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Principles of Radio Waves Propagation for Wireless Communication

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Abstract

This work presents the fundamental principles of radio communication systems, which include modulation, propagation, and demodulation processes. The system arrangement is divided into three major sections: the transmitter, transmission and receiver. The radio transmitter is used to produce radio waves and radiates them with the help of an antenna. The transmission is achieved with the transmitting antenna which radiates the radio waves in space in all directions with the velocity of light. Then the receiver receives the signal from the antenna and converts the signal back to its original form which is understandable by humans at the destination. It is found that radio waves are propagated from a transmitting to a receiving antenna by modifying the amplitude, frequency or the relative phase of the wave form in response to some message signal via modulation. The two types of modulation used in this work are amplitude modulation (AM) and frequency modulation (FM). The result obtained suggests that for amplitude modulated wave the amplitude of the carrier wave changes according to the intensity of the message signal. Also the amplitude variations of the carrier wave is at the message signal frequency whereas for frequency modulated wave it is found that the frequency deviation of FM signal depends on the amplitude of the modulating signal and the audio frequency (i.e. frequency of modulating signal) does not determine frequency deviation. This research holds great significance as it is able to integrate different theoretical knowledge gained through Astrophysics, Electronics and Telecommunication.

Keywords: *Radio communication, transmitter, receiver, modulation, demodulation, carrier wave AM wave, FM wave, sideband.*

Introduction

In this era of "information age" where wireless communication systems influence most of human activities and play a vital role in providing international communication facilities that was originally constrained by distance, thereby allowing communication efficiently over longer distances has attracted research interest. Information transfer, including speech, music, images, computer data, etc. via the design of efficient wireless communication systems represents a technological progress and significant breakthrough in the information communication technology.

Radio waves are typically thought of as electromagnetic signals that travel through space at a speed of approximately 300,000,000 meters per second. Thus, radio waves are the basic unit of wireless communication. Such waves radiated at the speed of light are transmitted not only by line of sight but also by deflection from the ionosphere [1]. The term "radio" which is most commonly associated with commercial radio broadcasting services encompasses the entire range of wireless communications technologies and services, including television, microwave, radar, shortwave radio, mobile, and satellite communications etc. There are four main modes of propagation of radio waves: ground wave, sky wave, and space wave. Sky Wave Propagation: This occurs when the signal is transmitted by the transmitting antenna is reflected by the ionosphere layer (sky) and received by the receiving antenna. Space Wave Propagation: This happens when there are no reflection, refraction, or deflection effects as the transmitting wave travels straight to the receiving antenna. Ground Wave Propagation: This occurs when the transmitting waves travel along the earth's surface and are received at the receiving antenna. Tropospheric Scatter Propagation: This is a form of radio communication that uses the scattering of radio waves off the Earth's troposphere to reach distant locations. This form of signal propagation works by reflecting the signal off minute atmospheric imperfections like water droplets or dust particles, which scatter it in various directions [2].

Generally, radio communication means the radiation of radio waves by the transmitting station, the propagation of these waves through space and their reception by the radio receiver. Information or message signals to be transmitted are called baseband signals [3] [4]. The baseband signals have a very low frequency and as result cannot be transmitted over long distances. Hence modulation process in which a very high-frequency carrier wave is used to transmit the low-frequency message signal is employed so that the transmitted signal continues to have all the information contained in the original message signal [5] [6].

The general principle of radio communication is that sounds and images are converted into electrical signals by a microphone (sounds) or video camera (images), amplified, and used to modulate a carrier wave that has been generated by an oscillator circuit in a transmitter. The modulated carrier is also amplified, and then applied to an antenna that converts the electrical signals to electromagnetic waves for radiation into space.. Receiving antennas intercept part of this radiation, change it back to the form of electrical signals, and feed it to a receiver as shown in Figure 1 [7][8][9].

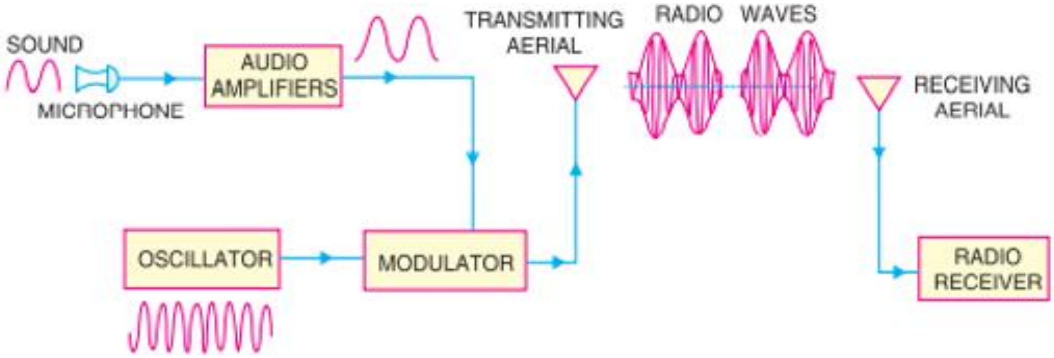

Figure1. *Generalprinciples of radio broadcasting, transmission and reception.*

In this paper we have provided comprehensive principles of radio broadcasting, transmission and reception with emphases on modulation and demodulation techniques

RELATED WORK

This section presents the knowledge essential to understanding the basic concept of radio communication. In principles, message (audio) signal cannot travel a long distance because of its low frequency and hence low signal strength. In addition to this, physical surroundings, such as external noise and travel distance will further lower the signal strength of a message signal. However, to send the message signal (modulating signal) to a long distance, we need to increase the signal strength of a message signal. This is achieved by creating a new high energy signal that transmits information over a farther distance, the low energy message signal is combined with the high energy or high frequency carrier signal as shown in Figure 2 [10][11].

