LAGOS CITY POLYTECHNIC

LECTURE NOTE

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Chapter One: **BASIC PRINCIPLES OF MODULATION & DEMODULATION**

Chapter Two: **AMPLITUDE MODULATION**

Chapter Three: **FREQUENCY MODULATION**

Chapter Four: **DEMODULATION TECHNIQUES**

Chapter Five: **DIGITAL MODULATION**

CHAPTER 1.0

BASIC PRINCIPLES OF MODULATION & DEMODULATION

Introduction

For successful transmission and reception of intelligence (code, voice, music etc.) by the use of radio waves, two processes are essential : (*i*) modulation and (*ii*) demodulation.

Speech and music etc. are sent thousands of kilometres away by a radio transmitter. The scene in front of a television camera is also sent many kilometres away to viewers. Similarly, a Moon probe or Venus probe checking its environments, sends the information it gathers millions of kilometres through space to receivers on earth. In all these cases, the carrier is the high-frequency radio wave. The intelligence i.e. sight, sound or other data collected by the probe is impressed on the radio wave and is carried along with it to the destination.

Modulation is the process of **combining the low-frequency signal with a very high-frequency radio wave called carrier wave (CW)**. The resultant wave is called **modulated carrier wave**. This job is done at the transmitting station.
Demodulation is the process of separating or **recovering the signal from the modulated carrier wave**. It is just the opposite of modulation and is performed at the receiving end.

It is the process of combining ***an audio frequency* (*AF*) *signal with a radio frequency(RF) carrier wave*.** The AF signal is also called a ***modulating wave*** and the resultant wave produced is called ***modulated wave***.
Modulation is the **superimposing** of a low frequency (audio signal) on a high frequency (carrier wave). It is the process through which audio, video, image, or text information is added to an electrical or optical carrier signal to be transmitted over a telecommunication or electronic medium

What is a Carrier Wave?

It is a high-frequency undamped radio wave produced by radio-frequency oscillators , the output of these oscillators is first amplified and then passed on to an antenna. This antenna radiates out these high-frequency (electromagnetic) waves into space. These waves have constant amplitude and travel with the velocity of light. They are inaudible *i.e*. by themselves they cannot produce any sound in the loudspeaker of a receiver. As their name shows, their job is to **carry the signal** (audio or video) from transmitting station to the receiving station. The resultant wave is called **modulated** carrier wave as shown in **figure 3.1**

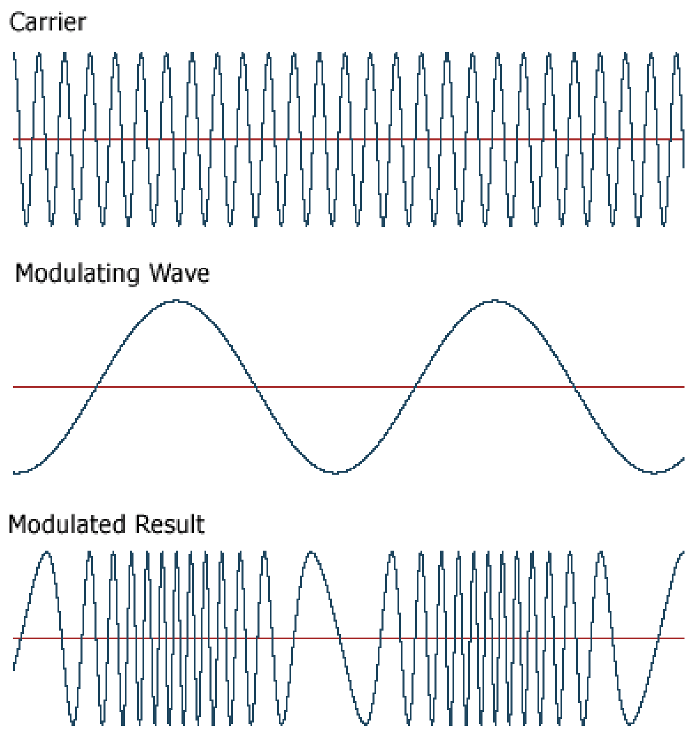

Figure 1.1 Carrier and modulating waves combined to form a modulated wave

Table 1.1: Differences between Modulation and Demodulation

Modulation	**Demodulation**
Encoding of information	Decoding of information
Superimposing	Retrieving
Varying some parameters like amplitude, frequency and phase	Extraction of the audio signal from the transmitted modulated wave
Takes place at the source/transmitting end	Takes place at the destination/receiving end
Frequency transformation from low to high	Frequency transformation from high to low
Circuit modulator needed	Circuit demodulator needed
Operation is simple	Operation is complex

Need for Modulation

Sometimes, beginners question the necessity of modulation *i.e*. using a carrier wave to carry the low-frequency signal from one place to another. Why not transmit the signals directly and save lot of botheration? Unfortunately, there are three main hurdles in the process of such direct transmission of audio-frequency signals:

1. They have relatively short range,
2. If everybody started transmitting these low-frequency signals directly, mutual interference will render all of them ineffective
3. Size of antennas required for their efficient radiation would be large i.e. about 75 km

For efficient radiation of a signal, the minimum length of an antenna is one quarter wavelength **($\lambda/4$).** The antenna length L is connected with the frequency of the signal wave by the relation $L = 75 \times 106/f$ metres. For transmitting an audio signal of $f = 1000$ Hz, $L = 75 \times 106/103 = 75{,}000$ m = 75 km ! In view of this immense size of antenna length, it is impractical to radiate audio-frequency signals directly into space.

Hence, the solution lies in modulation which enables a low-frequency signal to travel very large distances through space with the help of a high-frequency carrier wave. These carrier waves need reasonably-sized antennas and produce no interference with other transmitters operating in the same area.

Modulation is needed:

- For ease of radiation
- To reduce noise and interference
- To overcome equipment limitations

BENEFITS OF MODULATION

1. It helps to send a signal over a bandpass frequency range
2. It allows use of smaller antenna
3. It increases the range of communication
4. It improves quality of reception
5. It avoids mixing of signals
6. Multiplexing is possible

APPLICATIONS OF MODULATION

1. For broadcasting (radio and television), AM, FM, PM etc
2. GSM (global system for mobile communication)
3. Radar (Radio Detection and Ranging)
4. WiFi
5. Conversion of analog signal to digital signal

Methods of Modulation

The mathematical expression for a sinusoidal carrier wave is

$$e = E_C \sin(\omega_c t + \varphi) = E_C \sin(2\pi f_c t + \varphi)$$

Obviously, the waveform can be varied by any of its following three factors or parameters :
1. E_C — the amplitude, **2.** f_c — the frequency, **3.** φ — the phase.

Accordingly, there are three types of sine-wave modulations known as :

1. Amplitude Modulation (AM)

Here, the information or *AF* signal changes the amplitude of the carrier wave without changing its frequency or phase.

2. Frequency Modulation (FM)

In this case, the information signal changes the frequency of the carrier wave without changing its amplitude or phase.

3. Phase Modulation (PM)

Here, the information signal changes the phase of the carrier wave without changing its other two parameters.

Chapter 2.0

AMPLITUDE MODULATION

Amplitude Modulation

In this case, the **amplitude** of the carrier wave is varied in proportion to the **instantaneous amplitude** of the information signal or AF signal. Obviously, the amplitude (and hence the intensity) of the carrier wave is changed ***but not its frequency.*** Greater the amplitude of the AF signal, greater the fluctuations in the amplitude of the carrier wave.

The process of amplitude modulation is shown graphically in Figure. For the sake of simplicity, the *AF* signal has been assumed sinusoidal. The carrier wave by which it is desired to transmit the *AF* signal is shown. The resultant wave called modulated wave is also shown in the Figure.

The function of the modulator is to mix these two waves. All stations broadcasting on the standard broadcast band (550-1550 kHz) use *AM* modulation. If you observe the envelope of the modulated carrier wave, you will realize that it is an exact replica of the *AF* signal wave.

