Ch. 15 : Communication Systems

- Block diagram of Communication System → IMP
- What is meant by "Bandwidth"
- Medium of Transmission & Services supported.
  - Ground wave propagation
  - Sky wave propagation
  - Space wave propagation

  } IMP
- Modulation
  - why it is required?
  - Amplitude modulation
    - Derivation of an AM wave — IMP
    - Significance of "Modulation index" μ
    - Electronics → how to generate an AM ~~wave~~ signal → Block diagram only.
    - Receiver side detection circuit.

Draw a block diagram of generalized Communication System

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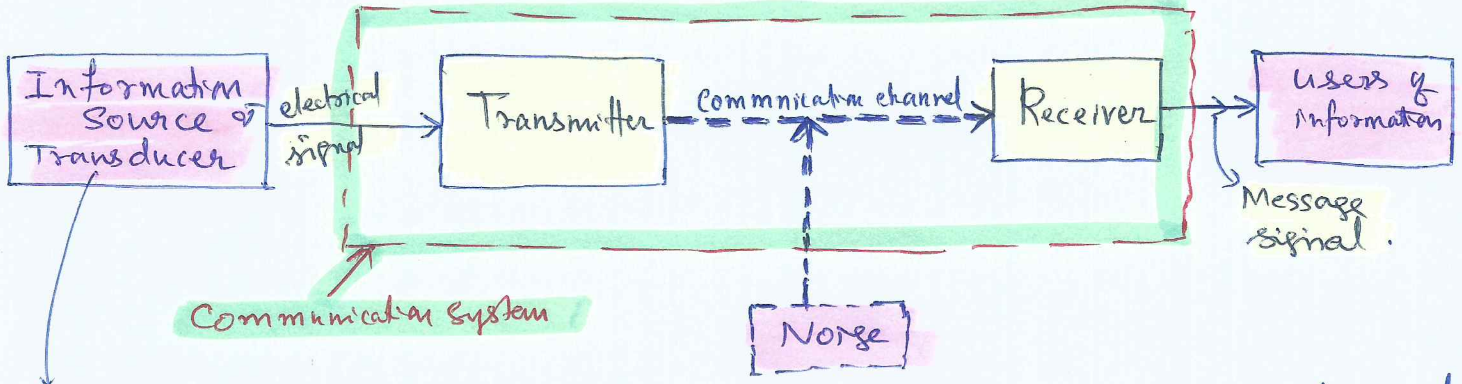

* Transducer is a device that converts ~~no~~ information into electrical signal and vice-versa.

1. Transmitter → The information (say in the form of speech) is converted to electrical signal using transducer (eg. microphone) and then processed, modulated, ~~and~~ amplified and fed to the communication link (communication channel or radiated thro' antenna)

2. Communication channel : The type of communication channel can be transmission wires, cables, optical fibres or air.

3. Receiver is at the user premises that ~~dem~~ receives the transmitted signal, demodulates and amplifies and feed to transducer that conveys original message to the user.

There are two modes of communication.
① point-to-point and ② Broadcast

1. In point-to-point communication mode, communication takes place betw a single transmitter and a receiver.
   eg. telephony.

2. In broadcast, there are large number of receivers for a single transmitter.
   eg: Radio, TV.

Bandwidth (BW) : (BW of "Signal" AND BW of a "Transmission channel")

➢ BW of a signal

- Bandwidth of an (electrical) signal is the total range of frequencies carried (associated) by a certain baseband signal (Transducer will convert other forms of energy into an electrical signal) OR
- The width of the frequency spectrum of a signal is known as BW of the signal ; BW = f_{max} - f_{min}
- Different types of signals have different bandwidths
  - Eg : Human speech : 300 Hz to 3100 Hz ; BW = 3100 – 300 = 2800Hz
  - Eg: Music : 20Hz to 20KHz ; BW ≈ 20KHz
  - Video signal ≈ 5 or 4.2 MHz or >> for high definition video content.
  - Digital signal (see below paragraph and the graph figure 15.3)
  - Analog signal BW is measured in terms of its frequency (hz) but digital signal BW is measured in terms of bit rate (bits per second, bps).
  - Bandwidth of signal is different from bandwidth of the medium/channel. The bandwidth of the medium should always be greater than the bandwidth of the signal to be transmitted else the transmitted signal will be either attenuated or distorted or both leading in loss of information.
- Digital signals are in the form of rectangular waves as shown in Fig. 15.3. One can show that this rectangular wave can be decomposed into a superposition of sinusoidal waves of frequencies +0, 2+0, 3+0, 4+0 ... n+0 where n is an integer extending to infinity and +0 = 1/T0. The fundamental (+0), fundamental (+0) + second harmonic (2+0) and fundamental (+0) + second harmonic (2+0) + third harmonic (3+0), are shown in the same figure to illustrate this fact.
- It is clear that to reproduce the rectangular wave shape exactly we need to superimpose all the harmonics +0, 2+0, 3+0, 4+0..., which implies an infinite bandwidth. However, for practical purposes, the contribution from higher harmonics can be neglected, thus limiting the bandwidth. As a result, received waves are a distorted version of the transmitted one. If the bandwidth is large enough to accommodate a few harmonics, the information is not lost and the rectangular signal is more or less recovered. This is so because the higher the harmonic, less is its contribution to the wave form.

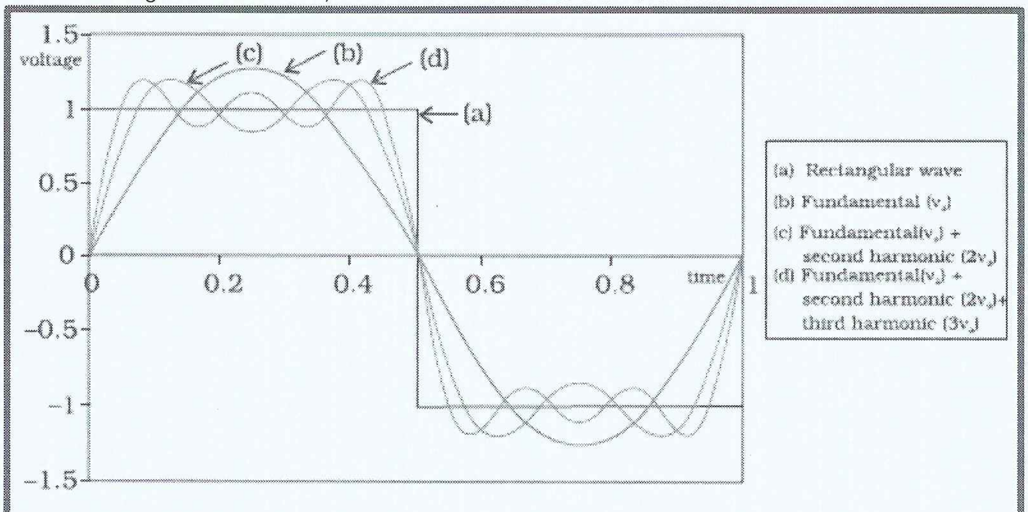

FIGURE 15.3 Approximation of a rectangular wave in terms of a fundamental sine wave and its harmonics.

➢ Bandwidth of a transmission channel

- It is the range of frequencies that can be accommodated by a communication channel.
- Similar to message signals, different types of transmission media offer different bandwidths. The commonly used transmission media are co-axial cable, optical fibre, free space etc..
  - Coaxial cable is a widely used wire medium, which offers a bandwidth of approximately 750 MHz. Such cables are normally operated below 18 GHz.
  - Communication through free space using radio waves takes place over a very wide range of frequencies: from a few hundreds of kHz to a few GHz. This range of frequencies is further subdivided and allocated for various services as indicated in table below.
  - Optical communication using fibres is performed in the frequency range of 1 THz to 1000 THz (microwaves to ultraviolet). An optical fibre can offer a transmission BW in excess of 100 GHz.
- Spectrum allocations are arrived at by an international agreement. The International Telecommunication Union (ITU) administers the present system of frequency allocations.
- See table below the **e-m spectrum** allocated by ITU for various services.

Abbr	Expansion	Frequency range	~ Wavelength range	Application
ELF	Extremely Low Frequency	3 Hz to 30 Hz	100000 km to 10000 km	Communication with submarines
SLF	Super Low Frequency	30 Hz to 300 Hz	10000 km to 1000 km	Communication with submarines
ULF	Ultra-Low Frequency	300 Hz to 3 KHz	1000 km to 100 km	Submarine communication, communication within mines
VLF	Very Low Frequency	3 kHz to 30 kHz	100 km to 10 km	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
LF	Low Frequency	30 kHz to 300 kHz	10 km to 1 km	Navigation, time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio
MF	**Medium Frequency**	**300 kHz to 3 MHz**	**1 km to 100 m**	**AM (medium-wave) broadcasts, amateur radio**
HF	**High Frequency**	**3 MHz to 30 MHz**	**100 m to 10 m**	**Shortwave broadcasts**
VHF	**Very High Frequency**	**30 MHz to 300 MHz**	**10 m to 1 m**	**FM, television broadcasts, land mobile and maritime mobile communications**
UHF	**Ultra-High Frequency**	**300 MHz to 3 GHz**	**1 m to 10 cm**	**Television broadcasts, mobile communication**
SHF	**Super High Frequency**	**3 GHz to 30 GHz**	**10 cm to 1 cm**	**Satellite television broadcasting (down-link/uplink), Direct Broadcast Satellite**
EHF	Extremely High Frequency	30 GHz to 300 GHz	1 cm to 1 mm	Radio astronomy, wireless LAN (802.11ad)
THF	Tremendously High Frequency	300 GHz to 3000 GHz	1 mm to 0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics,

➢ Exhaustive list - <u>For information only</u>

Abbr	Expansion	Frequency range	~ Wavelength range	Application
ELF	Extremely Low Frequency	3 Hz to 30 Hz	100000 km to 10000 km	Communication with submarines
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MF	Medium Frequency	300 kHz to 3 MHz	1 km to 100 m	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
HF	High Frequency	3 MHz to 30 MHz	100 m to 10 m	Shortwave broadcasts, citizens band radio, amateur radio and over-the-horizon aviation communications, RFID, over-the-horizon radar, automatic link establishment (ALE) / near-vertical incidence skywave (NVIS) radio communications, marine and mobile radio telephony
VHF	Very High Frequency	30 MHz to 300 MHz	10 m to 1 m	FM, television broadcasts, line-of-sight ground-to-aircraft and aircraft-to-aircraft communications, land mobile and maritime mobile communications, amateur radio, weather radio
UHF	Ultra-High Frequency	300 MHz to 3 GHz	1 m to 10 cm	Television broadcasts, microwave oven, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two-way radios such as land mobile, FRS and GMRS radios, amateur radio, satellite radio, Remote control Systems, ADSB
SHF	Super High Frequency	3 GHz to 30 GHz	10 cm to 1 cm	Radio astronomy, microwave devices/communications, wireless LAN, DSRC, most modern radars, communications satellites, cable and satellite television broadcasting, DBS, amateur radio, satellite radio
EHF	Extremely High Frequency	30 GHz to 300 GHz	1 cm to 1 mm	Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner, wireless LAN (802.11ad)
THF	Tremendously High Frequency	300 GHz to 3000 GHz	1 mm to 0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing, amateur radio

