Amateur Wireless Station Operators License Exam

Study material 2017

CHAPTER 6

Chapter 6 : Radio Wave propagation

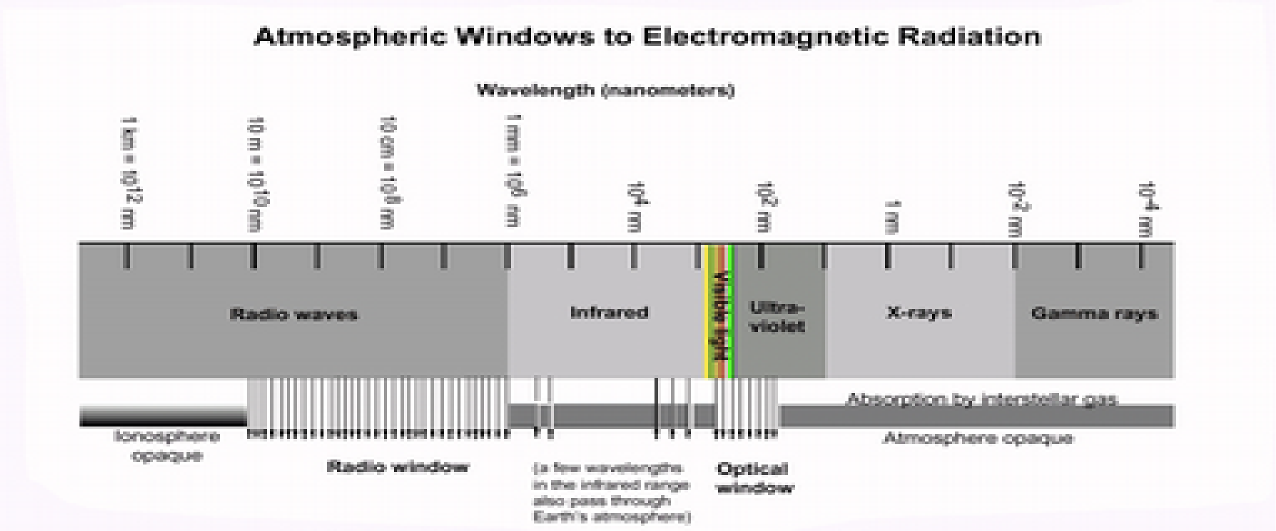
The electromagnetic Spectrum

The electromagnetic spectrum consists of waves of many wavelengths ranging from very long wavelength radio waves to very short wavelength gamma rays. Visible light, consisting of short wavelength waves, is placed near the middle of this spectrum.

Visible light can pass through window glass, but a solid wall will absorb a portion of the light and reflect the remaining portions. Like that glass is transparent to visible light, but a wall is opaque.

Since the atmosphere is transparent to visible light (while absorbing some of the light), astronomers who use telescopes can see things from far away using visible light to form images.

Earth's atmosphere, however, acts an opaque barrier to much of the electromagnetic spectrum. The atmosphere absorbs most of the wavelengths shorter than ultraviolet, most of the wavelengths between infrared and microwaves, and most of the longest radio waves. For radio astronomers this leaves only short wave radio to penetrate the atmosphere and bring information about the universe to our Earth-bound instruments. The main frequency ranges allowed to pass through the atmosphere are referred to as the radio window. The radio window consists of frequencies which range from about 5 MHz (5 million hertz) to 30 GHz (30 billion hertz). The low-frequency end of the window is limited by signals being reflected by the ionosphere back into space, while the upper limit is caused by absorption of the radio waves by water vapor and carbon dioxide in the atmosphere. As atmospheric conditions change the radio window can expand or shrink. On clear days with perfect conditions signals as high as 300GHz have been detected.



Wavebands

While considering problems related to the realization of the long - distance radio links, significant differences between the electromagnetic waves of various frequencies must be kept in mind. For example, low frequency waves (below 500 kHz) can bend themselves following Earth's curvature, while the HF waves are moving in streamlines, just as light. Some waves can be reverberated from the ionosphere, others are passing through it etc. According to characteristics of their outspread, radio waves can be classified into several groups or ranges: long, mid, short and ultra-short. Limits between the wavebands are not precise, with the raise of their frequency the waves are gradually losing some features while gaining some others. This division is shown in Table 1.

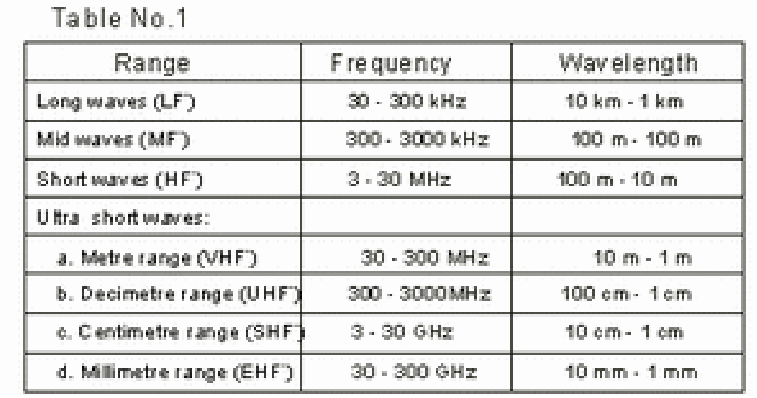


Table No.1

Range	Frequency	Wavelength
Long waves (LF)	30 - 300 kHz	10 km - 1 km
Mid waves (MF)	300 - 3000 kHz	100 m - 100 m
Short waves (HF)	3 - 30 MHz	100 m - 10 m
Ultra short waves:		
a. Metre range (VHF)	30 - 300 MHz	10 m - 1 m
b. Decimetre range (UHF)	300 - 3000MHz	100 cm - 1 cm
c. Centimetre range (SHF)	3 - 30 GHz	10 cm - 1 cm
d. Millimetre range (EHF)	30 - 300 GHz	10 mm - 1 mm

* LF low frequencies, MF mid frequencies, HF high frequencies, VHF very high frequencies, UHF ultra high frequencies, SHF super high frequencies, EHF extra high frequencies. Waves with wavelength smaller than 30 cm are also called the microwaves.

