G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

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Department of Electronics and Communication Engineering

Bridge Course
On
Satellite Communications

By

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Introduction

The term wireless communication was introduced in the 19th century and wireless communication technology has developed over the subsequent years. It is one of the most important mediums of transmission of information from one device to other devices. In this technology, the information can be transmitted through the air without requiring any cable or wires or other electronic conductors, by using electromagnetic waves like IR, RF, satellite, etc. In the present days, the wireless communication technology refers to a variety of wireless communication devices and technologies ranging from smart phones to computers, tabs, laptops, Bluetooth Technology, printers.

Communication Systems

The purpose of communication systems is to communicate information; the four most common sources of information are: speech (or sound), video and data. Regardless of the source, the information that is transmitted and received in a communication system consists of a signal, encoding the information in some appropriate fashion.

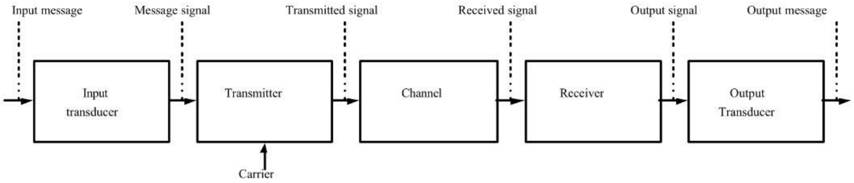


Figure 1: communication system

Figure 1 depicts the general layout of a communication system: an **input transducer** (e.g., a microphone) converts the **input message** into a **message signal** (e.g., a time varying voltage) that is transmitted over a **channel**, and converted by a **receiver** into an **output signal**.

An **output transducer** (e.g., a loudspeaker) converts the received signal into an **output message** (e.g.: sound). The transmitter performs a very important function on communication signals by encoding the signals in some fashion making use of a **carrier signal**.

The information is contained in a so-called **modulating signal** that modulates a carrier signal. Table summarized the **frequency band allocation** and typical applications in each frequency band.

There are two principal reasons for the use of a very broad spectrum of carrier frequencies. The first is that allowing for a broad spectrum permits many simultaneous users to broadcast information at different frequencies without interference among different transmissions; the second is that depending on the frequency of the carrier, the electromagnetic waves that are transmitted have different propagation characteristics. Thus, different carrier frequencies are better suited for propagating over long distances than others.

Frequency Band	Name	medium	Applications
3-30 kHz	Very Low Frequency	Wire pairs	Long-range navigation, sonar.
30-300 kHz	Low Frequency (LF)	Wire pairs	Navigational aids, radio beacons.
300-3000 kHz	Medium Frequency (MF)	Coaxial Cable	Maritime radio, direction finding, Coast Guard, commercial AM radio.
3-30 MHz	High Frequency (HF)	Coaxial Cable	Search and rescue, aircraft Communications with ships, telegraph, telephone and facsimile.
30-300 MHz	Very High Frequency (VHF)	Coaxial Cable	VHF television channels, FM radio, private aircraft, air traffic control, taxi
0.3-3 GHz	Ultra High Frequency (UHF)	Coaxial Cable	UHF television channels, Surveillance radar, satellite communications.
3-30 GHz	Super High Frequency (SHF)	Waveguide	Satellite communications, airborne radar, approach radar, weather
30-300 GHz	Extremely High Frequency (EHF)	Waveguide	Railroad service, radar landing systems, experimental.
> 300 GHz	Optical frequencies	Optical fiber	Wideband data, experimental.

Table 1 Frequency bands

Table 1 summarizes the frequency spectrum allocations used today

Classification of communication system

Communication systems can be classified into two basic families, based on the nature of the message signal: analog communication systems and digital communication systems. Another classification is based on the type of transmission: light wave vs. radio frequency, or RF transmission. A third classification is that of carrier vs. direct baseband transmission system. This latter classification is based on whether the signal of interest is directly transmitted (e.g., as in the case of the telegraph), or whether the signal modulates a carrier wave, as in the case of AM and FM radio transmission.

Communication channels

The modulated transmitted signal can reach the receiver in a number of ways. In some cases, communication systems are hard wired. Examples of this configuration are local area computer networks, local telephone systems and local cable TV networks. Depending on the frequency range, the transmitted signal can be carried by twisted wire pair, coaxial cable, waveguides, or optical fiber. However, in most communications systems, after the signal had been carried over a wire or cable, it is eventually broadcast over air by an antenna, to be received by a similar antenna elsewhere

The range of transmission can be significant – consider that signals can be received from the far reaches of the solar system via radio astronomy. The most common means of transmission of communication signals is via the broadcast of radio frequency waves over the air. To understand the different types of wave propagation, we need to briefly explain the geometry of the earth's atmosphere. With reference to Figure 2, the atmosphere is composed of layers, of which the troposphere and the ionosphere are the most important for radio wave transmission.