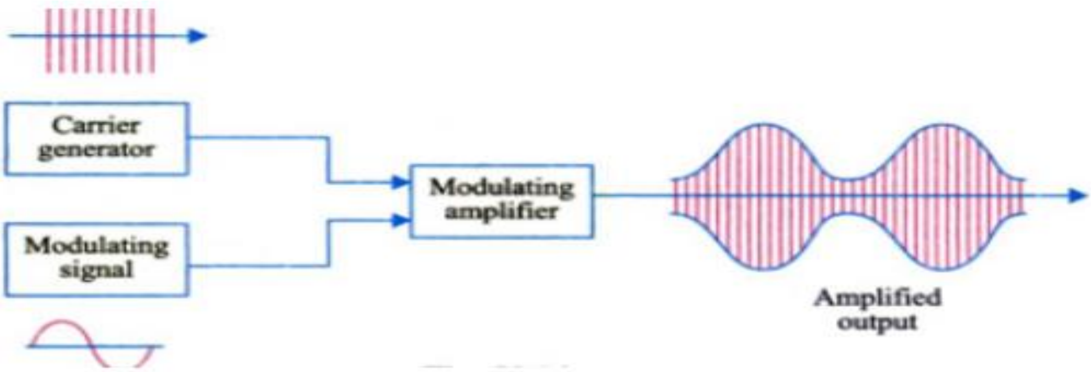

Figure2. *Modulation process.*

As a result, the carrier waves can be likened to a horse and the audio-frequency signal to a rider.

The process by which audio frequency signal or information is impressed on the carrier wave is known as modulation. Through space, the horse and rider move and enter the receiver at the receiving end, which separate the rider and horse. The rider, or audio-frequency signal, is transformed back into sound when the carrier wave, or horse, has been returned. This process by which the radio waves and audio waves are separated is known as detection or demodulation (reverse of modulation) [12]. Now we are dealing with two signals: 1. Original (“baseband”) message signal whose frequency is too low to transmit efficiently 2. Higher frequency (“carrier”) signal which we can transmit efficiently, so we use it to carry our baseband information.

Since both information and carrier signals are wave as shown in Figure 3 they can also be represented by a wave equation accordingly.

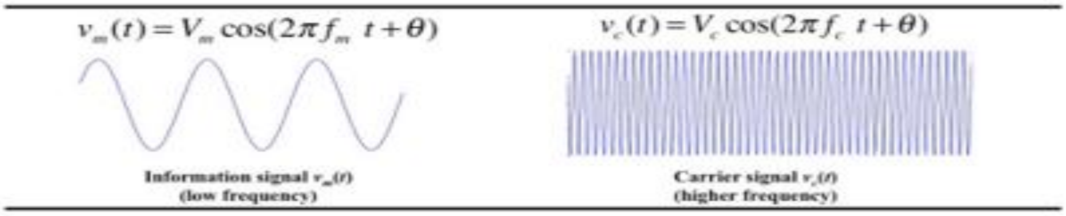

Figure3. *Information and carrier signals wave form.*

Mathematically, the cosine wave representing the higher-frequency carrier is given by:

$$V_C(t) = A_C \cos(2\pi f_C t + \emptyset_c) \quad (1)$$

A carrier wave has three defining properties, which are amplitude (A_C), frequency (f_C) and phase (∅_c). These three parameters are used to create different types of modulation. In the modulation process, a parameter of the carrier wave (such as amplitude, frequency or phase) is varied in accordance with the modulating signal. This variation acts as a code for data transmission. Thus, practically modulation is the process of varying any of these three properties (amplitude, frequency or phase) of a high frequency carrier using the lower-frequency information signal (baseband signal). Accordingly, there are three basic types of modulation, namely; (i) amplitude modulation (ii) frequency modulation (iii) phase modulation [13][14] The word "Modulation" implies change. The carrier signal contains no information, whereas the message signal does. Carrier signal is employ to transmit the information to a long distance which at the destination, the message signal is absorbed whereas the carrier signal is removed. The message signal's properties will not change during the modulation process, but only the carrier signal's characteristics. Since there is no information in the carrier signal, even if its properties are modified, the information it contains will remain unchanged. However, the message signal contains information; as a result, if we alter the message signal's properties, the information it carries will likewise alter.

As a result, we always modify the carrier signal's properties but not the message signal's. Modulation permits the transmission to occur at high frequency while it simultaneously allows the carrying of the message signal. [15][16][17].

