UEEEC0063

Solve fundamental electronic communications system problems

STUDENT WORKBOOK

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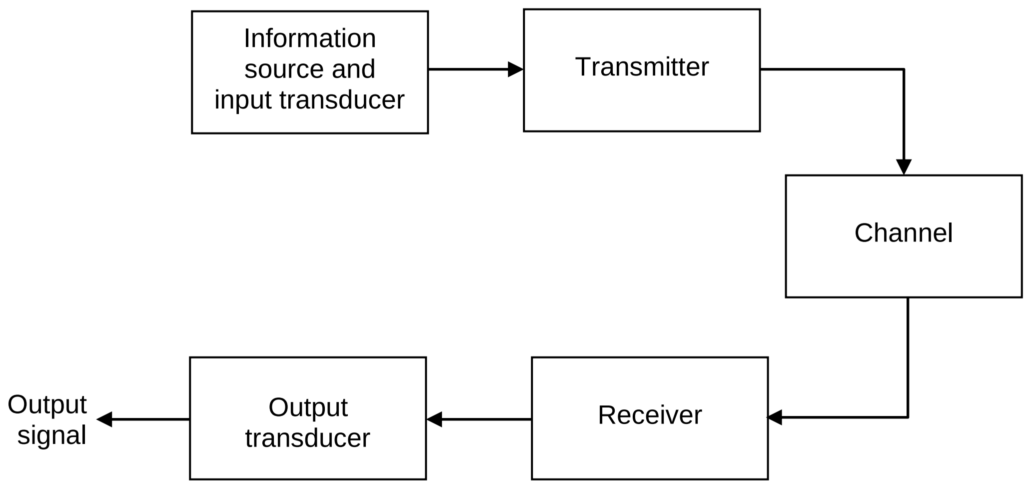
Unit 1 Elements of a communications system

The basic communications system

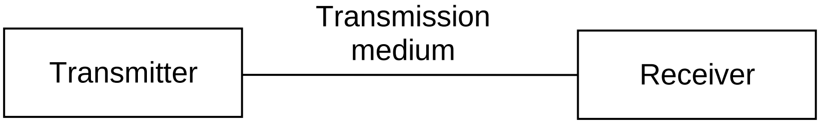
Communication systems are designed to send messages or information from a source that generates the message to one or more destinations. In general, a communication system can be represented by the functional block diagram shown below. The information generated by the source may be of the form of voice (speech source), a picture (image source), or any form of data (computer files for example).



Block diagram of a communication system.

A transducer is sometimes required to convert the information source into an electrical signal that is suitable for transmission. For example, a microphone serves as the transducer that converts sound pressure waves from speech into an electrical signal, and a video camera converts an image into an electrical signal. At the receiver, another transducer is required to convert the electrical signals that are received into a form that is suitable for the user; e.g., sound pressure waves, images, etc.

Major components of the communication system consist of three basic parts, the *transmitter,* the *transmission medium,* and the *receiver.*



The basic principle of a communication system is to transmit the signal to the receiver with minimum distortion so that the received signal is a duplicate of the original information.

The transmitted signal could be **digital** or **analogue**:

- Voice/music
- Video
- Data

Types of transmitted signals

Audio

Audio signals are characterised by the specific requirements of the human ear. The frequency range and the audio level that can be heard have defined limits.

Telephone conversation has prescribed power levels and a frequency range of 300 – 3400 hertz.

Studio quality sound mono or stereo signals for AM or FM radio stations have frequency ranges up to 15 KHz.

Many other audio signals may be transmitted. e.g. Police or emergency services radio systems, taxi and other transport services radio systems, aircraft and marine radio systems, military and security services, and mobile phones.

Video

Video signals are characterised usually by the combination of sound, picture and timing & control. The picture quality is set as a function of the characteristics of the human eye.

Video signals are the baseband information for:

- Analogue television
- Digital television
- Satellite television
- Cable television
- Internet
- Mobile phones
- Security systems

Data

Computer to computer signals using digital logic and any system that uses digital technologies. All analogue signals can be converted to digital with an analogue to digital converter.

For example:

- Digital television
- Digital radio
- Mobile phones
- Internet
- Secure digital communications systems such as police radios
- GPS

Characteristics of communications systems

There are three basic types of communication:

- Simplex
- Half duplex
- Duplex

Simplex

The sender transmits and the users receive on the same frequency.
Public broadcasting is an example.

Half duplex

The user can receive and transmit on one frequency but not at the same time. Half duplex requires only one channel.

Hand-held radios are half-duplex. You must push a button to talk, let go to receive. You cannot transmit and receive at the same time.

Duplex

The user transmits on one frequency and receives on another frequency simultaneously.

Multiplexing

This is a process used to send multiple independent communications signals over the same transmission medium. For example, thousands of telephone conversations can be carried on the same wire. There are several methods of accomplishing multiplexing.

When multiple signals are sent over a single transmission channel, the process that keeps the signals from interfering with one another is called multiplexing.

Frequency division multiplexing (FDM)

In FDM, each signal is given a unique carrier frequency. These frequencies must be chosen so that adjacent signals do not overlap. They must be separated by a frequency interval equal at least to the signal bandwidth.

In the telephone network each telephone conversation is separated by 4 kHz which is the telephone system bandwidth. Multiplexing capacity is the maximum number of independent signals that can be transmitted simultaneously. This is limited by both the bandwidth of the signals and the available bandwidth or the transmission medium.

Frequency multiplexing hierarchy used in telecommunications systems.

Name	Frequency Range	Number of Channels
Channel	0 – 4kHz	1
Group (12 channels)	60 – 108kHz	12
SuperGroup (5 groups)	312 – 552kHz	60
MasterGroup (5 supergroups)	812 – 2044kHz	300
SuperMasterGroup (3 mastergroups)	8516 – 12388kHz	900

The above chart shows standard frequencies used in the frequency hierarchy of a telecommunications system. Depending on the available bandwidth of the transmission medium (cable pair, coaxial cable or microwave radio link) one of these standard formats would be used.

For wireless communication, the available bandwidth is determined by the allocated frequency band. For example, AM radio signals must be in the 540-1600 kHz band. Therefore there are more than 100 possible carrier frequencies that may be assigned, at 9 kHz intervals. Likewise FM radio stations are at 200 kHz intervals in the range of 88-108 MHz allowing 100 stations in a local area.

Whilst these examples are not FDM they illustrate the limitation on the number of channels that can be implemented by the available bandwidth.

For any system using frequency division multiplexing, the channel capacity will be determined by available bandwidth and the signal bandwidth of each baseband frequency.

Time division multiplexing (TDM)

In TDM, each signal can occupy the entire bandwidth of a transmission medium, but is given a time slot of limited duration made available at regular intervals. This is a common method of communication for digital signals. It is natural to talk about the digital rate of transmission measured in bits per second (baud rate). .

Digital signals are often created from analogue baseband signals with an analogue to digital converter (ADC). These analogue signals can be audio or video.

Theoretically there is no maximum number of signals that can be multiplexed, but there is a limit on the overall transmission rate (i.e. the capacity in bits per second). Suppose we have a digital transmission channel with a capacity of 100 Mbps. If there is only one user, they could occupy the entire channel and transmit their signal at 100 Mbps. If there are 20 users, each will only have transmission rate of 5 Mbps.

Like the FDM system there is an organised system of sharing the time in a TDM system. The chart below shows the multiplexing hierarchy for digital systems.

Level of Multiplexing		Digital Speed	Number of Channels
0	ZDME (zero order) #	64 kb/s	1 voice channel
1	1DME (first order) #	2.048 Mb/s	30 voice channels
2	2DME	8.448 Mb/s	
3	3DME	34.368 Mb/s	
4	4DME	139.264 Mb/s	
5	5DME	565.148 Mb/s	

DME – Digital multiplex equipment

The system has predetermined time slots which set a fixed rate for any user. If the capacity is not filled, time slots go empty. This is the case for **synchronous** systems which rely on a fixed timing and is used in many telecommunications systems.

There are other digital multiplexing systems that can be used.

Unit 2 Introduction to radio communications

Radio communication is the wireless transmission of signals to convey intelligence or information by the modulation of electromagnetic waves. Typical forms of modulation are:

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)

Electromagnetic radiation travels by means of oscillating electromagnetic fields that do not require a medium of transport.

Information is carried by systematically changing (modulating) either the amplitude, frequency or phase of the carrier wave. (Sometimes more than one parameter)

When radio waves pass an electrical conductor, the oscillating fields induce an alternating current in the conductor. This can be detected and transformed into the original baseband intelligence.

Baseband signals

The baseband signal is the information to be transmitted. These signals can be audio (voice or music), video or data.

Analogue audio and video produce very complex wave forms continually varying in amplitude and frequency. For example, telephone systems are said to have a baseband frequency range of 0 – 4 kHz, FM radio stations have a baseband frequency range of 0 – 15 kHz. Baseband signals can be analogue or digital.

With this in mind, both digital and analogue transmission techniques need to be explored together with digital and analogue test equipment and procedures.

International standards

The frequencies used are set primarily by an international standards organisation [ISO]. And government allocates licences to use frequencies. As we will see in later chapters the bandwidths, frequencies and powers transmitted must comply with government regulations.

ACMA
Australian Communications and Media Authority is an independent Commonwealth statutory authority.
ACMA regulates communications and media to contribute to maximising the economic and social benefits of communications infrastructure, services, and content for Australia.

They regulate communications and media services in Australia.
ACMA is responsible for;

- setting and managing rules about communications and media services and markets
- licence people, organisations, and products to operate in Australia.
- looking into complaints and problems and taking action when rules aren't being followed.
- planning and managing the airwaves and make space for new services, like 5G.

The ACMA remit covers internet and phones, TV, radio and content, spectrum, and equipment compliance.

The ACMA regulates products by making rules under the:

- Broadcasting Services Act 1992
- Telecommunications Act 1997
- Radiocommunications Act 1992.

Your product might need to comply with our rules for:

- telecommunications equipment
- radiocommunications equipment
- electromagnetic compatibility (EMC)
- electromagnetic energy (EME).

We also regulate one part of broadcasting: the parental lock standard for digital TV.

Under the Radiocommunications Act 1992, the ACMA regulates;

- products that: are customer equipment or customer cabling and may connect to a telecommunications network or facility in Australia. (Telecommunications ACT 1997)
- transmitters and receivers, including transmitters that are in other products. (Radiocommunications ACT 1992).
- electrical and electronic products and most common household products (for example, white goods, kitchen appliances and IT equipment) (Radiocommunications ACT 1992).
- the maximum levels of electromagnetic energy from radiocommunications transmitters with an integral antenna. (Radiocommunications ACT 1992).

ITU

The International Telecommunication Union (ITU) is the United Nations specialized agency for information and communication technologies – ICTs.

Founded in 1865 to facilitate international connectivity in communications networks, we allocate global radio spectrum and satellite orbits, develop the technical standards that ensure networks and technologies seamlessly interconnect, and strive to improve access to ICTs to underserved communities worldwide. Every time you make a phone call via the mobile, access the Internet or send an email, you are benefitting from the work of ITU.

Uses of radio communication

Experiments in radio communication were carried out in the late 19th century and early 20th century.
The first radio communication systems used carrier wave (CW) modulation transmitting morse code. The first commercial broadcasters used amplitude modulation (AM).

In the 1940s and 1950s frequency modulation was developed..

Transmission of audio signals

There are many forms of radio services, the list below is only a few examples;

- AM broadcast radio transmitting music and voice in the medium frequency band. (MF)
- FM broadcast radio transmitting music and voice with higher fidelity in the very high frequency band. (VHF).
- Aviation and marine voice telephony radio systems.
- Civil and military high frequency voice telephony services using short wave radio in the high frequency band. (HF).

Transmission of telephony

Many telephony services are generally provided by local Telecommunication providers.

- Mobile phones transmit to and from local cell sites.
- Microwave radio links between telephone exchanges connect thousands of telephone calls.

Transmission of video

Video is an increasing market; there are many radio transmissions of video signals in both analogue and digital combinations:

- Television transmits pictures and sound as modulated radio waves.
- Internet
- Mobile phones

Navigation

- Radar (radio detection and ranging) detects objects at a distance by reflecting radio waves from them.
- GPS (global positioning system) detects your position on the earth's surface by linking with satellites in a geosynchronous orbit.
- Omega navigation low frequency transmitters at fixed locations.

Digital communications

- Digital television.
- Digital radios.
- Mobile phones.

Amateur radio

A hobby that some people enjoy communicating all around the world.

Radio control systems

Uses radio communications to control remotely control plant and equipment. UAV Aircraft are another application.

Modern radio communications

Any wireless systems such as Bluetooth

Broadcast systems

When a signal is transmitted that can be received by any receiver in the transmission area, such as –

- Television (TV).
- AM & FM radio.
- GPS Navigation systems.

Other systems

- The telephone network such as microwave radio links,
- Satellite telephone,
- Wireless Bluetooth,
- Wireless mouse and keyboards,
- Wireless data transmission networks
- Remote controls garage doors, motor cars, model planes and cars,
- Security systems and surveillance,
- Taxis, Auto clubs etc.
- Aircraft communications and radar,
- CB radios,
- Amateur radio.

Duplex systems

A good example is the mobile telephone network. Radio frequencies are transmitted and received from a cellular communications tower. This form of communication is dedicated to a single communications link to each mobile phone.

Transmission and reception of signals occur simultaneously

Simplex systems

This is a communication system that is either transmit only (broadcast radio and TV) or can only transmit or receive at any one time..

Transmitters

Signals are modulated using amplitude, frequency modulation or phase modulation and are amplified to the required power level.

This will vary from milliwatts to many kilowatts of power, dependent on the particular application. Lower frequency transmitters generally have higher power levels and higher frequency transmitter’s lower power levels.

Governments have control over the power levels allowed so that users of the frequency spectrum have fair access.

If a broadcast system such as television is used to cover a large area then the power of the transmitter needs to be high. The physical construction of the aerial has to be capable of handling the power from the transmitter.

The transmitter converts the electrical signal into a form that is suitable for transmission through the physical channel or transmission medium. For example, in radio and TV broadcast, the governing bodies specify the frequency range for each transmitting station. The communication system must translate the information signal to be transmitted into the appropriate frequency range that matches the frequency allocation assigned to the transmitter. Signals transmitted by multiple radio stations therefore will not interfere with one another. Similar functions are performed in telephone communication systems where the electrical speech signals from many users are transmitted over the same wire.

In addition to modulation, other functions that are usually performed at the transmitter site would be:

- filtering of the information-bearing signal.
- amplification of the modulated signal.
- radiation of the signal by means of a transmitting antenna if a wireless communication system.

Transmitter locations

Transmitters are usually located near to the antenna. This reduces the power losses in the transmission line feeding the antenna. The physical location is controlled by the frequency and typical mode of propagation.

- Ground wave usually central to the service area
- Space wave at a high location for line of sight transmission
- Sky wave very flexible as to location, but preferably on a low mound of high ground.

Each one of these types of transmission modes is fundamentally determined by the frequency, so the location of antenna is related to the frequency used and the service target of the transmission.

Transmission medium

The communications channel is the physical medium that is used to send the signal from the transmitter to the receiver.

The transmission medium can be transmission lines such as coaxial cable, wave guide, and fibre optic or free space.

Common to all these is the need to keep attenuation and noise introduced as low as possible.

Receivers

The function of the receiver is to recover the baseband signal contained in the received signal.

The received signal has to be of sufficient level to be processed, the type and construction of the antenna is important. Early amplification before processing is normal.

If the baseband signal is transmitted by carrier modulation, (AM, FM or PM) the receiver performs carrier demodulation in order to extract the baseband signal. The demodulated signal is generally degraded to some extent by noise and distortion. Besides performing the primary function of signal demodulation, the receiver also performs a number of peripheral functions, including signal filtering and noise suppression.

Summary

Radio communication uses modulated electromagnetic waves to transmit information..

ISO sets international standards for radio communication systems along with governments.

Wireless communications has a expanding base and is used extensively in everyday life.

Radio communication systems can be Duplex or Simplex.

Baseband signals for voice frequencies (telephone audio) range from 300Hz – 3.4kHz (4kHz).

Baseband signals for broadcast radio range from ....

- AM radio 40Hz – 7kHz
- FM radio 40Hz – 15kHz

Unit 3 Radio waves and the electromagnetic spectrum

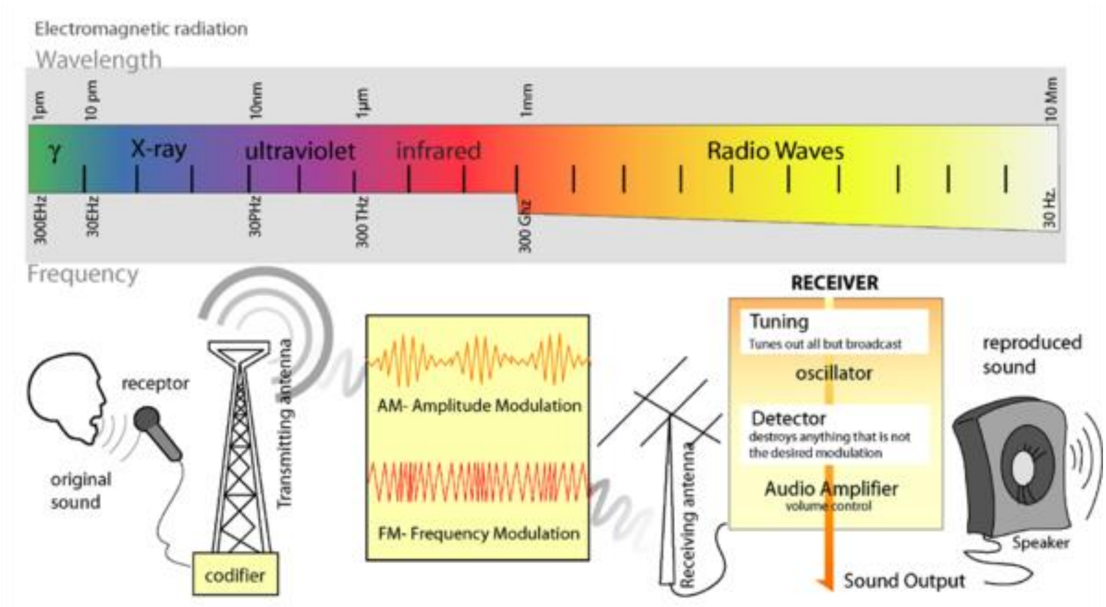
https://phet.colorado.edu/sims/cheerpj/radio-waves/latest/radio-waves.html?simulation=radio-waves

Characteristics of radio waves

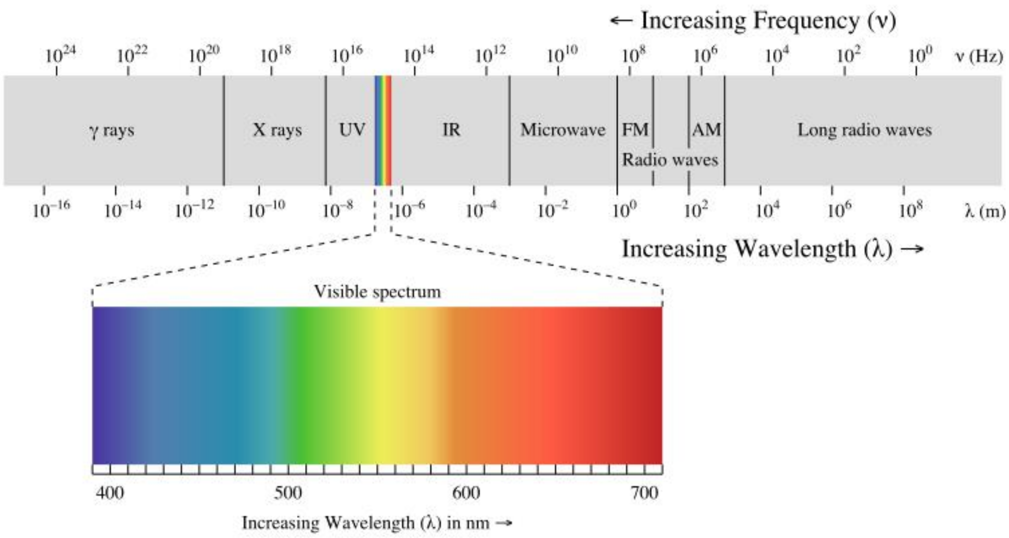
Radio waves are a part of the electromagnetic radiation spectrum, together others such as visible light, infrared and X-rays.

Radio waves have longer wavelengths compared to the shorter wavelengths of visible light, infrared and X-rays.

This also means the radio waves have lower frequencies.



