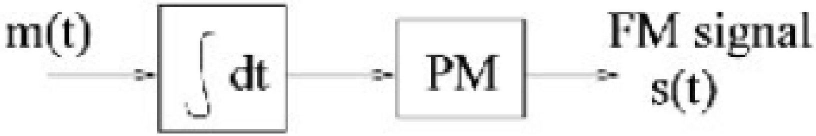
Comparison between AM and FM

8.	Space wave is used for propagation. So, radius of transmission is limited to line of sight.	Ground wave and sky wave propagation is used. Therefore, larger area is covered than FM.
9.	Hence, it is possible to operate several transmitters on same frequency.	Not possible to operate more channels on same frequency.
10.	FM transmission and reception equipment are more complex.	AM equipments are less complex.
11.	The number of sidebands having significant amplitudes depends on modulation index m_f.	Number of sidebands in AM will be constant and equal to 2.
12.	The information is contained in the frequency variation of the carrier.	The information is contained in the amplitude variation of the carrier.
13.	FM wave: 	AM wave: 
14.	Application : Radio, TV broadcasting, police wireless, point to point communications.	Applications: Radio and TV broadcasting.

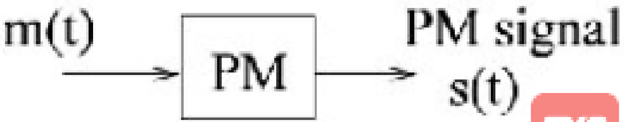
Relationship Between FM and PM

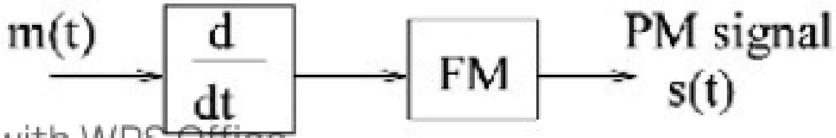
$$\text{FM of } m(t) \quad \Leftrightarrow \quad \text{PM of } \int_0^t m(\tau)d\tau$$





$$\text{PM of } m(t) \quad \Leftrightarrow \quad \text{FM of } \frac{dm(t)}{dt}$$





Advantages and Disadvantages of FM over AM

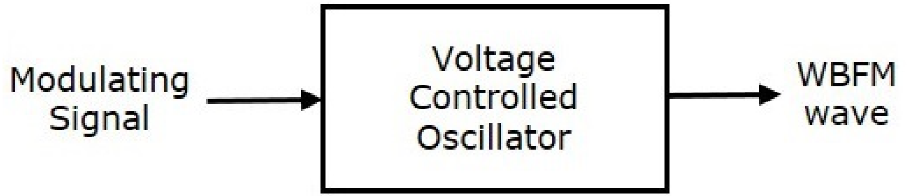
- Advantages
  - FM receivers may be fitted with an amplitude limiters to remove the amplitude variations caused by noise. FM is more immune to noise
  - It is possible to reduce noise still further by increasing the frequency deviation.
  - Standard frequency allocations provide a guard band between commercial FM stations. Due to this there is less adjacent channel interference than AM
  - FM broadcasts operate in the upper VHF and UHF frequency ranges at which there happens to be less noise than in MF and HF ranges occupied by AM
  - All transmitted power is useful in FM
- Disadvantage
  - A much wider channel typically 200 KHz is requires in FM against 10 KHz in AM broad cast.
  - FM transmitting and receiving equipments are more complex and hence more coslty

FM Generation

- The FM modulator circuits used for generating FM signals can be divided into two categories such as:
- The direct method or parameter variation method
- The Indirect method or the Armstrong method

The 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.
- An oscillator circuit whose frequency is controlled by a modulating voltage is called VCO.
- The frequency of VCO is varied to the modulating signal by putting a shunt voltage variable capacitor called Varactor
- Or the capacitance of a BJT or FET can be varied by miller effect.