Radio Frequencies

Astronomical radio sources emit over a wide range of frequencies. Their emission can be measured ranging from low frequencies to high frequencies. Jupiter for example emits radio waves from about 10 kHz up to about 300 GHz. This emission is broken into several groupings. The lowest being the kilo-metric emission which ranges from 10kHz up to 1000kHz. Other frequency groups include hecto-metric (1000KHz to 3MHz), decametric (3MHz to 40MHz), and decimetric (100MHz to 300GHz).

Radio waves produced on Earth are mostly man-made and are often at one specific frequency. In fact, this is one way astronomers can tell a signal created on Earth apart from an astronomical signal. If they are able to tune their receivers to a slightly higher or lower frequency and the signal disappears it is most likely an Earth based signal. Radio waves fall into three main categories with a variety of uses:

H.F. (High Frequency 3 to 30MHz)

Long Range communications. Shipping, Aircraft, World Broadcast Communications, Radio Amateurs. Use involves reflecting the signal off the ionosphere back down to waiting receiving stations. Prone to atmospheric changes causing fading and noise.Range from 500 to thousands of Kilometers.

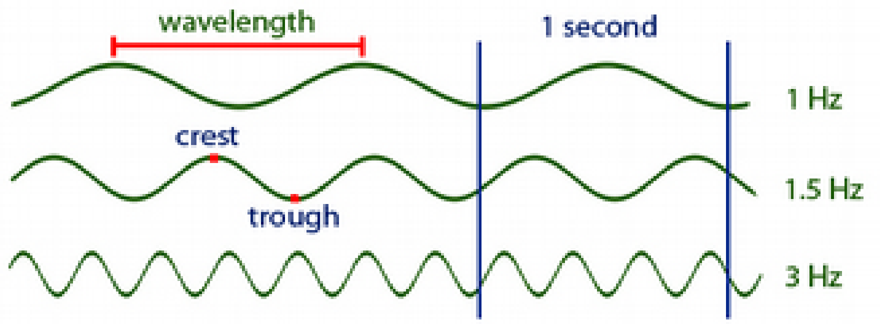
V.H.F. (Very High Frequency 30 - 300 MHz)

Medium range communications. Fleet vehicles, mobile, coastal shipping and air to tower communications. Range 70-100km (several hundred km in case of aircraft communications).

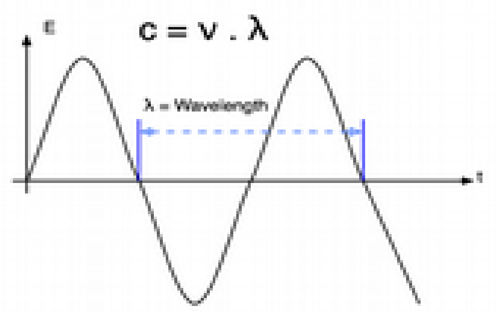
U.H.F (Ultra High Frequency 300-3000 MHz)

Police hand-held radios, cell-phones, T.V., and spacecraft to ground communications. In the high U.H.F. range the signal can "bounce" off buildings and reflect until it is detected by a receiver.

Frequency and wavelength



In the third column of the above table, wavelengths are given. Wavelength (λ) is distance that the wave passes moving at the speed of light (c=3x103 m/s), during the period that is equal to its oscillating period (T).



$$\lambda = c \times T.$$

Having in mind that the wave frequency is f=1/T, one can easily get to the well known expression that gives the relation between the wavelength and the frequency:

$$\lambda = \frac{c}{f}$$

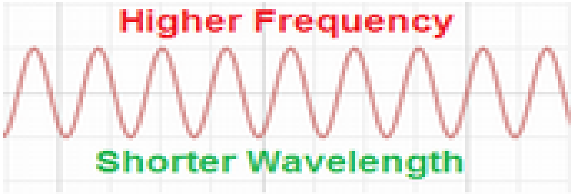
Using this formula one can calculate the wavelength knowing the frequency and vice versa.

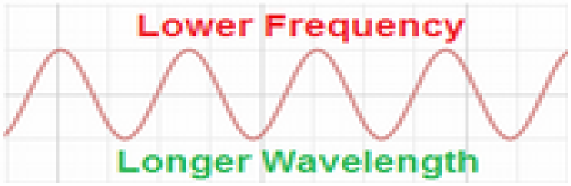
For example, wavelength of an FM transmitter emitting at f=100 MHz frequency is $L=3*10^8/100*10^6=3$ m.

Similar to that, wavelength of AIR Delhi is L=439 m, which makes its frequency equal to $f=3*10^8/439=684$ kHz.

Wavelength = 300 / frequency in MHz
145Mhz =300/145 = 2.069m

Simply:

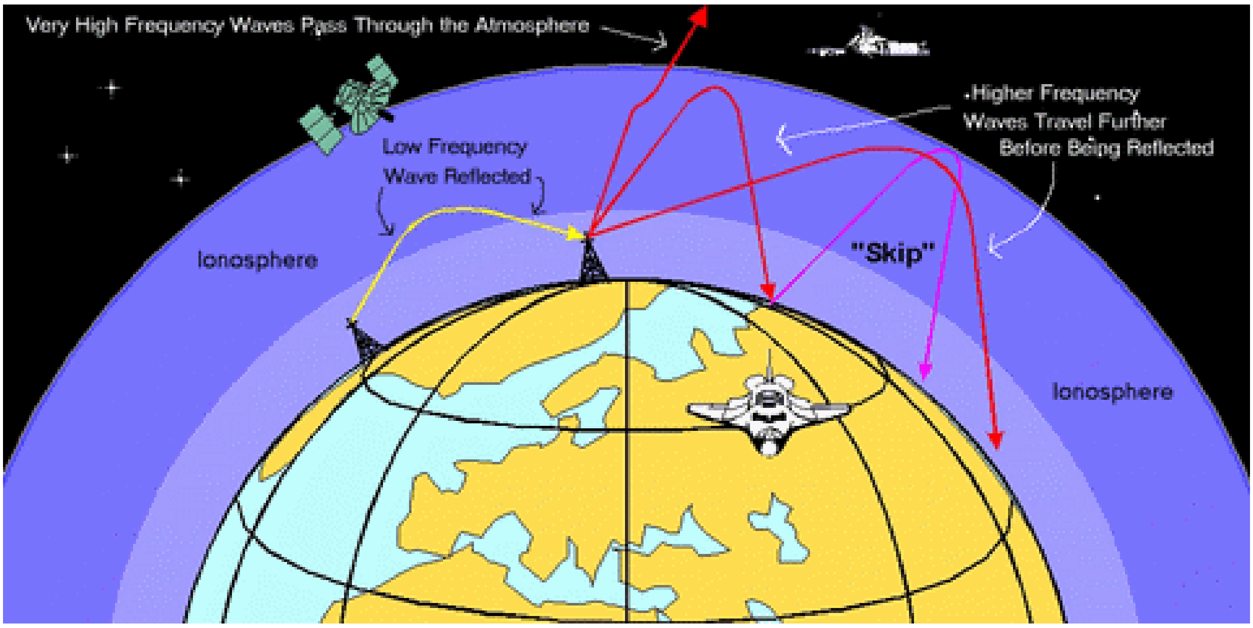




The ionosphere

The ionized part of the Earth's atmosphere is known as the ionosphere. Ultraviolet light from the sun collides with atoms in this region knocking electrons loose. This creates ions, or atoms with missing electrons. This is what gives the Ionosphere its name and it is the free electrons that cause the reflection and absorption of radio waves. When the sun is overhead during the day, most of the ionosphere is ionized due to the large amount of ultraviolet light coming from the sun. As radio waves enter Earth's atmosphere from space some of the waves are absorbed by the electrons in the ionosphere while others pass through and are detectable to ground based observers. The frequency of each of these waves is what determines whether or not it is absorbed or able to pass through the atmosphere. Low frequency radio waves do not travel very far through the atmosphere and are absorbed rather quickly. Higher frequency waves are able to pass through the atmosphere entirely and reach the ground.

This process also works in reverse for radio waves produced on the earth. The high frequency waves pass through the ionosphere and escape into space while the low frequency waves reflect off the ionosphere and essentially “skip” around the earth.



The Ionosphere and Radio wave Propagation

As electromagnetic waves, and in this case, radio signals travel, they interact with objects and the media in which they travel. As they do this the radio signals can be reflected, refracted or diffracted. These interactions cause the radio signals to change direction, and to reach areas which would not be possible if the radio signals traveled in a direct line.

The ionosphere is a particularly important region with regards to radio signal propagation and radio communications in general. Its properties govern the ways in which radio communications, particularly in the HF radio communications bands take place.

The ionosphere extends over more than one of the meteorological areas, encompassing the mesosphere and the thermosphere, it is an area that is characterized by the existence of positive ions (and more importantly for radio signals free electrons) and it is from the existence of the ions that it gains its name.

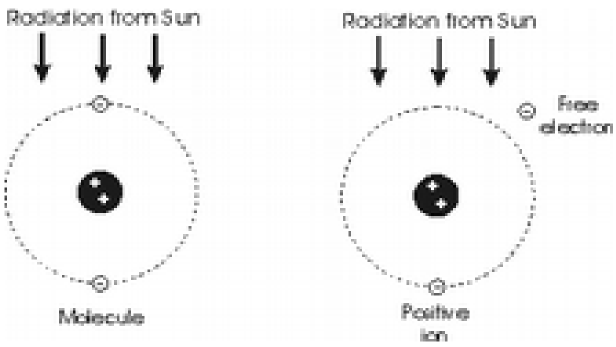
Basics:

The free electrons do not appear over the whole of the atmosphere. Instead it is found that the number of free electrons starts to rise at altitudes of approximately 30 kilometers. However it is not until altitudes of around 60 to 90 kilometers are reached that the concentration is sufficiently high to start to have a noticeable effect on radio signals and hence on radio communications systems. It is at this level that the ionosphere can be said to start.

The ionization in the ionosphere is caused mainly by radiation from the Sun. In addition to this, the very high temperatures and the low pressure result in the gases in the upper reaches of the atmosphere existing mainly in a mono-atomic form rather than existing as molecules. At lower altitudes, the gases are in the normal molecular form, but as the altitude increases the mono-atomic forms are more in abundance, and at altitudes of around 150 kilometers, most of the gases are in a mono-atomic form. This is very important because it is found that the mono-atomic forms of the gases are very much easier to ionize than the molecular forms.

Ionization:

The Sun emits vast quantities of radiation of all wavelengths and this travels towards the Earth, first reaching the outer areas of the atmosphere. In creating the ionization it is found that when radiation of sufficient intensity strikes an atom or a molecule, energy may be removed from the radiation and an electron removed, producing a free electron and a positive ion. In the example given below, the simple example of a helium atom is give, although other gases including oxygen and nitrogen are far more common.



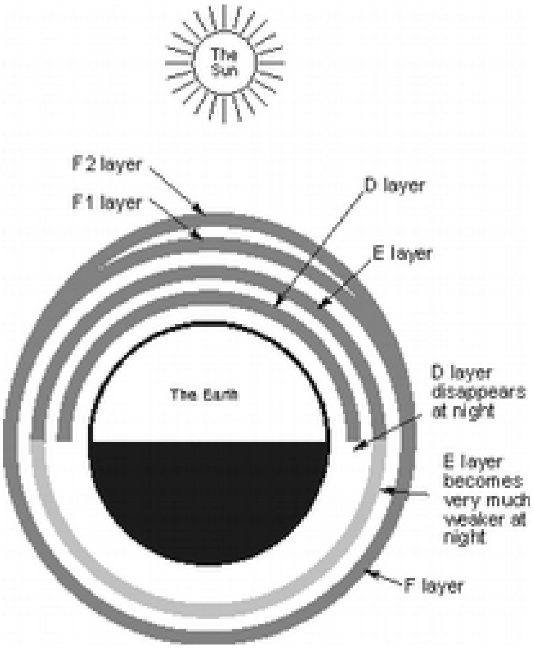
Ionization of molecules by solar radiation

The radiation from the Sun covers a vast spectrum of wavelengths. However in terms of the effect it has on the atoms of molecules it can be considered as photons. When a photon strikes the atom, or molecule, the photon transfers its energy to the electron as excess kinetic energy. Under some circumstances this excess energy may exceed the binding energy in the atom or molecule and the electron escapes the influence of the positive charge of the nucleus. This leaves a positively charged nucleus or ions and a negatively charged electron, although as there will be the same number of positive ions and negative electrons the whole gas still remains with an overall neutral charge.