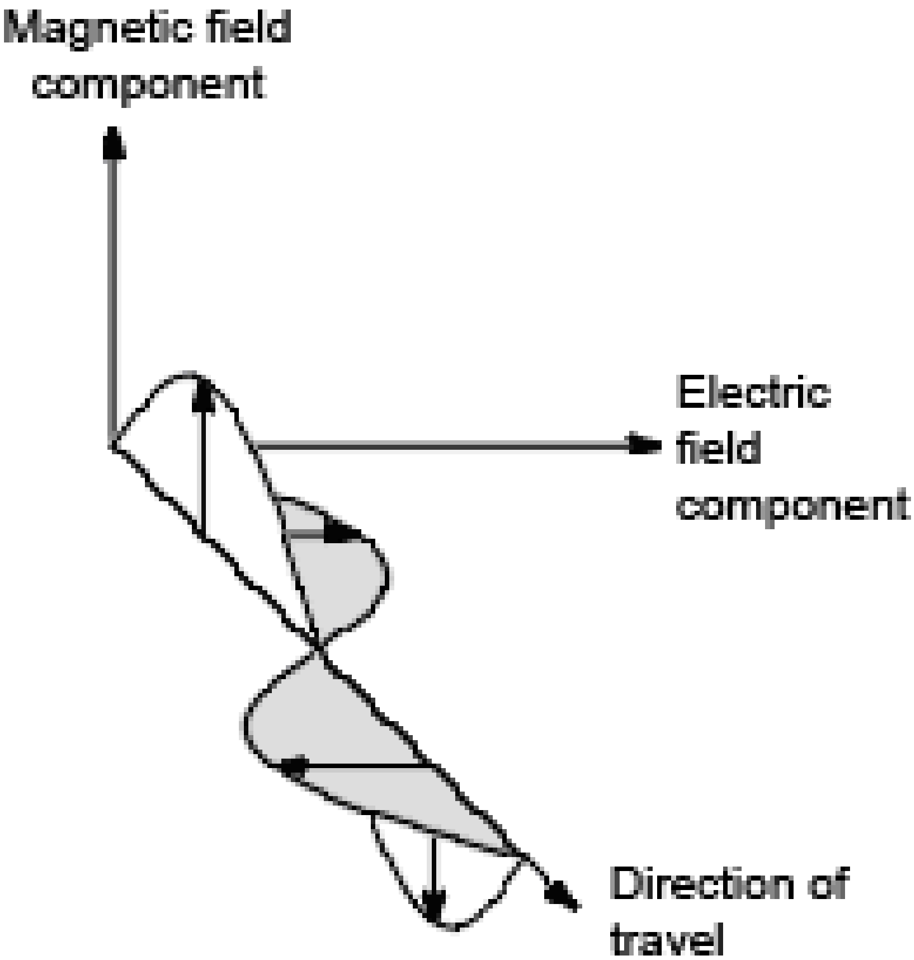
Electromagnetic spectrum



What is an electromagnetic *wave?*

An electromagnetic wave is the result of an interaction of an electric and magnetic field. An oscillating electric charge in a wire creates an electric field and a corresponding magnetic field. These two fields sustain themselves as a composite electromagnetic wave and can be propagated into space.

The electric and the magnetic components are at right angles with each other and at 90° to the direction of travel of the electromagnetic wave.



Polarisation of radio waves

The polarisation of a radio wave is designated the same as the plane of electric field. Polarisation is most important at the receiving antenna and has to have the same polarisation as the transmitted wave for best reception.

Radio waves are normally said to be vertically or horizontally polarized. But other derivations can be used such as circular polarisation.

Types of polarisation

- Linear polarisation
  - Vertical polarisation
  - Horizontal polarisation
- Circular polarisation
- Elliptical polarisation

Antenna polarisation

Different antenna polarisation is used dependent on the application. Linear polarization (either vertical or horizontal) is the most widely used for radio communications applications. Vertical polarisation is often used for mobile radio communications as many vertically polarized antenna designs have an omni-directional radiation pattern. This means that the antenna does not have to be re-orientated as the vehicle moves.

For other radio communications applications the polarisation is often determined by practical antenna considerations. Some large multi-element antenna arrays can be mounted in a horizontal plane more easily than in the vertical plane. This is because the antenna elements are at right angles to the vertical tower or pole on which they are mounted. This means there is less physical and electrical interference between the elements of the antenna and the tower or pole..

In some applications there are performance differences between horizontal and vertical polarisation. For example medium wave broadcast stations generally use vertical polarisation because ground wave propagation over the earth is considerably improved using vertical polarization. Horizontal polarization shows a marginal improvement for long distance communications using the ionosphere.

Circular polarisation is sometimes used for satellite radio communications as there are some advantages in terms of propagation and in overcoming the fading caused if the satellite is changing its relative orientation or by the fact that polarisation change can occur in the ionosphere.

Radio wave calculations
Velocity of propagation

Radio waves like all other electromagnetic radiation travel at a speed of nearly 300×10^6 m/s in a vacuum. Radio waves will travel more slowly through other mediums, but the difference is only slight and is usually ignored for practical calculations.

The relationship between velocity, frequency and wavelength is:

Velocity = Frequency x Wavelength

$$v = f \times \lambda$$

(Lambda) λ = wavelength in metres   f = frequency in Hertz

Wavelength

When early radio pioneers began working with radio waves, they generally described them in terms of their wavelength. Transmissions were said to be on *long waves, medium waves or short waves* and the wavelength was specified in meters.

The wavelength of a radio wave has significant effect on the design of an antenna. For example, an AM radio broadcast is very long; in comparison to TV receiver antenna which will have much shorted shorter aerial elements.

Frequency

Electromagnetic radiation is now normally described in terms of its frequency, in Hertz (Hz), Kilohertz (kHz), and Megahertz (MHz) and so on. In the microwave region we still tend to refer to the wavelength as well.

The scale used for frequency is logarithmic to cope with the large range in the frequency spectrum of radio waves.

Frequency banding is specified by the following:

ELF	extra low frequencies
VLF	very low frequencies
LF	low frequencies
MF	medium frequencies
HF	high frequencies
RF	radio frequencies
VHF	very high frequencies
UHF	ultra high frequencies
SHF	super high frequencies
EHF	extremely high frequencies

ELF	SLF	ULF	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
3 Hz	30 Hz	300 Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz
30 Hz	300 Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz

Radio wave propagation

Radio waves are a form of electromagnetic radiation similar to light. They exhibit the properties of wave motion in that they can be reflected, refracted or diffracted.

Propagation from an earth based transmitter can occur in four basic ways:

- Point to point – line of sight propagation.
- Ground wave - along the ground, bending slightly to follow the curvature of the Earth for some distance.
- Tropospheric ducting - travelling a longer distance than normal before coming back to the Earth's surface, because they are trapped in a layer of the Earth's atmosphere.
- Skip - refracted, or bent back to Earth by the ionosphere. (The ionosphere is a layer of charged particles in the Earth's outer atmosphere. These ionised gases make long-distance radio contacts possible on the high frequency (HF) bands.)

Propagation is the study of how radio waves travel from one point to another.

Line of sight propagation

This is when signals travel directly from the transmitting antenna to the receive Antenna. This mechanism occurs primarily only in the very high frequency (VHF) bands and above. TV and FM radio broadcasts are received as direct waves. These waves can experience reflection, diffraction or refraction and hence under certain circumstances may not be purely ‘line of sight’.

For example, knife edge diffraction can occur between a transmitting and receiving station over a hill which is in the direct path. Passive reflectors are sometimes used to re-direct signals to a different path direction. Buildings can also cause reflection of signals and hence non line of sight propagation.

The most distant point you can see when the sky is clear is called the visible horizon. It is only limited by the height of the observer above ground. From the top of a mountain you can see much farther than the 8 or 9 miles you can see over flat ground or water.

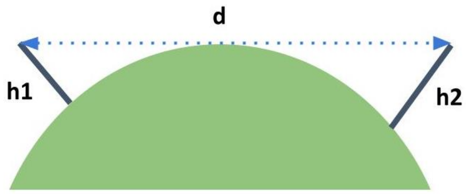
The troposphere consists of atmospheric regions close to the Earth's surface. Slight bending of radio waves occur in the troposphere, causing signals to return to Earth beyond the geometric horizon.

Radio horizon

Earth curvature presents a horizon that limits ‘line of sight’ propagation in the VHF, UHF and microwave frequencies.
The radio horizon is more than the optical range because the effect of the earth’s atmosphere is to cause a bending (refraction) of the radio wave. This carries the signal beyond the optical horizon.
Antenna height above the ground will be a factor, the higher the antenna the further the radio horizon.
The distance to the radio horizon is given by:

$$d_{\max}\, km = \sqrt{17h_T} + \sqrt{17h_R}$$

Where h_T *and* h_R are the heights of the transmitting and receiving antennas in metres.
The phenomena of diffraction will extend the range in practice beyond the radio horizon.



Formula:

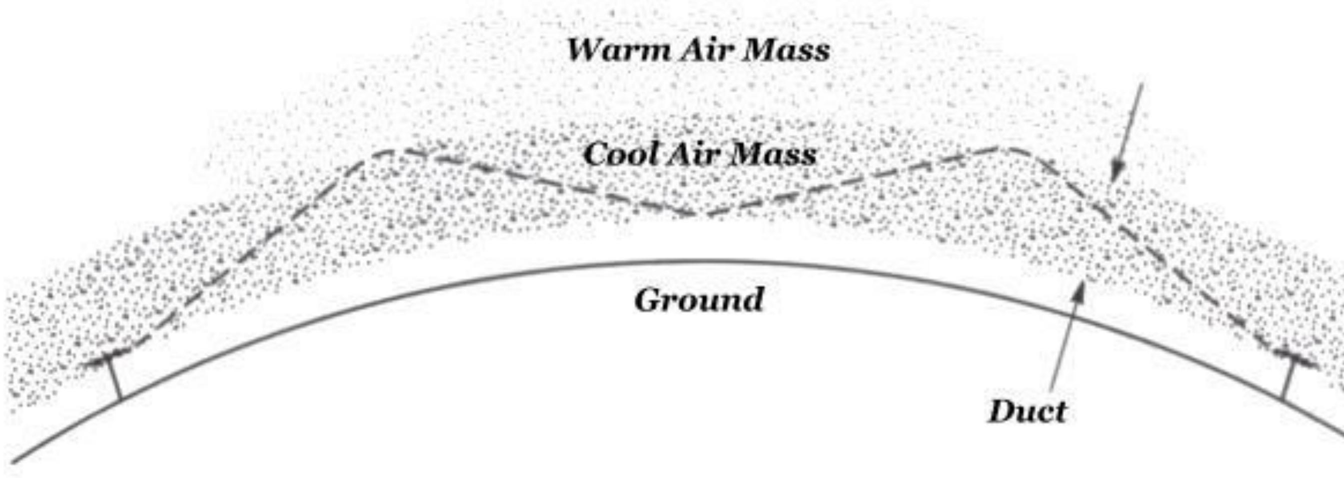
$$d_l = \sqrt{2Rh} \approx 3.57 * \sqrt{h}$$

$$d_r = 4.12 * \sqrt{h}$$

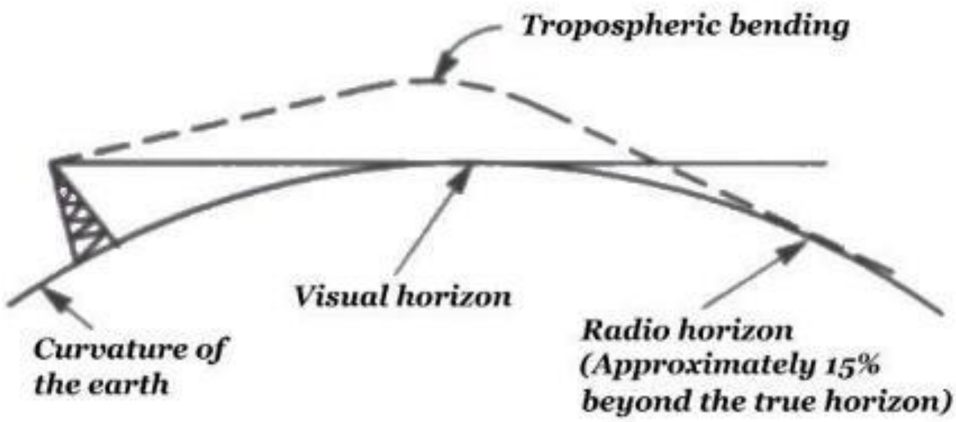
Tropospheric bending or ducting

This is evident over a wide range of frequencies, although it is most useful in the VHF/UHF region.

During the spring, summer, and autumn months, it is possible to make VHF and UHF contacts over long distances up to 1,000 miles or more. This occurs during certain weather conditions that cause tropospheric enhancement and tropospheric ducting.



The troposphere is the layer of the atmosphere just below the stratosphere. It extends upward approximately 7 to 10 miles. In this region clouds form and temperature decreases rapidly with altitude.
Under normal conditions, the temperature of the air gradually decreases with increasing height above ground. When there is a stable high-pressure system, a mass of warm air may overrun cold air, causing a temperature inversion. Radio waves trapped below the warm air mass can travel great distances with little loss. The area between the Earth and the warm air mass is known as a duct.



As radio waves travel through the troposphere, there will always be some signal loss. For any particular path through the troposphere, the signal loss increases as the frequency increases.

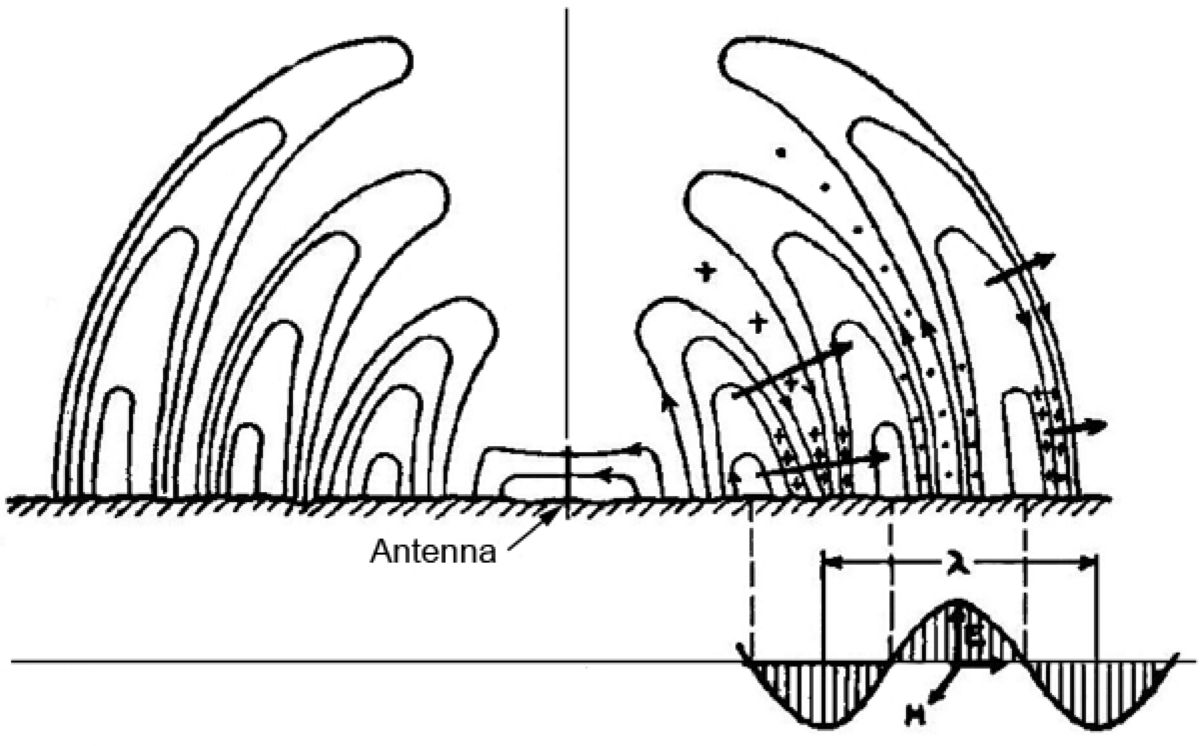
Tropospheric ducting is the most common type of enhanced propagation at UHF. Ducts usually form over water, but they can also form over land. A wide spread temperature inversion formed over an ocean may assist VHF or UHF signals travel several hundred miles. Tropospheric ducting supports communication of 950 miles or more over land and up to 2,500 miles over oceans.

Ground-wave propagation

Radio waves travel along the Earth's surface and even over hills, following the curvature of the Earth for some distance.

AM broadcasting signals travel by way of ground-wave propagation during the day. Ground wave works best at lower frequencies. AM broadcast stations at the high end of the band (1,600 KHz end) generally carry less than 100 miles during the day, but stations near the low frequency end can be heard up to 100 miles away.

It should be noted that vertically polarized transmission aerials are insulated from the ground and the electrostatic field is built from the aerial to the ground. Large earth mats in the ground at the transmitting antenna assist propagation and the carrying of currents induced in the ground by wave front. The wave front is shown in the diagram below.

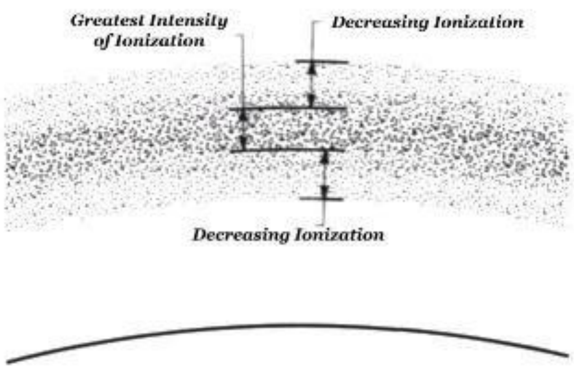


This diagram shows the development of the electrostatic field between aerial and ground followed by the next field virtually pushing the previous energy front away from the aerial at the speed of light. A diagram representing the wavelength (λ) of the propagated wave can be seen that the wave front consists of points of positive charge and

The ionosphere

The Earth's upper atmosphere (25 - 200 miles above the Earth) consists mainly of oxygen and nitrogen. There are traces of hydrogen, helium, and several other gases. The atoms making up these gases are electrically neutral: they have no charge and exhibit no electrical force outside their own structure. The gas atoms absorb ultraviolet radiation and other radiation from the sun. This enables electrons to escape the atom. These electrons are negatively charged particles, and the remaining portions of the gas atoms form positively charged particles. The positive and negative particles are called ions. The process by which ions are formed is called ionisation.

When ionised by solar radiation, this region, called the ionosphere, can refract (bend) radio waves. If the wave is bent enough, it returns to Earth. If the wave is not bent enough, it travels off into space. Worldwide communications using several skips can take place if conditions are right. This is the way long-distance radio signals travel.

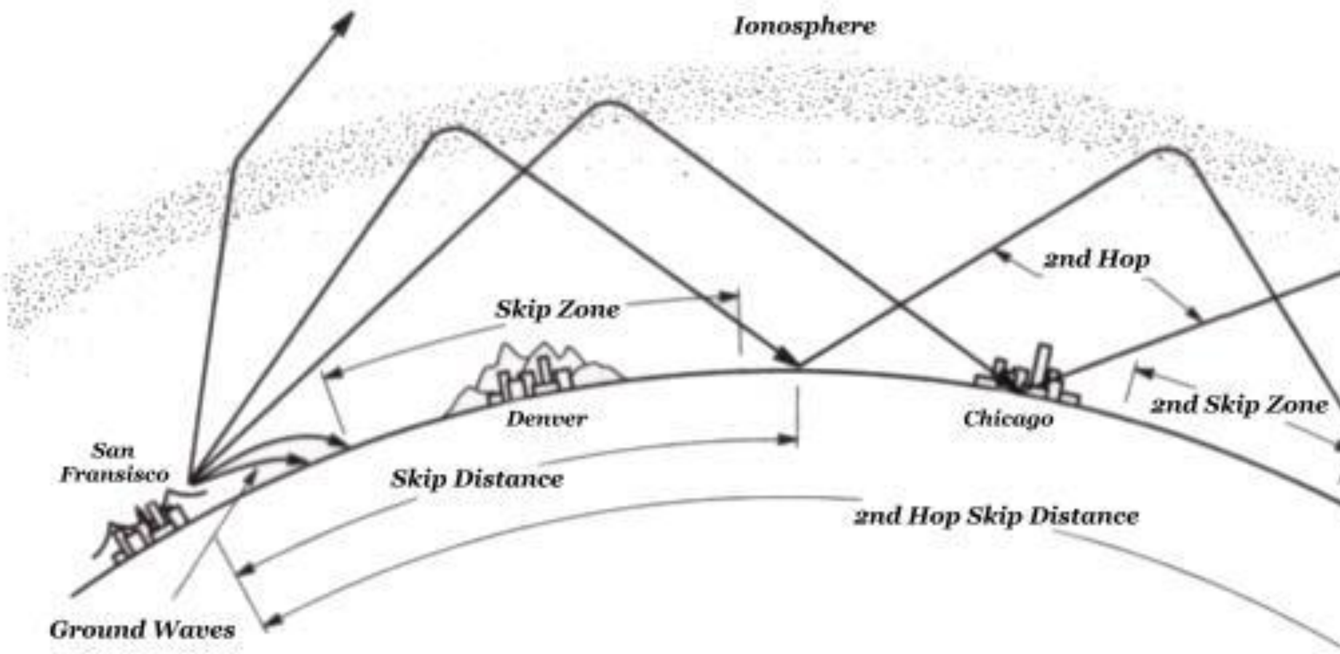


Two factors determine sky-wave propagation possibilities between two points, the frequency in use and the level of ionisation.

The higher the frequency of the radio wave, the less it is bent by the ionosphere. The highest frequency at which the ionosphere bends radio waves back to a desired location on Earth is called the M**aximum Useable Frequency (MUF).** The MUF for communication between two points depends on solar radiation strength and the time of day. Radio waves that travel beyond the horizon by refraction in the ionosphere are called sky waves. Sky-wave propagation takes place when a signal is returned to Earth by the ionosphere.