In summary

***(i)* fluctuations** in the amplitude of the carrier wave depend on the **signal amplitude**,

(*ii*) rate at which these fluctuations take place depends on the **frequency** of the audio signal

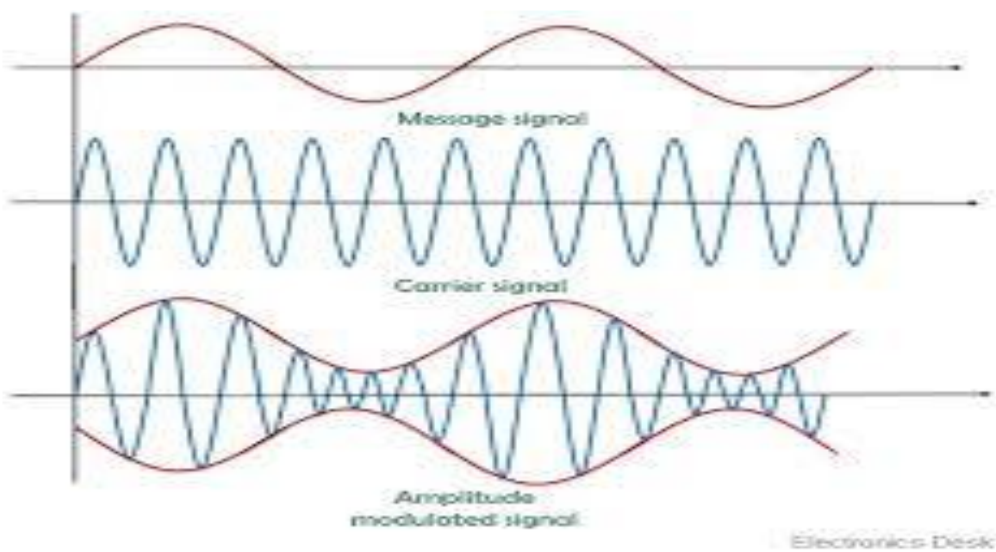

Figure 2.1 Message signal, carrier wave and their mixing

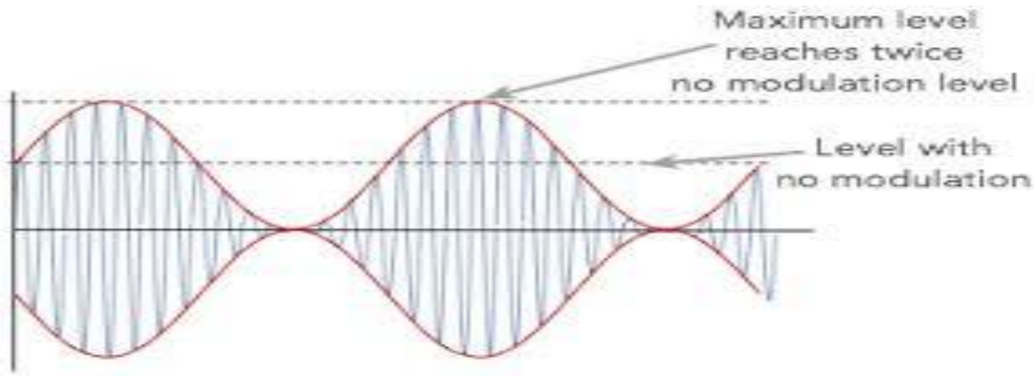

Figure 2.2 Modulated wave

Percent Modulation

It indicates the degree to which the AF signal modulates the carrier wave

$$\mathbf{m} = \frac{\text{maximum value of signal wave}}{\text{maximum value of carrier wave}} \times 100 = \frac{\text{Signal amplitude}}{\text{Carrier amplitude}} \times 100$$

This is referred to as **modulation index** (MI)
i.e m = (modulation factor) = M.I X 100

In the image below for amplitude modulated sine wave:

- **0%** unmodulated, the sine envelope is not visible at all;
- < 100% modulation depth is normal AM use;
- **100%** modulation depth, the sine envelope touch at y=0. Maximum modulation that can be retrieved with an envelope detector without distortion;
- > 100% modulation depth, "overmodulation", the original sine wave can no longer be detected with an envelope detector.

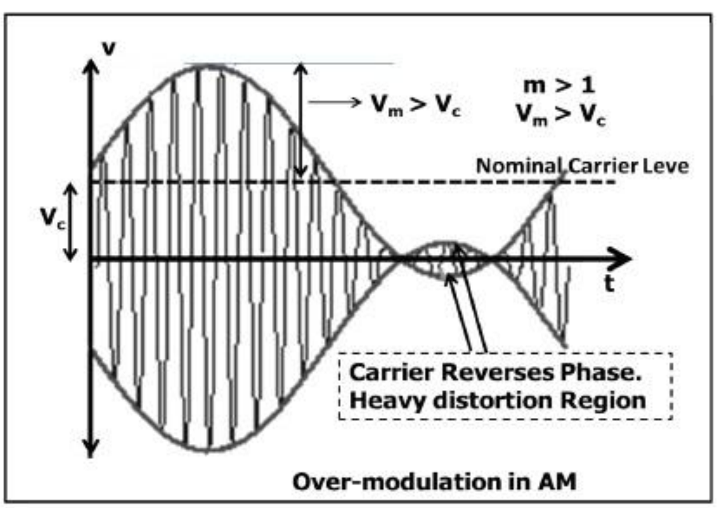

Figure 2.3

Over modulation isn't really of any significance to FM systems (unlike AM). If the modulation signal amplitude is too great, any decent frequency modulator will limit the signal so that it can't push the bandwidth of the modulated signal too wide in the frequency spectrum. In effect, the modulating signal becomes clipped.

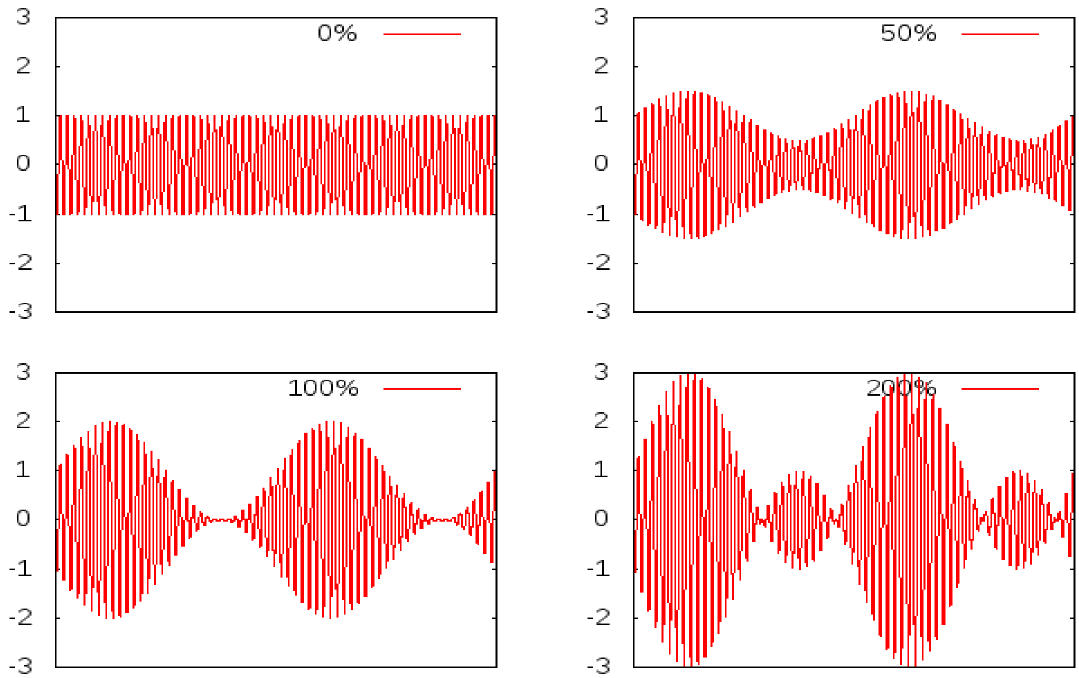

Figure 2.4: Various levels of modulation

The following points are the

- A carrier is used to make the wavelength smaller for practical transmission and to permit multiplexing.
- The spectrum is used to measure bandwidth (the range of frequencies) and the efficiency (the power in the side-bands compared to the total power)
- Bandwidth can be predicted using BW = 2 f_m where f_m = the maximum modulating frequency
- Efficiency depends only on the modulating index, m (the fraction of the carrier you modulate by)
- AM is limited to 33% efficiency because the modulation index cannot be increased to > 1.0 without introducing distortion in the receiver.

Upper and Lower Side Frequencies

An unmodulated carrier wave consists of only one single-frequency component of frequency ***fc***. When it is combined with a modulating signal of frequency **fm**, heterodyning action takes place.

As a result, two additional frequencies called **side frequencies** are produced. The *AM* wave is found to consist of three frequency components :

1. The original carrier frequency component, fc .
2. A higher frequency component ($fc + fm$). It is called the sum component.
3. A lower frequency component ($fc – fm$). It is called the difference component.