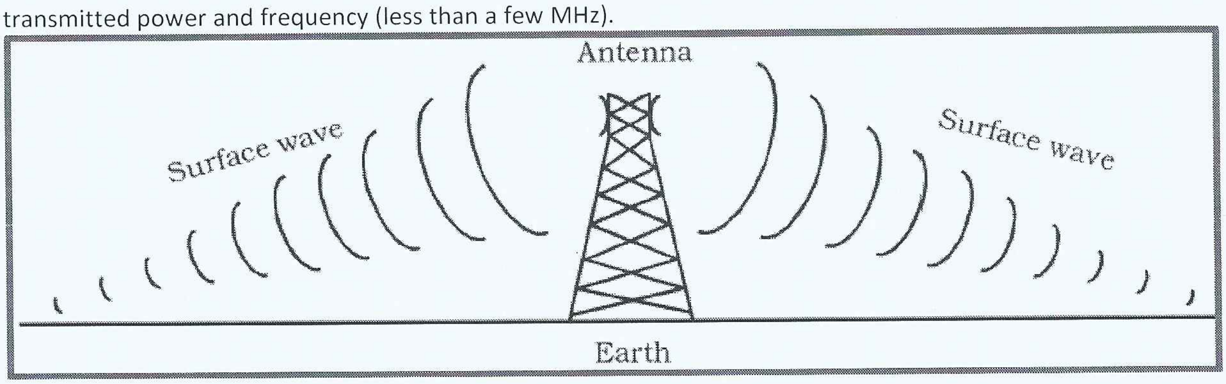
Propagation of Electromagnetic Waves (Ground wave, Sky wave, Space wave)

- In communication using radio waves, an antenna at the transmitter radiates the Electromagnetic waves (e-m waves), which travel through the space and reach the receiving antenna at the other end. As the e-m wave travels away from the transmitter, the strength of the wave keeps on decreasing.
- **Several factors influence the propagation of e-m waves and the path they follow**. At this point, it is also important to understand the composition of the earth's atmosphere as it plays a vital role in the propagation of e-m waves. A brief discussion on some useful layers of the atmosphere is given in the following table.
- The various modes by which e-m waves propagate from the transmitter to the receiver are
    - **Ground wave propagation (aka Surface wave propagation)**
    - **Sky wave propagation (aka Ionospheric propagation)**
    - **Space wave propagation.**

Ground wave propagation (aka Surface wave propagation)

To radiate signals with high efficiency, the antennas should have a size comparable to the wavelength of the signal (at least ≈ $\lambda/4$). At longer wavelengths (i.e., at lower frequencies), the antennas have large physical size and they are located on or very near to the ground.

In standard AM broadcast, ground based vertical towers are generally used as transmitting antennas. For such antennas, ground has a strong influence on the propagation of the signal. The mode of propagation is called surface wave propagation and the wave glides over the surface of the earth. A wave induces current in the ground over which it passes and it is attenuated as a result of absorption of energy by the earth. The attenuation of surface waves increases very rapidly with increase in frequency. The maximum range of coverage depends on the transmitted power and frequency (less than a few MHz).



Sky wave propagation (aka ionospheric propagation)

In the frequency range from a few MHz up to 30 to 40 MHz, long distance communication can be achieved by ionospheric reflection of radio waves back towards the earth. This mode of propagation is called sky wave propagation and is used by short wave broadcast services. The ionosphere is so called because of the presence of a large number of ions or charged particles. It extends from a height of ~ 65 Km to about 400 Km above the earth's surface. Ionisation occurs due to the absorption of the ultraviolet and other high-energy radiation coming from the sun by air molecules. The ionosphere is further subdivided into several layers, the details of which are given in Table 15.3. The degree of ionisation varies with the height. The density of atmosphere decreases with height. At great heights the solar radiation is intense but there are few molecules to be ionised. Close to the earth, even though the molecular concentration is very high, the radiation intensity is low so that the ionisation is again low. However, at some intermediate heights, there occurs a peak of ionisation density. The ionospheric layer acts as a reflector for a certain range of frequencies (3 to 30 MHz). Electromagnetic waves of frequencies higher than 30 MHz penetrate the ionosphere and escape. These phenomena are shown in the Fig. 15.4. The phenomenon of bending of e-m waves so that they are diverted towards the earth is similar to total internal reflection in optics.

P.T.O.

TABLE 15.3 DIFFERENT LAYERS OF ATMOSPHERE AND THEIR INTERACTION WITH THE PROPAGATING ELECTROMAGNETIC WAVES

Name of the stratum (layer)		Approximate height over earth's surface	Exists during	Frequencies most affected
Troposphere		10 km	Day and night	VHF (up to several GHz)
D (part of stratosphere)	PARTS OF IONOSPHERE	65-75 km	Day only	Reflects LF, absorbs MF and HF to some degree
E (part of Stratosphere)		100 km	Day only	Helps surface waves, reflects HF
F_1 (Part of Mesosphere)		170-190 km	Daytime, merges with F_2 at night	Partially absorbs HF waves yet allowing them to reach F_2
F_2 (Thermosphere)		300 km at night, 250-400 km during daytime	Day and night	Efficiently reflects HF waves, particularly at night

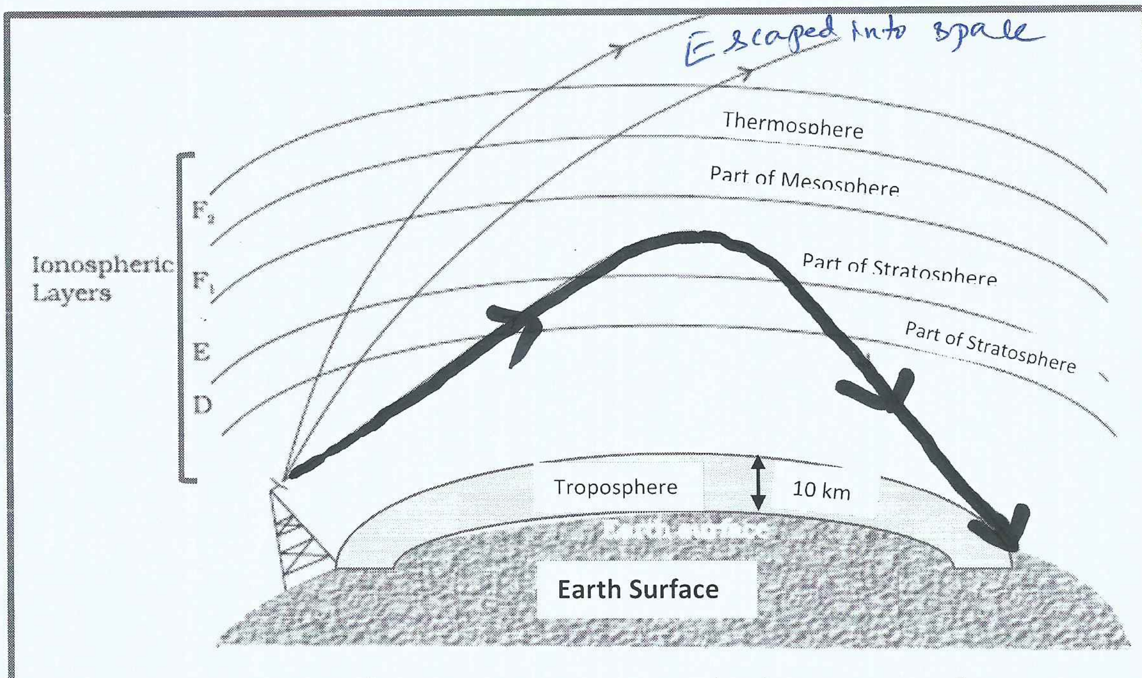
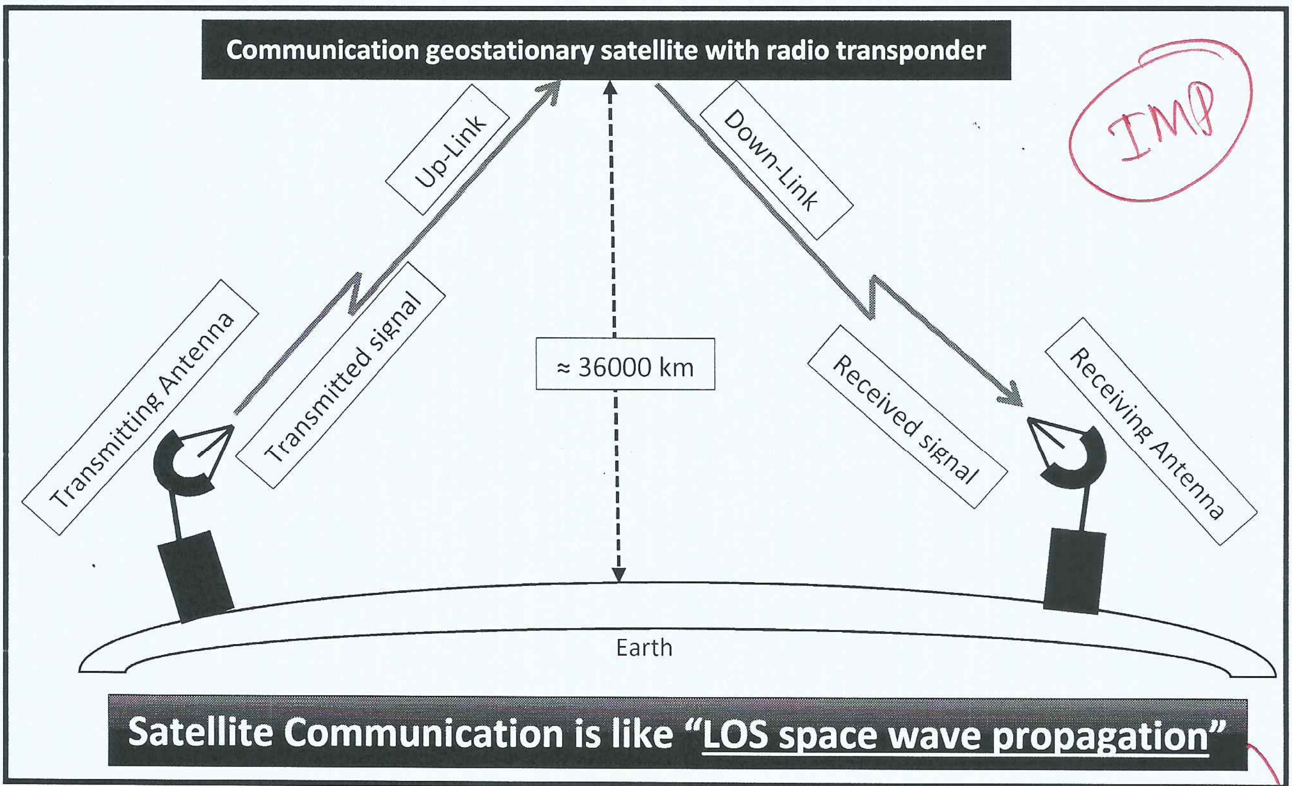


FIGURE 15.4 Sky wave propagation. The layer nomenclature is given in Table 15.3.

Space wave propagation

Another mode of radio wave propagation is by space waves. A space wave travels in a straight line from transmitting antenna to the receiving antenna. Space waves are used for line-of-sight (LOS) communication as well as satellite communication. **At frequencies above 40 MHz, communication is essentially limited to line-of-sight paths. At these frequencies, the antennas are relatively smaller and can be placed at heights of many wavelengths above the ground.**

- Space waves are used in two types of communication:
  - Line-of-sight (LOS) propagation
    - (transmitting antenna and receiving antenna are seeing each other)
  - Satellite communication
    - is like LOS, see below diagram, where in the transmitting antenna will be seeing the geostationary satellite and in the same way even the receiver is seeing the same satellite, so that information can be conveyed from transmitter to receiver via satellite.