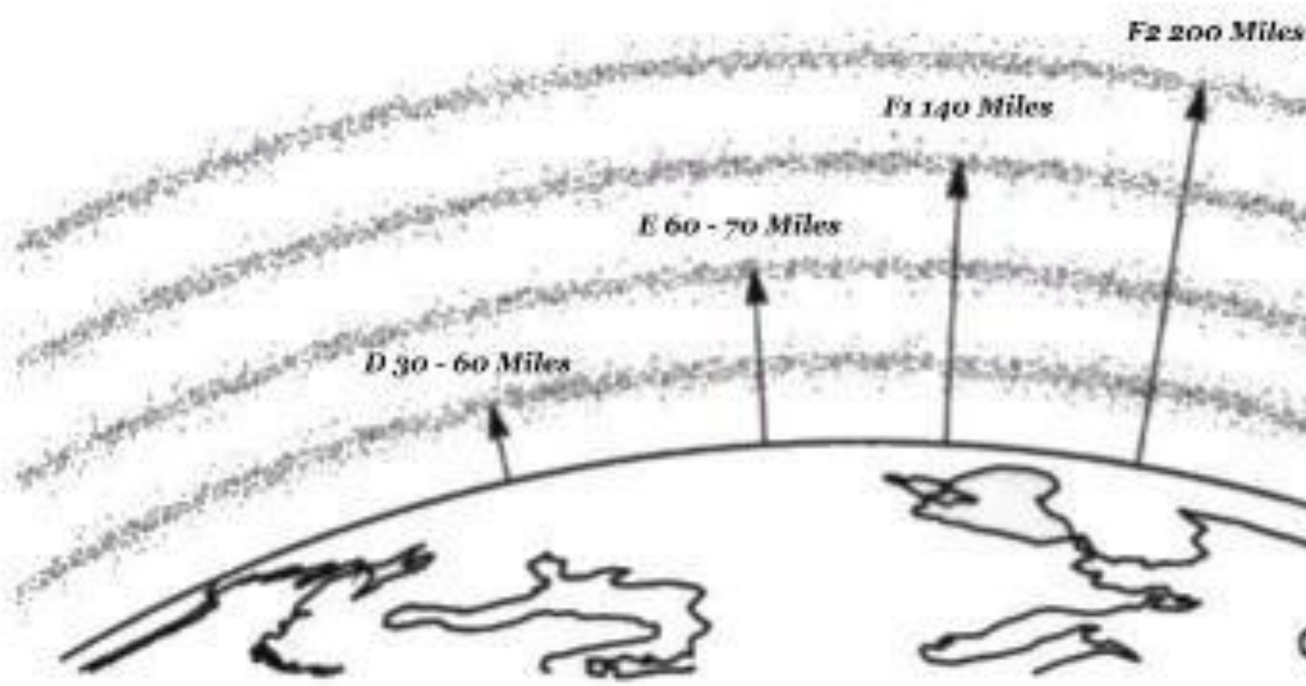
Ionisation of the ionosphere results from the sun's radiation striking the upper atmosphere. It is greatest during the day and during the summer. The amount of radiation coming from the sun varies through the day, season, and year. The radiation is closely related to visible sunspots (greyish-black blotches on the sun's surface). Sunspots vary in number and size over an 11year cycle. More sunspots usually mean more ionisation of the ionosphere. When sunspots are low, radiation and the MUF are lower. That is why HF communication is enhanced during times of greater sunspot activity.

Skip propagation has both a maximum and minimum range limit. That minimum is often greater than the ground-wave range. There is an area between the maximum ground-wave distance and the minimum skip distance where radio signals on a particular frequency will not reach. This "dead" area is called the skip zone. No signals will be heard in this area.



There are several ionised regions which appear at different heights in the atmosphere. Each region has a central region where the ionization is the greatest. The intensity of the ionization decreases above and below the central area in each region.

The ionosphere consists of several regions of charged particles. These regions have been given letter designations. Scientists started with the letter D just in case there were any undiscovered lower regions.



The D region:

The lowest region of the ionosphere affecting propagation is the D region. This region is in a relatively dense part of the atmosphere about 35 - 60 miles above the Earth. When atoms in this region absorb sunlight and form ions, the ions don't last very long. They quickly combine with free electrons to form neutral atoms again. The amount of ionization in this region varies widely, as it depends on how much sunlight hits the region. At noon, D region ionization is maximum or very close to it. By sunset, this ionization disappears. The D region is ineffective in refracting or bending high-frequency signals back to Earth.
The D region's major effect is to absorb energy from radio waves. As radio waves pass through the ionosphere, they give up energy which sets some of the ionised particles into

motion. Effects of absorption on lower frequencies are greater than on higher frequencies. Absorption also increases when there is more ionisation. The more ionisation, the more energy the radio waves lose passing through the ionosphere.

The E region:

The next region in the ionosphere is the E region, at an altitude of 60 to 70 miles. At this height, ionization produced by sunlight does not last very long. This makes the E region useful for bending radio waves only when it is in sunlight. Like the D region, the E region reaches maximum ionisation around midday. By early evening the ionization level is very low. The ionisation level reaches a minimum just before sunrise, local time. Using the E region, a radio signal can travel a maximum distance of about 1,250 miles in one hop. Sporadic E or E skip, is a type of sky-wave propagation that allows long-distance communications on the VHF bands. Although sporadic E only occurs during certain times of the year, it is the most common type of VHF sky-wave propagation.

The F region:

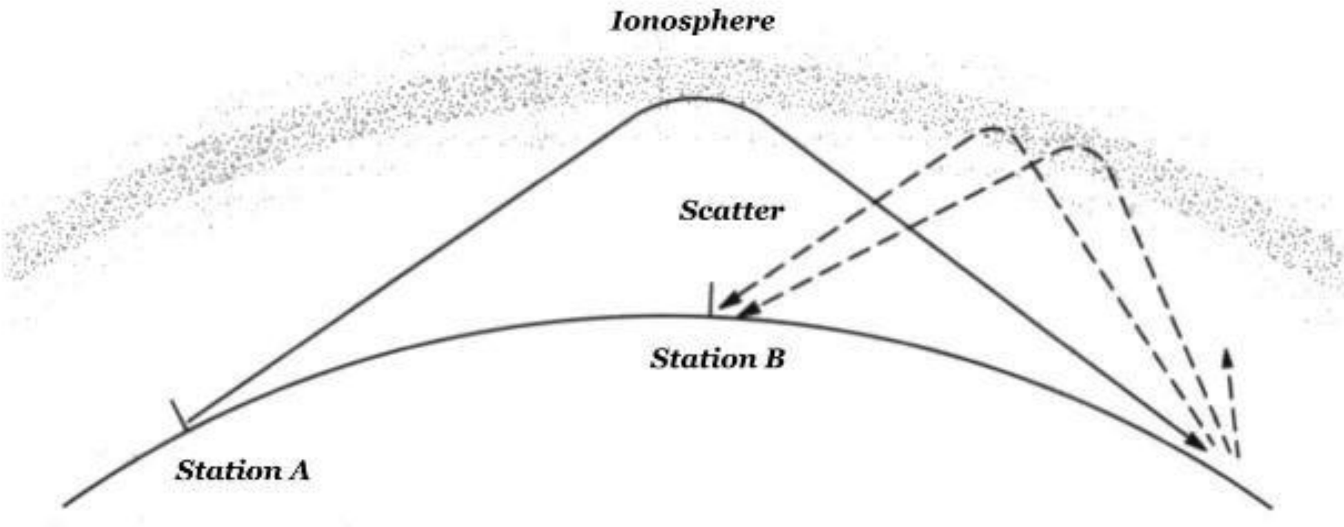
The region of the ionosphere most responsible for long-distance communication is the F region. This region is very large and ranges from about 100 to 310 miles above the Earth. The height depends on season, latitude, time of day, and solar activity. Ionization reaches a maximum shortly after noon local standard time, and tapers off very gradually towards sunset. At this altitude, the ions and electrons recombine very slowly. The F region remains ionised during the night, reaching a minimum just before sunrise. After sunrise, ionisation increases rapidly for the next few hours. Then it increases slowly to its noon time maximum.

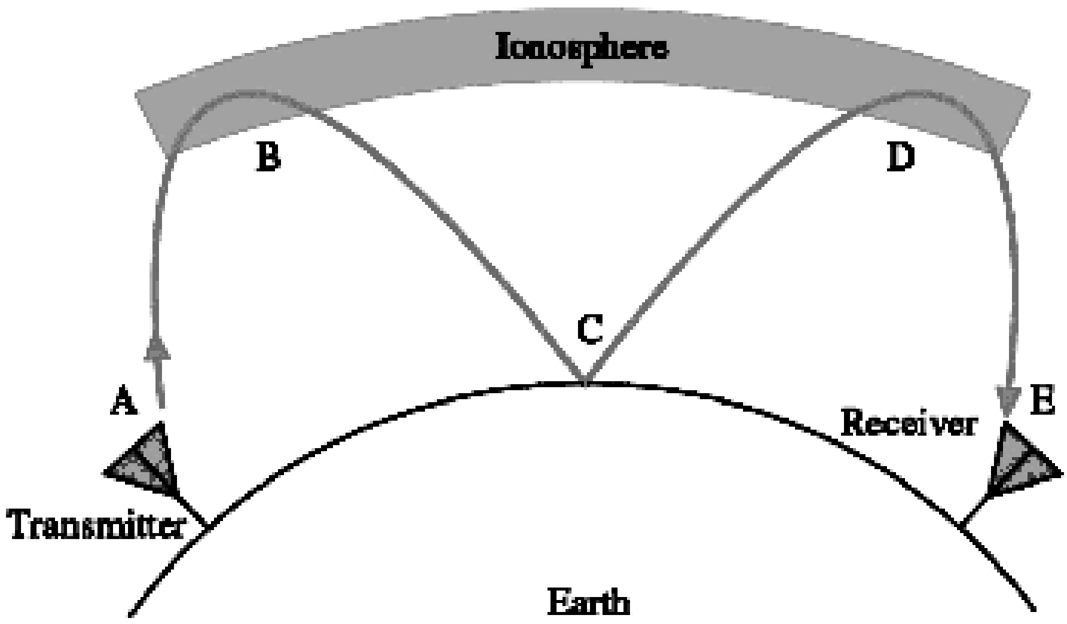
During the day, the F region splits into two parts, F1 and F2. The central part of F1 region forms at an altitude of about 140 miles. For the F2 region, the central region forms at about 200 miles above the Earth. These altitudes vary with the season of the year and other factors. At noon in the summer the F2 region can reach an altitude of 300 miles. At night, these two regions recombine to form a single F region slightly below the higher altitude. The F1 region does not have much to do with long-distance communications. Its effects are similar to those caused by the E region. A one-hop radio transmission travels a maximum of about 2,500 miles using the F2 region.

Scattering influences all electromagnetic-wave propagation. This alters the idealised patterns to a great degree. The Earth's atmosphere, ionospheric regions, and any objects in the path of radio signals scatter the energy. By understanding how scattering takes place, this propagation mode can be used to advantage.

There is an area between the outer limit of ground-wave propagation and the point where the first signals return from the ionosphere. The skip zone is often described as if communications between stations in each other's skip zone were impossible. There is some of the transmitted signal is scattered in the atmosphere, so the signal may be heard over much of the skip zone. A very sensitive receiver and good operating techniques are required to detect these signals.

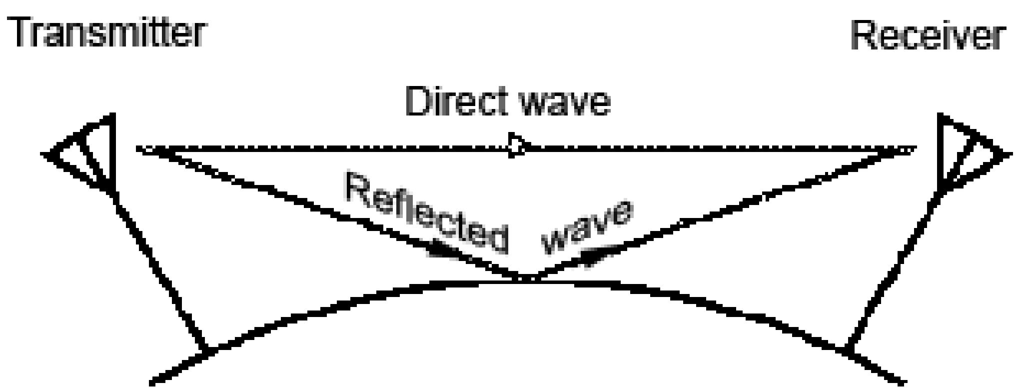
Scatter signals are generally weak and subject to distortion, because the signal can arrive at the receiver from many different directions. This type of scatter propagation is usable from just beyond the local range out to several hundred miles. Under ideal conditions, scatter propagation is possible over 3,000 miles or more. This form of propagation is sometimes called "backscatter", but the term "sidescatter" is more descriptive of what happens on such long paths.





Space wave transmission

Radiated energy travels essentially in a line of sight path, but can consist of direct and ground reflected waves which add together at the receiver antenna. Space wave transmission is used at frequencies above 30 MHz in the VHF frequency bands and above.



Reflected signals arriving at an antenna travel a greater distance than the direct wave. This can introduce fading in the signal strength as the combination of the direct and incident waves enhance or reduce the received signal.

Reflection of radio waves

When a radio wave encounters a change in medium, some or all of it may propagate into the new medium or be reflected from it. The part that enters the new medium is called the transmitted portion and the other the reflected portion.

Refraction of radio waves

Radio waves are refracted or bent when travelling from one medium to another. This is dependent on the refractive index of the medium. The phenomena occurs because the speed of propagation will change when moving from one medium to the next..

Interference in radio waves

All electromagnetic waves can be superimposed upon each other without limit. The electric and magnetic fields simply add at each point. If two waves with the same frequency are combined there will be a constant interference pattern caused by their superposition. Interference can either be constructive, meaning the strength increases as result, or destructive where the strength is reduced. This can lead to fading of the radio frequency signal.

Diffraction of radio waves

If a radio this wave passes through an opening, it will diffract, or spread out, from the opening. The degree to which the wave will spread out depends on the size of the opening relative to the wavelength. In the extreme case where the opening is very large compared to the wavelength, the wave will see no effect and will not diffract at all. At the other extreme, if the opening is very small, the wave will behave as if it were at its origin and spread out uniformly in all directions from the opening. In between, there will be some degree of diffraction.

Summary

The velocity of propagation of radio waves in air is 3×10^8 metres/sec

Velocity = frequency x wavelength.

Electromagnetic radiation consists of an electric and magnetic field at rights angles.

Polarisation of a radio wave is defined by the direction of the electric field.

The wavelength is the distance occupied by one cycle of a wave.

The frequency is the number wave cycles per second using the unit Hertz.

Radiation patterns are a measure of the directivity of the aerial.

Signal field strength (electric field) can be measured in micro volts per meter.

Ground wave propagation is vertically polarised.

Space wave transmission uses line of sight transmission.

Sky wave transmission makes use of the ionosphere.

The ionosphere is a gaseous layer affected by the sun.

Radio waves are exhibit reflection, refraction and diffraction.

Fading is caused changing signal strength at the receive antenna due to multiple signal paths from the transmitter.

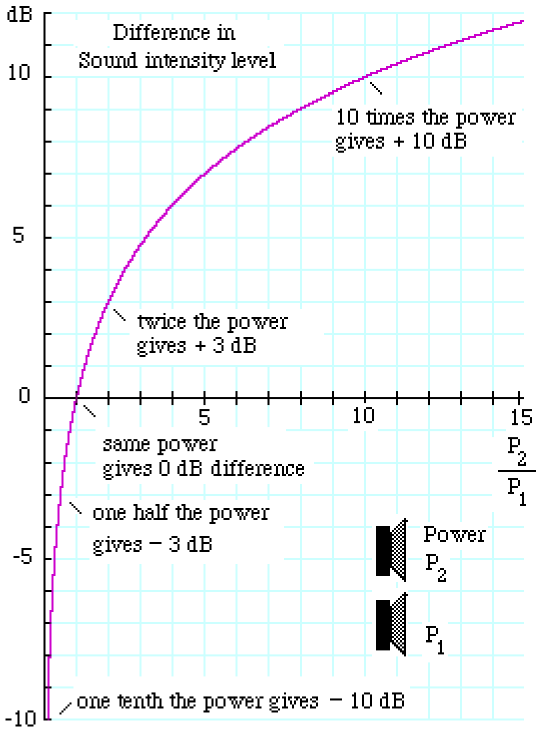
Power and voltage levels in communication systems

The basic unit of RF power is the watt.
In receive systems the voltages are often small and hence the µV (10^{-6} V) or mV (10^{-3}V) are frequently used.

Relative Levels

The universal measurement system adopted to describe the ***difference*** between two levels is the Decibel. (dB) The levels can be expressed in voltage, current or power. The decibel is a logarithmic unit.

$$Gain(in\ dB) = 10\ log\left(\frac{P_2}{P_1}\right)$$



The graph above is for sound intensity but is also applicable for RF power levels. The horizontal scale is $\frac{P_2}{P_1}$ and the vertical scale is the difference in levels in dB.
Twice the power difference is 3dB, half the power difference is -3dB, ten times the power is 10dB and one tenth the power -10dB.

Note the logarithmic nature of the graph which characterises measurements in decibels. Gains can be expressed in terms of voltage or currents.

Since Power = $\frac{V^2}{R}$

and provided the input resistance and load resistance are equal, the equation becomes ..

$$\text{Gain(dB)} = 20\log\frac{\text{Vout}}{\text{Vin}}$$

Similarly

$$\text{Gain(dB)} = 20\log\frac{\text{Iout}}{\text{Iin}}$$

Example 1:

A RF amplifier is driven with a power of 1.5 watts and delivers 35 watts to the antenna. Calculate its power gain.

$$\frac{\text{Gain (dB)} = 10\log(\text{Power Out})}{\text{Power In}}$$

$$\frac{= 10\log 35}{1.5}$$

$$= 13.68 \text{ dB}$$

Example 2:

A receiver has an input voltage of 2µV and an output voltage of 100mV. Calculate its voltage gain.

$$\text{Gain(dB)} = 20\log\frac{\text{Vout}}{\text{Vin}}$$

$$= 20\ log\frac{100 \times 10^{-3}}{2 \times 10^{-6}}$$

$$= 93.98 \text{ dB}$$

Example 3:

An attenuator has an input power of 1 watt and an output power of 0.5 Watt. Calculate the loss of power (attenuation) in dB.

$$\frac{\text{Gain (dB)} = 10\log(\text{Power Out})}{\text{Power In}}$$

$$\frac{= 10\log 0.5}{1}$$

$$= -3 \text{ dB}$$

Note that a loss is represented by a negative gain.

Absolute power levels

A common power unit used in communication engineering is the dBm.

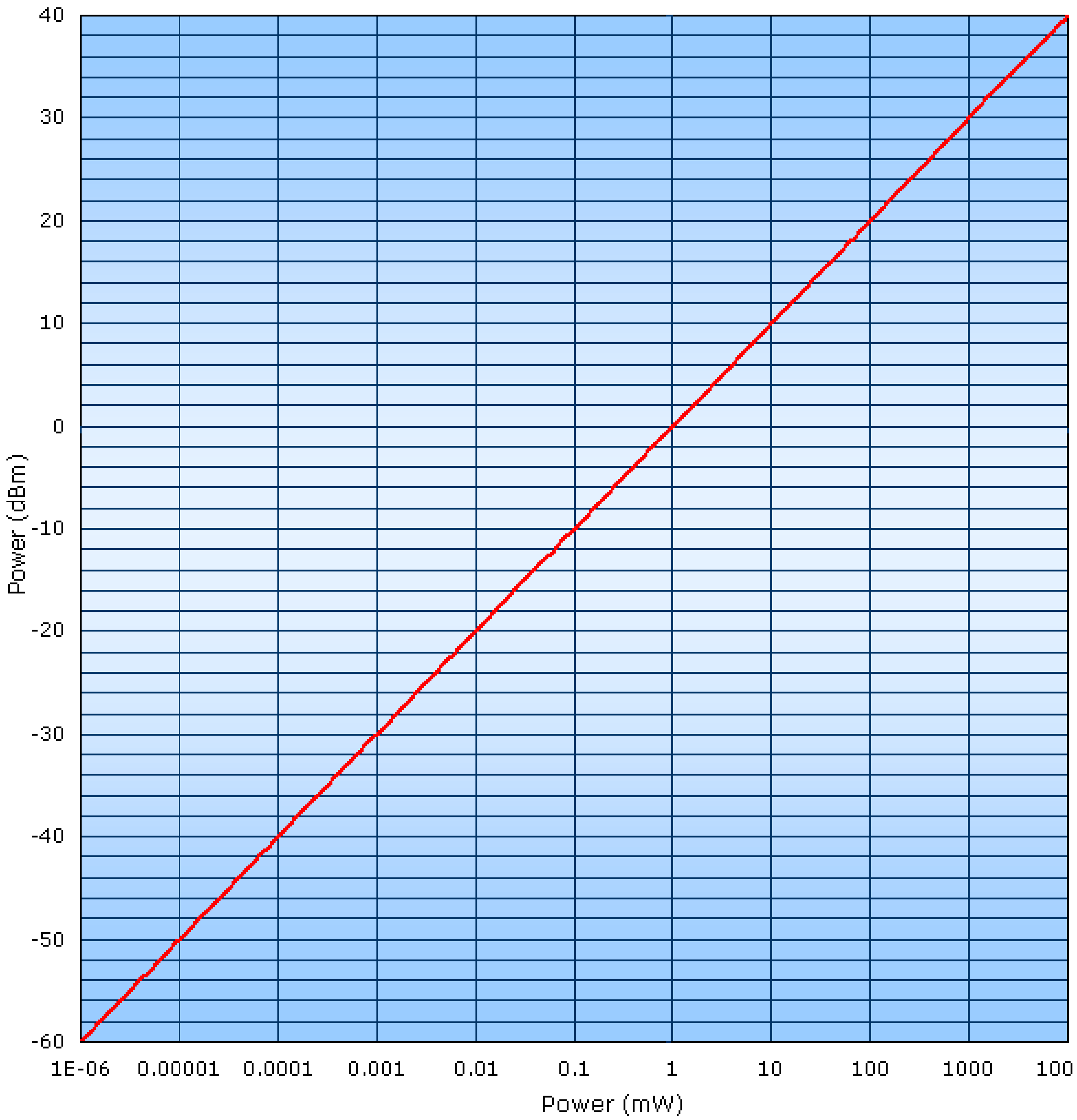
0dBm = 1 milliwatt

Voltage levels in receive systems are sometimes expressed in dBµV or dBmV.