The two new frequencies are called the **upper-side frequency** (*USF*) and **lower-side frequency** *LSF*) respectively and are symmetrically located around the carrier frequency.
The modulating frequency remains unchanged but does not appear in the amplifier output because the amplifier's load presents practically zero impedance to this low frequency.
These are shown in time domain in Figure below
The amplitude of the side frequencies depends on the value of *m*. The amplitude of each side frequency = $mA/2$ where *A* is the amplitude of unmodulated carrier wave

Example 2.1 *A 10-MHz sinusoidal carrier wave of amplitude 10 mV is modulated by a 5 kHz sinusoidal audio signal wave of amplitude 6 mV. Find the frequency components of the resultant modulated wave and their amplitudes.*

Solution. Here, fc = 10 MHz and fm = 5 kHz = 0.005 MHz. The modulated carrier contains the following frequencies :
1. original carrier wave of frequency fc = **10 MHz**
2. USF of frequency = 10 + 0.005 = **10.005 MHz**
3. LSF of frequency = 10 – 0.005 = **9.995 MHz**

Here,

$$\mathbf{m} = \frac{\text{maximum value of signal wave}}{\text{maximum value of carrier wave}} \times 100 = \frac{\text{Signal amplitude}}{\text{Carrier amplitude}} \times 100$$

$$= 6/10 = 0.6$$

Amplitude of *LSF* = *USF* = $mA/2 = 0.6 \times 10/2 =$ **3 mV**

It was assumed that the modulating signal was composed of one frequency component only. However, in a broadcasting station, the modulating signal is the human voice (or music) which contains waves with a frequency range of 20-4000 Hz. Each of these waves has its own *LSF* and *USF*. When combined together, they give rise to an upper-side **band** (*USB*) and a lower-side **band** (LSB). The *USB*, in fact, contains all sum components of the signal and carrier frequency whereas *LSB* contains their difference components.
The channel width (or bandwidth) is given by the difference between extreme frequencies i.e. between maximum frequency of *USB* and minimum frequency of *LSB*.
As seen, Channel width = 2 × maximum frequency of modulating signal = **2 × *fm (max)***

Example 2.2. *An audio signal given by 15 sin 2π (2000 t) amplitude-modulates a sinusoidal carrier wave 60 sin 2π (100,000) t.*
Determine :
(a) *modulation index,* ***(b)*** *percent modulation,* ***(c)*** *frequencies of signal and carrier,*
(d) *frequency spectrum of the modulated wave.*

Solution. Here, $B = 15$ and $A = 60$

(a) *M.I.* = *B/A* = *15/60* = **0.25**

(b) $m = M.I. \times 100 = 0.25 \times 100 = 25\%$

(*c*) f_m = **2000 Hz** — by inspection of the given equation

f_c = **100,000 Hz** — by inspection of the given equation

(*d*) The three frequencies present in the modulated *CW* are

(*i*) 100,000 Hz = **100 kHz**

(*ii*) 100,000 + 2000 = 102,000 Hz =**102 kHz**

(*iii*) 100,000 – 2000 = 98,000 Hz = **98 kHz**

Example 2.3. *A bandwidth of 15 MHz is available for AM transmission. If the maximum audio signal frequency used for modulating the carrier is not to exceed 15 kHz, how many stations can broadcast within this band simultaneously without interfering with each other*?

Solution. *BW* required by each station $= 2\, f_{m(max)} = 2 \times 15 = 30$ kHz

Hence, the number of station which can broadcast within this frequency band without interfering with one another is

= 15 MHz/30kHz = **500**

Example 2.4. *In a broadcasting studio, a 1000 kHz carrier is modulated by an audio signal of frequency range, 100-5000 Hz. Find* ***(i)*** *width or frequency range of sidebands* ***(ii)*** *maximum and minimum frequencies of USB* ***(iii)*** *maximum and minimum frequencies of LSB and* ***(iv)*** *width of the channel.*

Solution: (*i*) Width of sideband = 5000 – 100 = **4900 Hz**

(*ii*) Max. frequency of USB = 1000 + 5 = **1005 kHz**

Min. frequency of *USB* = 1000 + 0.1 = **1000.1 kHz**

(*iii*)Max. frequency of *LSB* = 1000 – 0.1 = **999.9 kHz**

Min. frequency of *LSB* = 1000 – 5 = **995 kHz**

(*iv*) Width of channel = 1005 – 995 = **10 kHz**

Example 2.5

A transmitter radiates 9kw without modulation and 10.125kw after modulation. Determine the depth of modulation.

Solution:

$P_c = 9\text{kw}$, $P_{mod} = 10.125\text{kw}$

Now $P_{mod} = P_c\,(1 + m_a^2/2)$

$(1 + m_a^2 / 2) = 10.125 / 9 = 1.125$

$m_a = \mathbf{0.5}$

Advantages of AM over FM

1. Circuits for AM transmitter and receiver are simple and less expensive
2. AM signal can go so far in propagation
3. AM never suffers multi-path filtering
4. AM is easier to listen to with portable radios, not needing external wire antenna with local contents

Limitations of AM

1. It's power is not efficient
2. The bandwidth is equal to double of the highest audio frequency (the bandwidth required by AM is less (2 fm)
3. AM are sensitive to high level of noise
4. AM has poorer sound quality

APPLICATIONS OF AM

In amplitude modulation (AM), amplitude of carrier signal is varied in accordance with message signal. Amplitude modulation has many real world applications. Those are:

- AM is used for broadcasting in long wave or medium wave or short wave bands.
- The Very High Frequency (VHF) transmission is processed by AM. Radio communication uses VHF.
- A special type of AM is Quadrature Amplitude Modulation (QAM). It is used for data transmission from short range transmission to cellular communications.

Forms of Amplitude Modulation

As shown, **one carrier** and **two sidebands** are produced in AM generation. It is found that it is not necessary to transmit all these signals to enable the receiver to reconstruct the original signal. Accordingly, we may attenuate or altogether remove the carrier or any one of the sidebands without affecting the communication process. The advantages would be

1. less transmitted power and **2.** less bandwidth required

The different suppressed component systems are :

FORMS OF AMPLITUDE MODULATION

(*a*)

- **DSB-SC**
  - It stands for double-sideband suppressed carrier system [Fig. below)]. Here, carrier component is suppressed thereby saving enormous amount of power. Carrier signal contains 66.7 per cent of the total transmitted power for m = 1, Hence, power saving amounts to 66.7% at 100% modulation

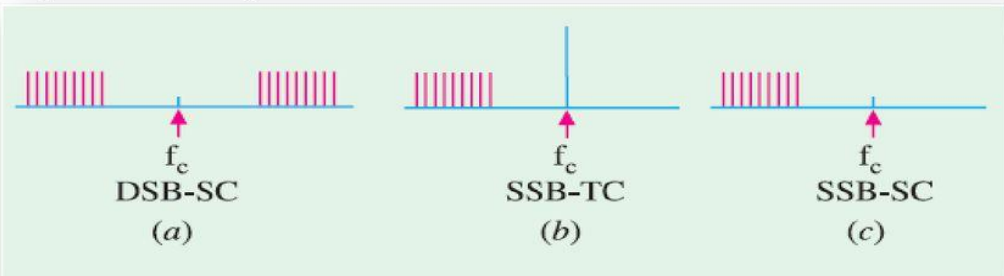

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Figure 2.5

(*b*) SSB-TC

In this case, one sideband is suppressed but the other sideband and carrier are transmitted. It is called ***single sideband transmitted carrier*** system. For m = 1, power saved is 1/6 of the total transmitted power

(*c*) SSB-SC

This is the **most dramatic suppression of all** because it suppresses one sideband and the carrier and transmits only the remaining sideband. In the standard or double-sideband full-carrier (*DSB.FC*) *AM*, carrier conveys **no information but contains maximum power**. Since the two sidebands are exact images of each other, they carry the same audio information. Hence, **all information is available in one sideband only**.

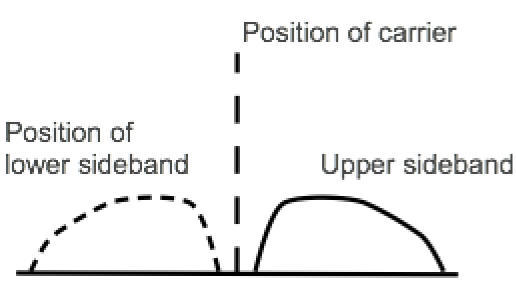


Figure 2.6

Obviously carrier is ***superfluous*** and one side band is ***redundant.*** Hence, one sideband and the carrier can be discarded with no loss of information. The result is *SSB* signal. The advantage of *SSB-SC* system are as follows :

1. Total saving of 83.3% in transmitted power (66.7% due to suppression of carrier wave and 16.6% due to suppression of one sideband). Hence, power is conserved in an SSB transmitter.
2. Bandwidth required is reduced by half *i.e*. 50%. Hence, twice as many channels can be multiplexed in a given frequency range.
3. The size of power supply required is very small. This fact assumes vital importance particularly in a spacecraft.
4. Since the SSB signal has narrower bandwidth, a narrower passband is permissible within the receiver, thereby limiting the noise pick up.
However, the main reason for wide spread use of *DSB-FC* (rather than *SSB-SC*) transmission in broadcasting is the relative simplicity of its modulating equipment

Methods of Amplitude Modulation

There are two methods of achieving amplitude modulation :
(*i*) Amplifier modulation,
(*ii*) Oscillator modulation.
.
Here, carrier and *AF* signal are fed to an amplifier and the result is an *AM* output
The modulation process takes place in the active device used in the amplifier.

Block Diagram of an AM Transmitter

Figure 3.9 shows the block diagram of a typical transmitter. The carrier wave is supplied by a crystal-controlled oscillator at the carrier frequency. It is followed by a tuned buffer amplifier and an *RF* output amplifier. The source of *AF* signal is a microphone. The audio signal is amplified by a low level audio amplifier and, finally, by a power amplifier. It is then combined with the carrier to produce a modulated carrier wave which is ultimately radiated out in the free space by the transmitter antenna as shown.