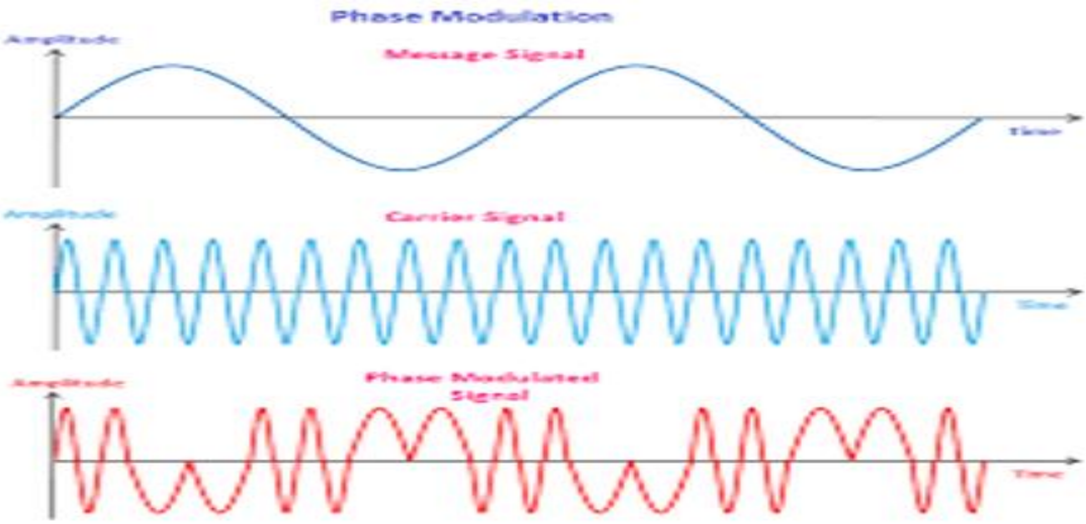

Figure4. *Phase modulation process.*

Using the straightforward phase modulation in Figure 4, it is possible to comprehend the modulation process. The first signal displays the message signal, which includes the message that will be sent to the target. The message signal is sometimes called as the modulating signal. The second signal is the carrier, which contains the high energy or high frequency signal and has properties like amplitude, frequency, and phase but lacks information. From transmitter to receiver, the message signal is transported by a carrier signal. The third signal is referred to as a modulated signal. A new signal created when the message signal and carrier signal combined. [18][19][20].

The instantaneous phase of the carrier signal varies in line with the instantaneous amplitude of the message signal, as can be seen from the three figures above. Radio broadcasting often use amplitude modulation. However, in television transmission, the picture signal is sent using amplitude modulation while the sound signal is sent using frequency modulation.

IMPORTANCE MODULATION IN RADIO WAVE PROPAGATION

The following factors make modulation crucial in communication systems [21]\:

It Decreases Antenna Length

The transmitting antenna emits the signal into free space, where it is picked up by the receiving antenna. In order to effectively transmit and receive the signal, the antenna height should be approximately equal to the wavelength of the signal to be transmitted.

Now,

$$Wavelength\ (\lambda) = \frac{Velocity\ (V)}{Frequency\ (f)} = \frac{3\ \times 10^8}{frequency\ (Hz)}\ metres$$

The audio signal has a very low frequency (i.e. 20 Hz to 20 kHz) and longer wavelength, so if the signal is transmitted directly into space, the length of the transmitting antenna required would be extremely large. For instance, to radiate an audio signal frequency of 20 kHz directly into space, we would need an antenna height of 15,000 meters as illustrated below.

$$Wavelength\ (\lambda) = \frac{Velocity\ (V)}{Frequency\ (f)} = \frac{3\ \times 10^8}{20KHz} = 15{,}000\ metres$$

The antenna of this height is practically impossible to construct. On the other hand, if the audio signal (20Hz) has been modulated by a carrier wave of 200MHz. Then, we would need an antenna height of 1.5 meters as indicated under.

$$Wavelength\ (\lambda) = \frac{Velocity\ (V)}{Frequency\ (f)} = \frac{3\ \times 10^8}{200\ MHz + 20\ Hz} = \frac{3\ \times 10^8}{(200\ \times 10^6) + 20} = 1.5\ metres$$

The antenna of this height is easily constructed.

It Enhances Communication Range

A wave's frequency determines its energy. The energy that a wave possesses increases with its frequency. Since the frequency of baseband audio transmissions is so low, they cannot be transmitted across long distances. The carrier signal, however, has a high frequency or high energy. Therefore, if the carrier signal is emitted directly into space, it may travel great distances. The low energy baseband signal must be mixed with the high energy carrier signal in order to effectively transmit the baseband signal over a long distance. The resulting signal frequency will shift from low frequency to high frequency when the low frequency or low energy baseband signal is combined with the high frequency or high energy carrier signal. As a result, it is now feasible to send information over long distances. As a matter of fact, communication range is increased.

It Makes Wireless Communication Possible

One ideal aspect of radio transmission is that it should be radiated into space rather than transported across wires. The baseband signals' frequency range is quite small (20 Hz to 20 KHz). Baseband transmissions have a weak signal, thus it is not possible to transmit them into space directly. High frequencies (over 20 kHz), nevertheless, make it possible to radiate electrical energy effectively. However, the baseband signal's frequency is changed from low to high frequency using the modulation approach. Therefore, the signal can be directly emitted into space after modulation.