0dBµV = $1 \times 10^{-6} V$

0dBmV = $1 \times 10^{-3} V$

dBm Power unit	mW Power unit	dBm Power unit	mW Power unit
+20	100 mW	-30	1 µW
+10	10 mW	-40	100 nW
0	1 mW	-50	10 nW
-10	100 µW	-60	1 nW
-20	10 µW	-70	100 pW



Example 4:

A voltage is expressed as +15dBµV. Calculate this value in volts.

$$\frac{15 = 20 \log \mathbf{Vout}}{\mathbf{1 \times 10^{-6}}}$$

$$\frac{0.75 = \log \mathbf{Vout}}{\mathbf{1 \times 10^{-6}}}$$

$$\frac{\text{Vout}}{1 \times 10^{-6}} = 10^{0}.75$$

$$\text{Vout} = 5.62 \times 10^{-6}\text{v}$$

Path loss calculations

A fibre optic communication system.

Example 5.

Absolute power levels in this example are expressed in dBm and refers to the input and output power levels.. The reference level used for optical systems is usually 1 mW, since the absolute transmitter power is often approximately this power level. The use of dBm as a unit of power is appropriate.

Sender power	-4 dBm
Receiver sensitivity	-27 dBm

(The receiver sensitivity in this example is the minimum required received power for correct operations)

Allowable degradation, or loss budget: -27 - (-4) = -23 dB

(This means the signal can be degraded by 23 dB in the transmission medium and still meet the minimum requirements for the receiver)

Signal attenuation in this example is defined in dB units and generally refers to the transmission path losses (lossy transmission path)

Signal decrease of 1st fibre section	7.3 dB
Signal decrease of 2nd section	4.8 dB
Signal decrease of 3rd section	6.9 dB

So the calculated transmission degradation of the complete link is 7.3 + 4.8 + 6.9 = 19 dB

Therefore spare system margin	-19 - (-23) = 4 dB

This means the received signal will be 4 dB above the required minimum at the receiver. Often a higher safety margin is designed into a system to allow for system degradation. This is particularly the case for radio transmissions that can be effected by external weather and other factors such as noise.

Propagation in free space

It can be shown that the path loss in free space is ...

$$L = (32.5 + 20\log_{10}d + 20\log_{10}f)\text{dB}$$

where d is the distance in kilometres and f the frequency in megahertz.

Example 6.

A satellite is at a height of 36,000 km above the earth operating on a frequency of 4 Ghz. The transmitting antenna gain is 15dB and the receiving antenna gain is 45dB. Calculate the path loss and the power received at the antenna if the transmitter power is 200W.

The free space path loss is ..

$$L = (32.5 + 20\log_{10} d + 20\log_{10} f)\text{dB}$$

$$= 32.5 + 20\log_{10} 36{,}000 + 20\log_{10} 4000$$

$$= 196 \text{ dB}$$

Allowing for the gain in the antennas, the path loss from the transmitter is ..

$$= -196 + 45 + 15$$

$$= -136 \text{ dB}$$

Now 136 dB represents a power ratio $10^{13.6}$

The received power will be ....

$$200\text{W} \div 10^{13.6}$$
$$= 5 \times 10^{-12} \text{ W}$$

If the receiver has a 50 ohm input impedance, the voltage at the receiver will be ...

$$= 15.8\ \mu\text{V}$$

Antennas

RF antennas (or aerials) are an essential element of any radio communications system, whether it is for a high power transmitter such as those used for broadcasting, or low power transmitters used for wireless technologies such as WLAN or remote control and sensing applications.

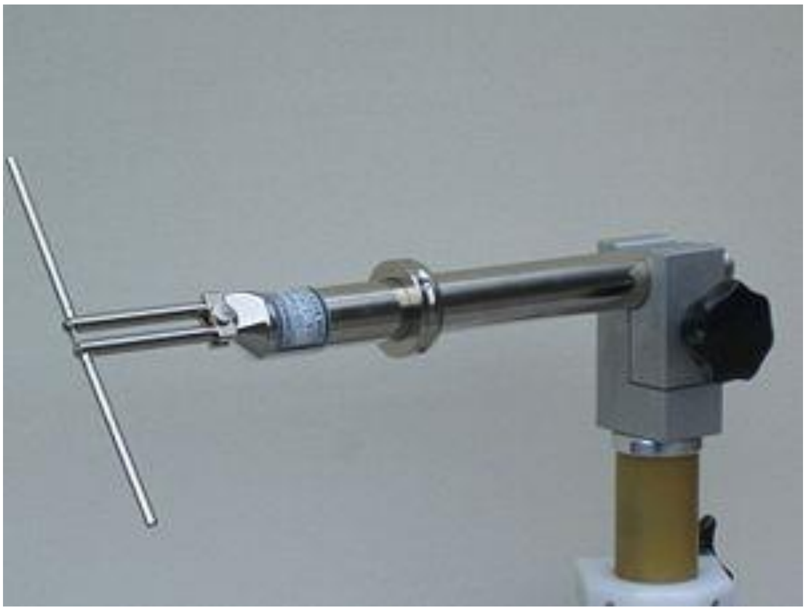
Antennas are used across the whole radio spectrum, from Extra Low Frequency (ELF) to the microwave bands. Whatever the power or frequency the basic antenna principles remains the same, although practical implementation has to change to meet the differing mechanical requirements of short or long wavelengths..

Antennas come in many forms such as:

- Dipole antenna
- Vertical antenna
- Loop antenna
- Wideband antenna
- Directional antenna

The dipole antenna

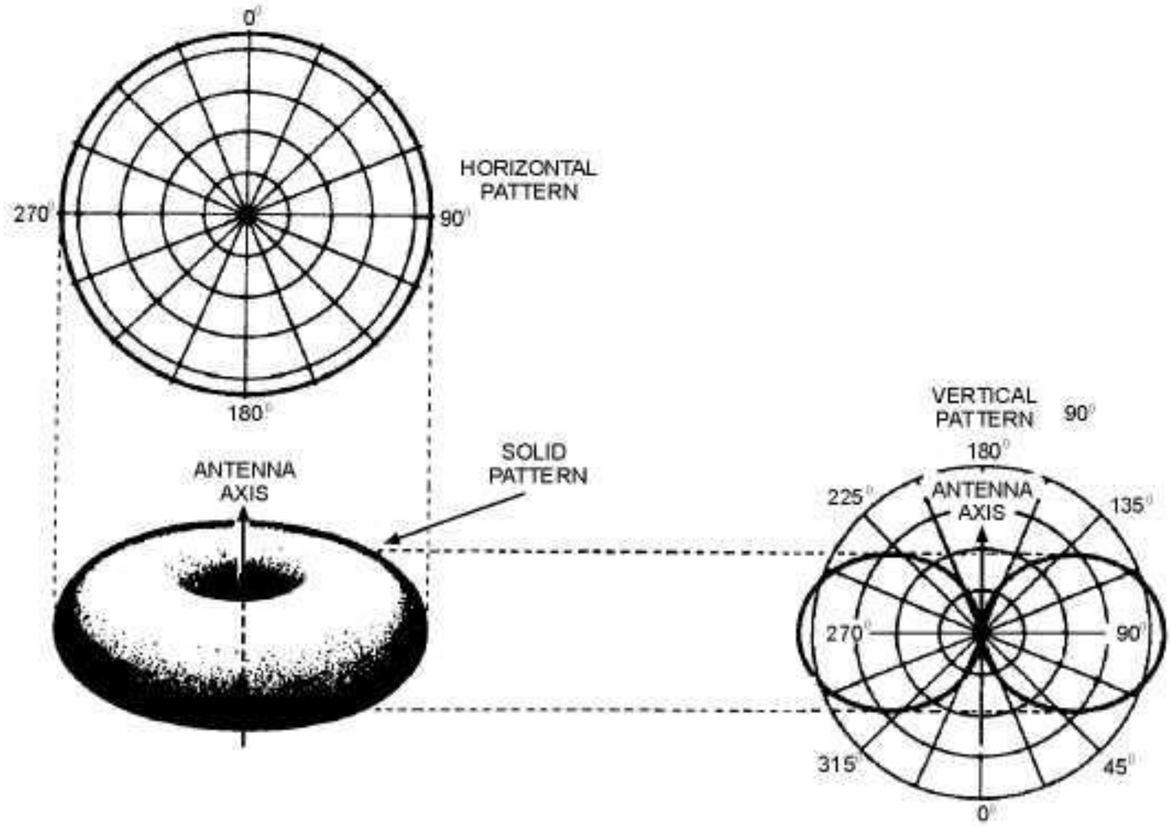
The dipole antenna is very widely used for radio transmitting and receiving applications. It also forms the essential element in many other types of antenna.



The basic half wave dipole antenna

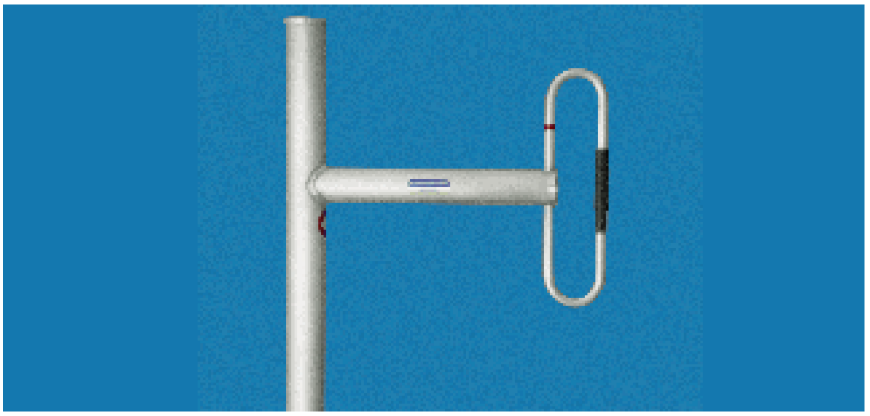
A polar diagram of an antenna shows the direction(s) of maximum radiation for a transmit antenna or sensitivity for a receive antenna.

The polar diagram of a half wave dipole antenna shows that the direction of maximum sensitivity or radiation is at right angles to the axis of the RF antenna. The radiation falls to a low level along the axis of the RF antenna.



Polar diagrams of a half wave dipole in free space

If the length of the dipole antenna is changed then the radiation pattern is altered. As the length of the antenna is extended it can be seen that the familiar figure of eight pattern changes to give main lobes and a few side lobes. The main lobes move progressively towards the axis of the antenna as the length increases

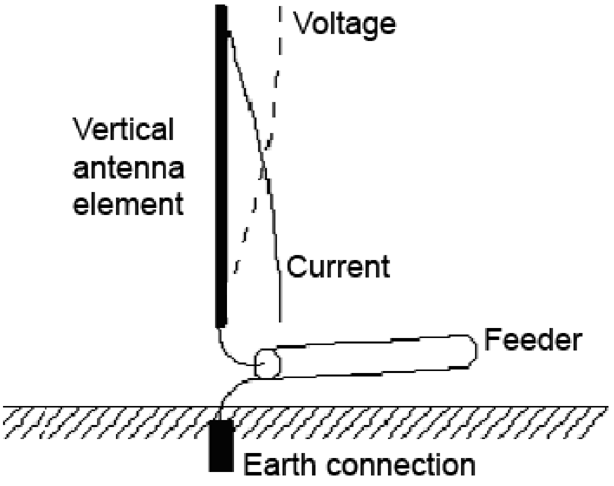


Folded dipole

The vertical antenna

Vertical antennas are used at all frequencies from MF up to VHF and beyond. They exist in a variety of forms including the quarter wave vertical and ground plane antennas. They are used for medium wave broadcasting as well as for mobile applications.

The reason for this widespread use is the omni-directional radiation pattern that they provide in the horizontal plane. This means that the antennas do not have to be re-orientated to maximise the signal as the mobile station moves its position relative to the antenna.



Principle of a vertical antenna

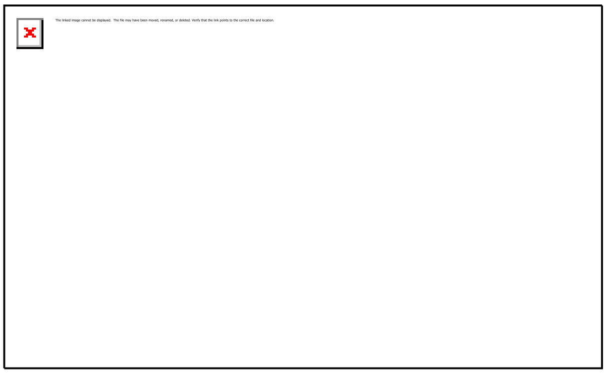
This antenna relies on a good ground plane as a reflecting surface.

Loop antennas

Loop antennas can be placed into two categories:

- Air-wound loops
- Ferrite-core loop sticks

The terms large or small refer to the size of the RF antenna when compared to a wavelength of the frequency in use.



Typical ferrite rod antenna assembly used in a portable radio

These antennas can be small compared to the received signal's wavelength, but exhibit directivity similar to a dipole.

Wideband antennas

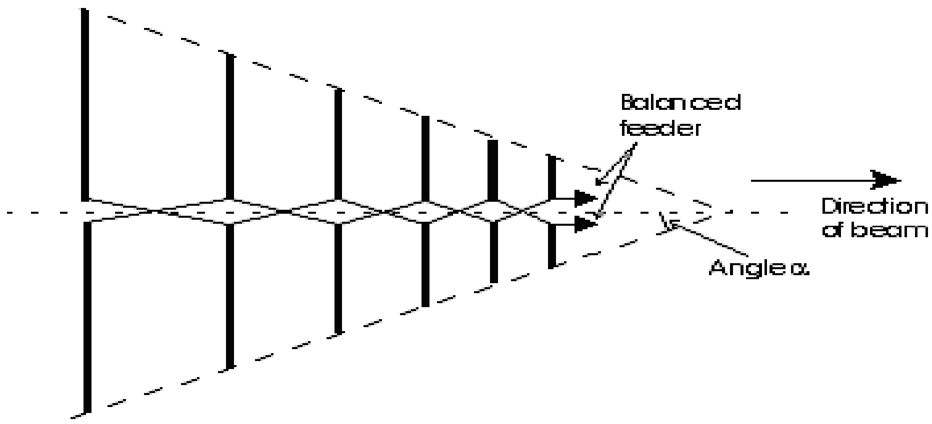
Discone antenna

The Discone antenna is used where an omni directional wide bandwidth design is needed. It finds many uses, particularly for all type of radio scanning and monitoring applications from the commercial or military monitoring services to the home scanner enthusiast for frequencies above 30 MHz.

Log periodic antenna

One of the major drawbacks with many antennas is that they have a relatively small bandwidth. The log periodic is able to provide directivity and gain while being able to operate over a wide bandwidth.

The log periodic antenna is used in a number of applications where a wide bandwidth is required along with directivity and a modest level of gain. It is sometimes used on the HF portion of the spectrum where operation is required on a number of frequencies to enable communication to be maintained. It is also used at VHF and UHF for a variety of applications, including some uses as a television receive antenna.

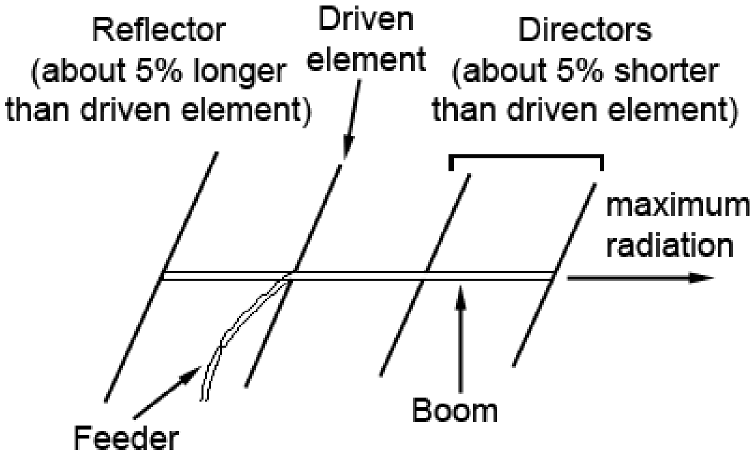


A log periodic antenna

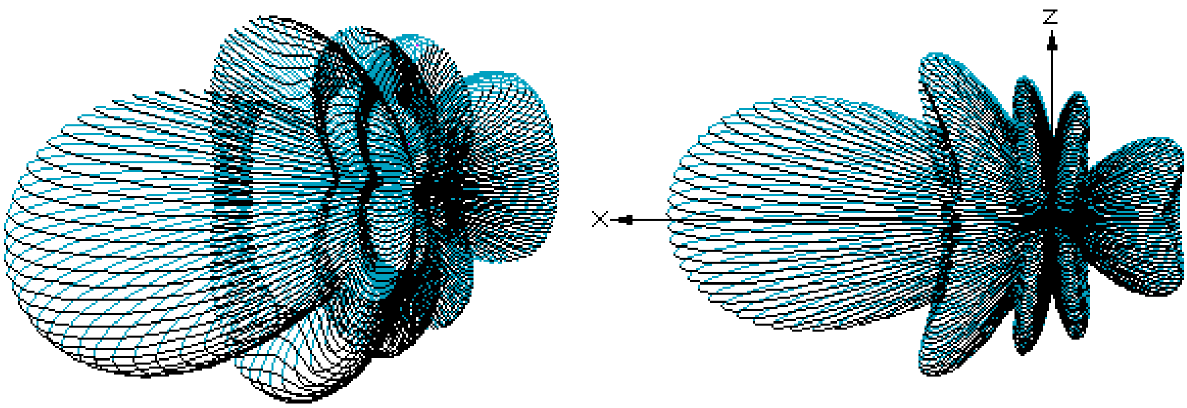
Directional antennas

There is a good variety of different types of directive antenna that can be used. Although the Yagi antenna is popular, other designs and approaches are more applicable in many instances.

- Yagi
- Log periodic
- parabolic reflector
- horn antenna

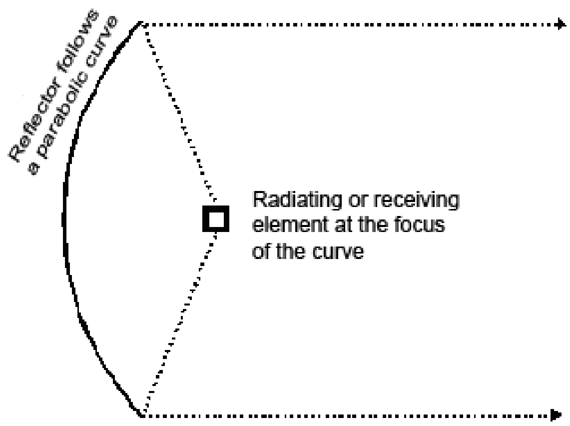


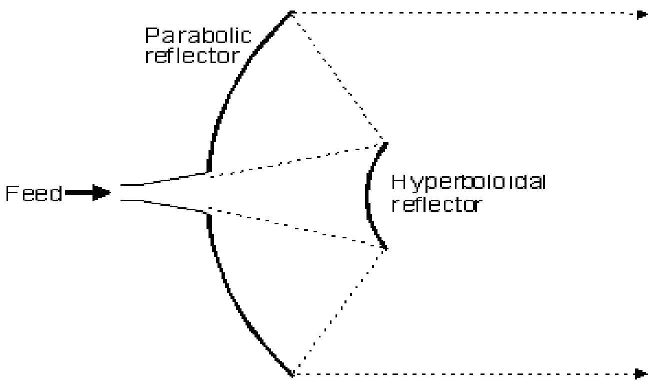
Yagi antenna



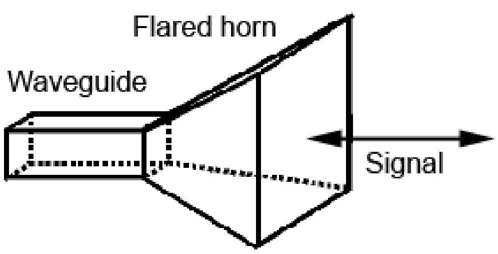
Yagi antenna polar diagram

Parabolic dish antenna are in wide spread use for line of sight communications. The basic principle is to concentrate the RF energy into a beam between transmitter and receiver.