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Because of line-of-sight nature of propagation, direct waves get blocked at some point by the curvature of the earth as illustrated in below. If the signal is to be received beyond the horizon then the receiving antenna must be high enough to intercept the line-of-sight waves.

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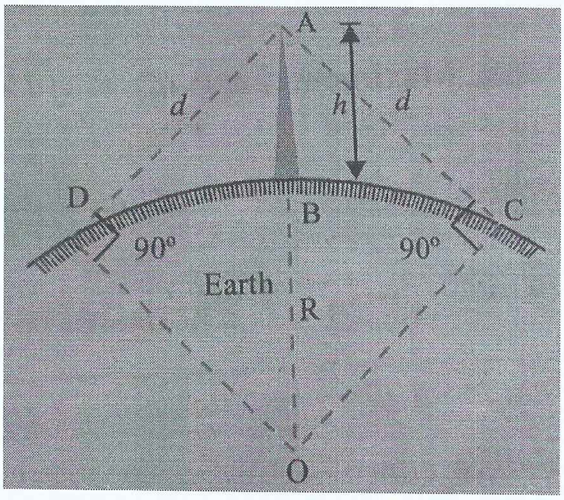
Height of the transmitting antenna

Consider a transmitting antenna AB of height h. No communication by direct signal is possible beyond points C and D on the surface of the earth having radius R as shown in figure to the right.

Calculate the distance up to which the TV signals can be received directly from the transmitting antenna.



Let OB = OC = R

Let AC = AD = d and AB = h

From right angled triangle ACO, we get

$AO^2 = AC^2 + OC^2$

$(R+h)^2 = d^2 + R^2$

$R^2 + h^2 + 2Rh = d^2 + R^2$

Therefore, $d^2 = h^2 + 2Rh$

Since R >>>> h, so h^2 can be ignored as compared to 2Rh

- $d^2 = 2Rh$
- $d = \sqrt{2Rh}$ ------------(1)
- This d is known as "Radio horizon" of the transmitting antenna
- Area covered by the TV signal = πd^2 (where d is the height of the antenna)
- Population covered = (Area covered) x (Population density)
- Higher the height of the transmitting antenna, higher is the range of the receiving the signal.

Maximum LOS distance between "Transmitting" and "Receiving" antennas

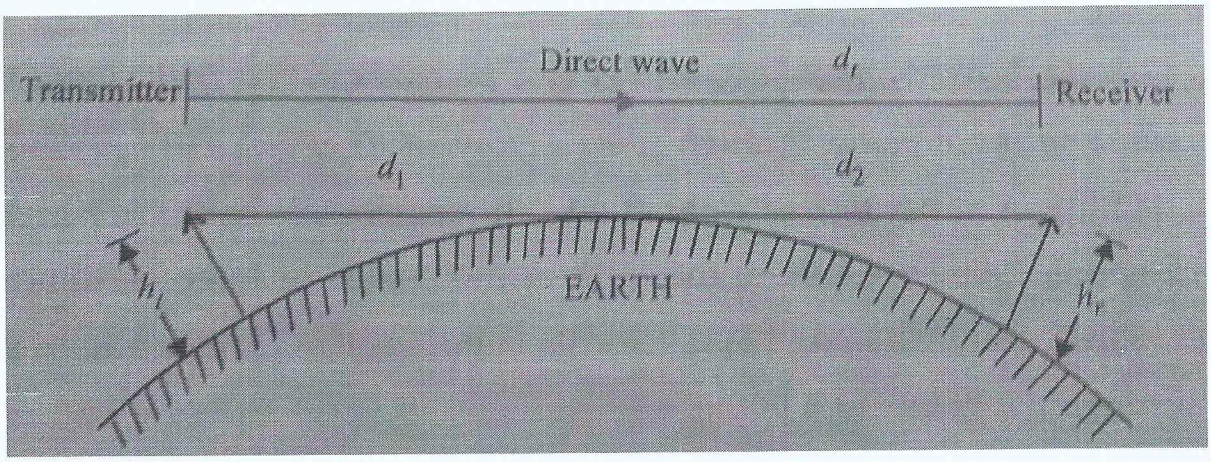


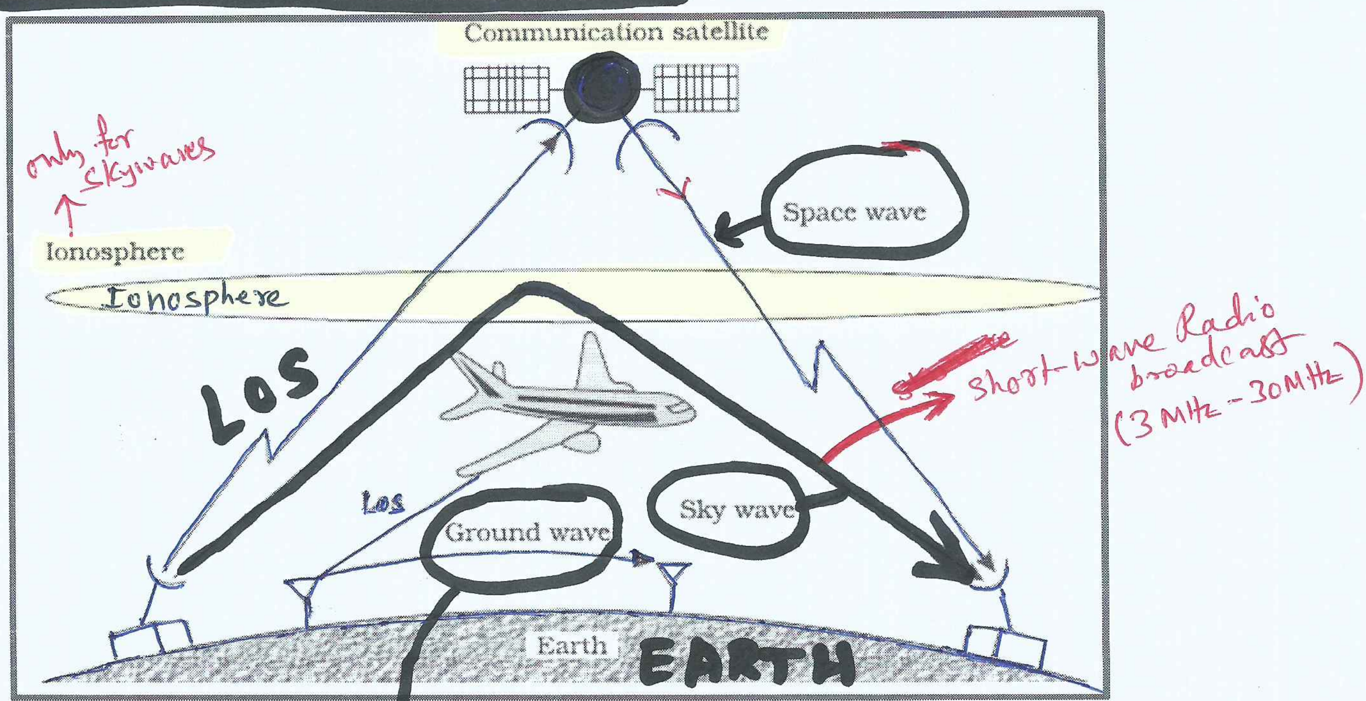
Figure shows the positions of transmitter and receiver on the earth for the propagation of space wave. Maximum LOS distance between "Transmitting" antenna and "Receiving" antenna depends upon the height of these antennas.

If h_t is the height of transmitting antenna and h_r is the height of receiving antenna, then the maximum LOS distance d_t for the communication through space wave is given by

$d_t = d_1 + d_2 = \sqrt{2Rh_t} + \sqrt{2Rh_r}$ ------------------ (2)

Thus, very high frequency signals can be transmitted without losses in air only if the receiving antenna directly intercepts the signals from the transmitting antenna. For example, for good and large coverage of TV programmes, tall antennas must be used for transmitting the TV signals. Microwave transmission on the surface of earth is possible if the transmitting and the receiving antennas are in a line-of-sight (LOS)

Various propagation modes in one figure.



used for AM Medium wave Radio broadcast.

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Some Important Wireless Communication Frequency Bands (Refer to this table for 12th standard)

Name of service → ITU allocates spectrum to various services	Band	Band range	Specific Frequency range of the service	Propagation Media or Modes of Propagation	Remarks
AM Medium Wave Radio Broadcast	MF	300 kHz to 3 MHz	540 kHz to 1600 KHz	Ground wave propagation (aka Surface wave propagation)	Ground wave propagation cannot be used for HF band. However, It can be used for LF band.
Short wave radio broadcast	**HF**	**3 MHz to 30 MHz**	**3 MHz to 30 MHz**	**Sky wave propagation (aka Ionospheric propagation)**	The Ionospheric layer acts as reflector for HF band range 3 MHz to 30 MHz. Electromagnetic waves of freq > 30 MHz penetrate the ionosphere and escape. **"Sky wave mode of propagation" is used by "short wave Radio broadcast services".**
FM Radio broadcast	VHF	30 MHz to 300 MHz	88 MHz to 108 MHz	Space wave propagation (LOS)	**A space wave travels in a straight line from transmitting antenna to the receiving antenna.** **Space waves are used in two types of communication :** ➢ **Line-of-sight (LOS) propagation.** ➢ **Satellite communication (same as LOS via satellite)**
TV broadcast	VHF	30 MHz to 300 MHz	54 – 72 MHz 76 – 88 MHz 174 – 276 MHz	Space wave propagation	
	UHF	300 MHz to 3 GHz	420 – 890 MHz		
Cellular mobile Phone service	UHF	300 MHz to 3 GHz	896 – 901 MHz (Mobile to Base station) 840 – 935 MHz (Base station to mobile)	Space wave propagation (LOS)	
Satellite Communication (for TV, data etc..)	SHF	3 GHz to 30 GHz	3.7 to 4.2 GHz (downlink from satellite using transponders) 5.9 to 6.4 GHz (uplink to satellite using transponders)	Space wave propagation	

"Message Signal" (aka "information Signal"
aka "Baseband signal"
aka "modulating signal")

→ Baseband signal is a band of frequencies representing the original signal, as delivered by the source of information.
→ No signal, in general, is a single frequency sinusoid, but it spreads over a range of frequencies called the "signal bandwidth" (BW).

- Speech signal → freq. ranges from 300 Hz to 3100 Hz. ∴ BW = 2800 Hz (mainly used for commercial telephonic conversation)
- Music signal → Range upto 20 kHz due to high frequencies produced by musical instruments. Range ≈ 20 Hz to 20 kHz. ∴ BW ≈ 20 kHz.
- TV signal (in India): Video signal BW = 5 MHz, ~~channel BW~~
channel BW allocated = 7 or 8 MHz
- TV signal (in US): Video BW = 4.2 MHz, Channel BW allocated = 6 MHz.

The above message signals voice (speech), music, video or computer data are called normally as baseband signals.

Modulation and its necessity.

What is modulation: In a carrier communication system, the baseband signal of a low-frequency spectrum is translated to a high-frequency spectrum. This is achieved through modulation. Modulation is defined as a process by virtue of which, some characteristic of a high-frequency sinusoidal wave is varied in accordance with the instantaneous amplitude of the baseband signal.

→ Two Signals are involved in the modulation process

1. Base band Signal → This baseband signal is to be transmitted to the receiver. The freq. of Baseband signal is generally low. In the modulation process, this "baseband" signal is called "modulating Signal"

2. Carrier Signal: The other signal involved in modulation process is a high-frequency sinusoidal wave. This signal is called as the carrier signal or carrier.