It Avoids Signals Mix-Up

Transmitting several messages at once via a single communication channel is one of the fundamental difficulties faced by communication engineering. Multiplexing is a technique that allows several signals or multiple signals to be merged into one signal and broadcast over a single communication channel. We are aware that the range of audible frequencies is 20 Hz to 20 KHz. When numerous baseband sound signals in the same frequency range—20 Hz to 20 KHz—are merged into one signal and sent over a single communication channel without modulation, the signals get muddled and the receiver is unable to distinguish between them. The modulation approach allows us to quickly solve this issue. The baseband sound waves of the same frequency range (i.e., 20 Hz to 20 KHz) are moved to other frequency ranges by applying modulation. As a result, within the overall bandwidth, each signal now has its own frequency range. After modula-tion, it is simple to broadcast numerous signals with various frequency ranges across a single communication channel without any mixing, and it is simple to separate them at the receiving end.

It Lowers the Noise Effect

An unwanted signal known as noise can enter a communication system through a channel, interfering with the broadcast signal. The weak signal power of a message prevents it from traveling far. A message signal's signal strength will be further diminished by the addition of outside noise. So, in order to transmit the message signal over a long distance, we must strengthen the message signal. Modulation is a technique that may be used to achieve this. A low energy or low frequency message signal is combined with a high energy or high frequency carrier signal in the modulation process to create a new high energy signal that transmits information over a long distance without being hampered by outside noise.

Factors Affecting Radio Wave Propagation [22]

Attenuation: this is loss of strength of a signal while propagating through the communication channel as shown in Figure 7. Though there are losses at the transmitter end and the receiver end still it is standard practice to assume transmitter and receiver as ideal. The losses due to attenuation can be compensated with amplification. Therefore it is not a serious problem.

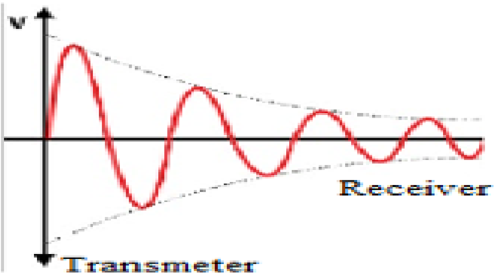

Figure5. *Attenuation process.*

Distortion: this is a waveform perturbations caused by the imperfect response of the system to the desired signal itself as shown in Figure 6. Distortion disappears when signal causing distortion is turned off or disappears. If channel has a linear but distorting response, then distortion may be corrected or at least reduced using filter devices called equalizers.

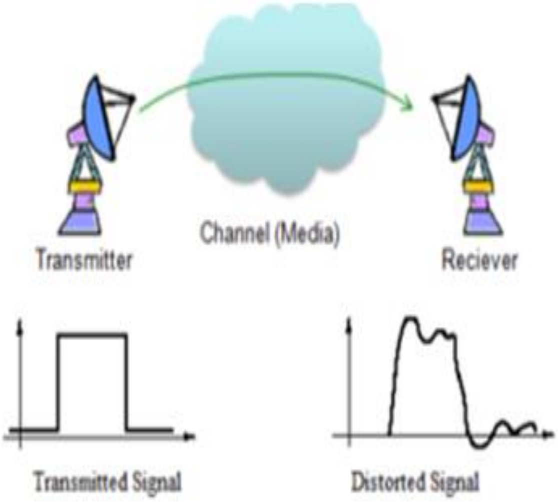

Figure6. *Distortion process.*

Interference: interference is the contamination due to extraneous signals from other transmitters, machinery, power lines, switching circuits and human sources as shown in Figure 7. It occurs mostly at the reception end as a result of the antenna there simultaneously collecting several signals. By forcing the unwanted signal to inhabit a separate frequency range than the interfering signal, effective filtering circuits eliminate interference.

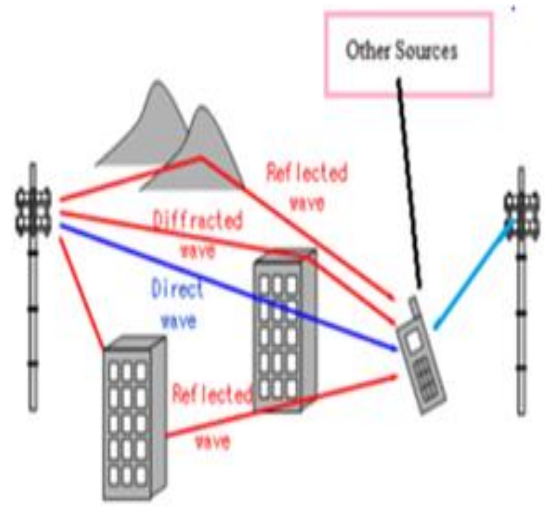

Figure7. *Interference process.*

Noise: this is refers to the unwanted signals that tend to disturb the transmission and processing of message signals in a communication system as shown in Figure 8. They are random and unpredictable electrical signals produced by natural processes. There might be internal or external noise. Electrical signals that have such random changes overlaid on them can damage information-carrying symbols partially or completely. Filters can lower noise but not totally remove it.