Parabolic dish antenna



Horn antenna

Radiation patterns and the propagation of radio waves

The process of communication involves the transmission of information from one location to another. The frequency of the carrier is the prime determinant of the transmission characteristics of a radio wave. The power of the transmitted signal is also important as all radio waves suffer attenuation. (path loss)

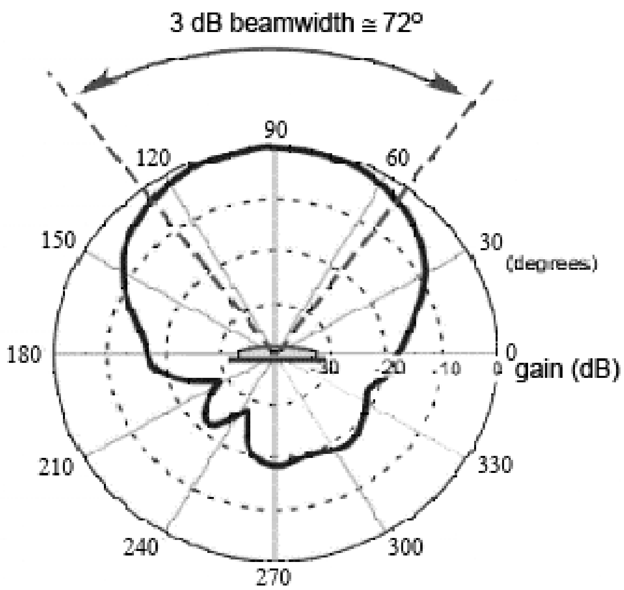
The radiation patterns from an antenna are controlled according to the application of the radio communications system.

- TV and broadcast radio antenna are usually omni-directional and propagate equally in all directions.

- Microwave radio links are line of sight transmission point to point communication. (Single transmitter to single receiver). The antennas exhibit a high degree of directivity.

The radiation patterns from an antenna can be determined by the measurement of the field strength at any point away from the antenna.

The field strength is usually plotted on a circular graphical chart (polar coordinated paper) as seen below. The strength of the field at any point away from the antenna is determined by the attenuation of the wave, the design of the antenna and the power of the transmitter. To plot a polar graph as shown below, the field strength will be measured at the same distance for the full 360˚ surrounding the aerial.



Radiation pattern from antenna

The field strength is measured in micro volts per metre, and can be measured by a field strength meter.

Noise in communication systems

Noise may be defined as any unwanted form of energy which reduces the intelligibility of a communication.
In any communication system, noise may interfere with the signal being communicated. The noise energy may arise from within the communication system or from sources external to it.

External noise

There are three major sources of external noise arriving at the receive antenna:

- Atmospheric noise generated by disturbances in the earth's environment.
- Galactic noise from outer space.
- Noise from external terrestrial sources.

Atmospheric Noise is often referred to as 'static' and is caused by electrical disturbances in the atmosphere, mainly due to lightning discharges. The energy intensity is inversely proportional to frequency such that it is rarely significant above 30 Mhz.

Extraterrestrial noise or 'space' noise originates from the sun (solar noise) and all of the other stars and radio sources in the universe (cosmic noise). Space noise occurs at all frequencies between approximately 8MHz and 1.5GHz.

Solar noise is due to the high temperature (6000°C) of the sun's surface. Solar noise occurs in cycles which peak about every 11 years with a 'super cycle' occurring about every 100 years. Solar noise has direct effects on some forms of radio transmission.

Industrial noise is due to man- made electrical sources. Any electric arc or spark gives rise to severe electromagnetic disturbances. It occurs over a frequency range of approximately 1MHz to 600MHz. The main sources are automobile and aircraft ignition, electric motors, switches, high voltage line leakage and fluorescent lighting.

Interference due to external transmitters

Another source unwanted signals are transmissions other than those which are intended for the communication system. These include:

- Out of band distortion products.
- Phase noise caused by local oscillators and mixers.
- Wideband noise.

Careful design can minimise these effects.

Internal noise

Internal noise is generated from within the communication system. In an electronic system, random electrical noise originates from three main sources. Thermal noise, white noise and flicker noise.

Thermal noise is also called ‘Johnson’ noise or Nyquist noise and is simply ‘resistive’ noise. It is present in every electrical conductor, whether or not it is connected. At all temperatures above zero Kelvin’s (-273°C), the electrons of a conductor are moving at random. Thus, at any given instant, there is a high probability that there will be more electrons at one end of a conductor than the other. Therefore a randomly varying electrical voltage exists across the conductor. Since random electron motion is proportional to temperature, so too is the ‘noise’ voltage produced. The noise voltage is also proportional to the resistance of the conductor because the resistance tends to isolate the electrostatic forces which act to bind electrons to their rest positions.

The rate or frequency of electron vibration is random and virtually unlimited. Therefore, the average energy of the noise is constant over the entire frequency spectrum. Such noise, which has constant energy across the spectrum, is called **White Noise.** This means that the total noise energy from this source which affects a system depends on the bandwidth of that system.

Johnson noise is given by:

$$P_{NOISE} = K \times T \times BW$$

Where K = Boltzman’s Constant (1.38$\times$ 10^{-23} J/DegreeK

T = Absolute Temperature (Degree K)

BW = Bandwidth

Flicker noise (pink noise) occurs as well as thermal noise in practical resistors due to mechanical imperfections in their manufacture. It is affected by such things as the uniformity of the conduction path, the quality of the lead connections and the breakdown of insulating films due to surface contaminants. Flicker noise is not broadband as with white noise, it reduces with frequency and is sometimes referred to as 1/f noise.

The following table shows the noise level of 1KΩ resistors of various types with 1mA current through them. The measurement bandwidth is 30Hz to 300Hz.

Carbon composition, red type, crimped connections	0.2µV - 5µV
Carbon composition, red type, soldered connections	0.1µV - 2µV
Carbon film	0.05 µV
Metal film	0.04 µV
Metal glaze	0.03 µV
Metal oxide film	0.03 µV
Thick film	0.02 µV
Wire wound, crimped connections	0.03 µV - .1 µV
Wire wound, welded connections	0.01 µV

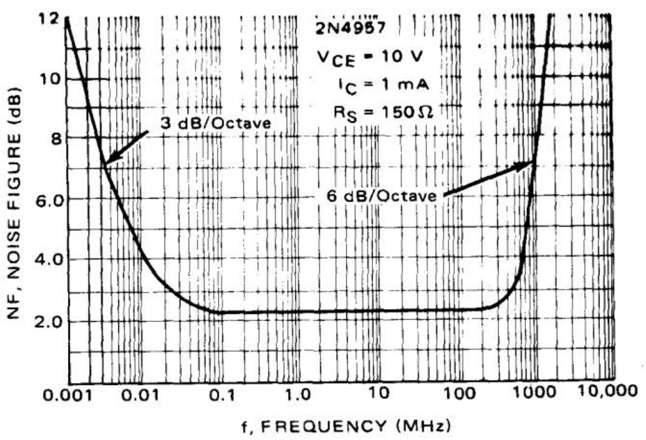
Noise in active devices

Semiconductor active devices are subject to all three types of noise phenomena previously dealt with. They are also subject to a further source of 1/f noise (flicker noise) called combination recombination noise. This occurs when electron-hole pairs are created in P-N junctions and also when they recombine. Flicker noise is most significant at low frequencies and become negligible above 1 KHz.

Transistors

Thermal noise occurs in the ‘bulk’ of the semiconductor material. Shot noise occurs at the P-N junctions, especially at the collector-base junction. The random arrival of charge carriers crossing into the collector causes shot noise on the collector output voltage. Shot noise is the major source of noise in transistors.

Combination-recombination noise occurring in the base region and will be amplified by the transistor. PNP transistors which have N type base regions are usually superior to NPN. transistors in this respect.



Noise figure Vs frequency for a 2N4957 transistor

Junction F.E.T.'s

Because JFET's do not have significant current flowing across P-N junctions, shot noise is much less of a problem. Most of the noise in JFET's is thermal noise due to the bulk resistance of the channel and shot noise caused by reverse gate leakage current. The latter will be amplified by the JFET However JFET's generally have superior noise characteristics to transistors. Unlike transistors, JFET noise is essentially independent of the quiescent current.

MOSFET's

Since a MOSFET does not have a PN junction in a noise sensitive position in its structure, it does not exhibit any significant shot noise. However, MOSFET's exhibit 10 to a 1000 times more flicker noise than JFET's, whose flicker noise is insignificant. This is thought to be due to combination-recombination of charges in the channel. Much of it may also be due to the 'on-chip' protective zener diodes. Therefore, MOSFET'S have much worse noise performance than transistors or JFET's and are only used where exceptionally high input resistances are required.

Integrated Circuits

Integrated circuits exhibit slightly higher noise levels than equivalent discrete component circuits. Their construction requires compromises which favour increased noise levels. However, I.C. fabrication techniques are improving in this respect.

Noise reduction techniques

Receive antenna directivity

To reduce the effects of noise in the early stages of a receiver the selection of an antenna with gain and directivity can improve the received signal to noise ratio.

Fading problems can sometimes be reduced if the receive antenna position is adjusted for best signal reception.

Cable from antenna to receiver

The cable and terminations should be high quality to reduce signal attenuation. Mast head amplifiers are sometimes used to amplify the signal from the antenna before it is fed down transmission line. This will improve the signal to noise ratio.

Effect of first stage RF amplification

The overall noise performance of a communications receiver is mainly determined by the first RF amplifier stage. The internal noise generated by the first stage will be subjected to the most amplification by the receive system. The first amplifier of any communications receiver should be designed for low noise performance.

Communications receiver bandwidth

As noise is broadband, the wider the bandwidth of the communications receiver, the greater the level of the noise introduced. Good filtering and selectivity will improve the signal to noise ratio as this reduces the bandwidth to the minimum required.

Level of modulation in transmitters

The level of modulation has an effect on the performance of communications systems. Thus the modulation depths are controlled to ensure the average is as high as possible. Circuits such as automatic level control (ALC) are designed to prevent over modulation which causes unwanted frequency products to be produced.

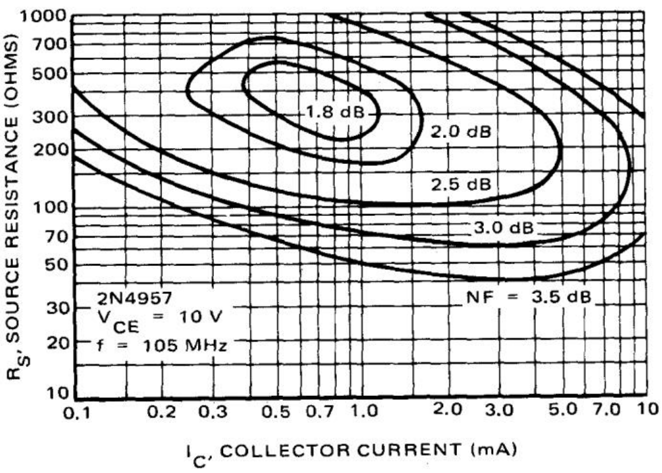
Quality of components

Better oscillators, amplifiers and modulators produce less distortion products, thus reducing out of band unwanted products, phase noise and wideband noise.

Shielding and earthing

The most common methods of noise reduction include proper equipment circuit design, shielding, grounding, filtering, isolation, separation and orientation, circuit impedance level control, cable design, and noise cancellation techniques.

Circuit design



Noise Contours for a 2N4957 Transistor

Careful circuit design such as transistor biasing can reduce internal noise from transistors and FETS to a minimum. For example, a design collector current selected between 0.4 and 1 ma coupled with a source resistance of 200 to 600 ohms will result in the lowest noise from a 2N4957 transistor.

Electromagnetic interference (EMI) is electromagnetic energy that adversely affects the performance of electrical/electronic equipment by creating undesirable responses or complete operational failure.

Radio frequency interference (RFI) is a special case of EMI and is usually divided into two general categories narrowband and broadband.

Electromagnetic compatibility (EMC) is the ability of electrical or electronic equipment/systems to function in the intended operating environment without causing or experiencing performance degradation due to EMI. It is important that electronic equipment designs ensure proper performance in the expected electromagnetic environment.

Measurement of noise

The noise power in a communications system can be measured with a Noise and Distortion Meter. Noise measurement requires an accurate true RMS voltmeter and is made in a defined bandwidth environment.

Signal to noise ratio

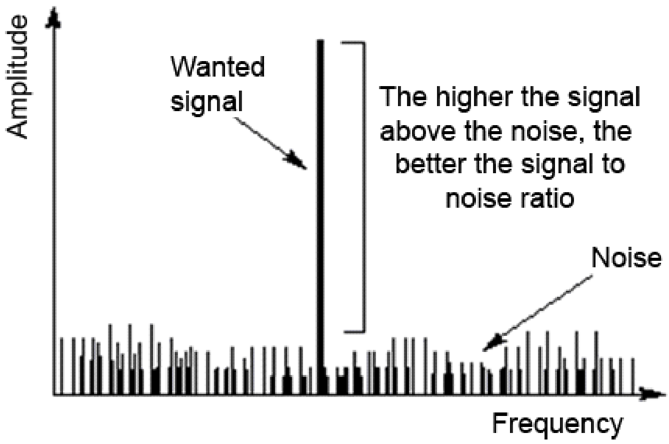
The signal to noise ratio in a system is defined as the ratio of the desired signal power Ps to the unwanted noise power Pn. This ratio may be measured at any point in the signal path of a system:

$$\text{Signal to Noise Ratio} = 10\log\frac{P_s}{P_n}\ \text{dB}$$

$$= 20\log\frac{V_s}{V_n}\ \text{dB}$$

When the ratio is expressed in dB, the voltage ratio gives the same figure as the power ratio. Since the signal and noise voltages Vs and Vn are measured at the same point they are measured across the same impedance.

Voice communications generally become unintelligible when the signal to noise ratio is less than 12 dB.



Signal strength versus noise

Typical system S/N ratios are:

AM radio	26 – 40 dB
FM radio	40 – 60 dB
Vinyl disc	40 – 50 dB
Compact disc	90 dB

The signal to noise ratio is useful for assessing the quality of the output of a system under a given set of conditions. However, it is not a useful basis for comparing the performance of one system against another because it does not indicate the degree to which the system itself contributes to the noise in its own output.

Noise factor

The noise factor (NF) of a system is defined as the ratio of the signal to noise power at the input of a system compared to that at its output at room temperature. (17°C = 290K)

$$Noise\ Factor = \frac{Input\frac{S}{N}\ Power}{Output\frac{S}{N}\ Power}$$

Noise figure

Noise Figure is the most usual way that manufacturer's express the noise performance of devices and amplifiers.

$$\frac{\text{Noise Figure(dB)} = 10\log\left(\text{Input}\frac{S}{N}\ \text{Power}\right)}{\text{Output}\frac{S}{N}\ \text{Power}}$$

The signal to noise ratio at the output of a system will always be worse (less than) that at its input as the system amplifies both the input signal and the input noise, but adds additional noise internally.

The difference between the input and output signal to noise power expressed in dB is the Noise Figure.

Noise figure represents the additional noise contributed by the system itself, over and above the noise entering its input. Thus, the noise figure can be used to compare the quality of systems, assuming the system and test equipment bandwidths are equal.

Noise figures of 1dB or less represent good system performance. For a system with gain, the amplifier stage nearest its input stage will contribute most towards increasing system noise. The internal noise generated by the first stage will be subjected to the most amplification by the system, this stage contributing most significantly to the overall noise performance.

Summary

Communication systems are designed to send messages or information to one or more destinations.

A communication system consists of the ***transmitter**,* the ***transmission medium**,* and the ***receiver.***

Audio signals are characterised by the specific requirements of the human ear.

The transmitter converts the electrical signal into a form that is suitable for transmission

The transmission medium could be a transmission line, coax cable, wave guide or free space

The receiver recovers the baseband signal contained in the transmitted signal.

Multiplexing is used to send multiple independent communications signals over the same transmission medium

Noise may be defined as any unwanted form of energy which reduces the intelligibility of a communication.

There are three categories of noise, external noise, internal noise and electromagnetic noise.

The signal to noise ratio is defined as the ratio of the desired signal power Ps to the unwanted noise power Pn

Unit 4 - Modulation and demodulation techniques

Characteristics of baseband signals

Generally a baseband signal is complex and contains more than a single frequency. There might be several different frequencies superimposed on each other. Signals such as voice, video or data are baseband signals.

A baseband signal has all the frequencies from the lowest to the highest frequency component with significant power.

The definition of baseband bandwidth is the bandwidth that exists before it is modulated or multiplexed or the baseband that results after de-multiplexing and demodulation.

While it is recognised that most baseband signals are complex, analysis of different modulation systems is usually conducted assuming the information to be transmitted is a single sinusoid.

The reason for modulation

If it is attempted to transmit ‘intelligence’ directly as an electromagnetic wave there are two main problems:

1. Direct transmission of intelligible signals would result in catastrophic interference problems, since the resulting electromagnetic waves would be all in approximately the same frequency range.

2. It is difficult to transmit low-frequency radio waves. Efficient transmission and reception of electromagnetic waves at low frequencies is not possible.

Both of these difficulties are resolved by raising the frequency of the intelligence to some much higher radio-frequency before transmission. The process by which this is achieved is called **modulation,** and the specific frequency used as a vehicle for the intelligence is called the **carrier frequency.**

Modulation is produced by varying one characteristic of the carrier controlled by the intelligence signal. The intelligence to be transmitted is often referred to as the baseband signal.
Since the carrier is a sine wave, modulation involves varying one or sometimes both of the carrier’s basic characteristics – amplitude and frequency (or Phase) – to convey intelligence.

The circuit to achieve these changes is called a **modulator**.

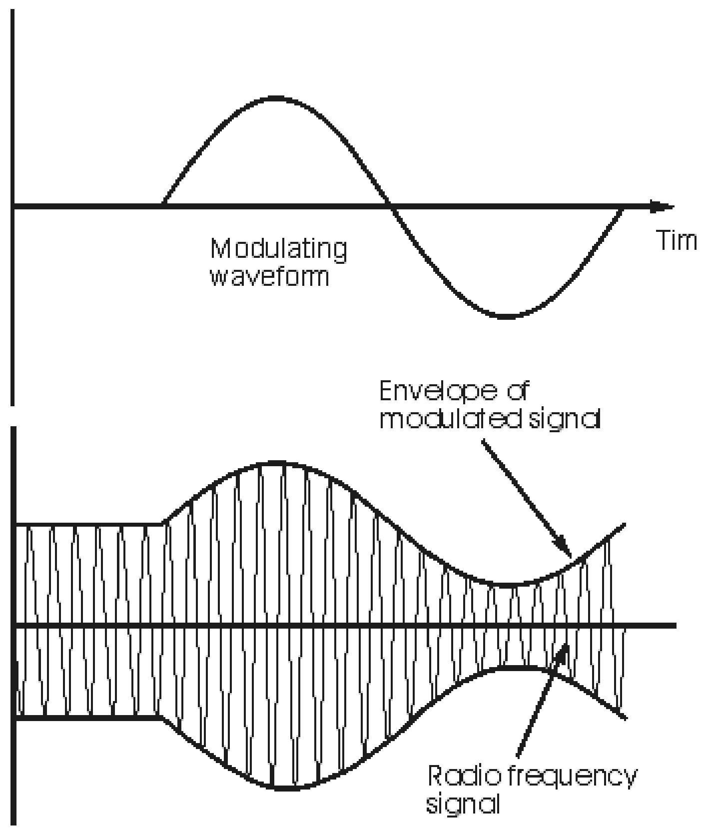
Demodulation reverses the process of modulation and involves reconstructing the baseband signal intelligence from the changing characteristics of a modulated radio wave. The circuit to achieve this is called a **de-modulator or a detector**.

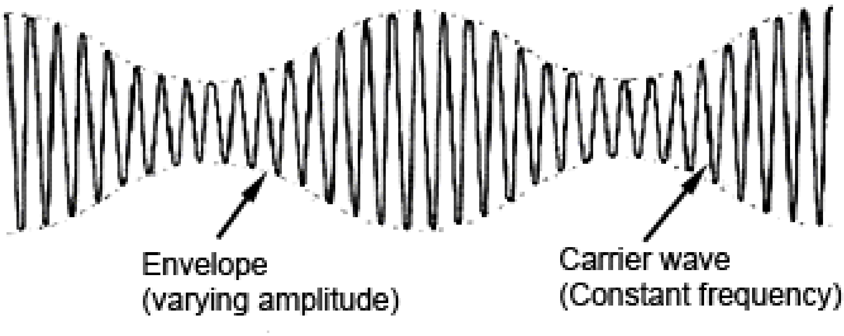
Types of modulation

AM – Amplitude Modulation
FM – Frequency Modulation
PM – Phase Modulation

Amplitude modulation (AM)

Amplitude modulation was one of the first types of modulation used in radio communications.





Advantages of amplitude modulation.

There are several advantages of amplitude modulation, and some of these reasons have meant that it is still in widespread use today:

- It is simple to implement
- it can be demodulated using a circuit consisting of very few components
- AM receivers are very cheap as no specialised components are needed.

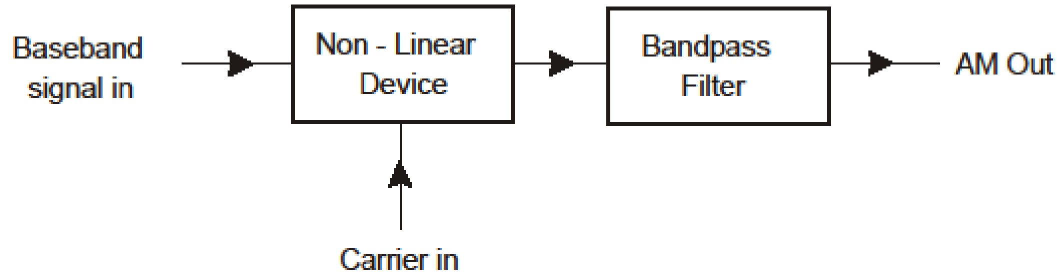
Disadvantages of amplitude modulation

- It is not efficient in terms of its RF power utilisation.
- It requires a bandwidth equal to twice that of the highest baseband frequency.
- It is affected by external noise noise because most noise is amplitude based.