⟹ IMP: $f_{\text{carrier signal}} \ggg f_{\text{baseband signal}}$.

Necessity of modulation:

If we want to transmit a base band signal directly (without modulation) over a long distance, it is ~~almost~~ practically unfeasible and we can even conclude that it is impossible to do ~~get~~ to get a quality reception using a receiver.

Need for modulation.

① Size of the antenna (length or height of antenna).

We need antenna for radiating a signal. In order to radiate ~~the~~ maximum power from the transmitter through ~~antenna~~ the antenna, the antenna should have a size comparable to the wavelength (λ) of the signal (at least $\lambda/4$ in dimension) so that the antenna properly senses the time variation of the signal.

→ Eg. Consider audio signal (max. 20 kHz) to be transmitted (or radiated from antenna). What should be the antenna size.

We know that $c = f\lambda$ $\therefore \lambda = \frac{c}{f} = \frac{3\times10^8\ ms^{-1}}{20\times10^3\ s^{-1}} = 1.5\times10^4\ m$

$= 15\ km$

Antenna ~~length~~ of 15 km → obviously, such a long antenna is not possible to construct, operate and maintain. Hence, direct transmission of such baseband signals is not practical.

→ If freq. to be radiated = 1 MHz (say), then

$\lambda = \frac{c}{f} = \frac{3\times10^8\ ms^{-1}}{10^6\ ms^{-1}} = \boxed{300\ m}$ which is a reasonable antenna length.

→ Therefore, there is a need of translating low frequency baseband signal into high frequencies before transmission.

② Effective power radiated by an Antenna and increase in communication Range

A theoritical study of radiation from a "linear antenna" (length l) shows that the power radiated from antenna $\propto (l/\lambda)^2$ $\Longrightarrow$ for same antenna length, the power radiated $\propto \left(\frac{1}{\lambda^2}\right)$ $\Longrightarrow$ power radiated increases with decreasing λ, or by increasing frequency. $\therefore$ Effective power radiated by a long wavelength baseband signal would be small. $\therefore$ For effective transmission, we need high frequencies. Since $E = hf \Longrightarrow$ energy radiated is also ~~large~~ more and ~~to~~ hence can travel longer distances. So, there is a need for some mechanism to translate low-freq. baseband signal to high frequency.

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(3) Mixing up of signals from different transmitters :

Another important against transmitting baseband signals directly is more practical in nature. If many people are talking at the same time, it is very difficult to distinguish between their audio.

→ In a similar way, if many transmitters are transmitting the baseband signal (say radio broadcast), all the signals from different transmitters get mixed up and there is no simple way to separate them at the receiver end.

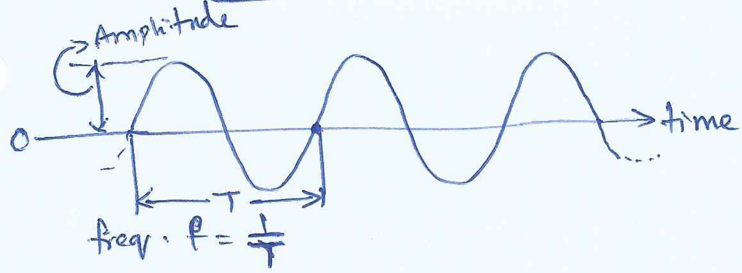
→ This calls for allocating a band of frequencies to each transmitter and from the other 2 reasons, a high frequency is used by transmitters in order to radiate power effectively.

The above arguments (antenna size, effective radiated power, range of communication, mixing up of signals) suggest that there is a need for translating the original low freq. information signal (baseband signal) into high-freq. wave before transmission such that translated signal continues to possess the information contained in the original signal.

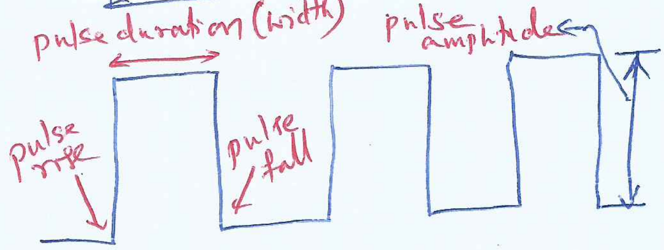
→ So, we take a high-freq. signal known as the "carrier" wave and a process known as "modulation" which attaches the information (baseband) signal to it.

→ The carrier wave may be continuous sinusoidal ~~wave~~ signal or in the form of pulses.

Sinusoidal Carrier



Pulse shaped Carrier



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- A sinusoidal carrier wave can be represented as

$$c(t) = A_c \sin(\omega_c t + \phi) \longrightarrow (1)$$

where $c(t)$ is the signal strength (voltage or current)
A_c is the ~~amplitude~~ peak amplitude of carrier wave.
$\omega_c = 2\pi f_c$ is the angular frequency
ϕ is the initial phase of the carrier wave.

- $c(t)$ sine wave carrier is a high-frequency signal generated at the transmitter and specific to a transmitter.
- The three parameters that can be changed by external signal are (1) Amplitude A_c (2) ω_c (3) ϕ.
- During the process of modulation, any of the above 3 parameters of carrier wave can be controlled by the baseband signal (message signal ~~or~~ information signal). In the modulation language, the base band signal is called "modulating signal".
- When the modulating signal controls the amplitude of carrier, the result will be Amplitude modulation.
- When the modulating signal controls the frequency of carrier, the result will be frequency modulation.
- When the modulating signal controls the phase ϕ of carrier, the result will be phase modulation.

Instead of sinusoidal carrier, if we use pulse shaped signal as carrier, we get different types of modulation.

→ The significant parameters of a pulse are:

→ pulse amplitude → If modulating signal controls the pulse amplitude of carrier, it results in "pulse Amplitude modulation" (PAM)

→ pulse width → Results in "pulse width modulation" (PWM) which is very popular.

→ pulse position → Results in "pulse position modulation" (PPM)

In 12th std. syllabus, we will deal with only

(i) Sinusoidal carrier ~~wa~~ undergoing Amplitude modulation only.

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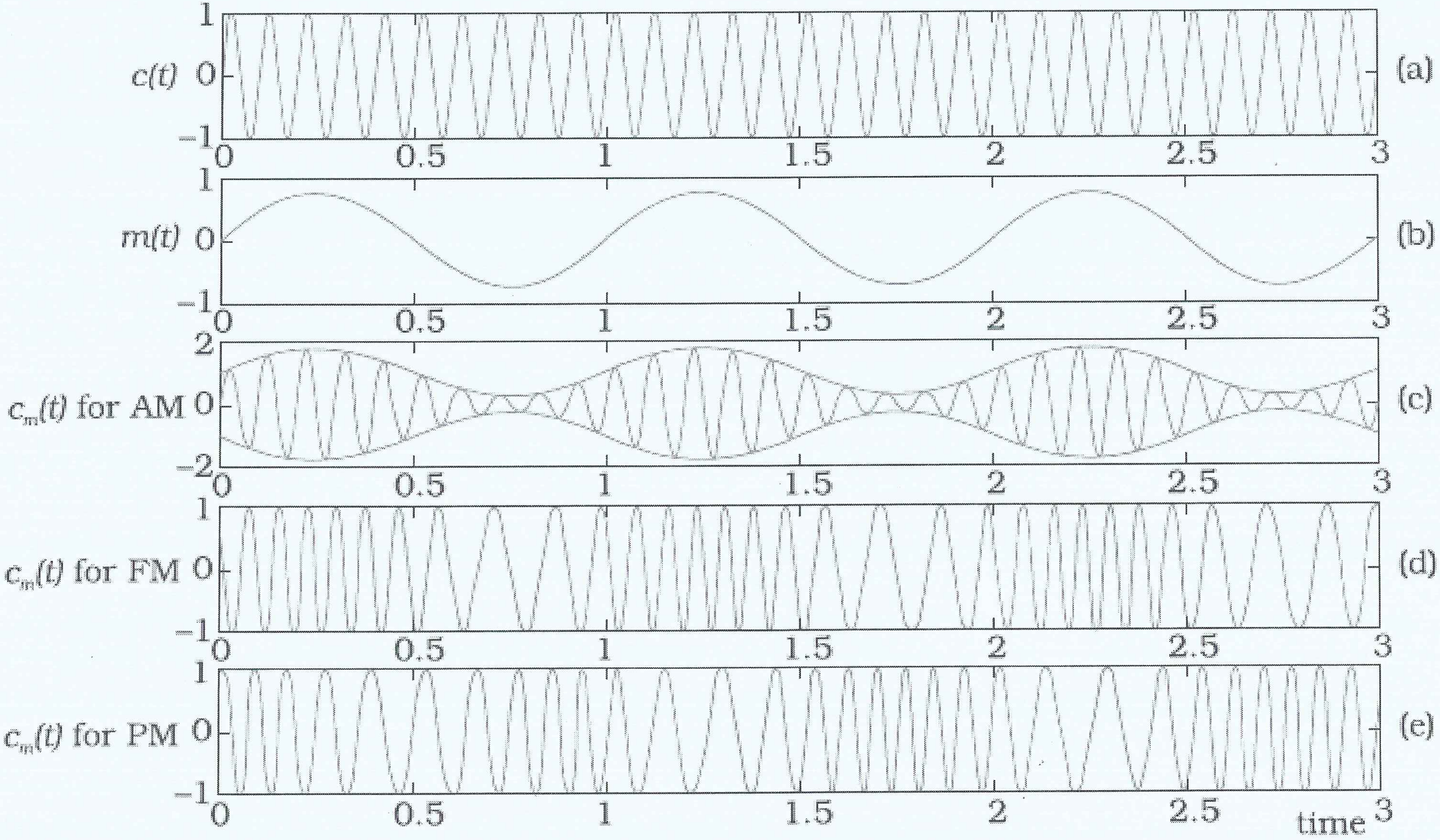
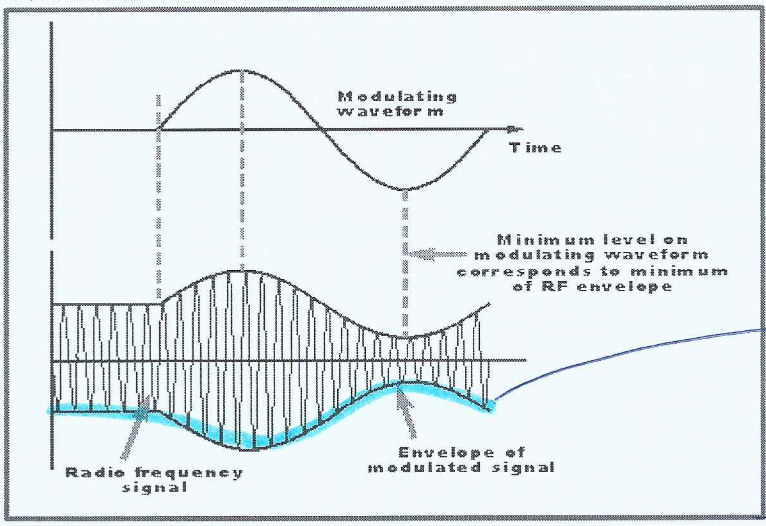


FIGURE 15.8 Modulation of a carrier wave: (a) a sinusoidal carrier wave; (b) a modulating signal; (c) amplitude modulation; (d) frequency modulation; and (e) phase modulation.