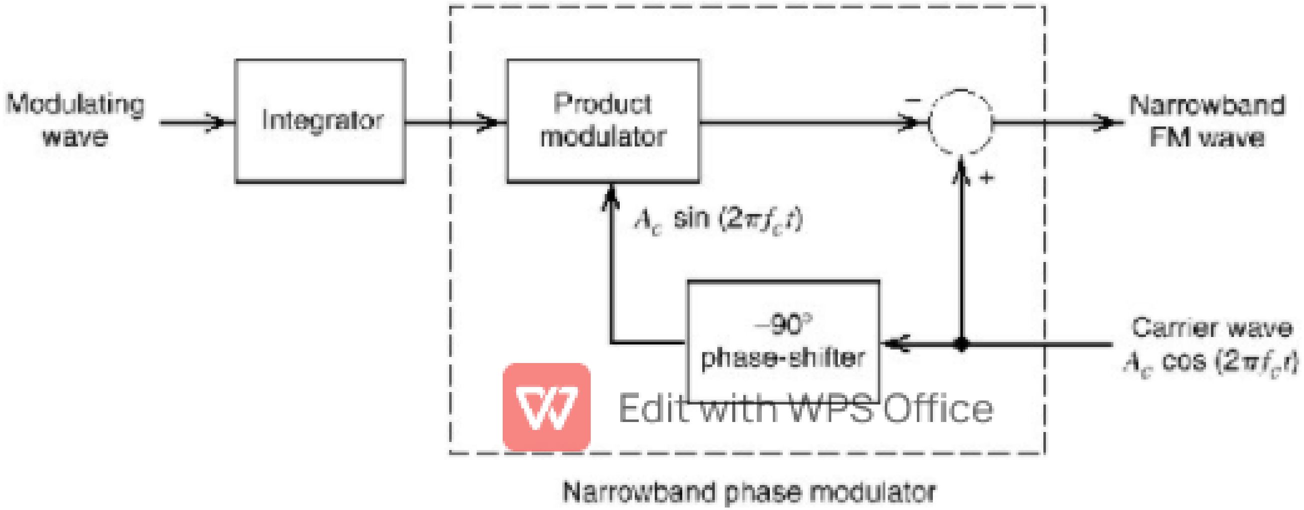


Indirect Method

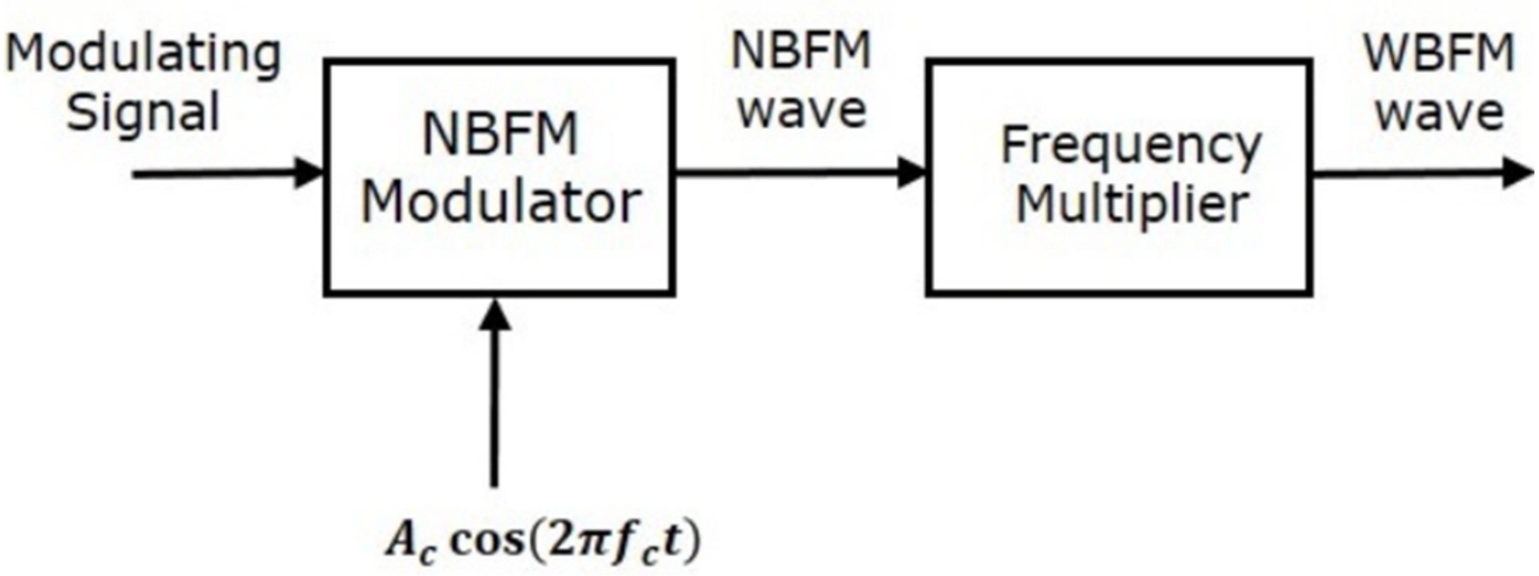
- This method is called as Indirect Method because we are generating a wide band FM wave indirectly.
- This means, first we will generate NBFM wave and then with the help of frequency multipliers we will get WBFM wave.