Most of the ionization in the ionosphere results from ultraviolet light, although this does not mean that other wavelengths do not have some effect. Additionally, each time an atom or molecule is ionized a small amount of energy is used. This means that as the radiation passes further into the atmosphere, its intensity reduces. It is for this reason that the ultraviolet radiation causes most of the ionization in the upper reaches of the ionosphere, but at lower altitudes the radiation that is able to penetrate further cause more of the ionization. Accordingly, extreme ultra-violet and X-Rays give rise to most of the ionization at lower altitudes. This reduction in these forms of radiation protects us on the surface of the Earth from the harmful effects of these rays.

The level of ionization varies over the extent of the ionosphere, being far from constant. One reason is that the level of radiation reduces with decreasing altitude. Also the density of the gases varies. In addition to this there is a variation in the proportions of mono-atomic and molecular forms of the gases, the mono-atomic forms of gases being far greater at higher altitudes. These and a variety of other phenomena mean that there are variations in the level of ionization with altitude.

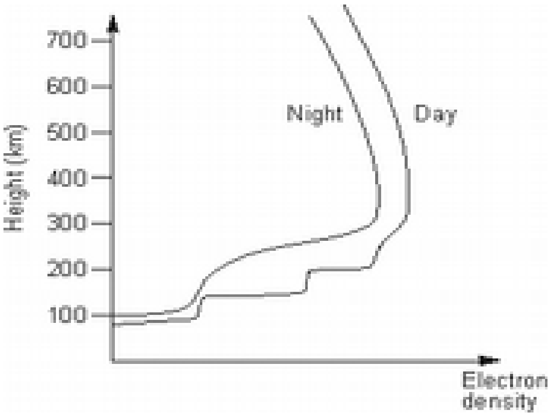
The level of ionization in the ionosphere also changes with time. It varies with the time of day, time of year, and according to many other external influences. One of the main reasons why the electron density varies is that the Sun, which gives rise to the ionization is only visible during the day. While the radiation from the Sun causes the atoms and molecules to split into free electrons and positive ions. The reverse effect also occurs. When a negative electron meets a positive ion, the fact that dissimilar charges attract means that they will be pulled towards one another and they may combine. This means that two opposite effects of splitting and recombination are taking place. This is known as a state of dynamic equilibrium. Accordingly the level of ionization is dependent upon the rate of ionization and recombination. This has a significant effect on radio communications.



A simplified view of the layers in the ionosphere over the period of a day

Other effects like the season and the state of the Sun also have a major effect. Sunspots and solar disturbances have a major impact on the level of radiation received. The season also has an effect. However very briefly, the radiation received from the Sun varies in the same way that heat from the Sun varies according to the season.

Ionospheric layers:
The traditional view of the ionosphere indicates a number of distinct layers, each affecting radio communications in slightly different ways. Indeed, the early discoveries of the ionosphere indicated that a number of layers were present. While this is a convenient way of picturing the structure of the ionosphere it is not exactly correct. Ionization exists over the whole of the ionosphere, its level varying with altitude. The peaks in level may be considered as the different layers or possibly more correctly, regions. These regions are given letter designations: D, E, and F regions. There is also a C region below the others, but the level of ionization is so low that it does not have any effect radio signals and radio communications, and it is rarely mentioned.



The typical electron distribution in the ionosphere

The different layers or regions in the ionosphere have different characteristics and affect radio communications in different ways. There are also differences in the exact way they are created and sustained. In view of this it is worth taking a closer look at each one in detail and the way they vary over the complete day during light and darkness.

D Region:
The D region is the lowest of the regions within the ionosphere that affects radio

communications signals to any degree. It is present at altitudes between about 60 and 90 kilometers and the radiation within it is only present during the day to an extent that affects radio waves noticeably. It is sustained by the radiation from the Sun and levels of ionization fall rapidly at dusk when the source of radiation is removed. It mainly has the affect of absorbing or attenuating radio communications signals particularly in the LF and MF portions of the radio spectrum, its affect reducing with frequency. At night it has little effect on most radio communications signals although there is still a sufficient level of ionization for it to refract VLF signals.

The layer is chiefly generated by the action of a form of radiation known as Lyman radiation which has a wavelength of 1215 Angstroms and ionizes nitric oxide gas present in the atmosphere. Hard X-Rays also contribute to the ionization, especially towards the peak of the solar cycle.

E Region:

The region above the D region is the E region. It exists at altitudes between about 100 and 125 kilometers. Instead of attenuating radio communications signals this layer chiefly refracts them, often to a degree where they are returned to earth. As such they appear to have been reflected by this layer. However this layer still acts as an attenuator to a certain degree.

Like the D region, the level of ionization falls relatively quickly after dark as the electrons and ions re-combine and it virtually disappears at night. However the residual night time ionization in the lower part of the E region causes some attenuation of signals in the lower portions of the HF part of the radio communication spectrum.

The ionization in this region results from a number of types of radiation. Soft X-Rays produce much of the ionization, although extreme ultra-violet (EUV) rays (very short wavelength ultra-violet light) also contribute. Broadly the radiation that produces ionization in this region has wavelengths between about 10 and 100 Angstroms. The degree to which all the constituents contribute depends upon the state of the Sun and the latitude at which the observations are made.

F Region:

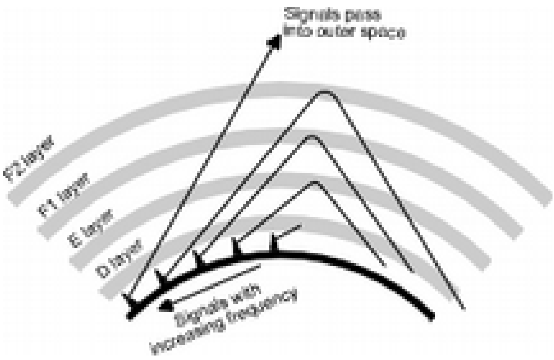
The most important region in the ionosphere for long distance HF radio communications is the F region. During the daytime when radiation is being received from the Sun, it often splits into two, the lower one being the F1 region and the higher one, the F2 region. Of these the F1 region is more of an inflection point in the electron density curve (seen above) and it generally only exists in the summer.