Derivation of Amplitude modulation Or Simplified analysis of standard AM



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In AM, we square the modulated signal and make it mirror of it => that is why we see this symmetrical diagram. ~~It~~ Squaring is mainly done to make propagation more powerful during transmission.

Consider a carrier wave (sine wave) of frequency f_c and amplitude A given by:

$c(t) = A_c \sin(w_c t)$; A_c is amplitude and w_c is the angular frequency = $2\pi f_c$

Let $m(t)$ represent the message signal (aka modulating signal).

$m(t) = A_m \sin(w_m t)$; A_m is amplitude and w_m is the angular frequency = $2\pi f_m$

In AM, amplitude of the carrier wave is altered in accordance with amplitude of message signal. Hence, the modulated signal $c_m(t)$ is written as

$c_m(t) = [A_c + A_m \sin(w_m t)] \sin(w_c t)$ → see amplitude of carrier has sine function meaning amplitude of carrier wave is altered in line with amplitude of message signal

$c_m(t) = A_c \sin(w_c t) + A_m \sin(w_m t) \sin(w_c t)$

$$c_m(t) = A_c \sin(w_c t) + \mu A_c \sin(w_m t) \sin(w_c t) \quad \text{------} \quad (1)$$

where $\mu = A_m/A_c$ = modulation index which defines depth of modulation and is kept < 1 to avoid over-modulation and to ease reconstruction of message signal at the receiver.

Using trigonometric relation $\sin A \sin B = ½ [\cos(A-B) - \cos(A+B)]$, we modify eq (1) as

$$c_m(t) = A_c \sin(w_c t) + \mu A_c/2 \cos(w_c - w_m)t - \mu A_c/2 \cos(w_c + w_m)t \quad \text{-------} \quad (2)$$

Eq (2) indicates that AM modulated signal containing carrier wave and side bands.

→ When an AM signal is created, the amplitude of the carrier is varied in line with the variations in intensity of the modulating signal. Here the envelope of the carrier can be seen to change in line with the modulating signal.

→ In receiver, envelope detection circuit is used to recover message signal and later is amplified before feeding it to speakers.

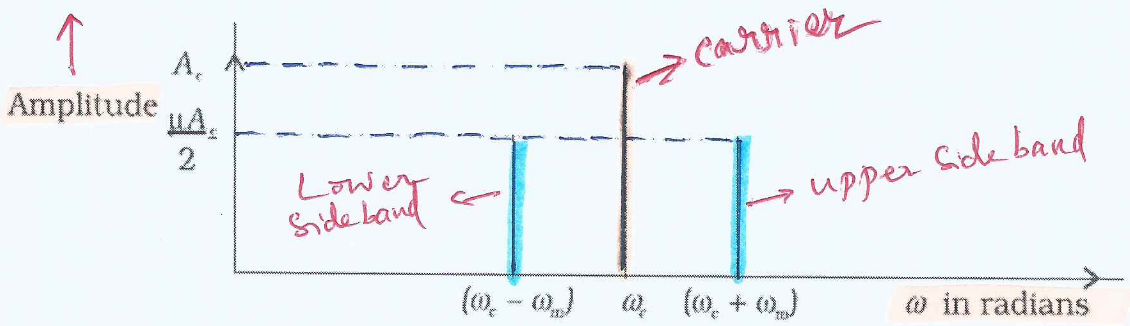
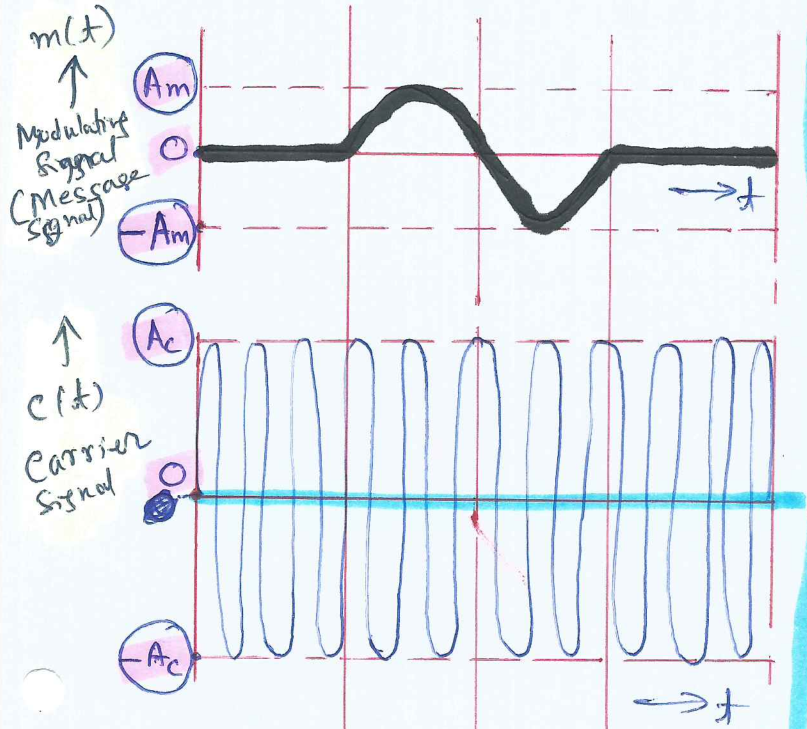


FIGURE 15.9 A plot of amplitude versus ω for an amplitude modulated signal.

Significance of "Modulation Index" (μ)



"Modulation Index" is equal to

$$\boxed{\mu = \frac{A_m}{A_c}} \rightarrow (1) \rightarrow \text{IMP}$$

μ can also be written as follows

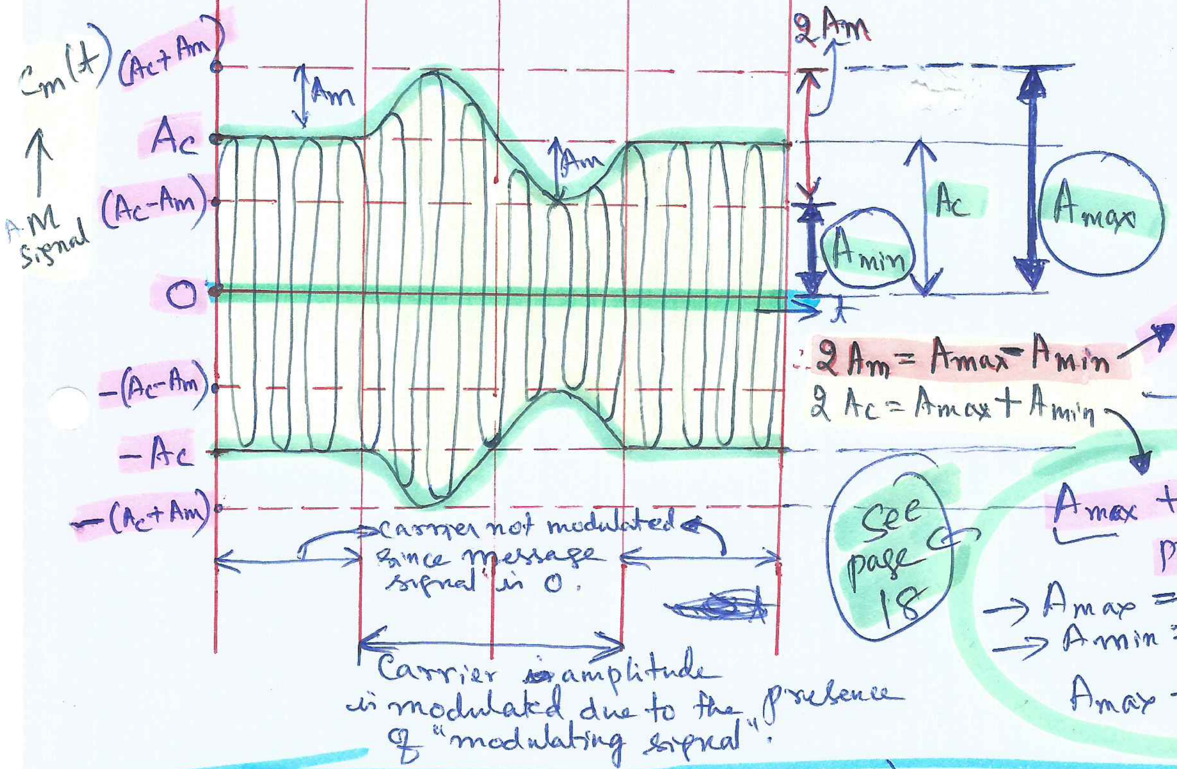
$$\mu = \frac{A_m}{A_c} = \frac{2A_m}{2A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

$$\boxed{\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}} \rightarrow (2)$$

$$\boxed{\% \mu = \left(\frac{A_{max} - A_{min}}{A_{max} + A_{min}}\right) \times 100} \rightarrow (3)$$

μ is kept less than 1 ($\mu < 1$) to avoid distortion

Very IMP



$\therefore 2A_m = A_{max} - A_{min}$ → From this diagram, it is very clear

$2A_c = A_{max} + A_{min}$ → IMP

See page 18

$A_{max} + A_{min} = 2A_c$
prove ?

$\rightarrow A_{max} = A_c + A_m$

$\rightarrow A_{min} = A_c - A_m$

$A_{max} + A_{min} = A_c + \cancel{A_m} + A_c - \cancel{A_m}$
$= 2A_c$.

→ If $\mu = 0$, $\Rightarrow A_m = 0$ (no message signal), there is no modulation $\Rightarrow$ carrier amplitude is unaltered.

→ If $\mu = \frac{1}{2} = \frac{A_m}{A_c}$ $\therefore \boxed{A_c = 2A_m}$ $\therefore \mu = \frac{1}{2} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = 2A_{max} - 2A_{min} = A_{max} + A_{min}$
(50% modulation) $= \boxed{A_{max} = 3A_{min}} \rightarrow$ IMP

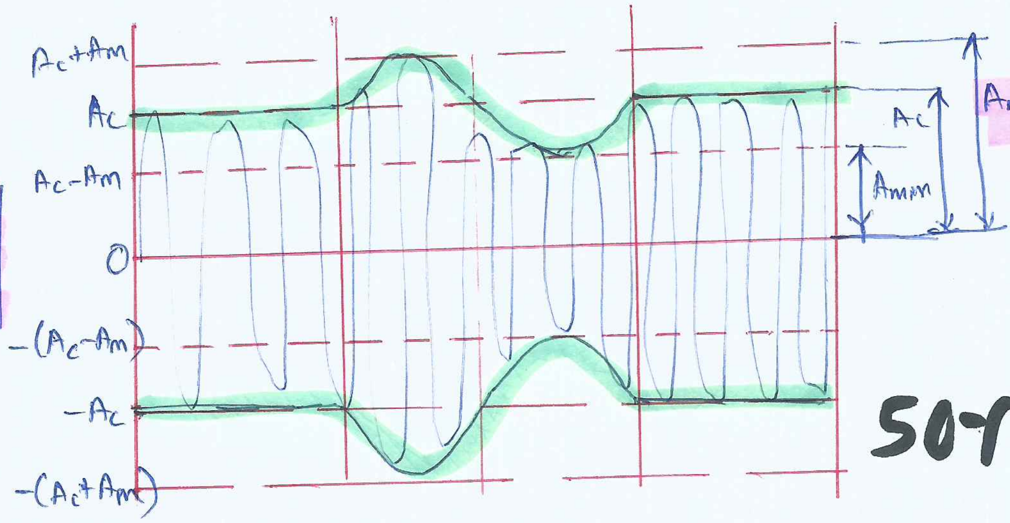
→ If $\mu = 1$, $A_m = A_c \Rightarrow A_{min} = 0 \Rightarrow$ 100% modulation

→ If $\mu > 1$, $A_m > A_c \Rightarrow$ there is over-modulation. In such a case, the AM wave is absent at the negative portion of the modulating signal and hence the information contained in the modulating wave will be distorted. Therefore μ is kept < 1 to ~~avoid~~ avoid over-modulation leading distortion of received signal.