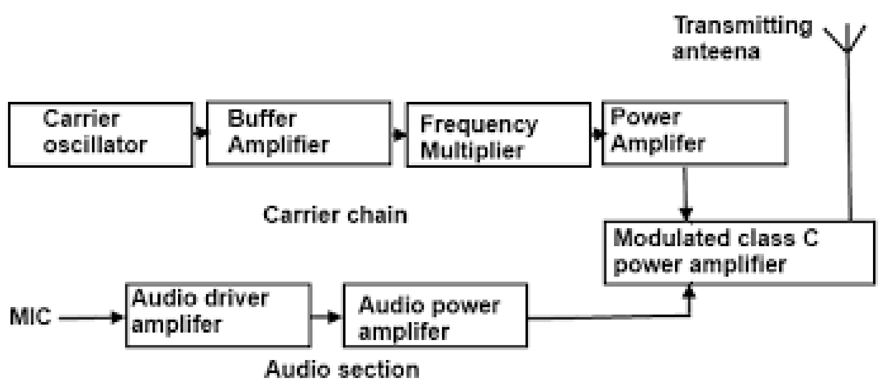


Figure 2.7 : Block Diagram of AM

ASSIGNMENT 2

1. The antenna current of an AM transmitter is 8A when only carrier is sent out. It increases to 8.93A when the carrier is sinusoidally modulated. Find the percentage modulation?
2. A carrier wave of 600watts is subjected to 100% amplitude modulation. Determine
   (i) Power in sideband (ii) power of modulated wave

QUIZ 2

1. What are the consequences of overmodulation?
2. A 40kw carrier is to be modulated to a level of 100%.
   (i) What is the carrier power after modulation
   (ii) How much audio power is required if the efficiency of the modulated RF amplifier is 72%

Chapter 3.0

FREQUENCY MODULATION

FREQUENCY MODULATION

Frequency modulation (**FM**) is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave. The term and technology is used in both **telecommunications and signal processing**.

In **analog** frequency modulation, such as FM radio broadcasting of an audio signal representing voice or music, the instantaneous **frequency deviation**, the difference between the frequency of the carrier and its center frequency, is proportional to the modulating signal.

In **frequency modulation,** the frequency of the carrier signal is varied in proportional to (in accordance with) the Amplitude of the input modulating signal. The input is a single tone sine wave. The carrier and the FM waveforms also are shown in the following figure.

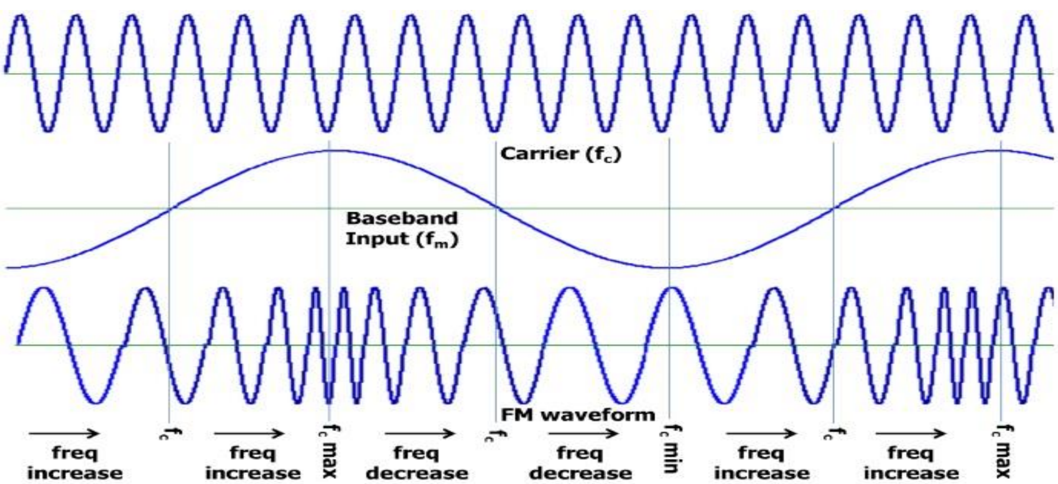


Figure 3.10: Frequency Modulation waveform

As the name shows, in this modulation, it is only the **frequency of the carrier which is changed and not its amplitude.** The **amount of change** in frequency is determined by the **amplitude** of the modulating signal whereas **rate of change** is determined by the **frequency** of the modulating signal. As shown in the figure above, in an *FM* carrier, information (or intelligence) is carried as variations in its frequency. As seen, frequency of the modulated carrier increases as the signal amplitude increases but decreases as the signal amplitude decreases. It is at its highest frequency (point *H*) when the signal amplitude is at its maximum positive value and is at its lowest frequency (point *L*) when signal amplitude has maximum negative value. When signal amplitude is zero, the carrier frequency is at its normal frequency *f*0 (also called ***resting or centre*** frequency.)**.** This **louder** signal causes **greater** frequency change in modulated carrier as indicated by ***increased bunching and spreading*** of the waves as compared with relatively

weaker signal. The **rate** at which frequency shift takes place depends on the signal frequency if the modulating signal is 1 kHz, then the modulated carrier will swing between its maximum frequency and lowest frequency 1000 times per second. If *fm* = 2 kHz, the rate of frequency swing would be twice as fast :
In short, we have established two important points about the nature of frequency modulation:

(i) The **amount** of frequency deviation (or shift or variation) depends on the **amplitude** (loudness) of the audio signal. ***Louder the sound, greater the frequency deviation and vice-versa.*** However, for the purposes of *FM* broadcasts, it has been internationally agreed to restrict maximum deviation to **75 kHz** on each side of the centre frequency for sounds of maximum loudness. Sounds of lesser loudness are permitted ***proportionately less frequency deviation*****.**

(*ii*) The **rate** of frequency deviation depends on the **signal frequency**.

Frequency Deviation and Carrier Swing

The frequency of an *FM* transmitterwithout signal input is called the **resting frequency** or **centre frequency** (*f0*) and is the allotted frequency of the transmitter. In simple words, it is the carrier frequency on which a station is allowed to broadcast.When the signal is applied, the carrier frequency deviates up and down from its resting value *f0*. This change or shift either above or below the resting frequency is called frequency deviation (Δf) The total variation in frequency from the lowest to the highest is called carrier swing (CS).

Obviously, **carrier swing** = 2 × frequency deviation of $CS = 2 \times \Delta f$

A maximum frequency deviation of 75 kHz is allowed for commercial *FM* broadcast stations inthe 88 to 168 MHz *VHF* band. Hence, *FM* channel width is 275 = 150 kHz. Allowing a 25 kHz guard band on either side, the channel width becomes = 2(75 + 25) = 200 kHz This guard band is meant to prevent interference between adjacent channels. However, a maximum frequency deviation of 25 kHz is allowed in the sound portion of the TV broadcast.

In *FM*, the highest audio frequency transmitted is 15 kHz. Consider an FM carrier of resting frequency 100 MHz. Since $(\Delta f)_{max}$ = 75 kHz, the carrier frequency can swing from the lowest value of 99.925 MHz to the highest value of 100.075 MHz. Of course, deviations lesser than 75 kHz corresponding to relatively softer sounds are always permissible.

Modulation Index

It is given by the ratio $mf = \frac{\text{frequencydeviation}}{\text{modulation frequency}} = \frac{\Delta f}{fm}$

Unlike amplitude modulation, this **modulation index can be greater than unity**. By knowing the value of *mf*, we can calculate the number of significant sidebands and the bandwidth of the *FM* signal.

Deviation Ratio

It is the worst-case modulation index in which maximum permitted frequency deviation and maximum permitted audio frequency are used

$$\therefore\ deviation\ ratio = \frac{(\Delta f)}{fm(max)}$$

Now, for *FM* broadcast stations, $(\Delta f)max$ = 75 kHz and maximum permitted frequency of modulating audio signal is 15 kHz

$$\therefore\ deviation\ ratio = \frac{75KHZ}{15KHZ} = 5$$

For sound portion of commercial TV deviation ratio = $\frac{25KHZ}{15KHZ}$ = 1.67

Percent Modulation

When applied to *FM*, this term has slightly different meaning than when applied to *AM*. In *FM*, it is given by the ratio of actual frequency deviation to the maximum allowed frequency deviation

$$m = \frac{(\Delta f)actual}{(\Delta f)max}$$

Obviously, 100% modulation corresponds to the case when actual deviation equals the maximum allowable frequency deviation. If, in some case, actual deviation is 50 kHz, then

$$m = \frac{50}{75} = 0.667 = 66.7\%$$

Value of $m = 0$ corresponds to zero deviation *i.e.* unmodulated carrier wave. It is seen from the above equation that $m \propto (\Delta f)actual$. It means that when **frequency deviation (*i.e.* signal loudness) is doubled, modulation is doubled.**

Example 3.6. *What is the modulation index of an FM carrier having a carrier swing of 100 kHz and a modulating signal of 5 kHz ?*

Solution. $CS = 2 \times \Delta f$

$$\therefore \Delta f = \frac{CS}{2} = \frac{100}{2} = 50Khz, \quad \therefore\ mf = \frac{(\Delta f)}{fm} = \frac{50}{5} = 10$$

Example. 3.7. *An FM transmission has a frequency deviation of 18.75 kHz. Calculate percent modulation if it is broadcast*

(i) *in the 88-108 MHz band* ***(ii)*** *as a portion of a TV broadcast*

Solution. (*i*) For this transmission band,

$(\Delta f)max = 75$ kHz $\therefore\ m = \frac{18.75}{75}$ X 100 = 25%

(***ii***) In this case, $(\Delta f)max = 25$ kHz $\therefore\ m = \frac{18.75}{25}$ X 100 = 75%

Example 3.8. *An FM signal has a resting frequency of 105 MHz and highest frequency of 105.03 MHz when modulated by a signal of frequency 5 kHz. Determine*

(*i*) *frequency deviation*, **(*ii*)** *carrier swing*, **(*iii*)** *modulation index*,
(*iv*) *percent modulation*, **(*v*)** *lowest frequency reached by the FM wave*.