Typically the F1 layer is found at around an altitude of 300 kilometers with the F2 layer above it at around 400 kilometers. The combined F layer may then be centered around 250 to 300 kilometers. The altitude of the all the layers in the ionosphere layers varies considerably and the F layer varies the most. As a result the figures given should only be taken as a rough guide. Being the highest of the ionospheric regions it is greatly affected by the state of the Sun as well as other factors including the time of day, the year and so forth.

The F layer acts as a “reflector” of signals in the HF portion of the radio spectrum enabling worldwide radio communications to be established. It is the main region associated with HF signal propagation.

Like the D and E layers the level of ionization of the F region varies over the course of the day, falling at night as the radiation from the Sun disappears. However the level of ionization remains much higher. The density of the gases is much lower and as a result the recombination of the ions and electrons takes place more slowly, at about a quarter of the rate that it occurs in the E region. As a result of this it still has an effect on radio signals at night being able to return many to Earth, although it has a reduced effect in some aspects.

The F region is at the highest region in the ionosphere and as such it experiences the most solar radiation. Much of the ionization results from ultra-violet light in the middle of the spectrum as well as those portions of the spectrum with very short wavelengths. Typically the radiation that causes the ionization is between the wavelengths of 100 and 1000 Angstroms, although extreme ultra-violet light is responsible for some ionization in the lower areas of the F region.



Summary:
The ionosphere is a continually changing area of the atmosphere. Extending from altitudes of around 60 kilometers to more than 400 kilometers it contains ions and free electrons. The free electrons affect the ways in which radio waves propagate in this region and they have a significant effect on HF radio communications.

The ionosphere can be categorized into a number of regions corresponding to peaks in the electron density. These regions are named the D, E, and F regions. In view of the fact that the radiation from the Sun is absorbed as it penetrates the atmosphere, different forms of radiation give rise to the ionization in the different regions as outlined in the summary table below:

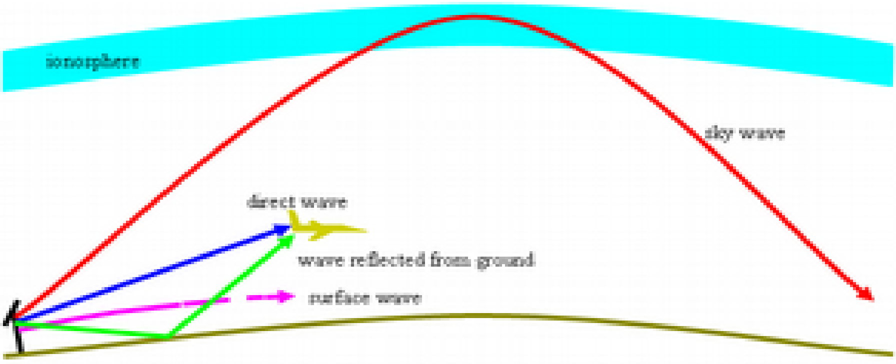
Summary of forms of radiation causing ionization in the ionosphere.

REGION	PRIMARY IONISING RADIATION FORMS
C	Cosmic
D	Lyman alpha, Hard X-Rays
E	Soft X-Rays and some Extreme Ultra-Violet
F1	Extreme Ultra-violet, and some Ultra-Violet
F2	Ultra-Violet

The ionosphere is a continually changing area. It is obviously affected by radiation from the Sun, and this changes as a result aspects including of the time of day, the geographical area of the world, and the state of the Sun. As a result radio communications using the ionosphere change from one day to the next, and even one hour to the next. Predicting how what radio communications will be possible and radio signals may propagate is of great interest to a variety of radio communications users ranging from broadcasters to radio amateurs and two way radio communications systems users to those with maritime mobile radio communications systems and many more.

Types of HF propagation

HF radio signals can propagate to a distant receiver, through ionosphere via;



- **Ground wave** - near the ground for short distances, up to 100 km over land and 300 km over sea. Attenuation(signal loss) of the wave depends on antenna height, polarization, frequency, ground types, terrain and/or sea state;

- **Direct or line-of-sight wave** - this wave may interact with the earth-reflected wave depending on terminal separation, frequency and polarization;
- **Sky wave** - refracted by the ionosphere, all distances

Skip Distance/Skip Zone

The **Skip distance** is the distance from the transmitter to the point where the sky wave is first returned to Earth. The size of the skip distance depends on the frequency of the wave, the angle of incidence, and the degree of ionization present.