AM wave for different values of μ :

⇒ if message signal is not there or if message amplitude $A_m > A_c$, we get different types of AM wave. Below figures show AM modulated wave for different μ.

$\mu = \frac{1}{2}$

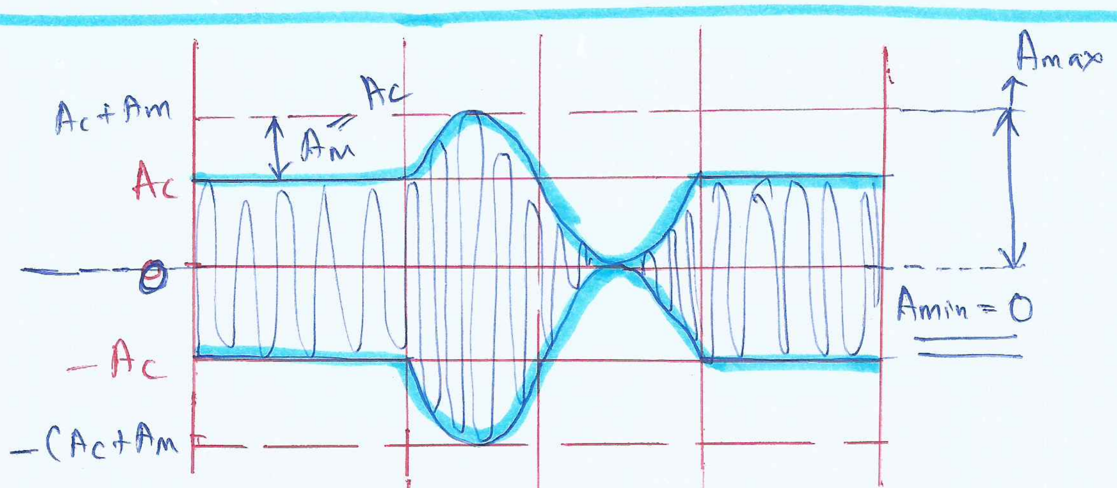


IMP

$A_{max} = 3\,A_{min}$

$\mu = \frac{1}{2}$

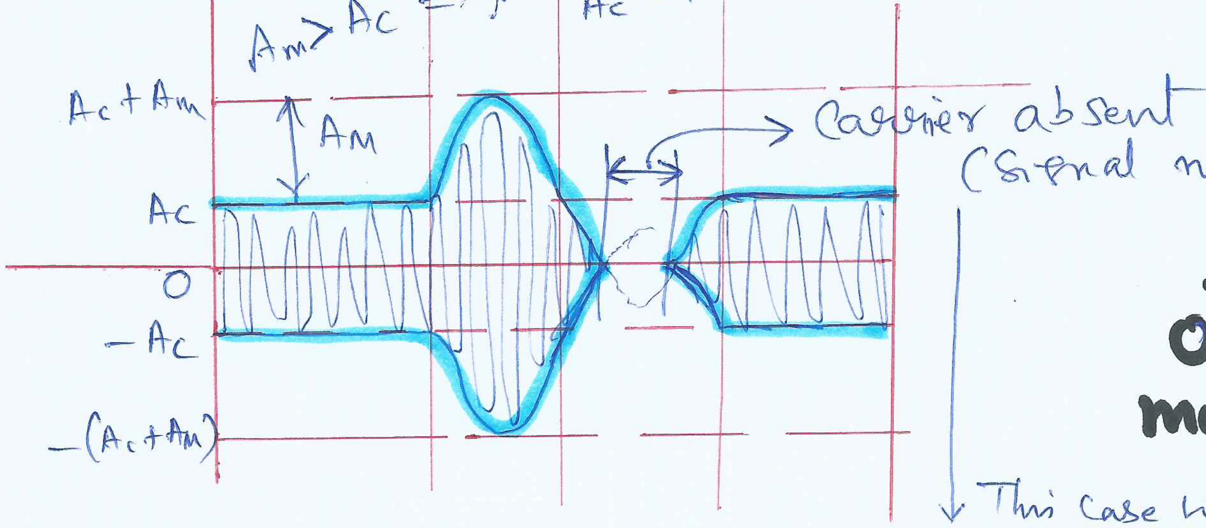
50% modulation



$\mu = 1$

100% Modulation

$A_m > A_c \Rightarrow \mu = \frac{A_m}{A_c} > 1$



$\mu > 1$

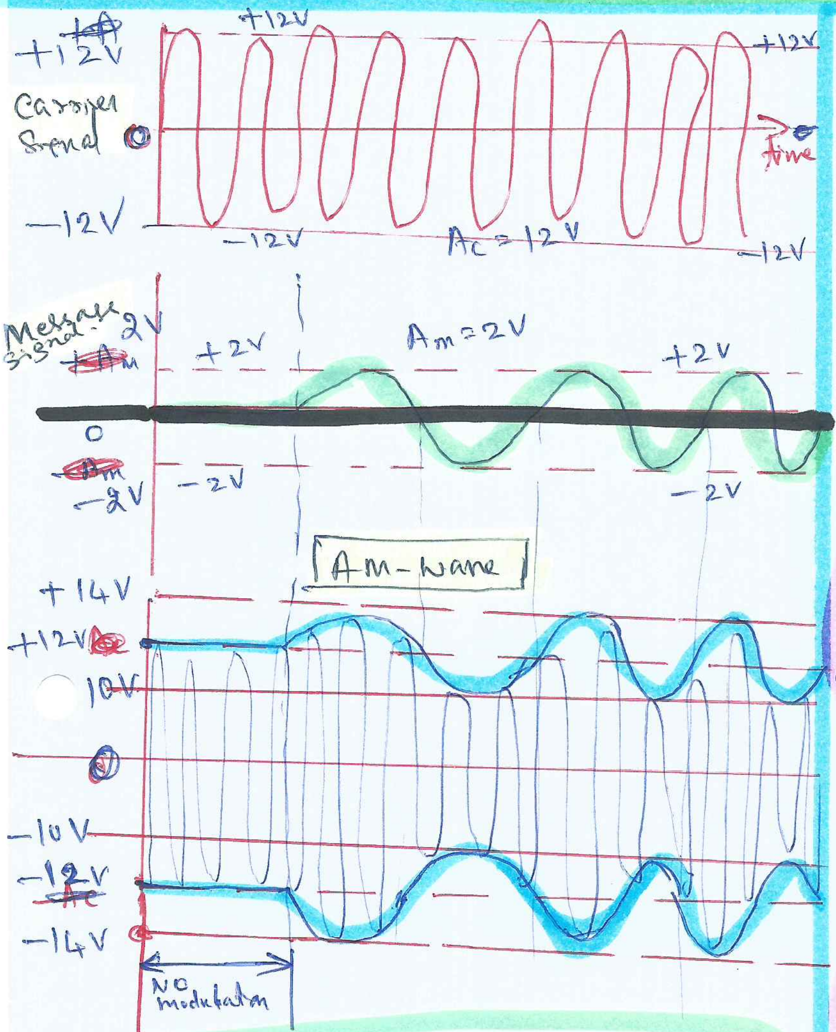
over modulation

This case where $A_m > A_c$ is known as over-modulation.

During over-over modulation, the receiver will miss in certain places carrier signal and hence cannot demodulate the signal. There could be signal (e.g. audio) distortion or missing audio

P.T.O.

Example: Carrier Amplitude $A_c = 12V$, modulating signal $= 2V$



$A_{max} = 14V$, $A_{min} = 10V$

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = \frac{14-10}{14+10} = \frac{4}{24} = \frac{1}{6}$$

$$\text{or } \mu = \frac{A_m}{A_c} = \frac{2V}{12V} = \frac{1}{6} \quad 17\% \text{ modulation}$$

If $A_c = 12V$, $A_m = 6V$

$$\mu = \frac{A_m}{A_c} = \frac{6}{12} = 0.5 \times 100 = 50\%$$

$\boxed{50\% \text{ modulation}}$

If $A_c = 12V$, $A_m = 12V$

$$\mu = \frac{A_m}{A_c} = 1 \times 100 = 100\%$$

$\boxed{100\% \text{ modulation}}$

If $A_c = 12V$, $A_m = \cancel{14V}\ 15V$

$$\mu = \frac{A_m}{A_c} = \frac{15V}{12V} = 1.25 \times 100 = 125\%$$

$\boxed{125\% \text{ modulation}}$

Commercial transmission sets $\mu = 87.5\%$. This is a standard value chosen such that the receivers will be able to demodulate the AM wave properly and produce undistorted message signal.

See page 16 : AM wave diagram

$\mu = \frac{A_m}{A_c} \rightarrow (1)$ this can be written as $\mu = \frac{2A_m}{2A_c}$

From AM wave diagram,

$2A_m = A_{max} - A_{min} \longrightarrow (2)$

To find what $2A_c$; from AM wave on page 16

$A_c = A_{min} + A_m$

$A_c = A_{max} - A_m$ Add

$2A_c = A_{max} + A_{min} \longrightarrow (3)$

From (2) and (3), we have

$$\boxed{\mu = \frac{2A_m}{2A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}} \longrightarrow (4)$$

here $A_{max} = 18$

$A_{min} = 6$

$$= \frac{18-6}{18+6} = \frac{12}{24} = \frac{1}{2}$$

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

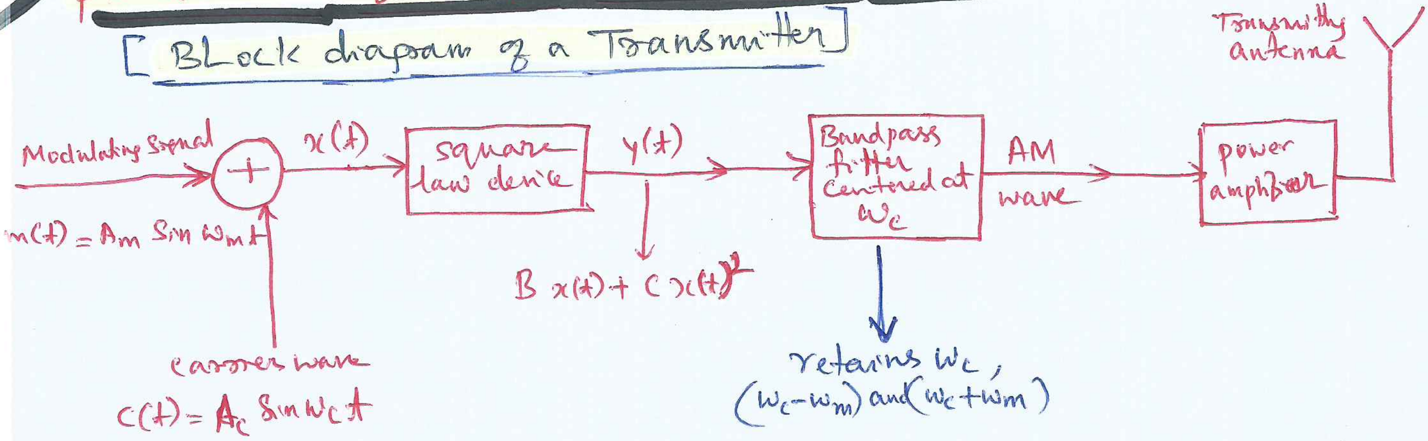
We know that for $\mu = 1/2$, $A_{max} = 3\ A_{min}$