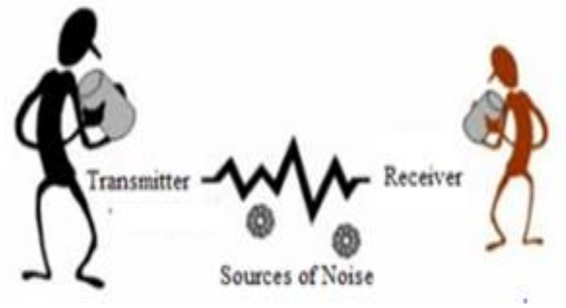

Figure8. *Noise process.*

MATERIALS AND METHODS

The method and approach we have used for the propagation of the radio wave include modulation and demodulation processes. The two most common types of modulation used in this work are amplitude modulation (AM) and frequency modulation (FM). A straight radio receiver was used to recover the baseband signal. The radio receiver performs two basic functions. The first step is to use demodulation techniques to extract the modulating signal from the carrier wave. The other is to offer selectivity. So that with vast number of stations on the radio frequency bands the receiver tunes stations on the required frequency and rejects the unwanted frequency bands. Diode detector is used for the demodulation.

Amplitude Modulation

In amplitude modulation, the amplitude (signal strength) of the carrier signal is varied in accordance with the amplitude (signal strength) of the message signal. In other word, the information (message signal) is transmitted over a carrier wave by varying its amplitude in accordance with the amplitude of the message signal. Additionally, the carrier signal's instantaneous amplitude varies in accordance with the message signal's instantaneous amplitude. In a typical amplitude modulation, only the amplitude of the carrier wave is changed while the frequency and phase of the carrier wave remain constant. The modulating signal or message signal which contains information, the high frequency carrier signal which contains no information and the resultant amplitude modulated signal respectively are as shown in Figure 9.

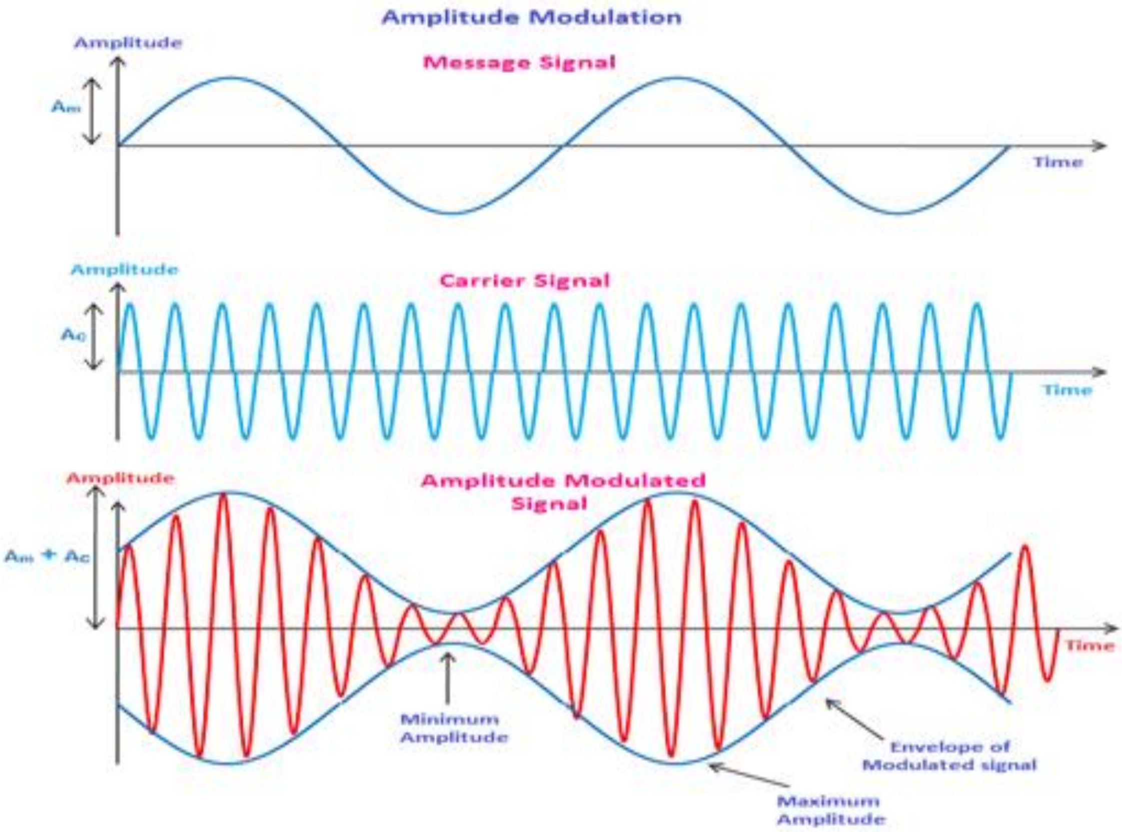

Figure9. *Amplitude modulation process.*

Frequency Modulation (FM)

In frequency modulation, the amplitude changes of the message signal determine the frequency of the carrier signal. In other words, the frequency of a carrier wave is changed in line with the amplitude of the information (message signal) to be conveyed. Additionally, instantaneous frequency of carrier signal is varied accordingly with instantaneous amplitude of message signal as shown in Figure 10.