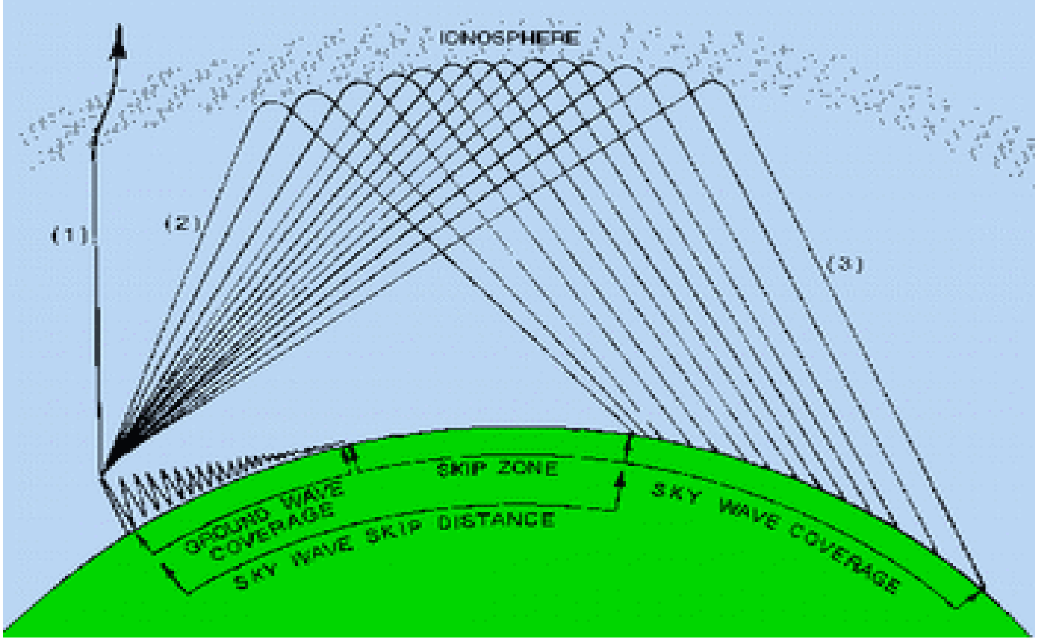


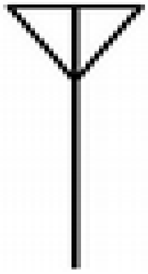
Fig: Relationship between skip zone, skip distance, and ground wave.

The **Skip Zone** is a zone of silence between the point where the ground wave becomes too weak for reception and the point where the sky wave is first returned to Earth. The size of the skip zone depends on the extent of the ground wave coverage and the skip distance. When the ground wave coverage is great enough or the skip distance is short enough that no zone of silence occurs, there is no skip zone.

Fading

The problem in receiving radio signals with variations in signal strength, is commonly known as FADING. There are several conditions that can produce fading. When a radio wave is refracted by the ionosphere or reflected from the Earth's surface, random changes in the polarization of the wave may occur. Vertically and horizontally mounted receiving antennas are designed to receive vertically and horizontally polarized waves, respectively. Therefore, changes in polarization cause changes in the received signal level because of the inability of the antenna to receive polarization changes. Fading also results from absorption of the RF energy in the ionosphere. Absorption fading occurs for a longer period than other types of fading, since absorption takes place slowly. Usually, however, fading on ionospheric circuits is mainly a result of multi-path propagation

Antenna or Aerial



An antenna (or aerial) is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an electric current oscillating at radio frequency (i.e. a high frequency alternating current (AC)) to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals, that is applied to a receiver to be amplified.

Antennas are essential components of all equipment that uses radio. They are used in systems such as radio broadcasting, broadcast television, two-way radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones, Bluetooth-enabled devices, wireless computer networks, baby monitors, and RFID tags on merchandise.

Typically an antenna consists of an arrangement of metallic conductors (elements), electrically connected (often through a transmission line) to the receiver or transmitter. An oscillating current of electrons forced through the antenna by a transmitter will create an oscillating magnetic field around the antenna elements, while the charge of the electrons also creates an oscillating electric field along the elements. These time-varying fields radiate away from the antenna into space as a moving transverse electromagnetic field wave. Conversely, during reception, the oscillating electric and magnetic fields of an incoming radio wave exert force on the electrons in the antenna elements, causing them to move back and forth, creating oscillating currents in the antenna.

The first antennas were built in 1888 by German physicist Heinrich Hertz in his pioneering experiments to prove the existence of electromagnetic waves predicted by the theory of James Clerk Maxwell. Hertz placed dipole antennas at the focal point of parabolic reflectors for both transmitting and receiving.

Type of antenna

Whether you see it or not, every wireless device uses an antenna to send and receive radio frequencies. The size and shape of an antenna depends on the size of the signal's wavelength. High radio frequencies, like those used in cell phones, have short wavelengths, so the antennas can be very small. Low-frequency radio signals have long wavelengths, so longer antennas are needed. Antennas can be made from almost any metal or alloy. The part that receives or sends a signal is called an element. Other parts you may see protruding from an antenna are called reflectors or directors, which help capture the signal on the element.

Antenna can be further classified on the basis of:

1 Frequency - VLF, LF, HF, VHF, UHF, Microwave, Millimeter wave antenna
2 Aperture - Wire, Parabolic Dish, Micro-strip Patch antenna
3. Polarization - Linear (Vertical/Horizontal), Circular polarization antenna
4. Radiation - Isotropic, Omni-directional, Directional, Hemispherical antenna

Base-Station and Directional Antennas

Radio-station towers and cell-phone towers are known as base-station antennas. These are omni-directional on the horizontal plane, meaning they can send and receive signals in any direction parallel to the horizon. Directional antennas focus on one direction only. Antennas mounted on parabolic dishes are directional. Other examples include corner reflectors, which are two plates at 90 degrees of each other to focus the signals, and Yagi antennas. Yagi antennas consist of several straight elements, each a half-wavelength long, with straight rods parallel to each element called reflectors or directors. The most common examples of Yagi antennas include VHF and UHF TV antennas and high-frequency amateur-radio antennas.

Vehicle Antennas

The antennas you see on vehicles, like trucks and emergency service vehicles, are called monopoles, or quarter-wave whip antennas. These antennas consist of a single vertical element, one-quarter wavelength long. When mounted on the metal roof of a vehicle, the roof becomes a ground plane reflector, making the vehicle and antenna a dipole antenna. The lower the frequency, the longer the monopole needs to be. For example, a 50 MHz low band VHF antenna should be 5 feet tall. A 850 MHz monopole is just 3.5 inches tall.

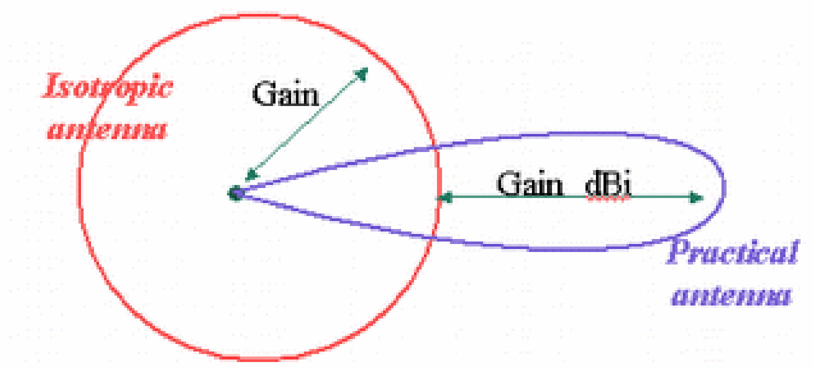
Portable Antennas

The antennas on older portable radios use a wire that is wound helically around a rod inside the radio. This keeps the antenna small enough that the radio can be worn on a belt or clipped to a lapel, but makes it easy to lose a signal. Because the wavelengths used by cell phones and laptop computers are so high (2.4GHz and 5.8GHz for Wi-Fi, for example), even the smallest case can accommodate several antennas inside. Until 1993, cell phones had external pull-out antennas. This feature was required because cell phone frequencies were in the 900 MHz range, close to that of cordless phones, requiring a much longer antenna than today.