$A_{max} = 18$

$A_{min} = 6$ $\Big\}$ $\therefore A_{max} = 3 \times A_{min}$

Production of Amplitude Modulated Wave and Transmission

[Block diagram of a Transmitter]



As shown in block diagram, the modulating signal $m(t) = A_m \sin\omega_m t$ is added to the carrier signal $c(t) = A_c \sin\omega_c t$ to produce

$$x(t) = A_m \sin\omega_m t + A_c \sin\omega_c t \rightarrow (1)$$

$x(t)$ is passed through a square law device which is a non-linear device which produces an output $y(t)$

$$y(t) = B\,x(t) + C\,x^2(t) \quad ; \text{ where } B \text{ and } C \text{ are constants.}$$

Using (1),

$$y(t) = \left[B A_m \sin\omega_m t + B A_c \sin\omega_c t\right] + C\left[A_m^2 \sin^2\omega_m t + A_c^2 \sin^2\omega_c t + 2 A_m A_c \sin\omega_m t \sin\omega_c t\right]$$

Using $\sin^2 A = \dfrac{(1-\cos 2A)}{2}$ and $\sin A \sin B = \dfrac{1}{2}\left[\cos(A-B) - \cos(A+B)\right]$

$$\therefore y(t) = \left[B A_m \sin\omega_m t + B A_c \sin\omega_c t\right] + C A_m^2\left(\frac{1-\cos 2\omega_m t}{2}\right) + C A_c^2\left(\frac{1-\cos 2\omega_c t}{2}\right) + \cancel{2} C A_m A_c\left[\frac{1}{\cancel{2}}\left[\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t\right]\right]$$

$$\therefore y(t) = \left[B A_m \sin\omega_m t + B A_c \sin\omega_c t\right] + \frac{C A_m^2}{2} + \frac{C A_c^2}{2} - \frac{C A_m^2}{2}\cos 2\omega_m t - \frac{C A_c^2}{2}\cos 2\omega_c t + C A_m A_c \cos(\omega_c - \omega_m)t - C A_m A_c \cos(\omega_c + \omega_m)t$$

$$y(t) = B A_m \sin\omega_m t + B A_c \sin\omega_c t + \frac{C}{2}(A_m^2 + A_c^2) - \frac{C A_m^2}{2}\cos 2\omega_m t - \frac{C A_c^2}{2}\cos 2\omega_c t + C A_m A_c \cos(\omega_c - \omega_m)t - C A_m A_c \cos(\omega_c + \omega_m)t \rightarrow (2)$$

In eqn (2), $\frac{C}{2}(A_m^2 + A_c^2)$ is a dc term and there are some waves with frequencies ω_m, ω_c, $2\omega_m$, $2\omega_c$, $(\omega_c - \omega_m)$ and $(\omega_c + \omega_m)$

P.T.O.

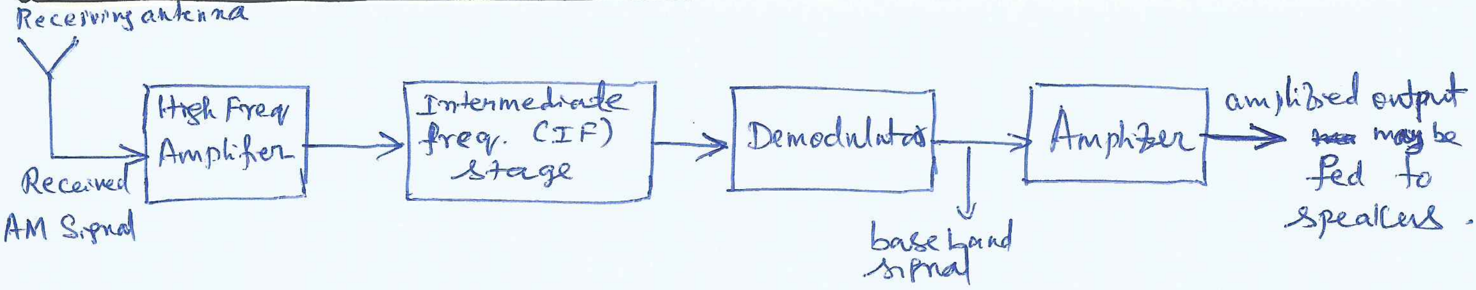
As shown in block diagram, y(t) is passed through a bandpass filter which is designed to reject dc, ω_m, $2\omega_m$ and $2\omega_c$ and retaining only frequencies ω_c, $(\omega_c-\omega_m)$ and $(\omega_c+\omega_m)$. Therefore output of bandpass filter is equal to

$$y(t)_{(\text{filtered})} = BA_c \sin\omega_c t + CA_mA_c\cos(\omega_c-\omega_m)t - CA_mA_c\cos(\omega_c+\omega_m)t \quad \longrightarrow (3)$$

EQ (3) is of the same form as AM modulated equation and output of bandpass filter is a AM wave.
It is then passed through power amplifier which provides necessary power and then the modulated signal is fed to an antenna of appropriate size for radiation.

Detection of AM wave :

Block diagram is given below



As shown in block diagram, when an AM wave is propagating in the atmosphere, it suffers attenuation and hence firstly the received AM signal is amplified and then high freq modulated signal is translated to a low ~~frequency~~ AM wave using IF stage. (no change happens in the modulated signal due to this translation).

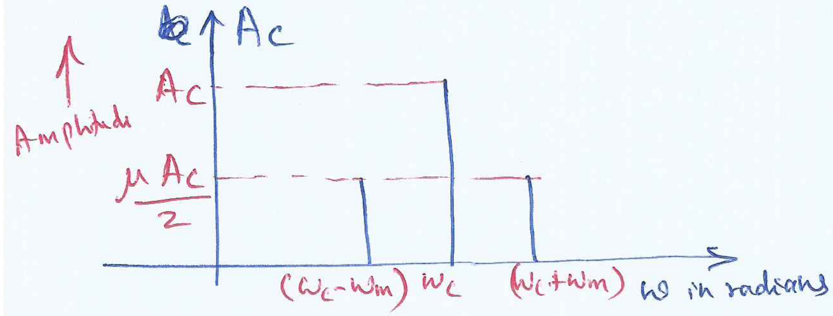
- IF stage is mainly used to get a constant low frequency modulated signal and ~~electronics of the~~ it is easy to build electronics ~~to~~ for low frequencies.
- From IF stage, the translated low-frequency AM wave is ~~passed~~ fed to a demodulator, which extracts the baseband signal from carrier. So, the output of demodulator is our information signal which then amplified and fed to speakers.

P.T.O.

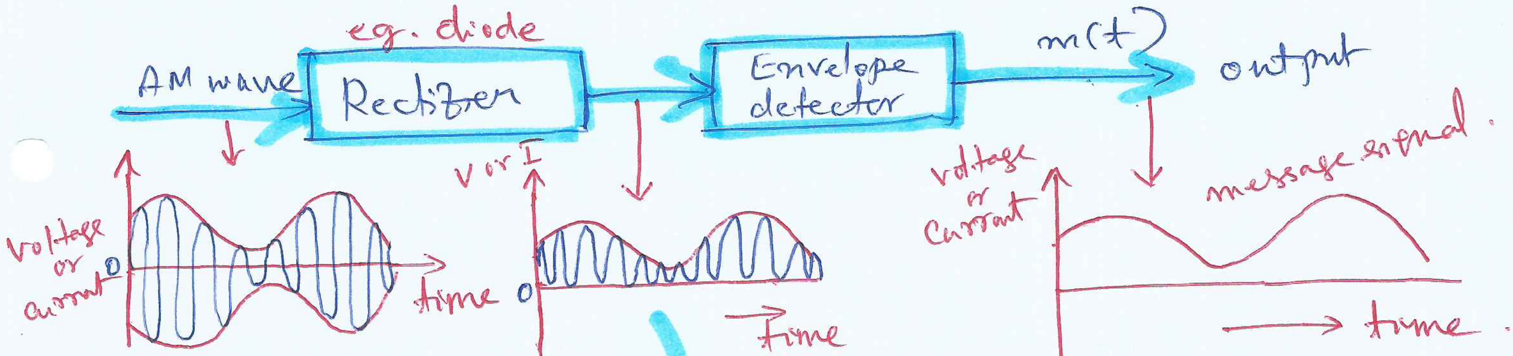
.... Contd.

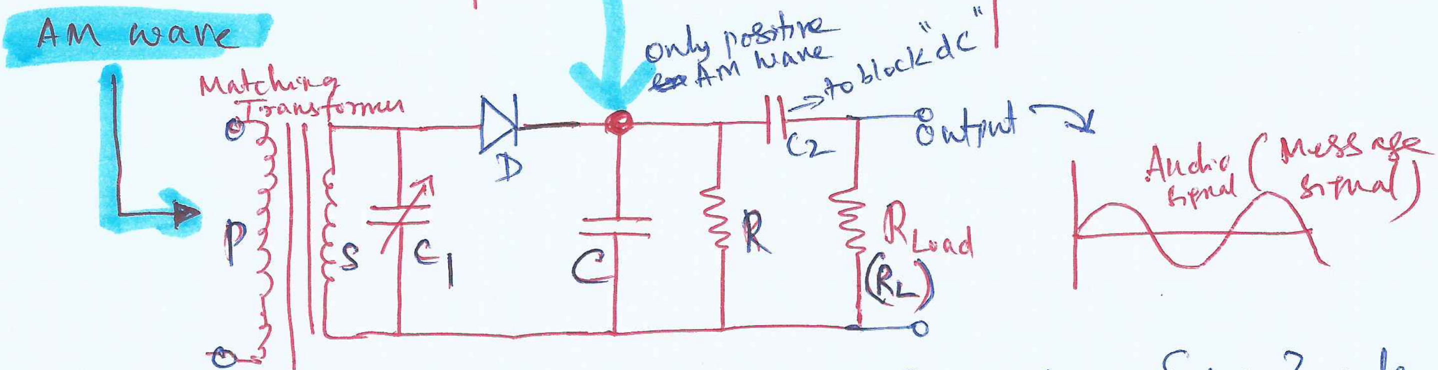
Demodulation (or detection) is the process of recovering the baseband signal from the modulated carrier wave.

Modulated (AM) Carrier frequency spectrum is as follows



So, transmitted AM wave contains ω_c and $(\omega_c \pm \omega_m)$. A simple rectifier can be used to recover original message signal.