Solution. (*i*) $\Delta f = 105.03 - 105 = 0.03$ MHz = **30 kHz**

(ii) $CS = 2 \times \Delta f = 2 \times 30 =$ **60 kHz**

(iii) $mf = \frac{30}{5} = 6$

(iv) $mf = \frac{30}{5}$ X 100 = 60%

(v) ***lowest frequency*** = 105 – 0.03 = **104.97 kHz**

FM Sidebands

In *FM*, when a carrier is modulated, a number of sidebands are formed.* Though theoretically their number is infinite, their strength becomes negligible after a few sidebands. They lie on both sides of the centre frequency spaced fm apart. Sidebands at equal distances from $f0$ have equal amplitudes. If $f0$ is the centre frequency and fm the frequency of the modulating signal, then *FM* carrier contains the following frequencies :

(*i*) $f0$ **(*ii*)** $f0 \pm fm$ **(*iii*)** $f0 \pm 2\ fm$ **(*iv*)** $f0 \pm 3\ fm$ and so on

The bandwidth occupied by the spectrum is $BW = 2nfm$ where n is the highest order of the significant sideband.
Another approximate expression for spectrum bandwidth is $BW = 2\ (1 + mf)fm$

$Now,\ mf = \frac{(\Delta f)}{fm},$ hence $BW = 2\ (\Delta f + fm)$

This expression is based on the assumption that sidebands having amplitudes less than 5% of the unmodulated carrier wave are negligible or when mf is at least 6.

Modulation Index and Number of Sidebands

It is found that the number of sidebands

1. depends ***directly*** on the amplitude of the modulating signal,

2. depends ***inversely*** on the frequency of the modulating signal.

Since frequency deviation is directly related to the amplitude of the modulating signal, the above two factors can be combined in one factor called **modulation index**.

Hence, number of sidebands depends on $mf = \Delta f / fm$

Obviously, the number of pairs of sidebands

(*i*) increases as frequency deviation (or amplitude of modulating signal) **increases**.
(*ii*) increases as the modulating signal frequency **decreases**.

Example 3.9. *A 5 kHz audio signal is used to frequency-modulate a 100 MHz carrier causing a frequency deviation of 20 kHz. Determine*

(i) *modulation index* ***(ii)*** *bandwidth of the FM signal*.

Solution. (*i*) $mf = \frac{(\Delta f)}{fm} = \frac{20}{5}$ - 4

When mf = 4, and n= 7,

$$BW = 14fm = 14 \times 5 = \textbf{70 kHz}$$

Example 3.10. *In an FM circuit, the modulation index is 10 and the higest modulation frequency is 20 kHz. What is the approximate bandwidth of the resultant FM signal ?*

Solution. Since the value of *mf* is more than 6, we will use the expression

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

$$Now\ mf = \frac{(\Delta f)}{fm} \quad or\ 10 = \frac{(\Delta f)}{20}, \ \therefore\ \Delta f = 200\text{ kHz}$$

$$\therefore \quad BW = 2\,(200 + 20) = \textbf{440 kHz}$$

Comparison Between AM and FM

Frequency modulation ***(FM)*** has the following **advantages** as compared to amplitude modulation **(*AM*)** :

1. All transmitted power in ***FM*** is useful whereas in ***AM*** most of it is in carrier which ***serves no useful purpose.***
2. It has high signal-to-noise (S/N) ratio. It is due to two reasons : firstly, there happens to be less noise at ***VHF*** band and secondly, ***FM*** receivers are fitted with amplitude limiters

which remove amplitude variations caused by noise.
3. Due to 'guard-band' there is hardly any adjacent-channel interference.
4. Since only transmitter ***frequency*** is modulated in ***FM***, only fraction of a watt of audio power is required to produce 100% modulation as compared to high power required in *AM*.

However, FM has the following **disadvantages** :

1. It requires **much wider channel** —almost 7 to 15 times as large as needed by AM.
2. It requires complex and expensive transmitting and receiving equipment.
3. Since FM reception is limited to only line of sight, area of reception for FM is much smaller than for *AM*.

APPLICATIONS OF FM

There are four major areas of application for *FM* transmission:
1. First use is in **FM** broadcast band 88-108 MHz with 200 kHz channels in which commercial *FM* stations broadcast programmes to their listeners.
2. Second use is in TV. Though video signal is amplitude-modulated, sound is transmitted by a separate transmitter which is frequency-modulated.
3. Third use is in the mobile or emergency services which transmit voice frequencies (20-4000 Hz) only.
4. Fourth use is in the amateur bands where again only voice frequencies are transmitted

ASSIGNMENT 3

1. The antenna current of an AM transmitter is 8A when only carrier is sent out. It increases to 8.93A when the carrier is sinusoidally modulated. Find the percentage modulation?
2. A carrier wave of 600watts is subjected to 100% amplitude modulation. Determine:
   (i)Power in sideband (ii) power of modulated wave
3. A 5 kHz audio signal is used to frequency-modulate a 100 MHz carrier causing a frequency deviation of 20 kHz. Determine
   (i) modulation index (ii) bandwidth of the FM signal.

QUIZ 3

1. An FM signal has a resting frequency of 95 MHz and highest frequency of 95.03 MHz when modulated by a signal of frequency 5 kHz. Determine

(i) frequency deviation, **(ii)** carrier swing, **(iii)** modulation index,
(iv) percent modulation, **(v)** lowest frequency reached by the FM wave.

PRACTICAL SESSION

- Students are to experiment how AM is generated using the necessary laboratory equipment
- A report is to be submitted after

CHAPTER 4.0

DIGITAL MODULATION

Digital modulation is the process of encoding a **digital** information signal into the amplitude, phase, or frequency of the transmitted signal. The encoding process affects the bandwidth of the transmitted signal and its robustness to channel impairments.

In electronics and telecommunications, **modulation** is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that typically contains information to be transmitted.

Digital Modulation provides more information capacity, high data security, quicker system availability with great quality communication. Hence, digital modulation techniques have a greater demand, for their capacity to convey larger amounts of data than analog modulation techniques.

T**o** create a digital signal, an analog signal must be modulated with a control signal to produce it. In digital radio, schemes, one or more carrier waves are amplitude, or frequency or phase modulated with a signal to produce a digital signal suitable for transmission.

In digital modulation, an analog carrier signal is modulated by a digital bit stream. Digital modulation methods can be considered as **digital-to-analog conversion**, and the corresponding **demodulation** or detection as **analog-to-digital conversion**

Most radio systems in the 20^{th} century used FM or AM to make the carrier carry the radio broadcast.

The **aim of analog modulation** is to transform an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog band-channel at a different frequency, for example over a limited radio frequency band or a cable TV network channel.

The **aim of digital modulation** is to transfer a digital bit stream over an analog bandpass channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to 300-3400Hz) or over a limited radio frequency band. Analog and digital modulation facilitate **frequency division multiplexing** (FDM), where several lowpass information signals are transferred simultaneously over the same shared physical medium using separate passband channels (several different carrier frequencies).

The aim of digital baseband modulation methods, also known as **line coding** is to transfer digital bit stream over a baseband channel, typically a non filtered copper-wire such as a serial bus or a wired local area network.

There are many types of digital modulation **techniques** and also their combinations, depending upon the need. Of them all, we will discuss the prominent ones.

ASK – Amplitude Shift Keying

The amplitude of the resultant output depends upon the input data whether it should be a zero level or a variation of positive and negative, depending upon the carrier frequency.

FSK – Frequency Shift Keying

The frequency of the output signal will be either high or low, depending upon the input data applied.

PSK – Phase Shift Keying

The phase of the output signal gets shifted depending upon the input. These are mainly of two types, namely Binary Phase Shift Keying BPSKBPSK and Quadrature Phase Shift Keying QPSKQPSK, according to the number of phase shifts. The other one is Differential Phase Shift Keying DPSKDPSK which changes the phase according to the previous value.