Basic antenna models

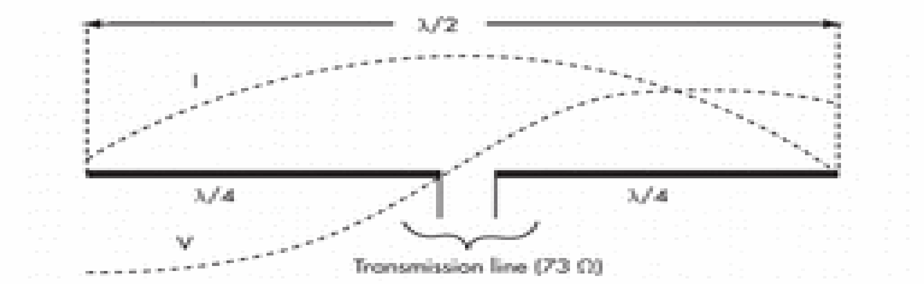
There are many variations of antennas. Below are a few basic models..

The isotropic radiator



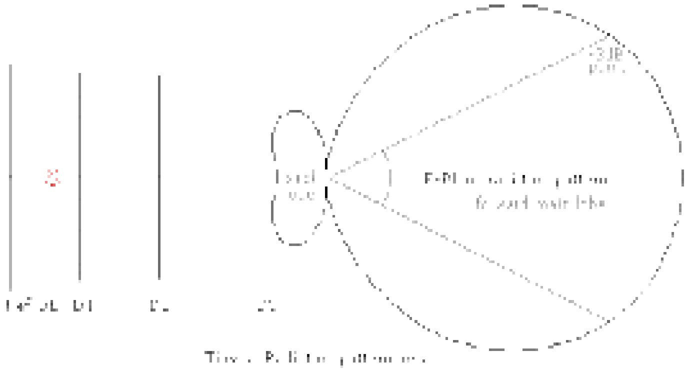
The isotropic radiator is a purely theoretical antenna that radiates equally in all directions. It is considered to be a point in space with no dimensions and no mass. This antenna cannot physically exist, but is useful as a theoretical model for comparison with all other antennas. Most antennas' gains are measured with reference to an isotropic radiator, and are rated in dBi (decibels with respect to an isotropic radiator).

Dipole antenna



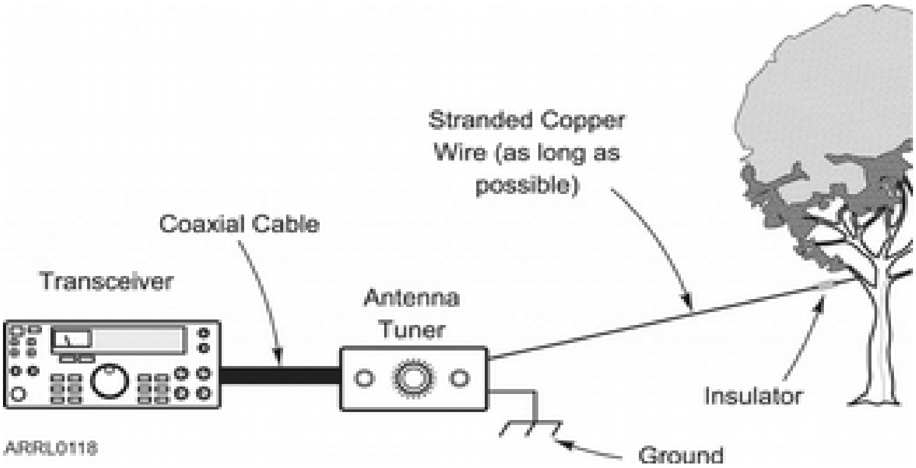
The dipole antenna is simply two wires pointed in opposite directions arranged either horizontally or vertically, with one end of each wire connected to the radio and the other end hanging free in space. Since this is the simplest practical antenna, it is also used as a reference model for other antennas; gain with respect to a dipole is labeled as dBd. Generally, the dipole is considered to be omni-directional in the plane perpendicular to the axis of the antenna, but it has deep nulls in the directions of the axis. Variations of the dipole include the folded dipole, the half wave antenna, the ground plane antenna, the whip, and the J-pole.

Yagi-Uda



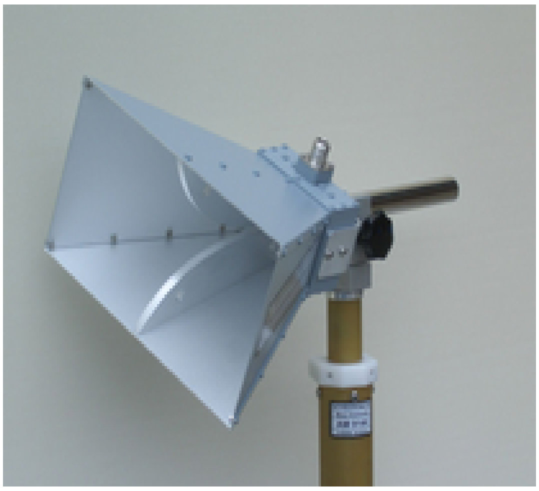
The Yagi-Uda antenna is a directional variation of the dipole with parasitic elements added which are functionality similar to adding a reflector and lenses (directors) to focus a filament light bulb.