The troposphere (up to about 20 km above sea level) is where the earth's air is contained; air density, temperature and humidity decrease with increasing altitude. The propagation of radio waves in air depends on various properties of the medium. The speed of propagation of electromagnetic waves and the refractive index of the medium (causing the deflection of the wave) increase with altitude; as a consequence, radio waves tend to bend back towards the earth as they propagate through the troposphere.

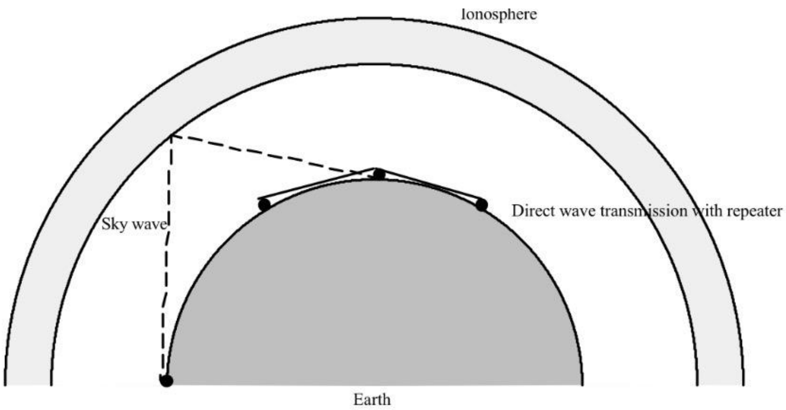


Figure 2 Propagation of radio frequency waves

The ionosphere is so called because of the ionization of the small amounts of air present at these altitudes (50 to 600 km); electromagnetic waves reaching the ionosphere may propagate through it with some losses (attenuation), or may be reflected down to earth, depending on the frequency of the transmissions. In general, frequencies above 30 MHz will propagate through the ionosphere, and are therefore suitable for space communications (see Web reference to radio astronomy above).

To achieve long range communications over the earth, use is made of so-called sky waves. These are waves that are reflected by the ionosphere, and permit reaching points beyond the horizon. The frequencies used for these waves are below 30 MHz to permit reflection from the ionosphere. Short-wave radio makes use of the sky wave. In Troposphere, the waves can also propagate beyond the horizon, but instead of being reflected, as in the case of sky waves, they bend around the earth because of diffusion (scattering).

Direct waves are used in line-of-sight transmission, where the transmitter and receiver are in the line of "sight" of one another. The earth's curvature is the primary limitation to the distance of such transmissions; however, due to reflections from the ground, and to ground and surface waves, this transmission can achieve greater distances than one would calculate simply based on the earth's curvature and the height of the antennas.

Coaxial cables are very commonly used for the transmission of radio-frequency waves over short to medium distances, typically in the frequency range between a fraction of a MHz to hundreds of MHz Coaxial cable consists of a copper core, surrounded by an insulating layer, in turn surrounded by a conductive (ground) layer and by an external protective sheath.

Today the most common example of the use of coaxial cables is the distribution of cable television signals from the receiving station to individual homes. An increasingly common type of communication systems is based on light wave transmission.

Light is also electromagnetic radiation, but at much higher frequencies than radio waves. The main drawback in the use of light as a carrier is that it needs to be enclosed in a guide to travel over significant distances; optical fibers are used to achieve such transmission. An optical fiber consists of a hair-thin strand of glass, the core, surrounded by a protective layer, the cladding. Snell's law of optics ensures that, if light enters the fiber at a sufficiently low angle of incidence, the transmission benefits from total internal reflection, confining the light signal to the core with minimal losses. High- speed computer communications networks are increasingly making use of optical fibers.

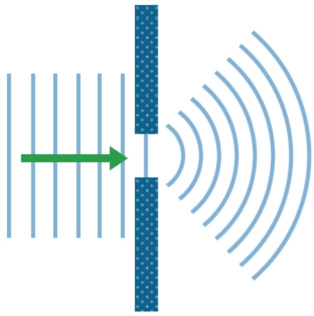
Radio waves and microwaves

Microwaves and radio waves are used to communicate with satellites. Microwaves pass straight through the atmosphere and are suitable for communicating with distant geostationary satellites, while radio waves are suitable for communicating with satellites in low orbit.