M-ary Encoding

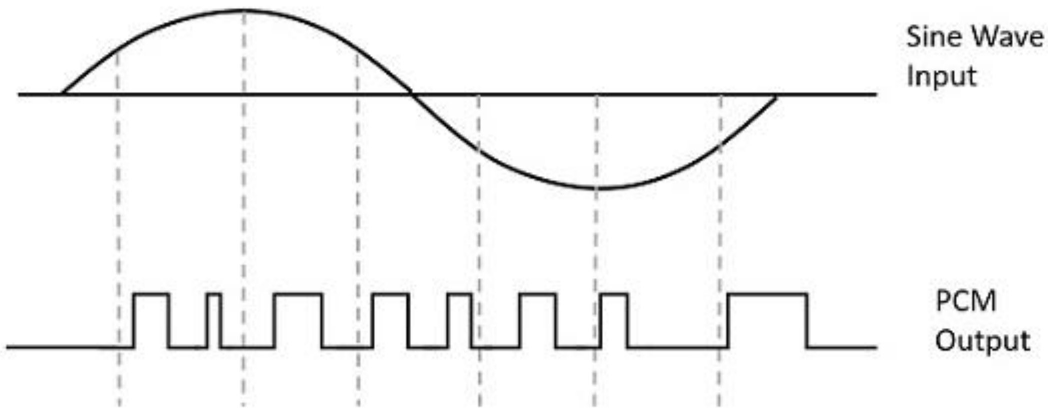
M-ary Encoding techniques are the methods where more than two bits are made to transmit simultaneously on a single signal. This helps in the reduction of bandwidth.

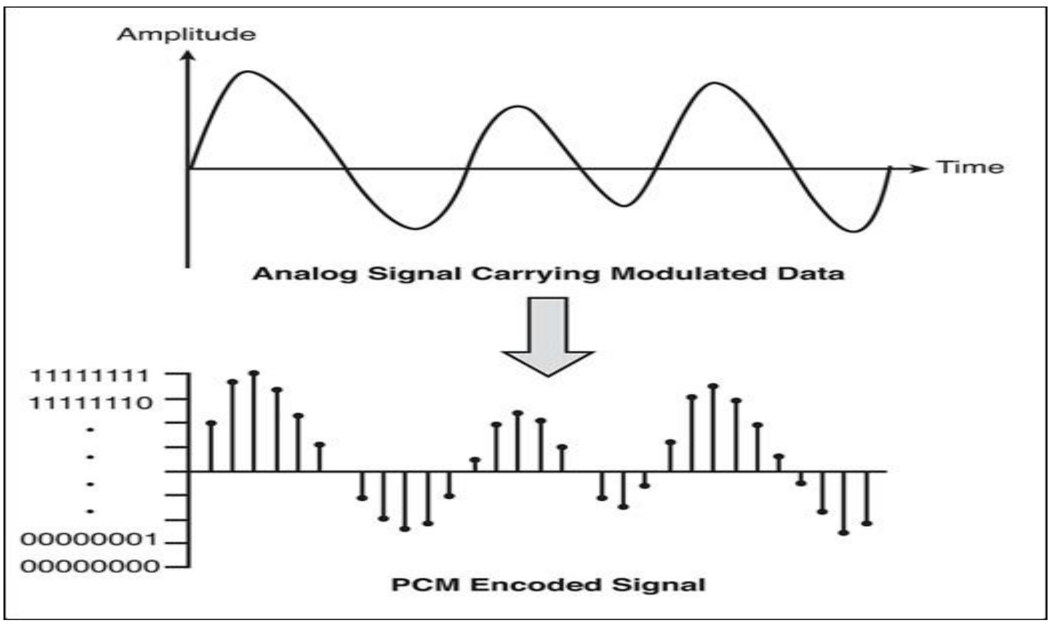
The types of M-ary techniques are −

- M-ary ASK
- M-ary FSK
- M-ary PSK

TYPES OF DIGITAL MODULATION

(1) Pulse code modulation is a method that is used to convert an analog signal into a digital signal so that a modified analog signal can be transmitted through the digital communication network. **PCM** is in binary form, so there will be only two possible states high and low (0 and 1).



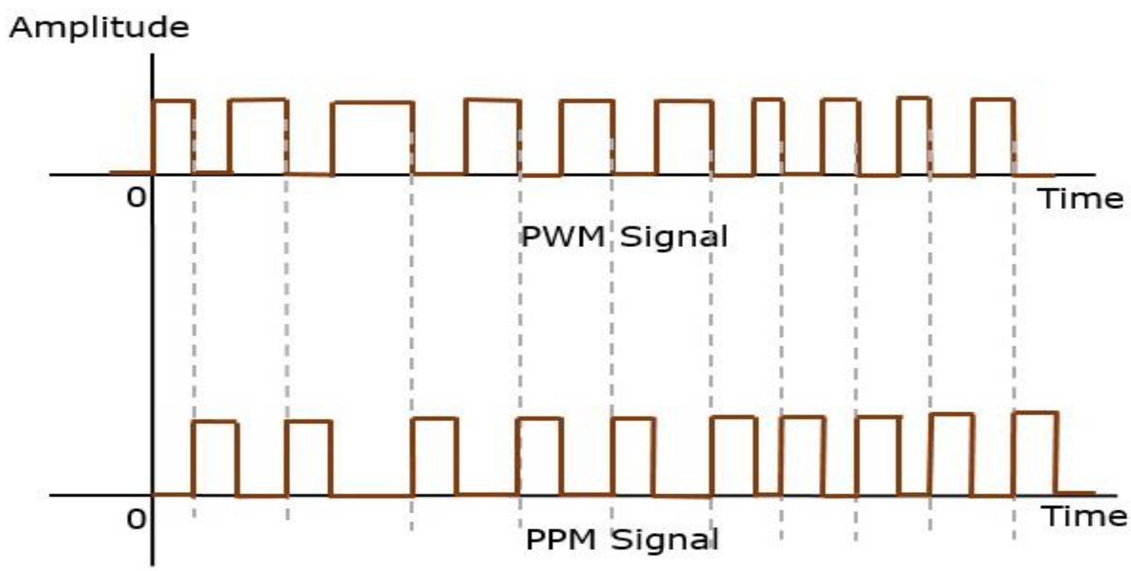


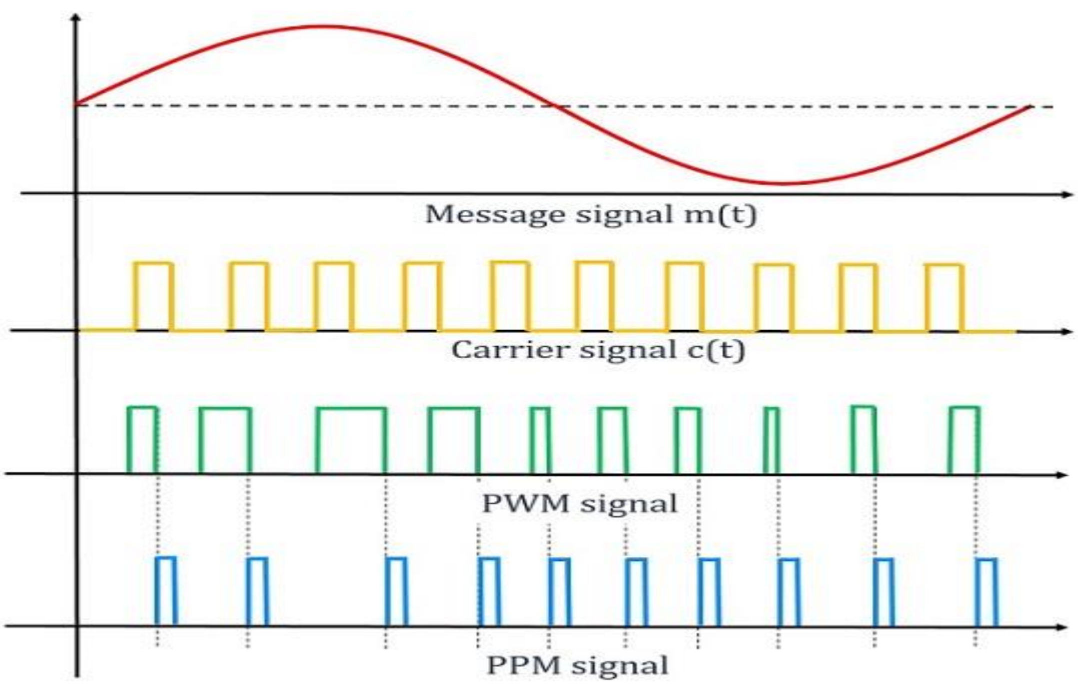
In this modulation technique, the amplitude of an analogue signal is converted to binary value represented as series of pulses.

Area of application of PCM

- Air- traffic control system
- Used in space communication
- Used in telephony
- Used in satellite transmission system
- For compressing data in compact disc
- For signal conversion
- Audio signals

(2) Pulse-position modulation (PPM) is a form of signal **modulation** in which M message bits are encoded by transmitting a single **pulse** in one of possible required time shifts. In this modulation, the amplitude and the width of the pulses are kept constant but the position of each pulse is varied in accordance with the amplitude of the sampled value of the modulating signal. In other words, the position of the pulses is changed with respect to the position of the reference pulses.