Generation of Narrowband FM

- Let $m(t) = V_m \cos w_m t$
- We have NBFM as $s(t) = A\, cos\omega_c t - A\, m_f\, \sin\omega_m t\, sin\omega_c t$



Indirect Method



Indirect Method

- This block diagram contains mainly two stages. In the first stage, the NBFM wave will be generated using NBFM modulator
- 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 non-linear device, which produces an output signal whose frequency is ‘n’ times the input signal frequency. Where, ‘n’ is the multiplication factor.
- If NBFM wave whose modulation index β is less than 1 is applied as the input of frequency multiplier, then the frequency multiplier produces an output signal, whose modulation index is ‘n’ times β
- Sometimes, we may require multiple stages of frequency multiplier and mixers in order to increase the frequency deviation and modulation index of FM wave.

Demodulation of FM signals

- The demodulators which demodulate the FM wave.
- The following two methods demodulate FM wave.
    - Frequency discrimination method
        - Simple slope
        - Balanced Slope
    - Phase discrimination method
        - Foster Seeley detector
        - Ratio detector
        - PLL-FM Demodulator

- Frequency discrimination method
- The FM demodulator performs the extraction of modulating signal as
    - It converts the FM signal into corresponding AM signal with the help of frequency dependent circuits whose output voltage depends on the input frequency. Such circuits are known as frequency discriminators.
    - The original modulating signal is recovered from this AM signal with the help of the envelope detector.

Frequency Discrimination Method

We know that the equation of FM wave is

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

Differentiate the above equation with respect to '**t**'.

$$\frac{ds(t)}{dt} = -A_c \left(2\pi f_c + 2\pi k_f m(t)\right) \sin\left(2\pi f_c t + 2\pi k_f \int m(t)\, dt\right)$$

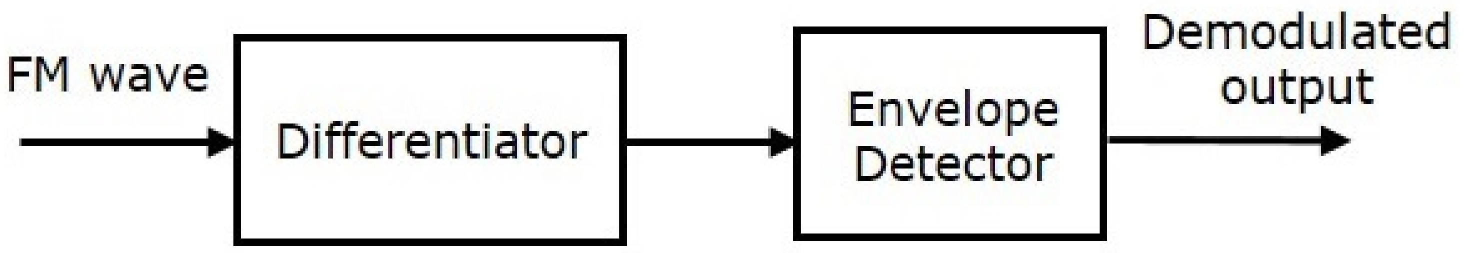
We can write, $-\sin\theta$ as $\sin\left(\theta - 180^0\right)$.

$$\Rightarrow \frac{ds(t)}{dt} = A_c \left(2\pi f_c + 2\pi k_f m(t)\right) \sin\left(2\pi f_c t + 2\pi k_f \int m(t)\, dt - 180^0\right)$$