Radio waves and microwaves are types of electromagnetic radiation. Both have communication uses. Radio waves are used to transmit television and radio programmes, while microwaves are used for mobile phones and Wi-Fi. However, they have different properties:

Radio waves have longer wavelengths and are reflected by the ionosphere part of the Earth's atmosphere).

Microwaves have shorter wavelengths and pass through the Earth's atmosphere.



Radio waves are reflected by the ionosphere, but microwaves pass straight through it

Effects of frequency

The way that electromagnetic waves behave in the atmosphere depends on their frequency. The table below summarizes this.

Increasing frequency →			
Frequency	Less than 30 MHz	30 MHz – 30 GHz	More than 30 GHz
Behavior	Reflected by the ionosphere	Waves pass straight through the atmosphere	Rain, dust and other atmospheric effects reduce the strength of the signal due to absorption and scattering
Low amounts of energy needed	Carbon dioxide is produced as a by-product	Less land needed	Higher amounts of energy needed
Wavelength	More than 10 m	10 m – 10 cm	Less than 10 cm

Geostationary and low orbit satellites

Geostationary satellites orbit the Earth above the equator once every 24 hours, while low polar orbit satellites pass over the poles and have much shorter orbit times.

Different frequencies are used to communicate with these satellites:

relatively high frequencies are used to communicate with geostationary satellites

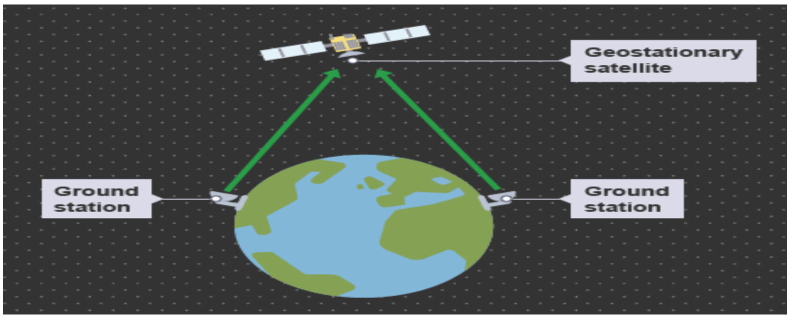
relatively low frequencies are used to communicate with low orbit satellites

Microwaves have a high enough frequency to pass through the Earth's atmosphere to reach geostationary satellites - which orbit high above the equator at a height of 36,000 km. However, **radio waves** with a lower frequency are able to reach the low orbit satellites.

Digital signals

Digital signals are used to communicate with satellites. Digital signals are affected by noise less than analogue signals, and they do not attenuate (lose energy) as quickly.

Information from Earth is transmitted to geostationary satellites using microwaves carrying digital signals. These signals are then retransmitted as microwaves. This may be to another satellite or back down to Earth. Satellite television dishes are examples of the sort of parabolic receivers needed.



Microwaves are used to communicate with geostationary satellites

The wavelength of the microwaves emitted by satellites is usually between 1 and 10 cm. The dishes that emit them from satellites usually have a diameter much larger than this. This produces very little diffraction, giving a narrow beam that does not spread out.

As a result, the transmitting and receiving dishes must be aligned exactly. You can see this by looking at a row of houses which have been fitted with satellite television dishes - all the dishes point in the same direction.

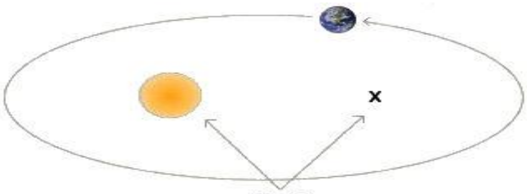
Kepler's Three Laws

In the early 1600s, Johannes Kepler proposed three laws of planetary motion. Kepler was able to summarize the carefully collected data of his mentor - Tycho Brahe - with three statements that described the motion of planets in a sun-centered solar system. Kepler's three laws of planetary motion can be described as follows:

The path of the planets about the sun is elliptical in shape, with the center of the sun being located at one focus. (The Law of Ellipses)

An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time. (The Law of Equal Areas)

The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)

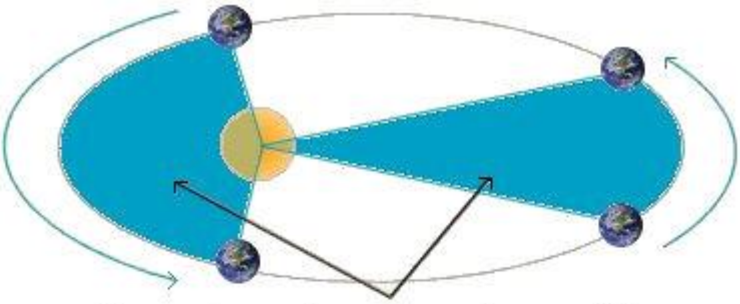


Foci

Law 1. The orbits of the planets are ellipses, with the Sun at one focus.