Waveform representation of PPM signal generation

Electronics Coach

.**Advantages of PPM**

- Noise interference is less and minimum due to constant amplitude
- It is easy to separate out signal from noise signal
- It has highest power efficiency among all the rest
- It requires less power compare to PCM due to short duration pulses

Disadvantages of PPM

- This method is the highest in complexity to implement
- It requires very large bandwidth compare to PAM

Applications of PPM

- Used for radio frequency communication
- For remote control in aircraft, cars, boat and other vehicles
- Responsible for conveying a transmitter' control to a receiver

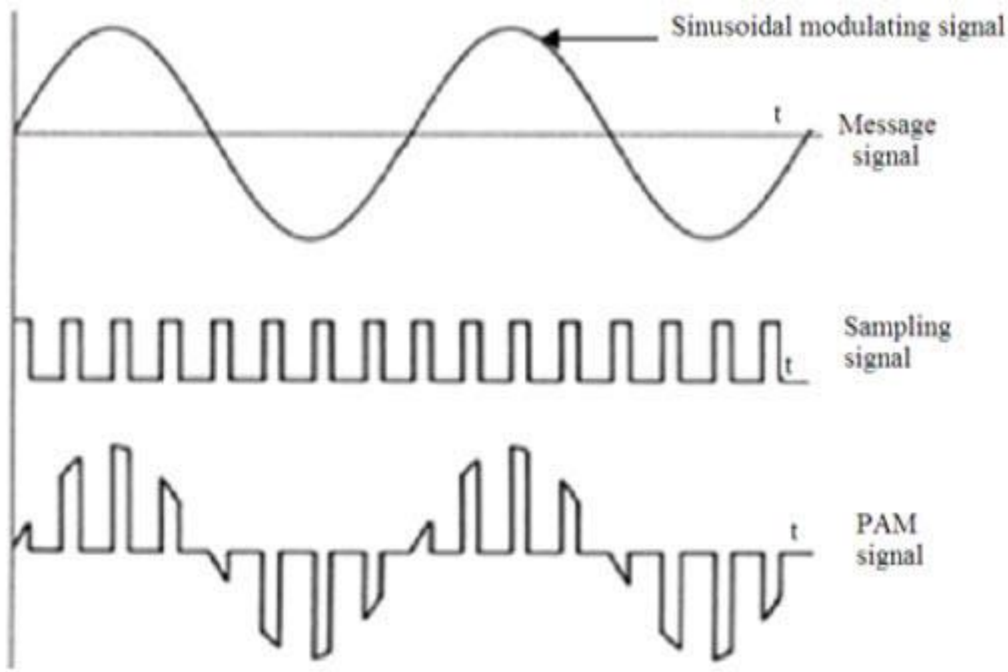
(3) Pulse-amplitude modulation (**PAM**), is a form of signal **modulation** where the message information is encoded in the **amplitude** of a series of signal **pulses**. It is an analog **pulse modulation** scheme in which the **amplitudes** of a train of carrier **pulses** are varied according to the sample value of the message signal.

In this technique, the signal is sampled at regular intervals and each sample is made proportional to the amplitude of the signal at the instant of sampling.

- it is the most efficient in terms of power and bandwidth utilization
- it is the simplest form of modulation
- it is analog-to-digital conversion method where the message information is encoded in the amplitude of the series of signal pulses

Area of Applications of PAM

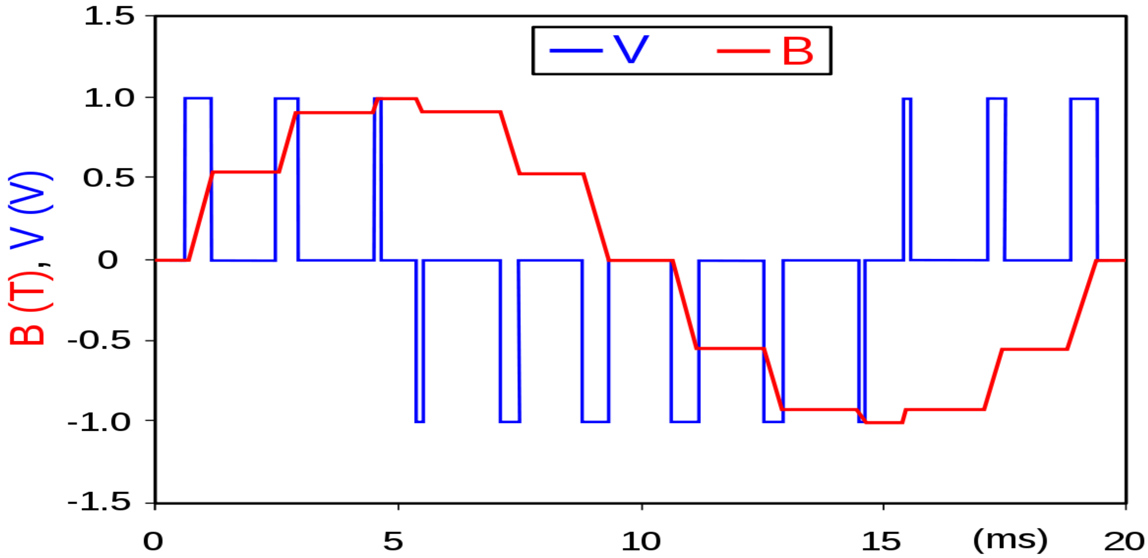
- used for Ethernet communication
- used in many micro-controllers for generating control signal used in photo biology
- used for coherent detection
- used in electronic driver for LED lighting
- for digital television
- radio frequency communication
- contactless smart card, HF RFID tags etc



(4) Pulse Width Modulation (**PWM**) is a fancy term for describing a type of digital signal.

it is a method for generating analog signal using a digital source. It is used for encoding the amplitude of a signal right into a pulse width or duration of another signal usually a carrier signal for transmission. In this technique, the width of the signal is varied in accordance with the pulse train.

Pulse width modulation is used in a variety of applications including sophisticated control circuitry. A common way we use them here at SparkFun is to control dimming of RGB LEDs or to control the direction of a servo.


V
B
1.5
1.0
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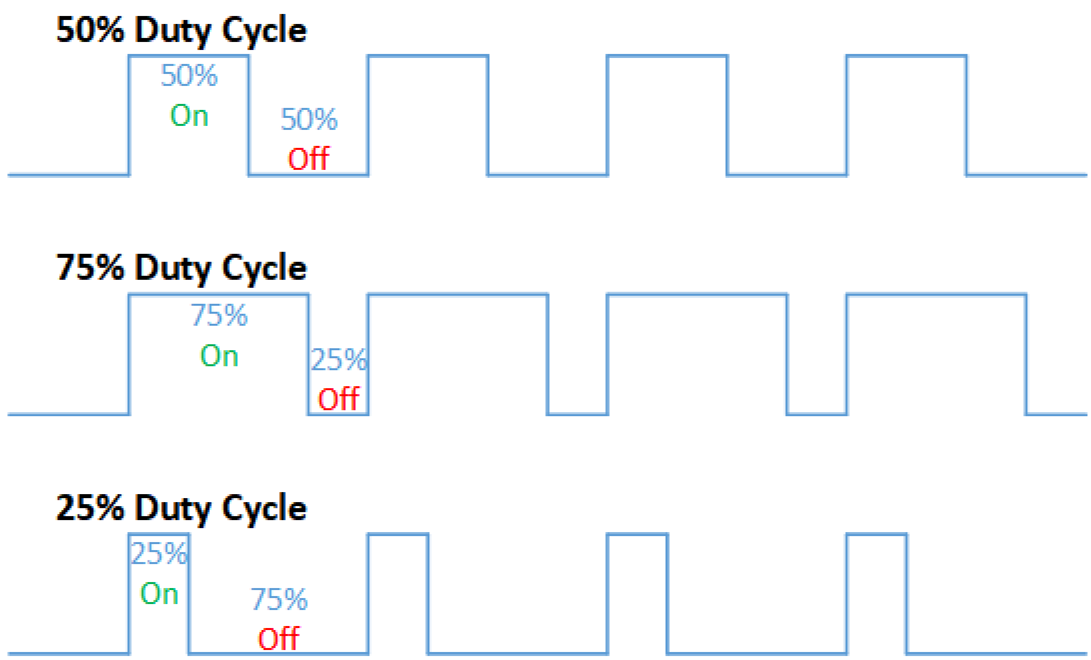
B (T), V (V)
0
5
10
15
(ms)
20


50% Duty Cycle
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75%
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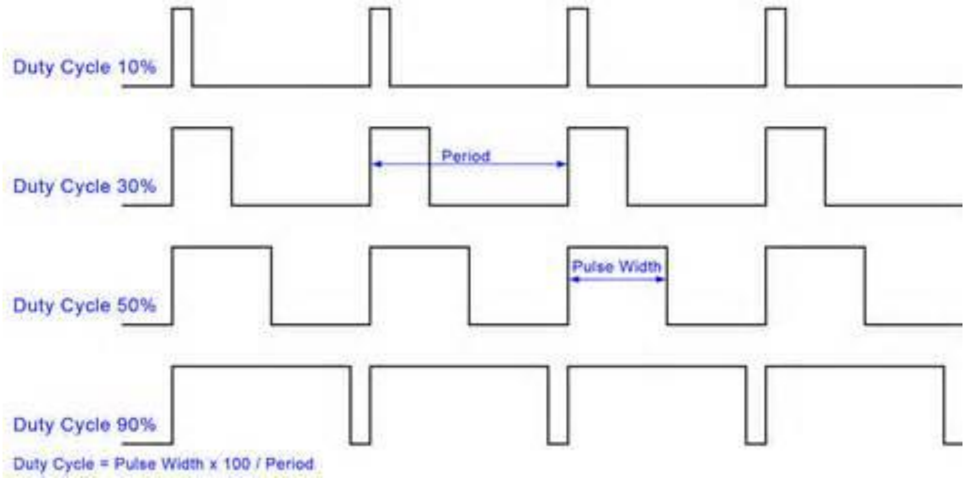