The basic amplitude modulator

The basic principle of an amplitude modulator is to apply the baseband intelligence signal and the carrier to a non-linear device where the effect is to produce signals at the output related to both the carrier and the baseband signal.

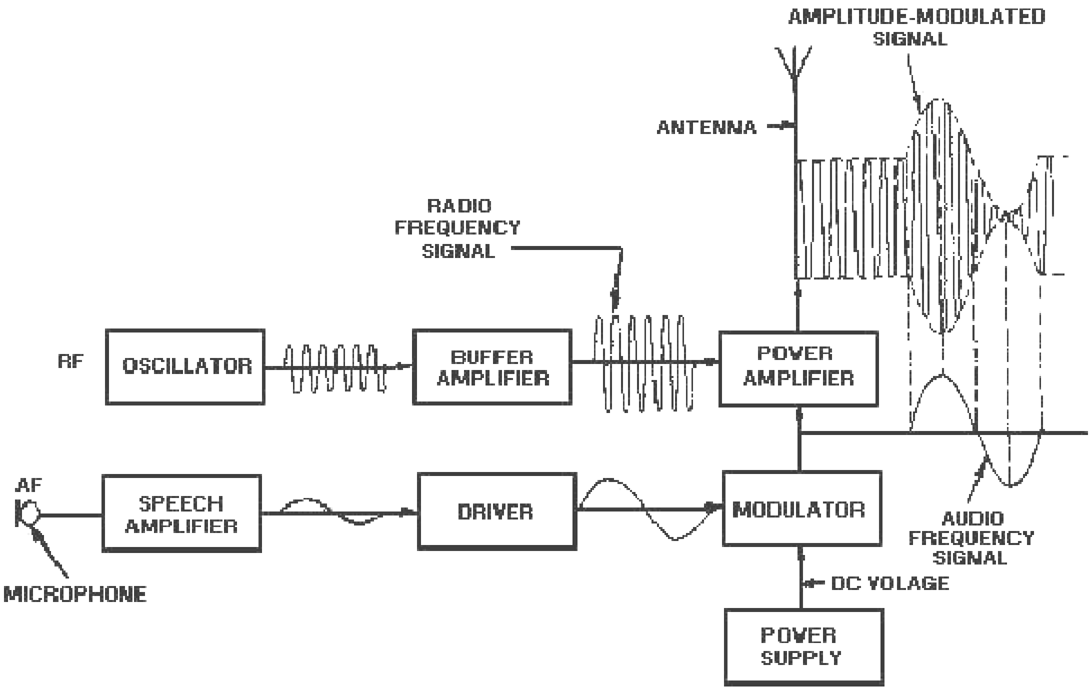
The output of the non linear device will consist of the carrier and the sum and difference frequencies plus other components. The band pass filter selects the carrier and the sum and difference frequencies and attenuates the other unwanted products.



If the carrier is fc and the baseband signal is fs, the output from the modulator will be fc, (fc + fs) and (fc – fs).

(fc +fs) is known as the upper sideband and (fc – fs) the lower sideband. If the baseband signal is complex, the upper and lower sidebands will also be complex. The upper and lower sidebands effectively contain the baseband signal information.

The total power of the transmitted signal varies with the modulating (baseband) signal. If there is no baseband signal the output will be the carrier only.



Block diagram of an amplitude modulator

In an amplitude-modulated wave, the amplitude of each cycle varies in accordance with the intelligence amplitude (modulating signal).

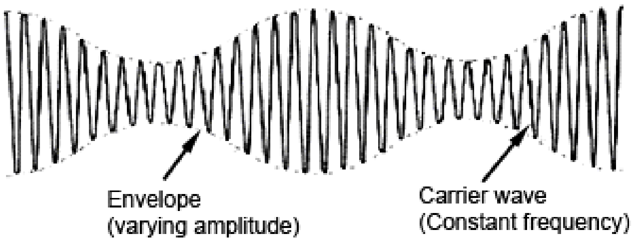
The higher the amplitude of the modulating signal the higher the change in amplitude of the resultant modulated wave.

The frequency of the modulating signal is conveyed by the **rate of change** of amplitude. The higher modulating frequencies change the amplitude of the resultant wave faster.

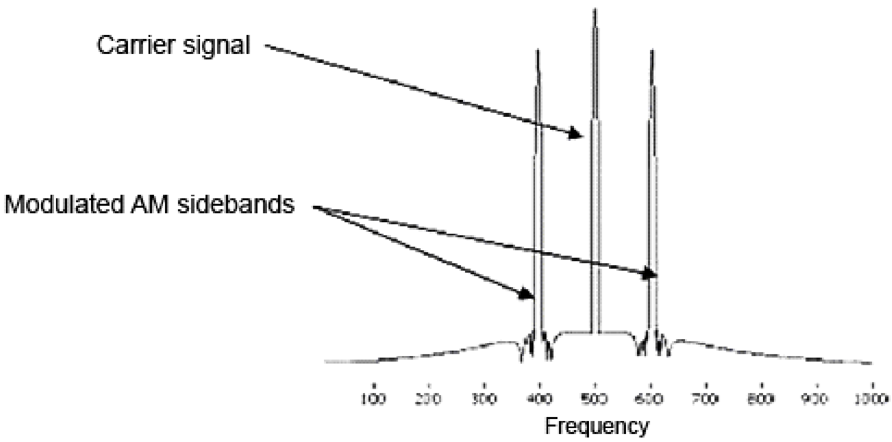
Voice, music and video are complex signals, i.e. they consist of many frequencies and different amplitudes. When modulated they produce very complex outputs. To more easily analyse modulation we use single a sine wave as the baseband signal.

What is an amplitude modulated signal?

Amplitude modulation is a type of modulation where the amplitude of the carrier signal is varied in accordance with the information signal.



Time domain display of an amplitude modulated wave



Frequency domain display of an amplitude modulated wave

Limitations of AM commercial radio

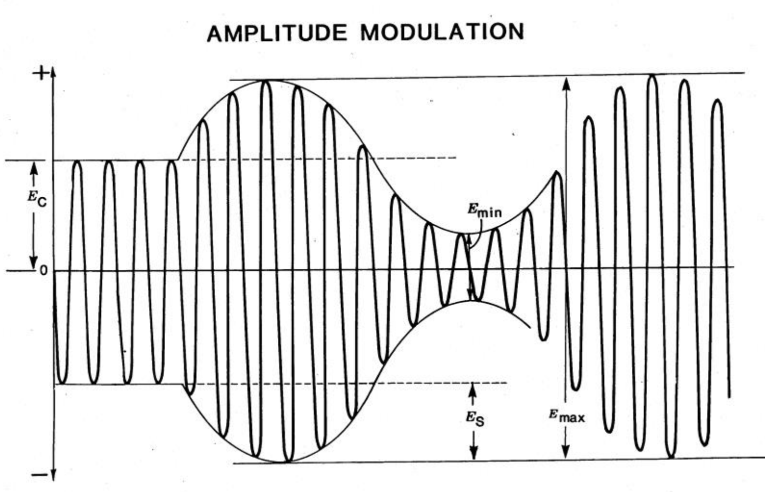
Because of its susceptibility to atmospheric interference and generally lower-fidelity sound, AM broadcasting is better suited to talk radio and news programming, while music radio moved to FM broadcasting in the 1970's. Frequency response for AM radio is typically 40 Hz – 7 kHz with a 50 dB S/N ratio.

AM is still used for aircraft communications.

Percentage modulation

The level of modulation that is applied to a signal is called the modulation Index. This index should not exceed 1 as this causes the generation of RF products that will exceed the channel bandwidth. This is known as over modulation or splatter. The received signal will also be distorted.

Transmit stations using Amplitude Modulation limit the level of the intelligence signal to prevent over modulating. The maximum modulation without distortion is 100%. The relationship between the carrier voltage and the signal voltage determines the percentage modulation.



$$\text{Modulation Index } m = \frac{E_s}{E_c}$$

The modulation index is often expressed as a percentage.

Frequency components in an amplitude modulated wave

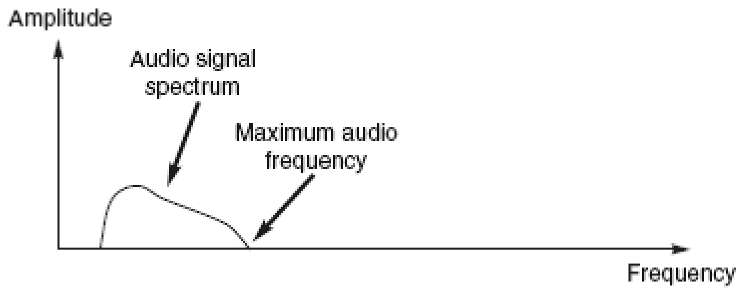
The output of an amplitude modulator consists of:

- The carrier frequency fc
- Sum and difference frequencies (fc + fs) and (fc - fs)

Where fs is the baseband signal.

Baseband signal

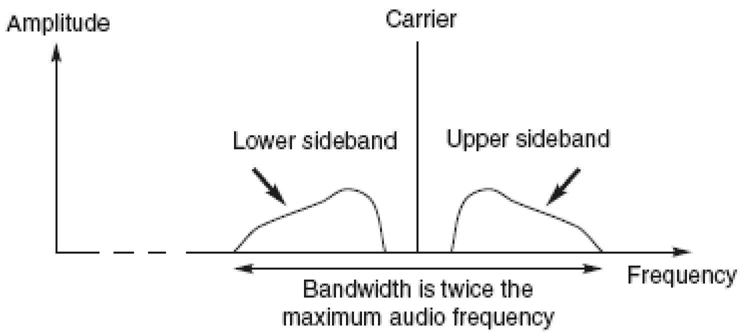
The diagram below shows a group of frequencies and their relative amplitude levels. (The baseband signal)



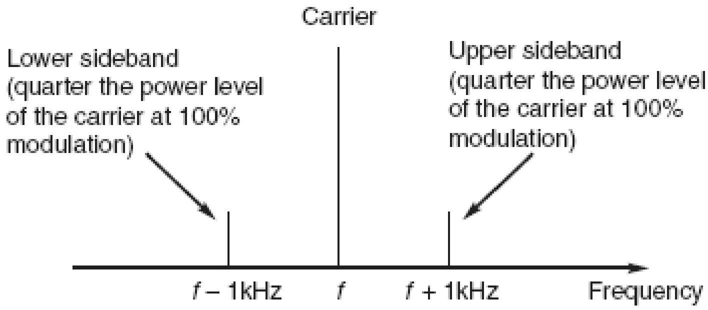
The Baseband signal

After modulation signals

The upper sidebands are the frequency of the carrier plus the signal frequencies.
The lower sidebands are the frequency of the carrier minus the signal frequencies.



The modulated wave



The frequency spectrum showing modulation with a 1 kHz baseband signal and resulting power levels

Viewing amplitude modulated waves

An amplitude modulated wave can be viewed in the time domain with an oscilloscope. The modulation index can be determined from this display. The oscilloscope has to be capable of displaying signals at the carrier frequency.

A spectrum analyser can be used view the frequency relationship between the carrier, the upper and lower sidebands and their relative power levels. A high quality instrument is required to show resolve sidebands generated by an audio baseband signal.

Power in an amplitude modulated wave

The total transmitted power is distributed amongst the three components of the output, the carrier wave, the upper sideband and the lower sideband.

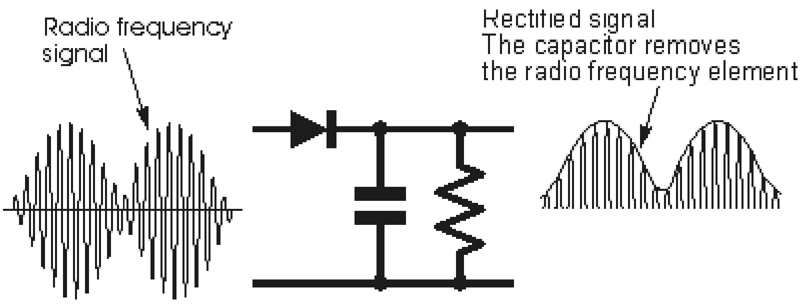
$$Psb = \frac{1}{2}m^2Pc$$

Psb	power in the sidebands
m	modulation percentage as a fraction
Pc	power in the carrier

For a 100% modulated wave, the total sideband power is equal to 50% of the carrier power.

Amplitude demodulation

The demodulation or detection process should recover the intelligence signal with minimum distortion. A demodulator is sometimes referred to as a detector.



Basic principle of amplitude demodulation

The action of the demodulator is similar to the modulation process in that a nonlinear device is used to distort the modulated wave.

These signals are then processed by a low pass filter followed by a dc blocking capacitor.

Summary – Amplitude modulation

Amplitude modulated signals are susceptible to atmospheric interference.

The modulation index m is used to represent the depth of modulation.

The relationship between the voltage of the carrier and the voltage of the signal will determine the percentage modulation.

An amplitude modulated wave has a carrier plus the upper sideband and the lower sidebands.

The demodulation process should recover the intelligence signal without introducing distortion.

A non linear electronic device is used to demodulate the RF signal.

Demodulation is sometimes called detection.

The output of the detector is filtered to recover the baseband signal.

Frequency modulation (FM)

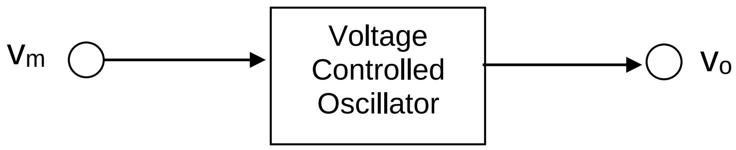
FM changes the frequency of the modulated wave proportionally to the amplitude on the baseband signal.

Basic principle of frequency modulation

The amplitude of the modulating signal will cause the signal to swing above and below the carrier or centre frequency. The higher the amplitude of the modulating signal the larger the swing above and below the centre frequency.

The maximum possible change in frequency is known as the **frequency deviation Δf.** This is usually expressed as +/- XX Khz.

The rate of change of the carrier frequency is dependent on the frequency of the baseband signal. The higher the modulating frequency, the faster the change in the carrier frequency.



The components of an FM wave are very complex and produce increased bandwidth requirements for a channel compared to AM (unless the deviation is small).
The modulation process produces multiple side frequencies.

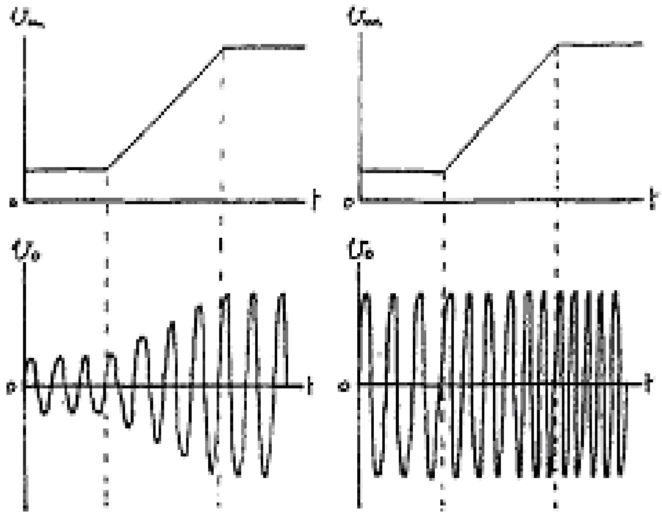
The modulation index for FM is:

$$m_f = \frac{\Delta f}{f_s}$$

The higher the modulation index, the more side frequencies are generated and the wider the bandwidth required for the channel.

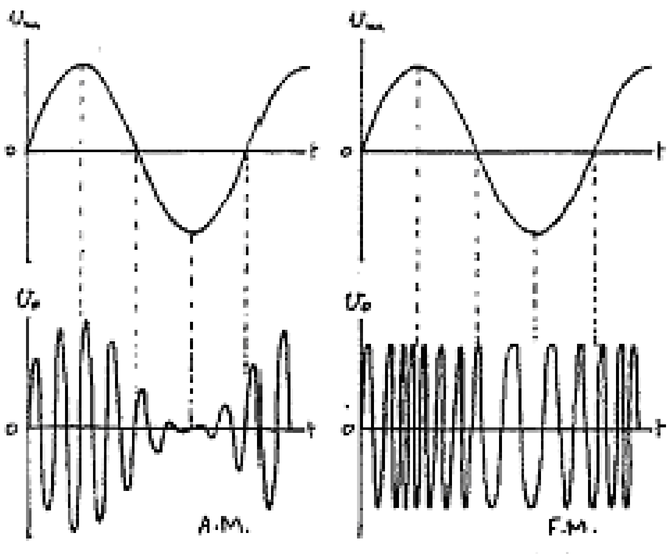
FM broadcasting in Australia has a maximum deviation of +/- 50 Khz. If the baseband signal has a maximum frequency of 15 Khz, the channel bandwidth required is 200 Khz.

An AM system for the same baseband signal would require a channel bandwidthy of 30 Khz.



An AM and FM signal modulated by a ramp baseband signal

The AM output shows no change in frequency as the voltage of the modulating signal rises. However the amplitude of the output does change. The FM output changes frequency with no change in amplitude.



An AM and FM signal modulated by a sinusoidal baseband signal

Power in a frequency modulated wave

The intelligence in an FM wave is in the side frequencies. The side frequency power increases as the level of modulation increases. This is because the number of side frequencies increase with increased modulation index.

The total power of a frequency modulated wave does not change however; it is the same for all levels of modulation. The *distribution* of power between the carrier and the side frequencies does change.

Self help question

FM Applet: visit this internet site to learn more about the power in the sidebands of a frequency modulated wave. Note, your PC must have Java$_{TM}$ installed; if Java is not installed, then go to *http://www.java.com* and install Java first.

URL for the site is: *http://cnyack.homestead.com/files/modulation/modfm.htm*

- Set the carrier frequency to 25ωC, vary the modulating frequency ωm. Note the spectrum analysis specially the spacing between the signal power points. What is the relationship between the modulation frequency and the sideband frequency location?

- Set the carrier frequency to 25ωC, and the frequency deviation ωd to 1. Vary the modulating frequency ωm. Note the spectrum analysis specially the power levels and the number of sidebands. Now increase the frequency deviation ωd to 3, vary the modulating frequency again and make comments on the power in the carrier and the sidebands.

- Draw a frequency spectrum analysis of a carrier frequency of 25 KHz with a modulation index of 3 and modulating frequency of 1 KHz.

Frequency demodulation

The demodulation process should recover the intelligence signal without introducing distortion.

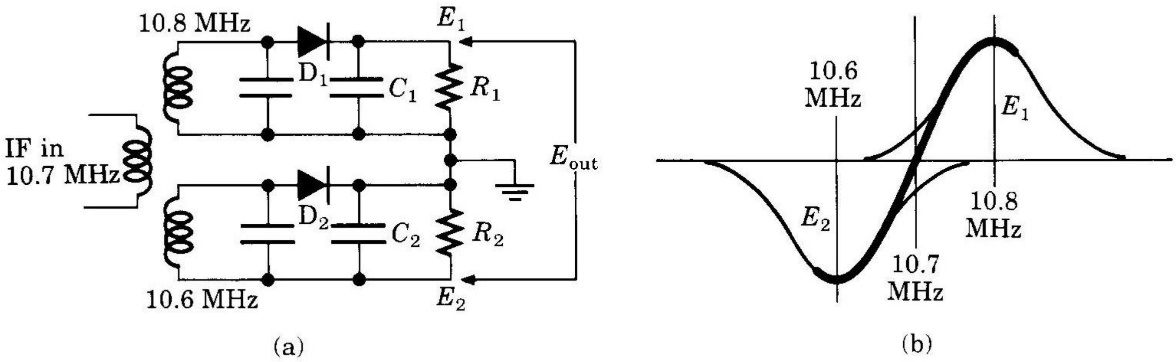
The basic principle of frequency demodulation

FM demodulators must convert frequency variations of the input signal into amplitude variations at the output.

Fm detectors (discriminators)

FM detectors convert the frequency variations of the carrier back into a representation of the original modulating signal.

Basic Slope Detector



The Slope Detector comprises two diode or envelope detectors. The transformer secondaries in the diagram are tuned to 10.8 and 10.6 MHz respectively. When the input signal is 10.7 MHz (the centre or carrier frequency) the output voltages E_1 and E_2 are equal and opposite and E_{OUT} is zero.

When the input signal is above 10.7 MHz, E_1 is greater than E_2, resulting in a positive output voltage. When E_1 is less than E_2, there will be a negative output voltage. The typical 'S' response characteristic for a FM detector is shown in the diagram above. The disadvantage of this circuit is that there are two tuned circuits for alignment.

Integrated circuits using phase locked loops are used in modern FM receivers.

Interference Suppression

The main advantage of FM over AM is improved S/N performance as an FM demodulator will not respond to amplitude based noise.

Wide band and narrow band FM

When a signal is frequency modulated, the carrier shifts in frequency corresponding to the amplitude of the baseband signal.

The maximum allowable deviation is governed by a number of factors including the bandwidth available for the channel. FM signals with a high deviation have a superior S/N performance although they naturally occupy a greater bandwidth. As a result of these conflicting requirements, different levels of deviation are used according to the application.

Narrow band frequency modulation (NBFM) with typical deviations of +/- 3 kHz or more are used for point to point voice frequency communications. Much higher levels of deviation are used for broadcasting (+/- 50 kHz or +/- 75 khz.). This is called wide band FM (WBFM).