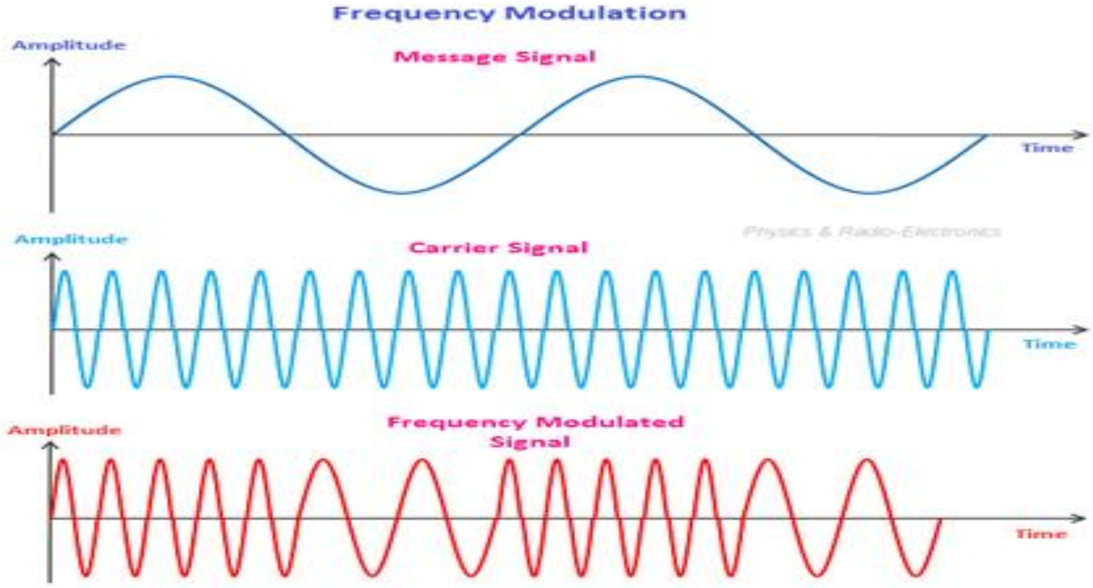

Figure10. *Frequency modulation process.*

Demodulation

Demodulation is the reverse process of modulation

to recover the message signal (audio signal) from the modulated wave at the receiver. To send the audio signal farther to a receiver, modulation is done at the broadcasting station. It is important to extract the audio signal from the modulated wave after the radio receiver receives it. This is possible in the radio receiver through a process known as demodulation. In demodulation, the combination of carrier and message signal are separated from each other, to have an original information signal as shown in Figure 11.

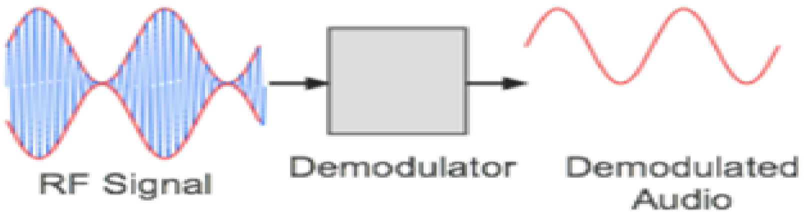

Figure11. *Demodulation process.*

Diode Detector for AM Signals

A detector is a device that transforms high frequency radio signals into low frequency audio signals that may be heard through headphones or amplified and delivered through a loudspeaker. We have seen that AM modulated wave has positive and negative halves exactly equal that form the modulation envelop as shown in Figure 12. Thus, average current is zero and speaker cannot respond.

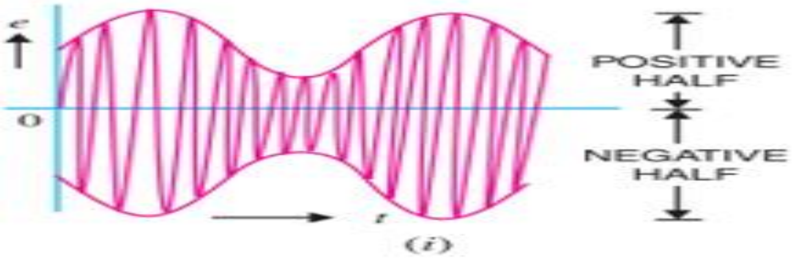

Figure12. *Showing AM modulated wave.*

One way to recover the message signal from the modulated carrier is to isolate just the envelope from the rest of the modulated signal. Envelope detection is the name given to this kind of AM demodulation, and it only requires two stages at its most basic level. First, the modulated signal is rectified, leaving behind only the positive half. As seen in Figure 13, the second stage filters away the carrier's high-frequency components to leave just the low-frequency audio stream.