Area of Applications of PWM

- measurement and control
- speed control (in DC motor)
- heating elements
- controlling the direction of servo motors
- controlling the dimming of RGB LEDs

ASSIGNMENT

1. Explain three industrial areas where and how digital modulation is utilized
2. In a broadcasting studio, a 1000 kHz carrier is modulated by an audio signal of frequency range, 100-5000 Hz. Find
   (i) width or frequency range of sidebands
   (ii) maximum andminimum frequencies of USB
   (iii) maximum and minimum frequencies of LSB and
   (iv) width of the channel.
3. A carrier wave of 600watts is subjected to 100% amplitude modulation. Determine :
   a. Power in sideband (ii) power of modulated wave

QUIZ

1. Explain any two types of digital modulation, state their advantages, applications and sketch their diagrams
2. A transmitter radiates 9kw without modulation and 10.125kw after modulation. Determine the depth of modulation.
3. State three reasons why modulation is necesary

CHAPTER 5.0

Demodulation or Detection of AM & FM Signals

When the *RF* modulated waves, radiated out from the transmitter antenna, after travelling through space, strike the receiving aerials, they induce very weak *RF* currents and voltages in them. If these high-frequency currents are passed through headphones or loudspeakers, they produce no effect on them because all such sound-producing devices are unable to respond to such high frequencies due to large inertia of their vibrating discs etc. Neither will such *RF* currents produce any effect on human ear because their frequencies are much beyond the audible frequencies (20 to 20,000 approximately). Hence, it is necessary to demodulate them first in order that the sound-producing devices may be actuated by audio-frequency current similar to that used for modulating the carrier wave at the broadcasting station.
This process of ***recovering AF signal from the modulated carrier wave is known as demodulation or detection.***

The demodulation of an *AM* wave involves two operations :

(*i*) rectification of the modulated wave and
(*ii*) elimination of the *RF* component of the modulated wave.

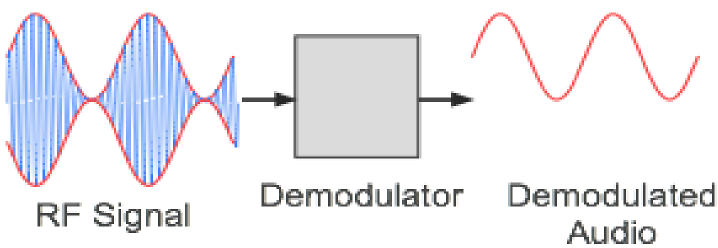

Figure 5.1: **AM Demodulation principle**

Essentials of AM Detection

For recovering the *AF* waveform from modulated wave (a mixture of *AF* wave and *RF* carrier), it is essential to find some way of reducing (or better, eliminating) one half of the modulated wave. The result of this elimination (or rectification) would be that the average value of the wave would not be zero because, now, the impulse would be all in one direction as shown in the Fig.. If this new wave is now passed through a headphone shunted by a suitable capacitor, then *AF* wave will pass through the headphone whereas the *RF* wave will be by-passed by the capacitor (because the high inductance of magnet coils of the headphones will offer tremendous impendance to *RF* currents). Hence, two will become separated.

Amplitude modulation may be demodulated through the following means

- Diode detectors
- Transistor detectors

Diode Detector (Envelope Demodulator) for AM Signals

Diode detection is also known as **envelope-detection** or **linear detection**. In appearance, it looks like an ordinary half-wave rectifier circuit with capacitor input as shown in Fig. 4.1. It is called **envelope detection** because it recovers the *AF* signal envelope from the composite signal. Similarly, diode detector is called **linear detector** because its output ***is proportional to the voltage of the input signal*.***

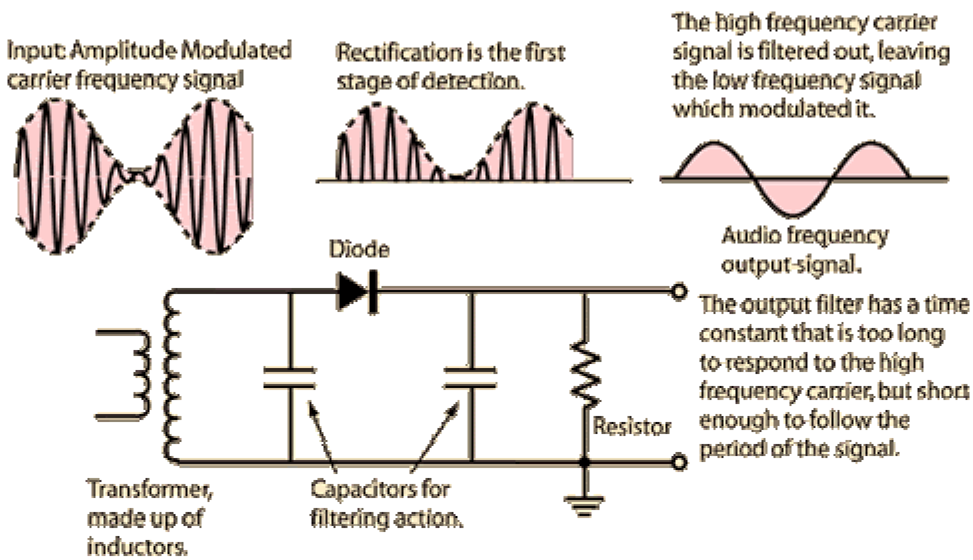

Figure 5.2: Diode Detector circuit

Advantages

Diode detectors are extensively used in AM broadcast receivers because they have the following advantages :

1. They can handle comparatively large input signals;
2. They can be operated as linear or power detectors;
3. They rectify with negligible distortion and, hence, have good linearity;
4. They are well-adopted for use in simple automatic-gain control circuits.

Disadvantages

However, the disadvantages are that

1. They do not have the ability to amplify the rectified signal by themselves as is done by a transistor detector. However, it is not a very serious drawback since signal amplification can be affected both before and after rectification;
2. while conducting, the diode consumes some power which reduces the *Q* of its tuned circuit as well as its gain and selectivity.

FM Detection

As discussed earlier, an *FM* carrier signal contains information (or intelligence we wish to convey) in the form of frequency variations above and below the centre frequency of the carrier. For recovering the information, we must first convert the *FM* signal in such a way that it appears as a modulated *RF* voltage across the diode. A simple method of converting frequency variations into voltage variations is to make use of the principle that reactance (of coil or capacitor) varies with frequency. When an *FM* signal is applied to an inductor, the current flowing through it varies in amplitude according to the changes in frequency of the applied signal. Now, changes in frequency of the *FM* signal depend on the amplitude of the modulating *AF* signal. Hence, the current in the inductor varies as per the amplitude of the original modulating signal. In this way, frequency changes in *FM* signal are converted into amplitude changes in current. These changes in current when passed through a resistor produce corresponding changes in voltage. Hence, we find that, ultimately, frequency variations in *FM* signal are converted into voltage changes. Also, there exists a linear relation between the two – something essential for distortion-less demodulation.

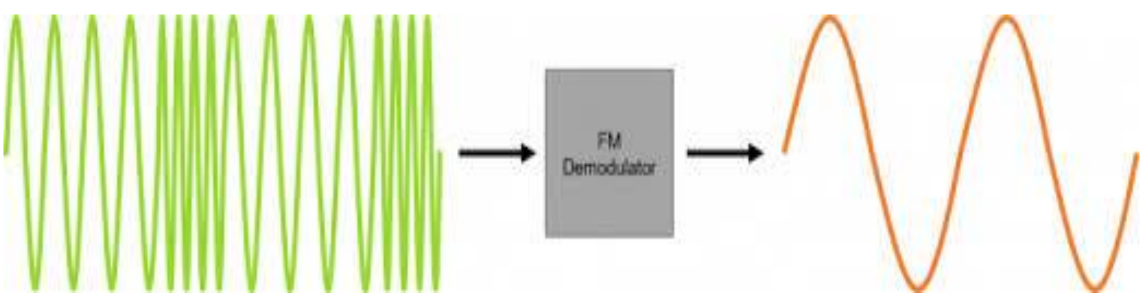

Figure 5.3: **FM Detector wzvefrom, seperating the AF signal**

FM demodulation may be carried out with the help of ***(i)*** ratio detector and ***(ii)*** quadrature detector.

Demodulation of an *FM* wave involves three operations ***(i)*** conversion of frequency changes produced by modulating signal into corresponding amplitude changes, ***(ii)*** rectification of the modulating signal and ***(iii)*** elimination of *RF* component of the modulated wave.

ASSIGNMENTS

1. List the different methods of detecting AM and FM signals
2. Explain one method each form the list above
3. Sketch the circuit of the diode detector and explain

QUIZ

1. Define demodulation
2. State five differences between modulation and demodulation