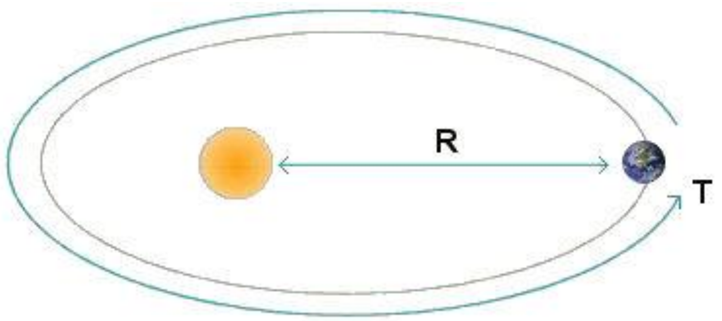
Any ellipse has two geometrical points called the foci (focus for singular). There is no physical significance of the focus without the Sun but it does have mathematical significance. The total distance from a planet to each of the foci added together is always the same regardless of where the planet is in its orbit.

The importance of this is that by not assuming the orbits are perfect circles, the accuracy of predictions in the Sun-centered theory was (for the first time) greater than those of the Earth-centered theory.



Sweeping out equal area in equal time

Law 2. The line joining a planet to the Sun sweeps out equal areas in equal times as the planet travels around the ellipse.



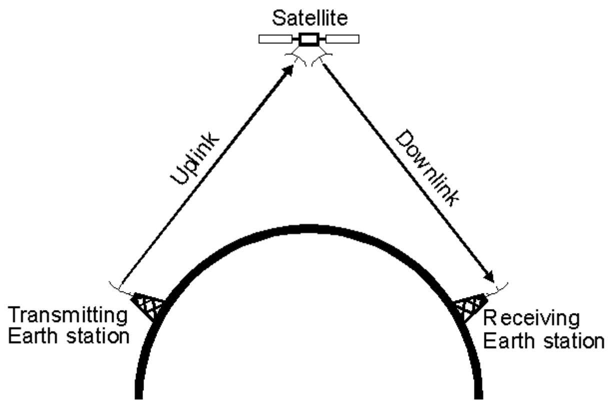
Law 3. The square of the total time period (T) of the orbit is proportional to the cube of the average distance of the planet to the Sun (R).

In any given amount of time, 30 days for instance, the planet sweeps out the same amount of area regardless of which 30 day period you choose. Therefore the planet moves faster when it is nearer the Sun and slower when it is farther from the Sun. A planet moves with constantly changing speed as it moves about its orbit. The fastest a planet moves is at perihelion (closest) and the slowest is at aphelion (farthest).

This law is sometimes referred to as the law of harmonies. It compares the orbital time period and radius of an orbit of any planet, to those of the other planets. The discovery Kepler made is that the *ratio* of the squares of the revolutionary time periods to the cubes of the average distances from the Sun, is the same for every planet.

Satellite communications

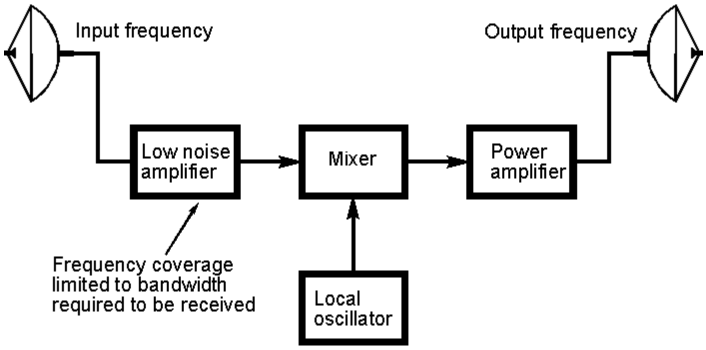
When used for communications, a satellite acts as a repeater. Its height above the Earth means that signals can be transmitted over distances that are very much greater than the line of sight. An earth station transmits the signal up to the satellite. This is called the up-link and is transmitted on one frequency. The satellite receives the signal and retransmits it on what is termed the down link which is on another frequency.