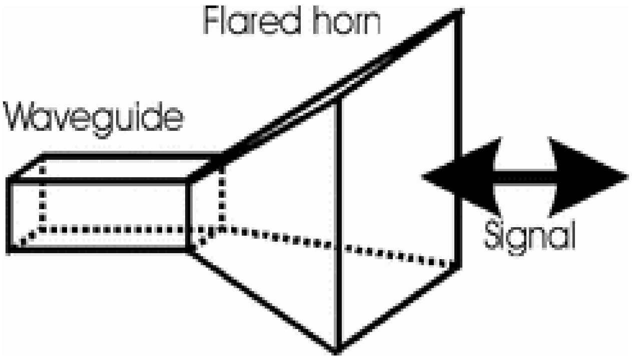
Random wire antenna



The random wire antenna is simply a very long (at least one quarter wavelength[citation needed]) wire with one end connected to the radio and the other in free space, arranged in any way most convenient for the space available. Folding will reduce effectiveness and make theoretical analysis extremely difficult. (The added length helps more than the folding typically hurts.) Typically, a random wire antenna will also require an antenna tuner, as it might have a random impedance that varies non-linearly with frequency.

Horn antenna





The horn antenna is used where high gain is needed, the wavelength is short (microwave) and space is not an issue. Horns can be narrow band or wide band, depending on their shape. A horn can be built for any frequency, but horns for lower frequencies are typically impractical. Horns are also frequently used as reference antennas.

Parabolic antenna

The parabolic antenna consists of an active element at the focus of a parabolic reflector to reflect the waves into a plane wave. Like the horn it is used for high gain, microwave applications, such as satellite dishes.

Patch antenna

The patch antenna consists mainly of a square conductor mounted over a ground plane. Another example of a planar antenna is the tapered slot antenna (TSA), as the Vivaldi-antenna.

Frequency Counter

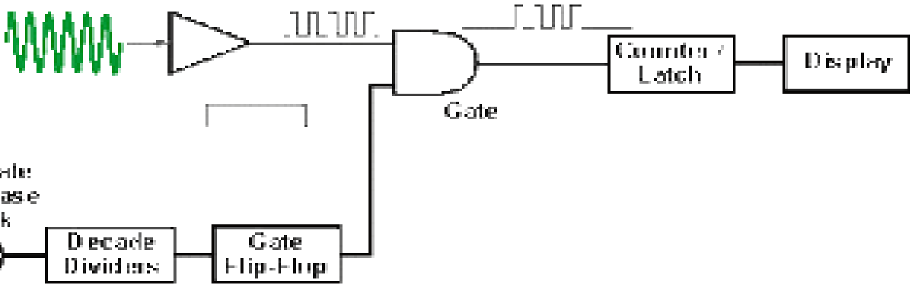
Digital frequency counters and timers are widely used items of test equipment within the electronics industry for measuring the frequency of repetitive signals and measuring the elapsed time between events. In particular, digital frequency counters are used for radio frequency (RF) measurements where it is important to test or measure the precise frequency of a particular signal.

The requirements for frequency counters and interval timers are slightly different. However it is often possible to utilize the same basic test instrument to perform both functions, and as a result frequency counter-timers are widely available. These frequency counter timers are more commonly found as general purpose laboratory test equipment. Where higher frequencies are to be measured, the timer element is not included and the test equipment is just a frequency counter.

RF frequency counter basics

RF frequency counters and timers are items of test equipment that operate by counting events within a set period or discovering what a period is by counting a number of precisely timed events. The time periods within which events are counted, or the precisely timed events can be generated using a highly stable quartz crystal oscillator. This may even be oven controlled, and in this way a very accurate reference is obtained.

Within the basic counter there are several main blocks:



Input: When the signal enters the frequency counter it enters the input amplifier where the signal is converted into a logic rectangular wave for processing within the digital circuitry in the rest of the counter. Normally this stage contains a Schmitt trigger circuit so that noise does not cause spurious edges that would give rise to additional pulses that would be counted. Trigger levels and sensitivity are controlled within this area of the frequency counter.

Accurate time-base / clock: In order to create the various gate / timing signals within the frequency counter an accurate timebase or clock is required. This is typically is a crystal oscillator and in high quality test instruments it will be an oven controlled crystal oscillator. In many instruments, there will be the capability to use a better quality external oscillator, or to use the frequency counter oscillator for other instruments. This is also beneficial when it is necessary to lock a number of instruments to the same standard.

Decade dividers and flip-flop: The clock oscillator is used to provide an accurately timed gate signal that will allow through pulses from the incoming signal. This is generated fromth e clock by dividing the clock signal by decade dividers and then feeding this into a flip flop to give the enabling pulse for the main gate

Gate: The precisely timed gate enabling signal from the clock is applied to one input of a gate and the other has a train of pulses from the incoming signal. The resultant output from the gate is a series of pulses for a precise amount of time. For example if the incoming signal was at 1 MHz and the gate was opened for 1 second, then 1 million pulses would be allowed through.

Counter/ latch: The counter takes the incoming pulses from the gate. It has a set of divide-by-10 stages (number equal to the number of display digits minus 1). Each stage divides by ten and therefore as they are chained the first stage is the input divided by ten, the next is the input divided by 10 x 10, and so forth. These counter outputs are then used to drive the display. In order to hold the output in place while the figures are being displayed, the output is latched. Typically the latch will hold the last result while the counter is counting a new reading. In this way the display will remain static until a new result can be displayed at which point the latch will be updated and the new reading presented to the display.

Display: The display takes the output from the latch and displays it in a normal readable format. LCD, or LED displays are the most common. There is a digit for each decade the counter can display. Obviously other relevant information may be displayed on the display as well.
It is important that the gate time is accurately generated. This is done by having a highly accurate frequency source within the frequency counter. Typically these will operate at a frequency of 10 MHz and this needs to be divided to give the required gate time. Figures of 0.01, 0.1, 1, and 10 seconds may be selected. The shorter times obviously enable the display to be refreshed more often, but against this the count accuracy is less.

The reason that the gate time determines the resolution of the frequency counter is that it can normally only count complete cycles, as each crossing represents a cycle. This a gate time of one second will enable frequency resolutions of 1 Hz to be gained, and a ten second gate time will enable resolutions down to 0.1 Hz. It is worth noting that the measurement resolution is a not a percentage of the measurement, but instead it is fixed amount relating only to the gate time.