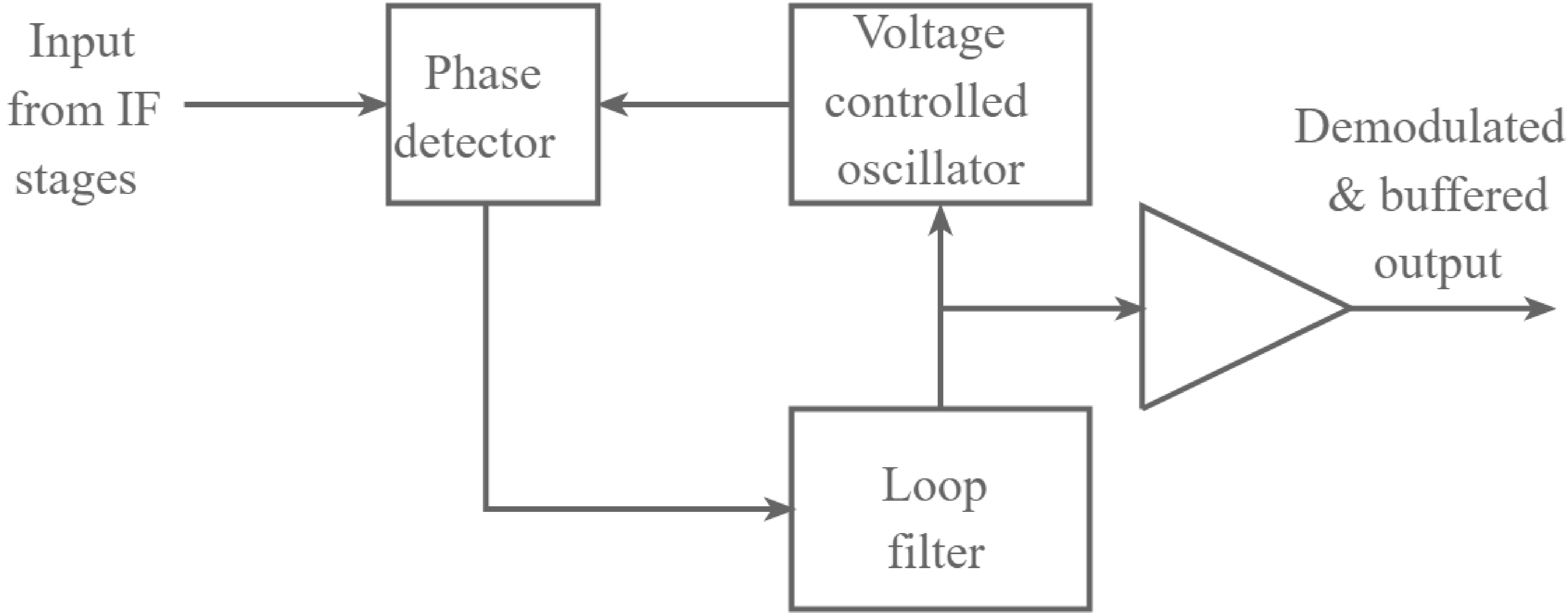
$$\Rightarrow \frac{ds(t)}{dt} = A_c \left(2\pi f_c\right) \left[1 + \left(\frac{k_f}{f_c}\right) m(t)\right] \sin\left(2\pi f_c t + 2\pi k_f \int m(t)\, dt - 180^0\right)$$

Frequency Discrimination Method

- In the above equation, the amplitude term resembles the envelope of AM wave and the angle term resembles the angle of FM wave.
- Here, our requirement is the modulating signal m(t). Hence, we can recover it from the envelope of AM wave.



Phase discrimination method



Phase discrimination method

- The working of a PLL is as follows –

- A Phase detector is a multiplier and it produces two frequency components at its output – sum of the frequencies fin and fout and difference of frequencies fin & fout
- Phase detector produces a DC voltage, which is proportional to the phase difference between the input signal having frequency of fin and feedback (output) signal having frequency of fout
- An active low pass filter produces a DC voltage at its output, after eliminating high frequency component present in the output of the phase detector. It also amplifies the signal.
- A VCO produces a signal having a certain frequency, when there is no input applied to it. This frequency can be shifted to either side by applying a DC voltage to it. Therefore, the frequency deviation is directly proportional to the DC voltage present at the output of a low pass filter.