Using a satellite for long distance communications

The circuitry in the satellite that acts as the receiver, frequency changer, and transmitter is called a transponder. This basically consists of a low noise amplifier, a frequency changer consisting a mixer and local oscillator, and then a high power amplifier. The filter on the input is used to make sure that any out of band signals such as the transponder output are reduced to acceptable levels so that the amplifier is not overloaded. Similarly the output from the amplifiers is filtered to make sure that spurious signals are reduced to acceptable levels. Figures used in here are the same as those mentioned earlier, and are only given as an example. The signal is received and amplified to a suitable level. It is then applied to the mixer to change the frequency in the same way that occurs in a super heterodyne radio receiver. As a result the communications satellite receives in one band of frequencies and transmits in another.

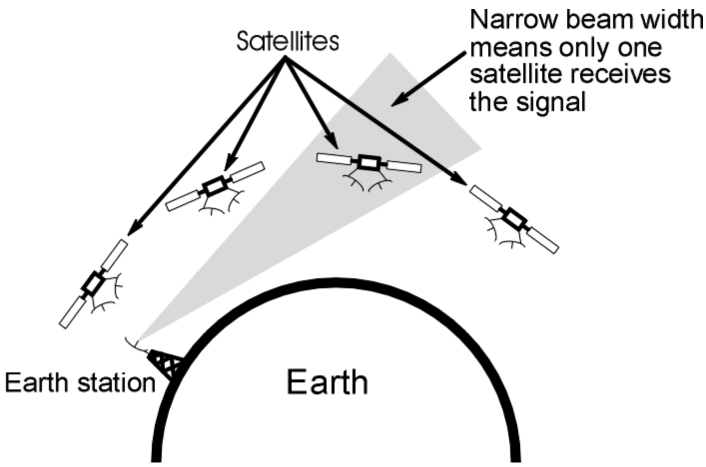
In view of the fact that the receiver and transmitter are operating at the same time and in close proximity, care has to be taken in the design of the satellite that the transmitter does not interfere with the receiver. This might result from spurious signals arising from the transmitter, or the receiver may become de-sensitised by the strong signal being received from the transmitter. The filters already mentioned are used to reduce these effects.



Block diagram of a basic satellite transponder

Signals transmitted to satellites usually consist of a large number of signals multiplexed onto a main transmission. In this way one transmission from the ground can carry a large number of telephone circuits or even a number of television signals. This approach is operationally far more effective than having a large number of individual transmitters.

Obviously one satellite will be unable to carry all the traffic across the Atlantic. Further capacity can be achieved using several satellites on different bands, or by physically separating them apart from one another. In this way the beamwidth of the antenna can be used to distinguish between different satellites. Normally antennas with very high gains are used, and these have very narrow beamwidths, allowing satellites to be separated by just a few degrees.



Separating satellites by position

Circular satellite orbit definitions

Circular orbits are classified in a number of ways. Terms such as Low Earth orbit, Geostationary orbit and the like detail distinctive elements of the orbit. A summary of circular orbit definitions is given in the table below:

Orbit Name	**Orbit Initials**	**Orbit Altitude(Km Above Earth's Surface)**	**Details**
Low Earth Orbit	LEO	200 - 1200	
Medium Earth Orbit	MEO	1200 - 35790	
Geosynchronous Orbit	GSO	35790	Orbits once a day, but not necessarily in the same direction as the rotation of the Earth - not necessarily stationary
Geostationary Orbit	GEO	35790	Orbits once a day and moves in the same direction as the Earth and therefore appears stationary above the same point on the Earth's surface. Can only be above the Equator.
High Earth Orbit	HEO	Above 35790	

In some applications high Earth orbits may be required. For these applications the satellite will take longer than 24 hours to orbit the Earth, and path lengths may become very long resulting in additional delays for the round trip from the Earth to the satellite and back as well as increasing the levels of path loss.

The choice of the satellite orbit will depend on its applications. While geostationary orbits are popular for applications such as direct broadcasting and for communications satellites, others such as GPS and even those satellites used for mobile phones are much lower.

How does Satellite communication work?

It works on two main components:

- Ground base or the Earth
- Space component

In this mode of communication, the satellite stationed at the space receives signals from the earth with the aid of an antenna. The signals are amplified to an optimum level and then with the help of transponders they are retransmitted back to the earth. The earth station then receives the signal from the satellite, and preamplifiers it and helps in the communication. Hence in this mode of communication, it was the satellite which helped in the transmission of signals from the earth and then back to the earth, thus justifying the name.

Where is it used?

In ships, where generally mobile phones fail to operate, satellite phones are helpful in communication. Satellite phones work on the above principle. Satellite radio, satellite television as well as Satellite internet also operate on the principle of satellite communication. Satellite mode of communication is primarily helpful in remote areas where broadband facilities fail to operate.