Other forms of modulation and wireless systems

Bluetooth

Bluetooth is a wireless system that can carry data at speeds up to 721 Kbps in its basic form and offers up to three voice channels. Bluetooth technology enables a user to replace cables between devices such as printers, fax machines, desktop computers and peripherals, and a host of other digital devices. The technology is intended to be placed in a low cost module that can be easily incorporated into electronics devices of all types. Bluetooth uses the licence free Industrial, Scientific and Medical (ISM) frequency band for its radio signals and enables communications to be established between devices up to a maximum distance of 100 metres. Running in the 2.4 GHz ISM band, Bluetooth employs frequency hopping techniques with the carrier modulated using Gaussian Frequency Shift Keying (GFSK).

WiMAX

WiMAX is a broadband wireless data communications technology based around the IEE 802.16 standard providing high speed data over a wide area. The letters of WiMAX stand for Worldwide Interoperability for Microwave Access (AXess), and it is a technology for point to multipoint wireless networking. WiMAX technology is expected to meet the needs of a large variety of users from those in developed nations wanting to install a new high speed data network very cheaply without the cost and time required to install a wired network, to those in rural areas needing fast access where wired solutions may not be viable because of the distances and costs involved. Additionally it is being used for mobile applications, proving high speed data to users on the move.

Digital modulation

Digital modulation has many forms and will be covered in greater detail in the next unit. Digital modulation includes:

- Phase shift keying.
- Frequency shift keying.
- Amplitude shift keying.
- Quadrature amplitude modulation.

In all of the above methods, each of the phases, frequencies or amplitudes are assigned a unique pattern of binary bits. Usually, each phase, frequency or amplitude encodes an equal number of bits. This number of bits comprises the **symbol** that is represented by the particular phase, frequency or amplitude.

Unit 6 Radio transmitters

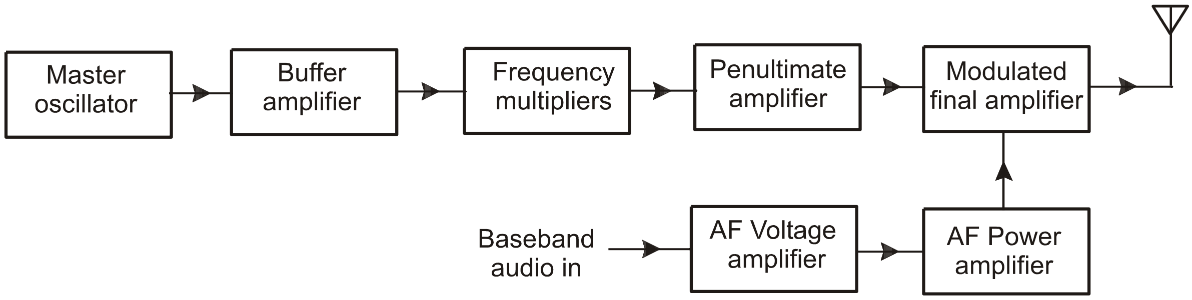
Transmitter functions

The function of a transmitter is:
:

- To generate the radio frequency carrier and amplify it to an appropriate power level.
  .
- To modulate the carrier with the intelligence or baseband signal.
- Undertake the above processes without introducing significant noise and distortion.
- Prevent the modulation from exceeding the permitted level.
- Produce a clean output spectrum with minimum signals outside the permitted bandwidth.

Amplitude modulation – high-level modulation

The modulation process is performed at high power levels. Both the carrier frequency and the baseband signals are amplified and the modulation process will occur in the final power amplifier before transmission.



High level modulation

If the RF power amplifier is 10 KW, then the modulator power will be 5 KW. (Practically a little higher to allow for losses)

In some transmitter designs in order to obtain better quality Amplitude Modulation the penultimate RF stage may need to be subject to modulation as well as the final stage. Direct series coupling from the modulation amplifier is also possible, although this requires a higher DC supply voltage.

Advantages

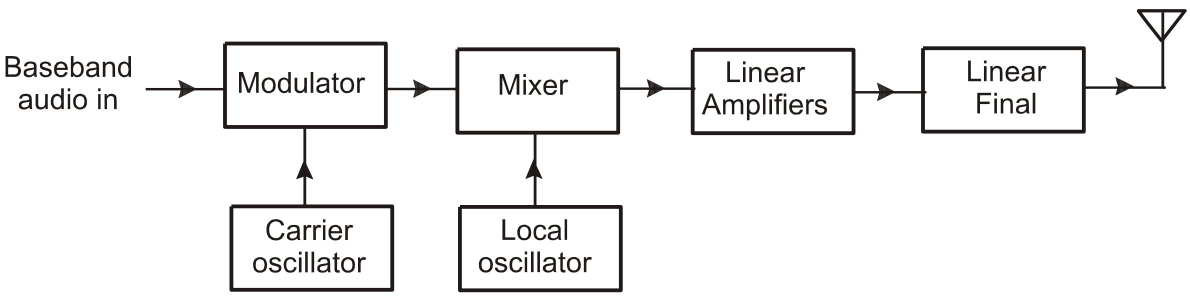
The RF amplifiers are all biased in Class C and therefore efficient from the point of view of current drawn from the power supply.

Disadvantages

A large modulation amplifier is needed to drive the modulated RF stage at least equal to 50% of the RF power of the transmitter itself. Traditionally the modulation is applied using an audio transformer which is very bulky and expensive.

Low level modulation

The modulation process is undertaken at low power levels (typically 0dBm). Class AB or A linear amplifiers must be used to develop the required output power.



Low level modulation

Most modern AM transmitters use low level modulation.

Advantage

It is much easier and cheaper to design a low distortion modulation circuit at low power levels.

Disadvantage

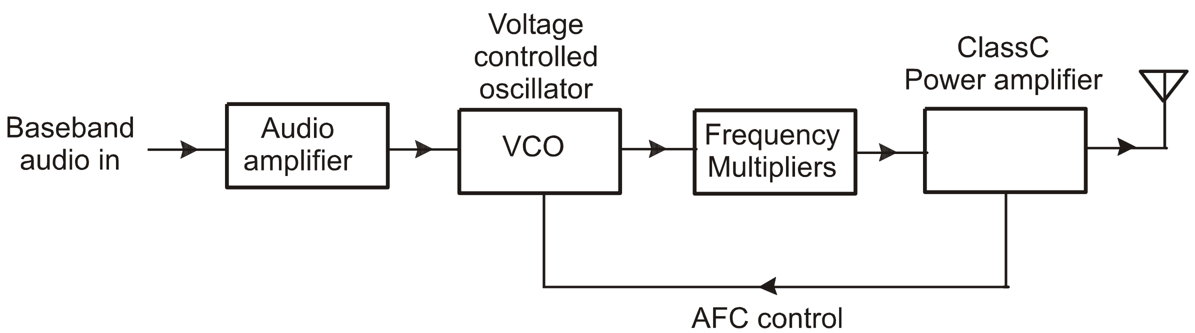
Linear RF amplifiers are inefficient. Worst case for a Class A amplifier is less than 50%.

Frequency modulated transmitters

Frequency modulation is used for many applications from wideband FM broadcast to narrowband handheld transceivers. The type and method of producing FM mainly depends on the bandwidth required.

FM transmitters are usually used on frequencies above 30MHz due to their bandwidth requirements

In the diagram below it can be seen that the audio signal from the audio amplifier changes the frequency of the oscillator producing a frequency modulated signal ready for RF amplification and transmission. The FM oscillator is a VCO (voltage controlled oscillator) and will change frequency dependent on the amplitude of the applied modulating signal.



A simple FM transmitter

Class C power amplifiers can be used for FM as no intelligence is contained in amplitude based variations of the carrier. Class C operation does produce large amounts of harmonics and after each stage filtering is used to keep any spurious signals to within acceptable levels.

As the deviation produced by the modulation process is small, frequency multipliers are used

AFC is automatic frequency control and is a DC control signal applied to ensure the stability of the VCO.

RF Power Amplifiers

Valves are usually used for high power systems.

Advantages of valves

- Very linear (especially triodes) making it viable to use them in low distortion linear amplifier applications.
- High input impedance.
- Can be constructed on a scale that can dissipate large amounts of heat. (some devices even being water cooled).
- Electrically very robust, they can tolerate overloads which would destroy bipolar transistor systems.

For these reasons valves remain viable technology for very high power applications such as Radio & TV broadcasting.

Disadvantages of valves

- High cost
- Heater supplies are required for the cathodes.
- Multiple voltage power supplies are required.
- Dangerously high voltages are required for the anodes.
- Valves have a shorter working life than solid state components due to various failure mechanisms (cathode poisoning, breakages or shorts internally, notably of the heater or grid structures)
- Available in a single polarity only. Transistors and FETS are available in complementary polarities (e.g., NPN/PNP/ or NChannel/PChannel), making possible many circuit configurations that cannot be realised with valves.

Solid state (semiconductors)

Semiconductors are used for low and medium power RF power applications.

Summary

The function of a transmitter is to:

- generate the radio frequency carrier and amplify it to an appropriate power level.
.
- modulate the carrier with the intelligence or baseband signal.
- undertake the above processes without introducing significant noise and distortion.
- prevent the modulation from exceeding the permitted level.
- produce a clean output spectrum with minimum signals outside the permitted bandwidth.

High level modulation is performed at high power levels usually at the final power amplifier.

Low level modulation is performed in the early stages of the transmitter and is the preferred option in modern AM transmitters.

RF circuits in low level modulation require a higher current power supply than for an equivalent high level modulation circuit.

Unit 5 communication receivers

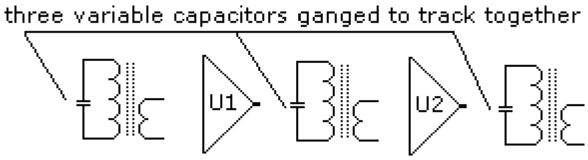
Introduction to communication receivers

Radio receivers are designed to perform four functions:

- To separate the wanted RF signal from all other signals which may be induced in the antenna.
- To amplify the wanted RF signal to a usable level.
- To demodulate or "detect" the RF signal separating the intelligence information from the RF carrier.
- Interface the intelligence information to the user. This normally involves amplification.

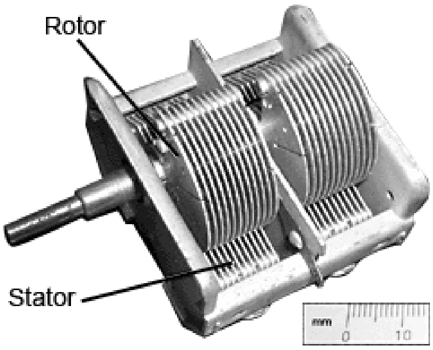
The tuned radio receiver (TRF) receiver

The T.R.F. (tuned radio frequency) receiver was among the first designs available. The basic principle was that all RF stages are simultaneously tuned to the received frequency before detection and subsequent amplification of the baseband signal.



Ganged capacitors and multi stages of a TRF receiver

Multi stage or ganged variable capacitors are used to provide the tuning. The sensitivity of a receiver is greatly improved by the addition of RF amplification before detection. The selectivity is also improved by having multiple tuned RF stages of amplification

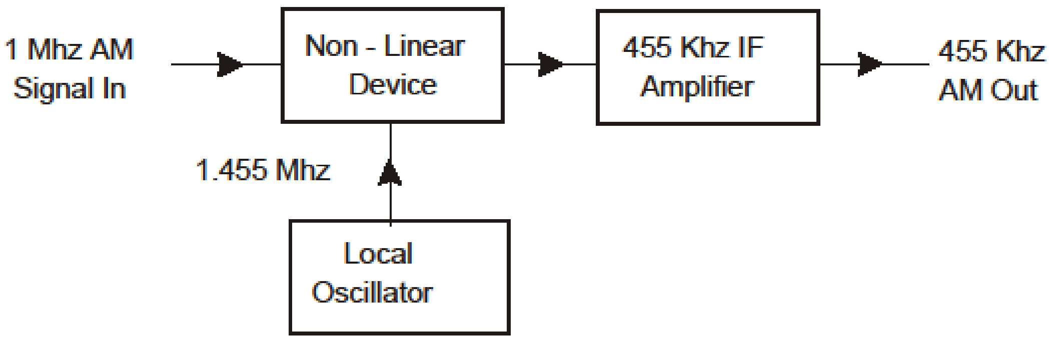


Two stage ganged capacitor

It is very difficult to produce accurate simultaneous tuning of each stage as the circuit Q or selectivity of the tuned circuits change.

TRF receivers have been replaced by receivers using the superheterodyne principle which overcomes these tuning difficulties.

The superheterodyne principle



A mixer uses a non linear device that produces signals at its output that are not present at its inputs. A mixer and an AM modulator work on the same principle, the difference being on what frequency products are selected at the output.

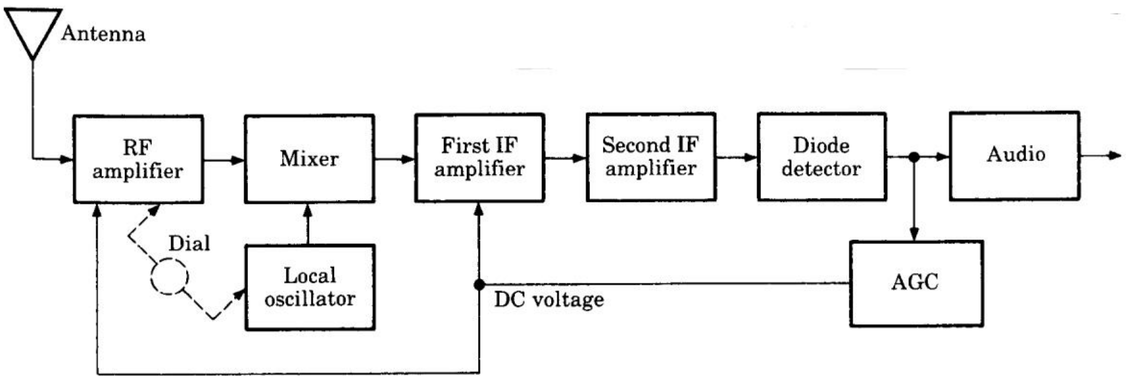
The aim of the superheterodyne receiver is to overcome the problems of tuning in the TRF receiver. An IF (intermediate frequency) amplifier is used which is has fixed tuning. (Usually 455 kHz or 10.7 MHz)

Frequency products at the output of the non-linear device include the difference product between the 1.455 MHz local oscillator and the 1 MHz AM signal in. This 455 kHz signal possesses all the characteristics of the 1 MHz AM signal. (ie it is AM modulated)

This 455 kHz AM signal is amplified by the 455 kHz. IF amplifiers.

If the local oscillator frequency is changed then a different frequency signal will be mixed to produce the required IF frequency output of the mixer.

Tuning is therefore accomplished by varying the frequency of the local oscillator within superheterodyne receiver.



Block diagram of a superheterodyne AM receiver

AGC is automatic gain control which changes the gain of the system to keep the output level independent of changing input signal strength.

The RF amplifier, mixer and local oscillator are tuned simultaneously and provide some selectivity to the receiver. The IF amplifier is the major contributor to the overall gain and selectivity of the receiver however.

In some simple receivers, the function of RF amplifier, mixer and local oscillator are performed by a single stage.

Image frequency

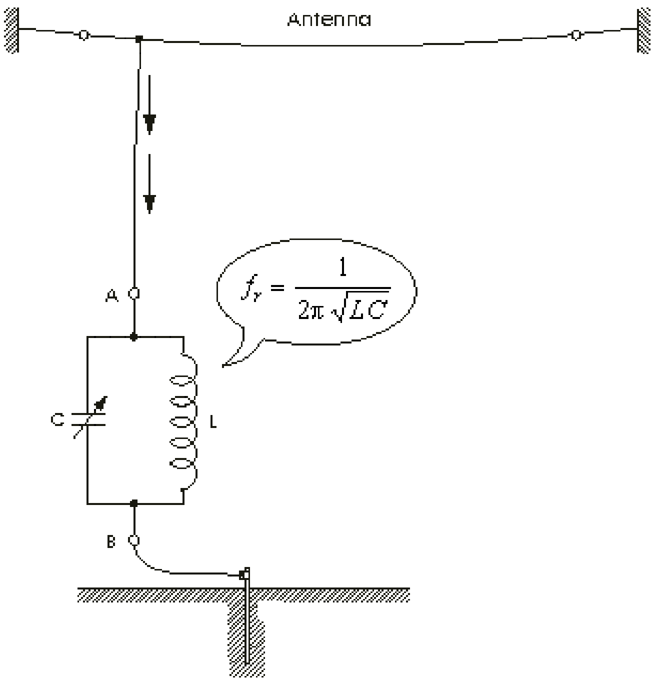
If the receiver is tuned for a 1 Mhz input signal and the local oscillator is 1.455 Mhz, an input
signal of 1.910 Mhz will produce an output of 455 Khz. This signal will be reduced by the frequency selective circuits in the RF amplifier and input of the mixer, but still may be of sufficient level to create interference.

This frequency is known as the image frequency.

$$\text{Image Frequency} = \text{Tuned Frequency} + (2 \times \text{IF Frequency})$$

Receiving antennae

For any given RF signal, an antenna which can effectively transmit the signal will be also effective for receiving it. The electrical properties of transmitting and receiving antennae are identical. If such an antenna was resonant at the desired frequency, it will also serve as the tuning function of the receiver.



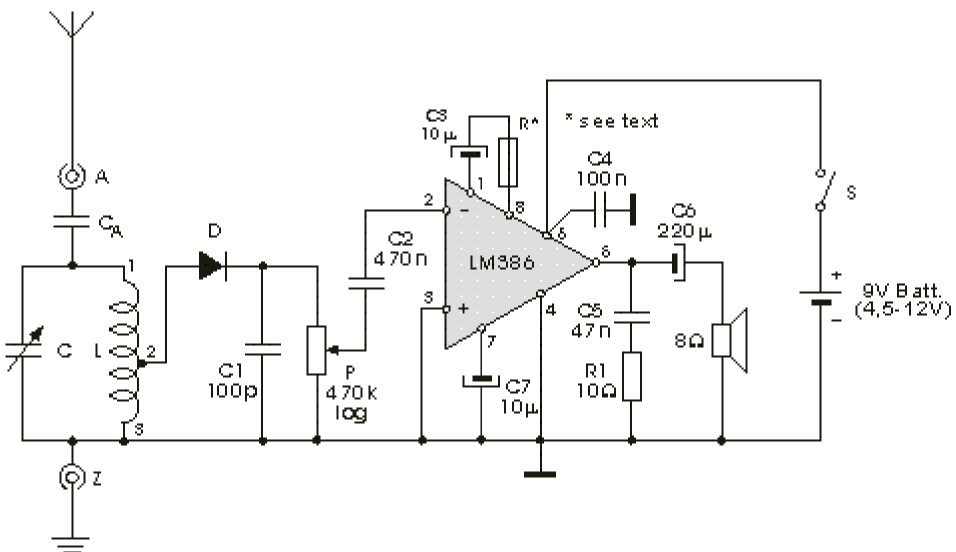
The physical and mechanical dimensions of most transmitting antenna would prohibit their use contained in receivers. The power handling requirements of transmitting antennae range from several watts to several thousand watts. For receiving antennae, the range is from several µW to several mW. Thus much lighter construction is economical for receiving antennae.

A practical receiving antenna has enough bandwidth to receive more than one station on most frequency bands. The antenna must have sufficient bandwidth to accommodate all possible wanted signals. Tuning usually takes place after such an antenna receives the signals.

The gain of an antenna is measured in dB and is a function of the mechanical or physical construction of the antenna.

Integrated radio receivers

Integrated circuits can provide near fully functioning radio receivers. The diagram below shows such a circuit.



Summary

Radio receivers are essentially designed to perform four functions

- To separate the wanted RF signal from all other signals which may be induced in the antenna.
- To amplify the wanted RF signal to a usable level.

- To demodulate or “detect” the RF signal separating the intelligence information from the RF carrier.

- Interface the intelligence information to the user. This normally involves amplification.

Sensitivity is the ability of the receiver to amplify weak signals.

Selectivity is the ability of the receiver to reject stations on adjacent frequencies

Fidelity is a measure of how faithfully the receiver reproduces the original intelligence signal.

Unit 7 Occupational health and safety

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Lockout/Tagout

Electrical power may be removed when high powered installations are inspected, serviced, or repaired. To ensure the safety of personnel working with the equipment, power is removed and the equipment must be locked out and tagged out.
Equipment is locked out and tagged out before any preventive maintenance or servicing is performed.

Lockout is the process of removing the source of electrical power and installing a lock which prevents the power from being turned ON. Tagout is the process of placing a danger tag on the source of electrical power which indicates that the equipment may not be operated until the danger tag is removed.