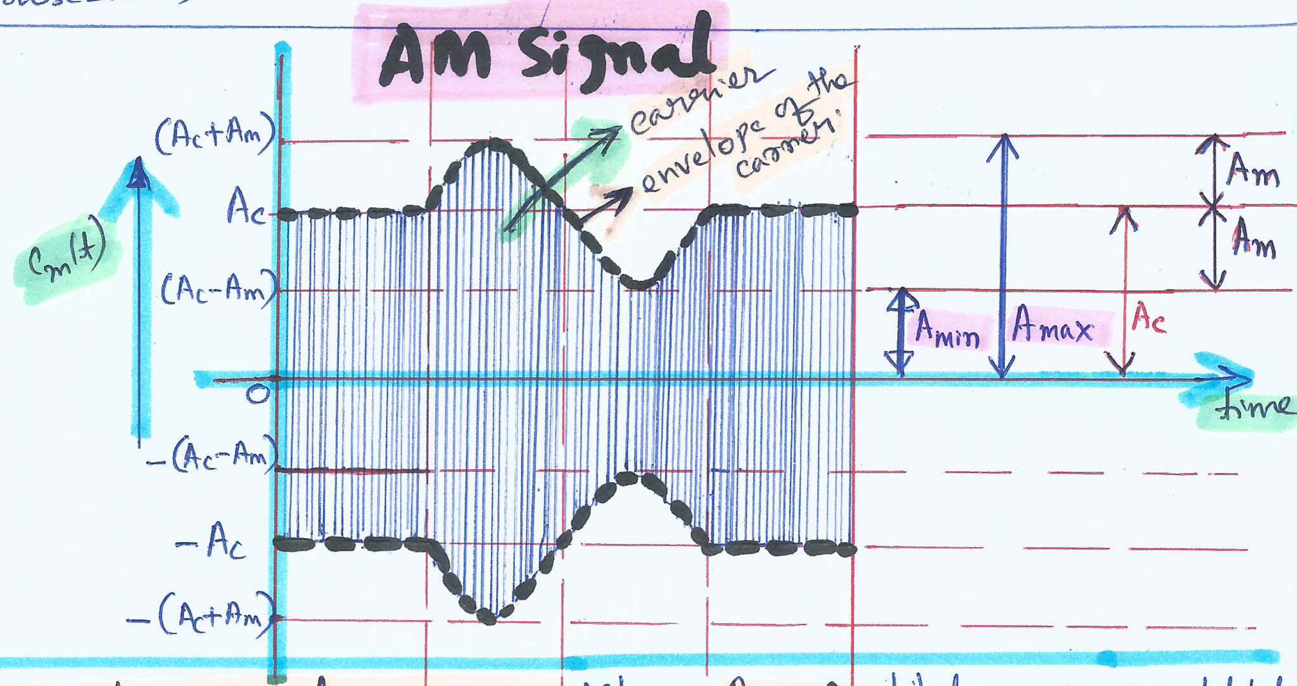


Inductance of Secondary of transformer (L) and C_1 {LC_1} acts as a tank circuit and by tuning C_1, circuit is brought to resonance with the input AM wave. This way AM wave is received and passes through diode D, which removes –ve half as shown in figure.

- C is chosen a low value and we know that $X_C = \frac{1}{2\pi f c}$ ⇒ offers high ~~high resistance~~ impedence to low frequency and low impedence to high frequencies. So, high frequency carrier is bypassed to ground and voltage on C is the low freq. envelope → which is our message signal that appears across R. Value of RC is chosen in a such a way that $(1/f_c) << RC$, where f_c is the freq. of carrier wave.
- C_2 is used to 'block dc'.

Some more Info

- Amplitude Modulation Index (μ) describes the extent to which the amplitude of carrier wave is changed by the modulating (baseband) signal. It thus determines the quality and strength of the transmitted signal.
- If μ is small, the variation in carrier-wave amplitude will be small and the baseband signal (eg. audio) being transmitted will be weak. The greater the μ, the stronger and clearer will be the baseband signal during reception.
- If, however, $\mu > 1$, the carrier-wave is overmodulated, the received audio (baseband) signal will be distorted (in the receiver).



Modulation index $\mu = \frac{A_m}{A_c} \rightarrow ①$

where A_c = Amplitude of ~~car~~ unmodulated carrier

A_m = Amplitude of baseband signal.

We can have 2 equations for μ

① $\mu = \frac{A_m}{A_c} \rightarrow ①$

$$\boxed{\% \mu = \frac{A_m}{A_c} \times 100} \rightarrow ⑦$$

※ Depending on the given problem, either ① or ⑦ will be useful OR ⑤ or ⑥ will be useful.

IMP

② $\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$; where A_{max} = Max. amplitude of the modulated carrier

A_{min} = Min amplitude of the modulated carrier

How?

We know that $\mu = \frac{A_m}{A_c}$

$\mu = \frac{2A_m}{2A_c} \rightarrow ②$ $\Rightarrow$ Find $2A_m$ and $2A_c$?

- From AM wave diagram, $\boxed{2A_m = A_{max} - A_{min}} \rightarrow ③$
- To find $2A_c$: From AM wave diagram

$A_c = A_{min} + \cancel{A_m}$

also $A_c = A_{max} - \cancel{A_m}$

adding $2A_c = A_{max} + A_{min} \rightarrow ④$

From ③ and ④, we get

$$\boxed{\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}} \rightarrow ⑤$$

$$\boxed{\% \mu = \frac{(A_{max} - A_{min})}{(A_{max} + A_{min})} \times 100} \rightarrow ⑥$$

Numericals.

AM signal is given by

$$C_m(t) = (A_c + A_m \sin \omega_m t) \sin \omega_c t \rightarrow (1)$$

$$C_m(t) = A_c \left[1 + \frac{A_m}{A_c} \sin \omega_m t\right] \sin \omega_c t \rightarrow (2)$$

$$C_m(t) = A_c \left[1 + \mu \sin \omega_m t\right] \sin \omega_c t \rightarrow (3)$$

OR
OR
Any of these can be used depending on problem.

(1) The AM voltage $C_m(t)$ is given by $C_m(t) = 150[1 + 0.5 \sin 3250t] \sin(5\times10^5 t)$.
Calculate (i) μ (ii) modulating freq. (iii) carrier freq. (iv) carrier amplitude.

Given $C_m(t) = 150\,[1 + 0.5 \sin 3250 t] \sin(5\times10^5 t)$

This is of the form $C_m(t) = A_c[1 + \mu \sin \omega_m t] \sin \omega_c t$; Therefore

(i) $\mu = 0.5$

(ii) $f_m = ?$ $\rightarrow \omega_m = 2\pi f_m = 3250$ $\therefore f_m = \frac{\cancel{3250}^{1625}}{\cancel{2}\pi} = 517\ Hz.$

(iii) $f_c = ?$ $\rightarrow \omega_c = 2\pi f_c = 5\times10^5$ $\therefore f_c = \frac{5\times10^5}{2\pi} = 79.6\ KHz$

(iv) $A_c = ?$ $\rightarrow$ already given $A_c = 150\,V$ (carrier amplitude)

(2) A carrier wave of amplitude 100 V and freq 1000 KHz is amplitude-modulated by a 50 V, 1000 Hz audio sine-wave signal. What is μ?

$\cancel{\mu = \frac{A_c}{A_m} = \frac{100\,V}{5}}$ $\mu = \frac{A_m}{A_c} = \frac{50\,V}{100\,V} = \frac{1}{2} = 0.5$ (50% modulation)

(3) A carrier wave has an amplitude of 500 mV. The modulating signal causes it to vary from 200 mV to 800 mV. What is the % modulation.

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

Given $A_{max} = 800\ mV$
$A_{min} = 200\ mV$

$$= \frac{800 - 200}{800 + 200} = \frac{\cancel{600}^{3}}{\cancel{1000}_{5}} = 0.6 \quad \therefore \%\mu = 0.6 \times 100 = 60\%\ \text{modulation}$$

(4) A sinusoidal audio signal given by $15 \sin 2\pi(2000t)$ modulates a sinusoidal carrier wave given by $60 \sin 2\pi(100{,}000t)$. Find μ and freq. spectrum of the modulated wave.

Given $A_m = 15$, $f_m = 2000\,Hz$, $A_c = 60$, $f_c = 100{,}000\ Hz$

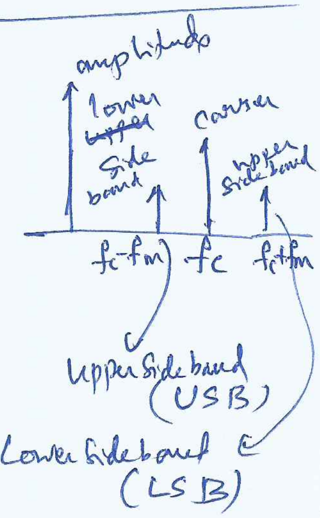
$BW = \cancel{f_c} + f_m - \cancel{f_c} + f_m = 2 f_m$

$$\mu = \frac{A_m}{A_c} = \frac{15}{60} = \frac{1}{4} = 0.25 \quad (25\%\ \text{modulation})$$

The 3 freq. present in the modulated wave are

- carrier freq. $f_c = 100{,}000\,Hz = 100\ KHz$
- $USB = f_c + f_m = (100 + 2)\ KHz = 102\ KHz$
- $LSB = f_c - f_m = (100 - 2)\ KHz = 98\ KHz$

$BW \rightarrow (102 - 98)^{KHz} = \cancel{4\,Hz}$
$= 4\ KHz$
$= 2 f_m$



(5) A 10 MHz carrier wave of amplitude 20 mV is modulated by a 5 KHz audio signal of amplitude 12 mV. Find the frequencies of the upper and the lower side bands of the resultant AM wave and their amplitudes.

Given $f_c = 10\,MHz$, $A_c = 20\,mV$, $f_m = 5\,KHz$, $A_m = 12\,mV$

Formula: $e_m(t) = A_c \sin(w_c t) + \frac{\mu A_c}{2}\cos(w_c - w_m)t - \frac{\mu A_c}{2}\cos(w_c + w_m)t$

USB freq $= f_c + f_m = 10\,MHz + 5\,KHz = 10{,}000\,KHz + 5\,KHz$
$= 10{,}005\,KHz$
$= \underline{10.005\,MHz}$

LSB freq $= f_c - f_m = 10\,MHz - 5\,KHz = (10{,}000 - 5)\,KHz$
$= 9995\,KHz$
$= \underline{9.995\,MHz}$

USB amplitude $=$ LSB amplitude $= \frac{\mu A_c}{2}$

$\mu = \frac{A_m}{A_c} = \frac{\cancel{12}^{3}\,\cancel{mV}}{\cancel{20}_{5}\,\cancel{mV}} = 0.6$

$\therefore$ USB or LSB amplitude $= \frac{0.6}{\cancel{2}} \times \cancel{20}^{10}\,mV = \boxed{6\,mV}$

(6) A bandwidth of 20 MHz is available for AM transmission. If the audio-signal modulating freq is not to exceed 20 KHz how many stations can broadcast within this band without interfering one another?

$\rightarrow$ BW required by each station is $2 f_m$
$= 2 \times 20\,KHz = 40\,KHz$

$\therefore$ Hence the number of stations within 20 MHz bandwidth is

$\frac{20\,MHz}{40\,KHz} = \frac{\cancel{20{,}000}^{500}\,KHz}{\cancel{40}\,KHz} = \underline{500\ \text{Stations}}$

Question

Q: (i) What does the term LOS communication mean? Name the types of waves that are used for this communication.

(ii) A TV tower has a height of 400 m at a given place. Calculate its coverage range if the radius of earth = 6400 km

→ (i) LOS communication : LOS represents "Line of Sight" communication in which the waves travel in a straight line from transmitting antenna to the receiving antenna. Due to the nature of this LOS communication, direct waves get blocked at some point by the curvature of the earth.

Space waves are used for LOS communication as well as satellite communication.

(ii) Radio horizon of the transmitting antenna :

$$d_T = \sqrt{2Rh_T} = \sqrt{2\times 6400\times 10^3 \times 400}$$
$$= \sqrt{20\times 64\times 10^6\times 4}$$
$$= \sqrt{20}\times 8\times 10^3\times 2$$
$$= 16{,}000\sqrt{20}\ m$$
$$= 71554\ m$$

$$\therefore \text{Coverage range} = \pi d_T^2 = \pi (71554\ m^2)$$
$$= 224794\ m^2$$