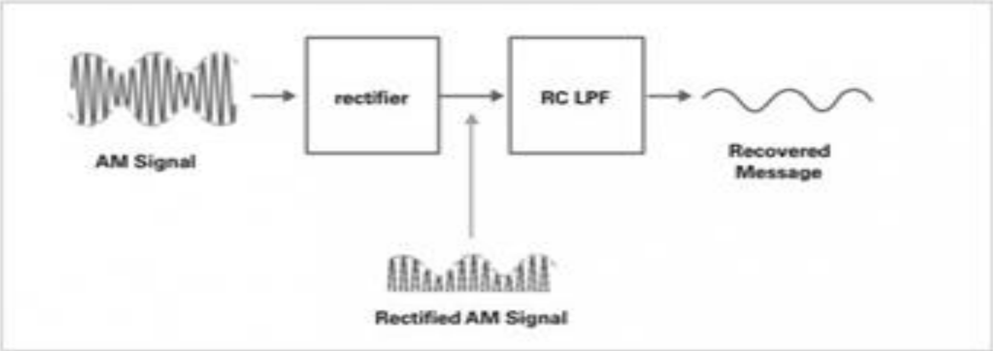

Figure13. *Detection process in radio detector.*

As illustrated in Figure 14, the envelope detector circuit consists of a diode, a capacitor, and a resistor and functions similarly to a half-wave rectifier and low-pass filter.

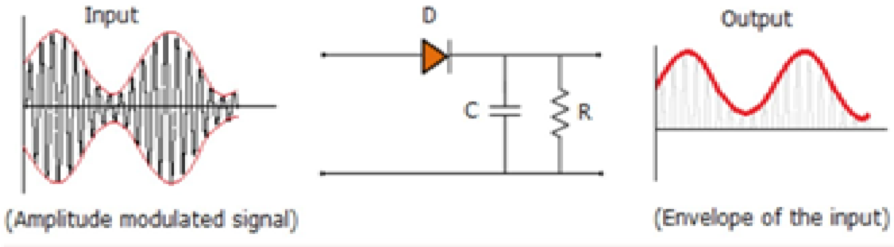

Figure14. *Radio detector.*

The filter capacitor (C), the load resistance (R), and the detector diode (D), make up this circuit. The diode conducts and current flows through R during the positive half cycle of an AM signal, but during the negative half cycle, the diode is reverse biased and no current flows. Therefore, crossing resistance R, only the positive half of the AM wave is visible. While filtering out RF carrier waves and allowing an envelope of the input to be seen as output, the capacitor across R has low impedance at the carrier frequency and much higher impedance at the modulating frequency. When passed through a suitable device, say, a headphone, the original sound can be heard.

Straight Radio Receiver

A radio receiver is a reverse of a radio transmitter which reproduces the modulated or radio waves into sound waves. Here, the receiving antenna receives the radio waves from different broadcasting stations. The radio frequency amplifier uses a tuned parallel circuit to choose the required radio wave. This chosen radio wave is amplified by the tuned RF amplifier. The detector circuit, which includes a PN diode, receives the radio signal that has been amplified. The audio signal is taken from the radio wave via this circuit. The audio signal, which has undergone one or more steps of audio amplification, is the output of the detector. The loud speaker receives the amplified audio stream in order to reproduce sound. The functional block diagram of a straight (simple) radio receiver is shown in Figure 15.

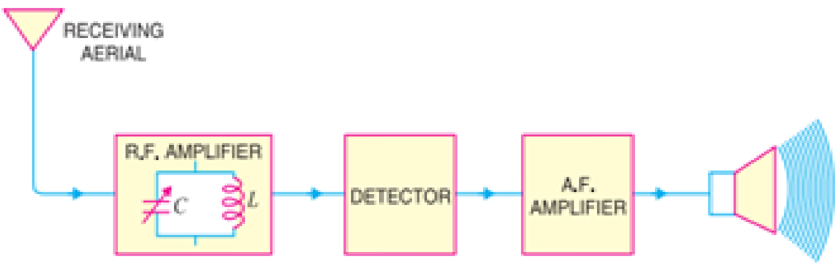

Figure15. *Straight radio receiver.*

Results And Discussion

The result demonstrates that the amplitude of the carrier wave's positive and negative half cycles is changed during amplitude modulation in line with the instantaneous amplitude of the message signal. The amplitude modulated (AM) wave's positive and negative peaks may be seen to be linked by an imaginary line. On the AM wave, this fictitious line is known as the envelope. The AM wave's envelope mimics the message signal in terms of form. As a result, this envelope aids in accurately reproducing the message signal's form. The result shown in the Figure 5 suggests that for amplitude modulated AM wave the amplitude of the carrier wave changes according to the intensity of the signal. Also the amplitude variations of the carrier wave is at the signal frequency and the frequency of the amplitude modulated wave remains the same with carrier frequency. It is also observed that in AM wave when a carrier is modulated with a message signal, other frequencies are detected. These new frequencies are caused by modulation and are called sideband frequencies. They are generated above and below the carrier frequency. The sideband frequencies that are created above the carrier frequency are called upper sideband frequencies or higher frequency component (fc + fs) called the sum component and the sideband frequencies that are created below the carrier frequency called lower sideband frequencies or lower frequency component (fc - fs) called the sum component. These two new frequencies are symmetrically located around the carrier frequency as shown in Figure 16.