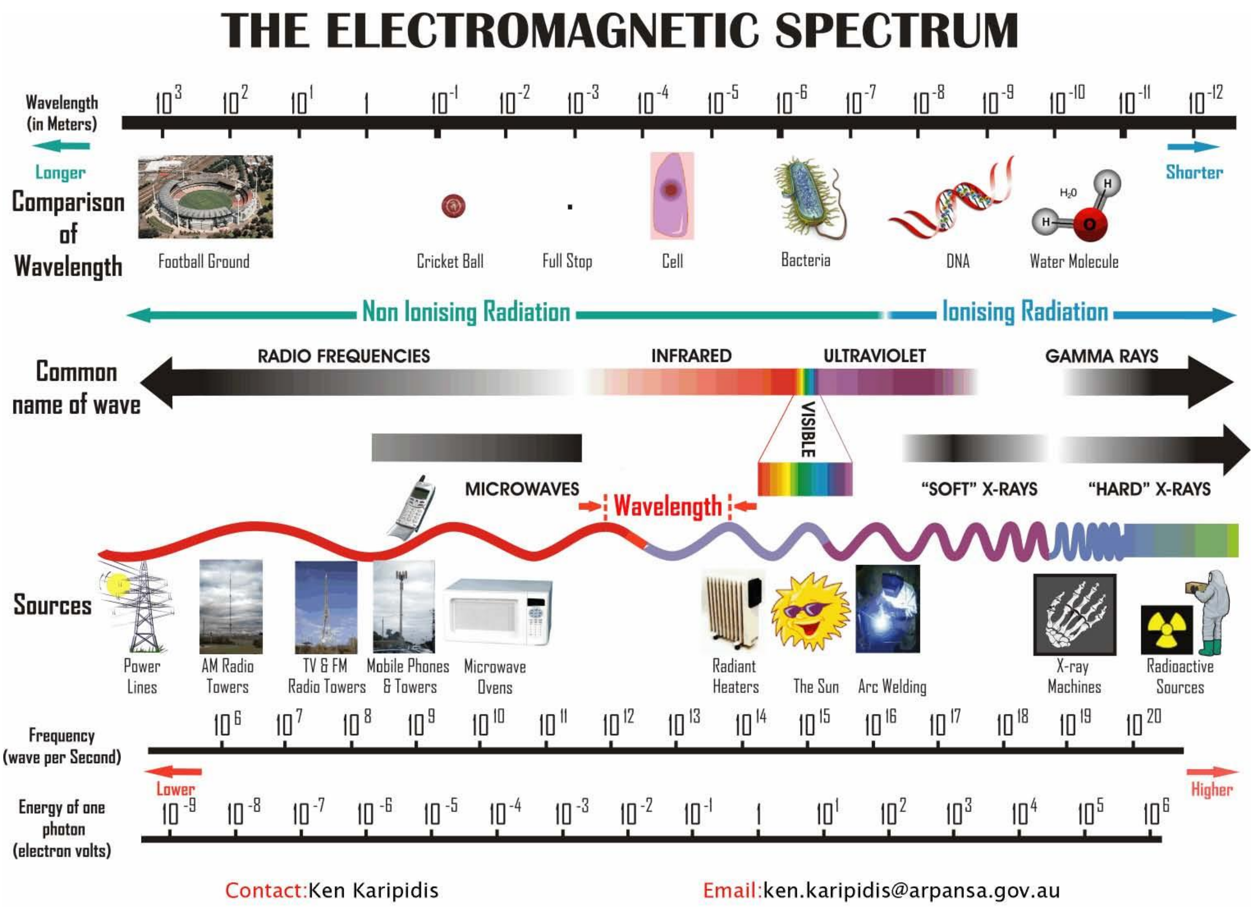
A danger tag has the same importance and purpose as a lock and is used alone only when a lock does not fit the disconnect device. The danger tag should be attached at the disconnect device with a tag tie or equivalent and should have space for the worker's name, craft, and other required information. A danger tag must withstand the elements and expected atmosphere for as long as the tag remains in place.
A lockout/tagout is used when:

- servicing equipment that does not require power to be ON to perform the service
- removing or bypassing a safety device
- the danger exists of being injured if equipment power is turned ON. (eg high energy radiation)

Electromagnetic radiation
Electromagnetic radiation (EMR) is emitted by natural sources such as the Sun and by terrestrial based artificial sources. EMR possesses wave properties in that it can be reflected, refracted and diffracted. Visible light is one small section of the electromagnetic spectrum.
RF workers are often exposed to high powered radio frequency EMR which comes from artificial sources such as:

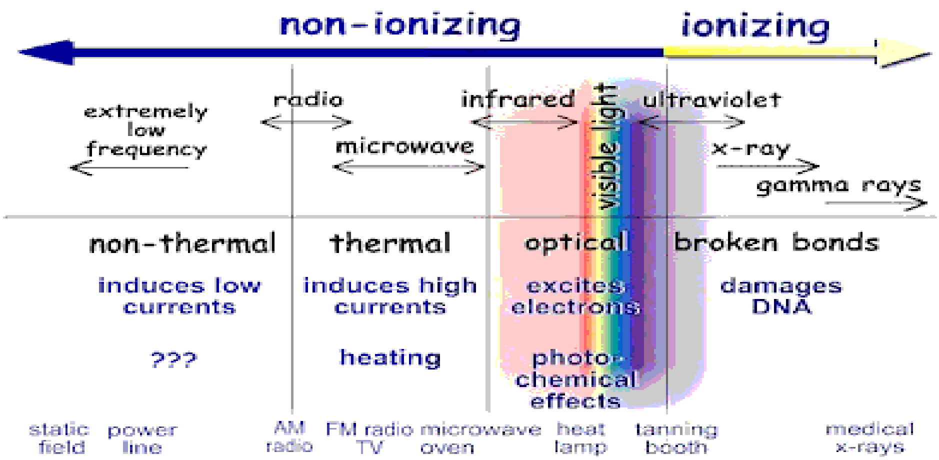
- mobile phone base stations
- broadcast towers

- radar facilities
- electrical and electronic equipment.



RF EMR is classified as non-ionizing radiation. This means that it is not able to directly impart enough energy to a molecule or atom to break chemical bonds or remove electrons. In contrast, ionizing radiation (such as X-rays) can strip electrons from atoms and molecules. This process produces molecular changes that can lead to damage in biological tissue.

It is important that the terms ionizing and non-ionizing not be confused when discussing biological effects of EMR. This is because each type of radiation interacts differently with the human body.



One of the important differences between ionizing and non-ionizing radiation is that **non-ionising radiation is non-cumulative.** This means that an exposure at one time will not effect the maximum permissible exposure at a later time.

Biological effects of exposure to EMR

A biological effect occurs when a change can be measured in a biological system after the introduction of some type of stimuli. However, a biological effect, in and of itself, does not necessarily suggest the existence of a biological hazard. A biological effect only becomes a biological hazard when it causes impairment to the health of the individual or his or her offspring.

It has been known for many years that exposure to sufficiently high levels of RF EMR can heat biological tissue and potentially cause tissue damage. This is because the human body is unable to cope with the excessive heat generated during exposure to very high RF levels. However, studies have shown that environmental levels of RF EMR routinely encountered by the public are far below the levels needed to produce significant heating and increased body temperature.

At relatively low level of exposure to RF EMR (that is, field intensities lower than those that would produce measurable heating), the evidence for production of harmful biological effects is ambiguous and unproven. Although there have been studies reporting a range of biological effects at low levels, there has been no determination that such effects might indicate a human health hazard, even with regard to long-term exposure.

In Australia ARPANSA (Australian Radiation Protection and Nuclear Safety Agency) is responsible for the publication of standards associated with exposure to RF EMR. Information on studies of exposure to radiofrequency fields and human health is available from Annex 4 and Annex 5 of the ARPANSA standard *Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz*.

ARPANSA Radiation Protection Series

The Radiation Protection Series is published by ARPANSA to promote practices which protect human health and the environment from the possible harmful effects of radiation. ARPANSA is assisted in this task by its Radiation Health and Safety Advisory Council, which reviews the publication program for the Series and endorses documents for publication, and by its Radiation Health Committee, which oversees the preparation of draft documents and recommends publication. There are four categories of publication in the Series.

Radiation protection standards set fundamental requirements for safety. They are prescriptive in style and may be referenced by regulatory instruments in State, Territory or Commonwealth jurisdictions. They may contain key procedural requirements regarded as essential for best international practice in radiation protection, and fundamental quantitative requirements, such as exposure limits.

Codes of practice are also prescriptive in style and may be referenced by regulations or conditions of license. They contain practice-specific requirements that must be satisfied to ensure an acceptable level of safety in dealings involving exposure to radiation. Requirements are expressed in 'must' statements.

Recommendations provide guidance on fundamental principles for radiation protection. They are written in an explanatory and non-regulatory style and describe the basic concepts and objectives of best international practice. Where there are related Radiation Protection Standards and Codes of Practice, they are based on the fundamental principles in the Recommendations.

Safety guides provide practice-specific guidance on achieving the requirements set out in Radiation Protection Standards and Codes of Practice. They are non-prescriptive in style, but may recommend good practices. Guidance is expressed in 'should' statements, indicating that the measures recommended, or equivalent alternatives, are normally necessary in order to comply with the requirements of the Radiation Protection Standards and Codes of Practice.
All publications in the Radiation Protection Series are informed by public comment during drafting, and Radiation Protection Standards and Codes of Practice, which may serve a regulatory function, are subject to a process of regulatory review.

Basic restrictions for exposure to RF EMR

Specific absorption rate (SAR)
This is related to the rise in temperature caused by the absorption of RF fields by the body. SAR is defined as the rate of absorption of Electromagnetic Energy per unit mass of biological tissue.

$$\mathrm{SAR} = \frac{\sigma \times E^2}{\rho}$$

Where σ is the sample conductivity, E is the RMS electric field and ρ is the sample density .

Spatial peak SAR is used to describe the highest level of absorption averaged over a small mass or area of the body.(eg the head)
WBA refers to 'Whole of body SAR'
Quantities such as SAR can only be measured in a laboratory environment.

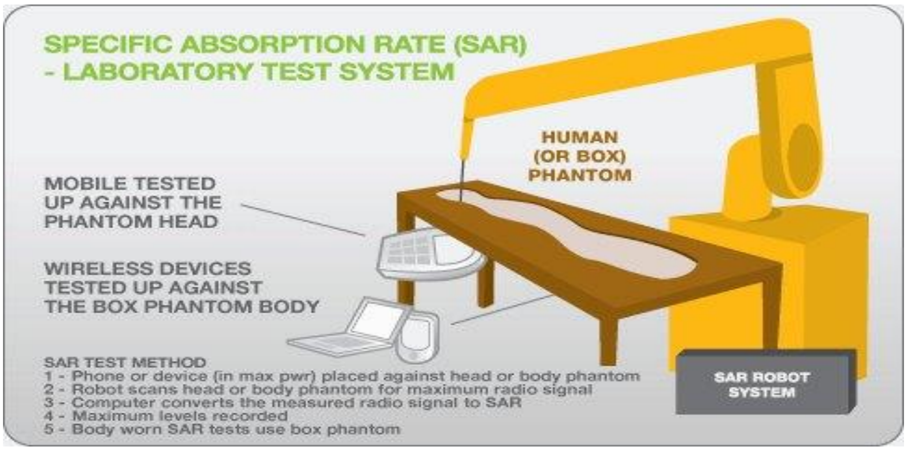


TABLE 2

**BASIC RESTRICTIONS FOR
WHOLE BODY AVERAGE SAR AND SPATIAL PEAK SAR**

Exposure category	Frequency range	Whole-body average SAR (W/kg)	Spatial peak SAR in the head & torso (W/kg)	Spatial peak SAR in limbs (W/kg)
Occupational	100 kHz–6 GHz	0.4	10	20
General public	100 kHz–6 GHz	0.08	2	4

Note that there are different standards for Occupational Workers and the General Public.
It is assumed that Occupational Workers are trained in RF Safety and are aware of the dangers in a high powered RF environment.

'Reference Levels' are also published which specify maximum permissible levels of electric and magnetic fields and power density. Instruments for these measurements are readily available.

TABLE 1

RELATIONSHIP BETWEEN BASIC RESTRICTIONS AND REFERENCE LEVELS

Basic restriction	Corresponding reference levels
Instantaneous spatial peak rms current density (3 kHz-10 MHz)	Instantaneous rms E and/or H (3 kHz - 10 MHz) and instantaneous contact currents (3 kHz - 10 MHz)
Whole body average SAR (100 kHz - 6 GHz)	Time averaged rms E and/or H (100 kHz – 6 GHz)
Spatial peak SAR in limbs (100 kHz – 6 GHz)	Time averaged rms E and/or H (100 kHz– 6 GHz) and/or induced limb currents for the legs and arms (10 MHz-110 MHz) and contact point currents (100 kHz - 110 MHz)
Spatial peak SAR in head & torso (100 kHz - 6 GHz)	Time averaged rms E and/or H (100 kHz - 6 GHz)
Spatial peak SA in the head (300 MHz - 6 GHz)	Instantaneous rms E and/or H or equivalent power flux density (300 MHz - 6 GHz)
Instantaneous spatial peak SAR in head & torso (10 MHz - 6 GHz)	Instantaneous rms E and/or H or equivalent power flux density (10 MHz - 6 GHz)
Time averaged and instantaneous power flux density (6 GHz–300 GHz)	Time averaged and instantaneous rms E and/or H (6 GHz - 300 GHz)

NOTE: The 'and/or' implies that the either both quantities or individual quantities can be measured to show compliance with the basic restrictions, depending on the circumstances of exposure.

Reference Levels

E = Electric Field Intensity (Volts/Metre)

H = Magnetic Field Intensity (Amps/Metre)

S = Power Density = E × H (Watts/Metre^2)

All quantities are time averaged over a six minute period.

TABLE 7

REFERENCE LEVELS FOR TIME AVERAGED EXPOSURE TO RMS ELECTRIC AND MAGNETIC FIELDS (UNPERTURBED FIELDS)

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density S_{eq} (W/m²)
Occupational	100 kHz – 1 MHz	614	$1.63/f$	–
	1 MHz – 10 MHz	$614/f$	$1.63/f$	$1000/f^2$ (see note 5)
	10 MHz – 400 MHz	61.4	0.163	10 (see note 5)
	400 MHz – 2 GHz	$3.07 \times f^{0.5}$	$0.00814 \times f^{0.5}$	$f/40$
	2 GHz – 300 GHz	137	0.364	50
General public	100 kHz – 150 kHz	86.8	4.86	–
	150 kHz – 1 MHz	86.8	$0.729/f$	–
	1 MHz – 10 MHz	$86.8/f^{0.5}$	$0.729/f$	–
	10 MHz – 400 MHz	27.4	0.0729	2 (see note 6)
	400 MHz – 2 GHz	$1.37 \times f^{0.5}$	$0.00364 \times f^{0.5}$	$f/200$
	2 GHz – 300 GHz	61.4	0.163	10

TABLE 8

REFERENCE LEVELS FOR EXPOSURE TO INSTANTANEOUS RMS ELECTRIC AND MAGNETIC FIELDS (UNPERTURBED FIELDS)

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density S_{eq} (W/m²)
Occupational	3 Khz – 65 kHz	614	25.0	—
	65 kHz – 100 kHz	614	$1.63 / f$	—
	100 kHz – 1 MHz	$3452 \times f^{0.75}$	$9.16 / f^{0.25}$	—
	1MHz – 10 MHz	$3452 / f^{0.25}$	$9.16 / f^{0.25}$	$(10^9 / f)^{0.5}$ (see note 4)
	10 MHz – 400 MHz	1941	5.15	10 000 (see note 4)
	400 MHz – 2 GHz	$97 \times f^{0.5}$	$0.258 \times f^{0.5}$	$25 \times f$
	2 GHz – 300 GHz	4340	11.5	50 000
General public	3 kHz – 100 kHz	86.8	4.86	—
	100 kHz – 150 kHz	$488 \times f^{0.75}$	4.86	—
	150 kHz – 1 MHz	$488 \times f^{0.75}$	$3.47 / f^{0.178}$	—
	1 MHz – 10 MHz	$488 \times f^{0.25}$	$3.47 / f^{0.178}$	—
	10 MHz – 400 MHz	868	2.30	2 000 (see note 5)
	400 MHz – 2 GHz	$43.4 \times f^{0.5}$	$0.115 \times f^{0.5}$	$5 \times f$
	2 GHz – 300 GHz	1941	5.15	10 000

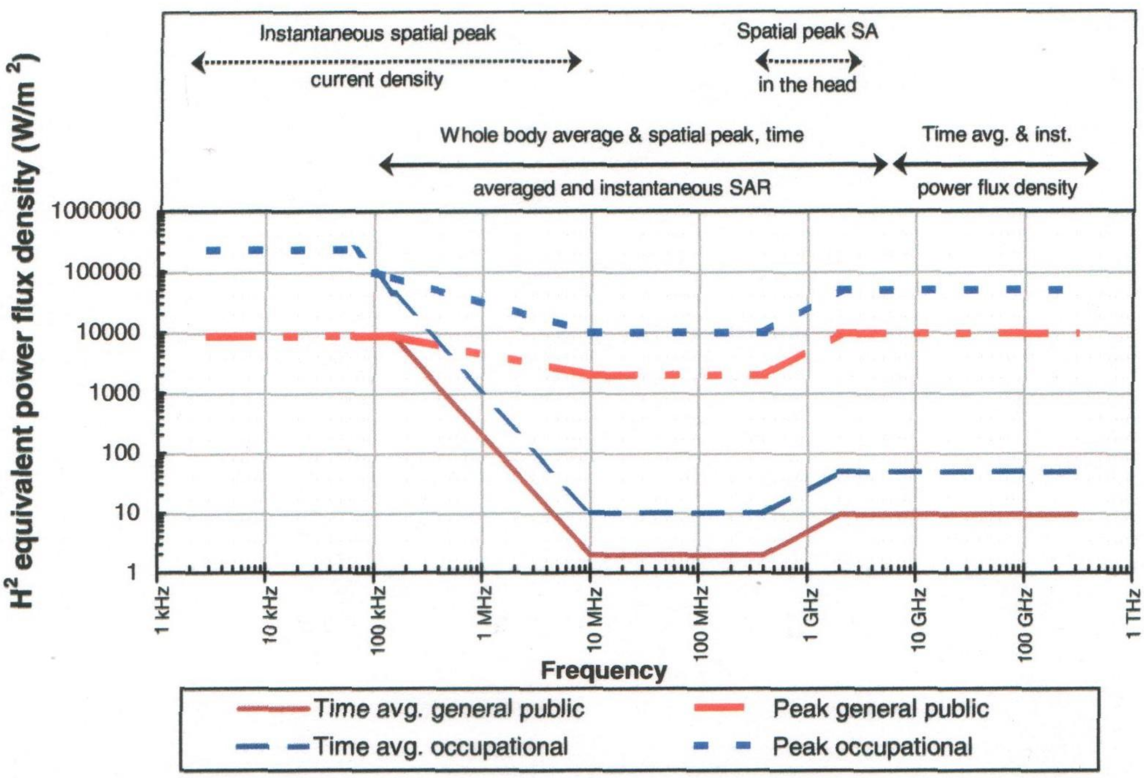
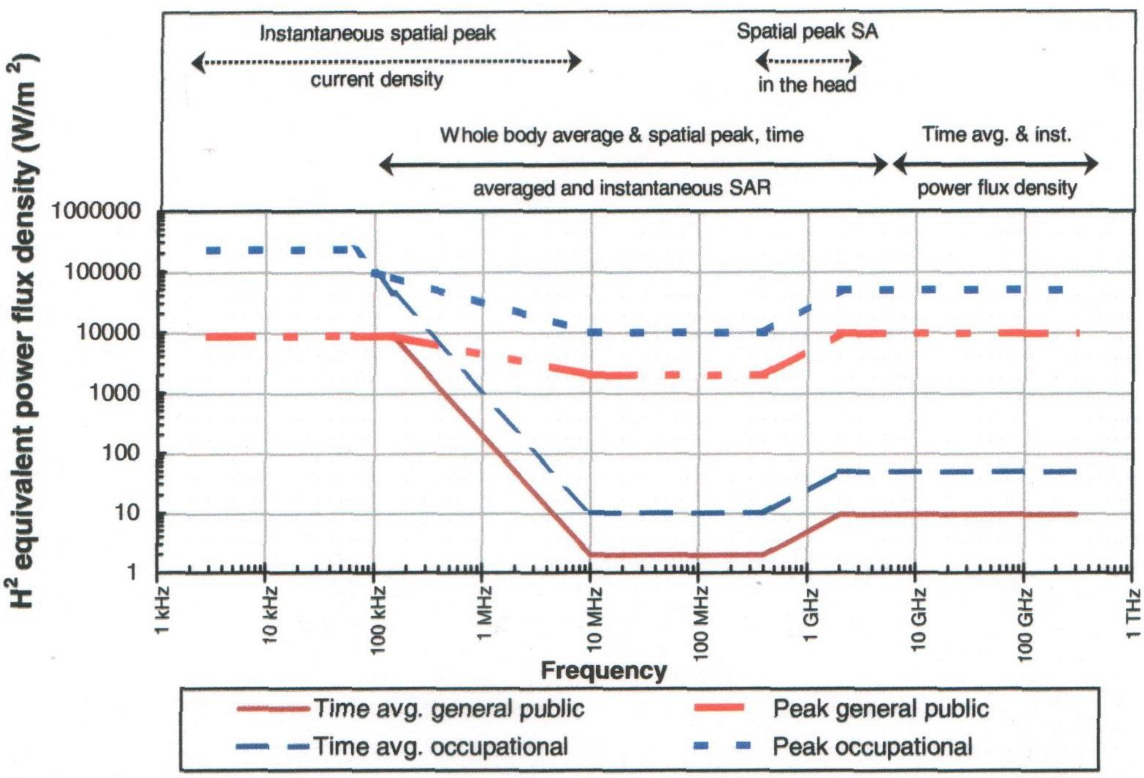


Figure 4 Equivalent power flux density for peak and time averaged exposure to magnetic fields (refer Tables 7 and 8 and look-up tables in Schedules 2 and 3).



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