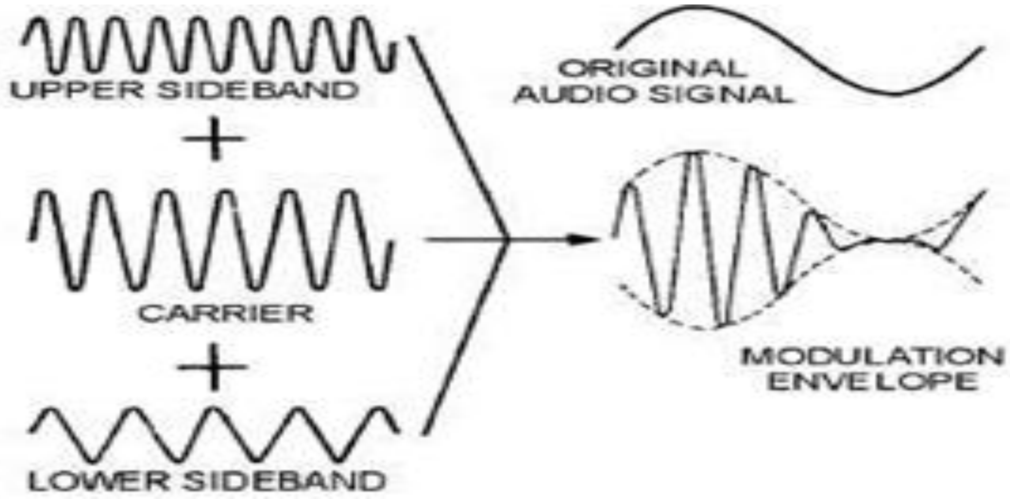

Figure16. *Carrier and sidebands of an amplitude modulated wave.*

As a result, we may attenuate or eliminate the carrier or any individual sideband without having any impact on how signals are sent or the communication process.

The advantages would be: less transmitted power and less bandwidth required. The bandwidth or channel width (BW) of the signal can be obtained as the difference between extreme frequencies i.e. between maximum frequency and minimum frequency. In an AM wave, the bandwidth BW is from (fc – fs) to (fc + fs) i.e., BW = 2 fs. Therefore, we arrive at a very important conclusion although not shown here, that in amplitude modulation, bandwidth is twice the maximum frequency of modulating signal. The tuned amplifier which is called upon to amplify the modulated wave must have the required bandwidth to include the sideband frequencies. If the tuned amplifier has insufficient bandwidth, the upper sideband frequencies may not be reproduced by the radio receiver.

Only the frequency of the carrier wave is altered in frequency modulation to match the signal. The modulated wave's amplitude, or the amplitude of the carrier wave, does not change. The instantaneous amplitude of the signal determines the frequency fluctuations of the carrier wave. The carrier frequency remains unaltered when the signal voltage is zero. When the signal approaches its positive peaks, the carrier frequency is increased to maximum as shown by the closely spaced cycles. However, during the negative peaks of signal, the carrier frequency is reduced to minimum as shown by the widely spaced cycles. The result also indicates that for frequency modulated FM wave shown in Figure 10. The frequency deviation of FM signal depends on the amplitude of the modulating signal. When there is no modulation or when the modulating voltage is zero, the frequency is referred to as centre frequency. The frequency variation is not determined by the audio frequency (i.e the frequency of the modulating signal). Furthermore, any signal that is modulated produces sidebands. In the case of an amplitude modulated signal they are easy to determine, but for frequency modulation is not quite easy. They are dependent upon the not only the deviation, but also the level of deviation, i.e. the modulation index. The total spectrum is an infinite series of discrete spectral components expressed by a complex formula using Bessel functions of the first kind. FM wave contains an infinite number of sidebands thus suggesting an infinite bandwidth requirement for transmission or reception. The sidebands are at $(fc \pm fm)$, $(fc \pm 2fm)$, $(fc \pm 3fm)$ ⋯. The number of sideband components are decided by maximum frequency deviation of the carrier signal Δf and the frequency of the message signal fm. Therefore, minimum practical bandwidth required to transmit an FM signal will be BW = 2 [Δf + fm].

Additionally, it was noted that the following functions must be carried out by radio receivers in order to properly recover the message signal from the carrier: A part of the traveling radio waves must be blocked by the receiving aerial. The receiving aerial intercepted a number of radio waves, and the radio receiver must choose the one it wants to receive. Tuned parallel LC circuits are required for this purpose. These circuits only choose radio frequencies that resonate with them. The tuned frequency amplifiers must increase the signal strength of the chosen radio wave. The radio wave that has been amplified must be retrieved for the audio signal. The audio signal must be boosted using the appropriate amount of audio-amplifiers. For sound reproduction, the amplified audio signal needs to be delivered to the speaker.

Conclusion and Future Scope

The principle of radio wave propagation for wireless communication is here presented. In conclusion, radio waves from a radio transmitter are coupled into free space by the transmitter antenna, and these radio waves are received by a receiving antenna and then coupled into a receiver for detection. The two types of modulation used in this work are amplitude modulation (AM) and frequency modulation (FM). Thus AM wave is found to comprise of three frequency components: The carrier frequency, upper side-band frequency and lower side band frequency components. It is found also that in FM, when a carrier is modulated, a number of sidebands are formed. Theoretically their number is infinite and their strength becomes negligible after a few sidebands. The number of pair of sidebands increases as amplitude of modulating signal increases. It also increases as the modulating signal frequency decreases. This research holds a great theoretical and practical significance as it enhances the understanding and practical skill involves in both the electronics and telecommunication engineering fields and is able to integrate different theoretical knowledge gained through Astrophysics, Electronics and Telecommunication. To simulate the waveform for different degree of modulations, further research is needed.

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