
Effect of Ionosphere on Radio Wave Propagation

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Abstract

We discuss various topics concerning the propagation of radio waves on the ionosphere. The effects of ionosphere on radio wave propagation are identified. The three layers of the ionosphere F, E, D are play an important role on RW propagation; the F layer obtained during the day and night time, used for long distance propagation but the E and D layer are obtained only on the day time, they are responsible for high frequency waves. An important relation between RW and the ionosphere are discussed. It is found that the higher frequency is, the less its tendency to bend. The sky waves, ground waves and space waves are discussed and the characteristics can be described. The sky wave influenced by many chemical and physical phenomena. It used to communicate over long distances and allows transmitted signals to be reflected (bounced) off a portion of the Earth's ionosphere but Ground waves are continually in contact with the earth's Surface and do not make use of reflection from the Ionosphere.

Key words:- Waves; Ionosphere

1. Introduction

The ionosphere is the ionized component of the atmosphere. It is lying between a height of about 50km to over 500km. Ionization is the process in which electrons which are negatively charged are removed from neutral atoms or molecules to positively charged ions and free electrons. It has an ionized gas which is called plasma (4th state of matter). It is ionized by radiation from the sun. Ionosphere contains four clouds like layer of electrically charged, which enables radio wave to be propagated to great distance around the earth. Ionosphere is formed when extreme (UV) light from the sun strikes the electrons from neutral atoms in the ionosphere [1].

Radio waves are a form of radiant energy that propagate through the space at the speed of light $C = 3 \times 10^8$ m/s. It is EMW in free space consists of E and B field, each at right angles of each other.

RW propagation is phenomena of RF energy traveling through the earth's atmosphere, as well as through empty space above the atmosphere. It is science and study of RW reflection, refraction, diffraction, absorption, polarization and scattering. Because of its complex interaction, RW propagation is examined in three regions as ground wave or surface wave, space wave and sky wave propagation. As the frequency of radio wave increases its period decrease and wave length is also decrease. As EMW travel from Transmitted antenna the strength of the wave is decreasing. At longer wave lengths that at lower frequency, the antenna have large physical size and are located very near to earth [2]. In the frequency range from a few MHz up to 30 to 40 MHz; long distance communication can be achieved by ionosphere reflection of RW back toward the earth. In propagation RW produce both E-field and B-fields. Direction of electric component of field is called polarization of EM

field. Thus of E-field vertical, the wave vertically polarized and horizontal horizontally polarized [3]. Guglielmol Marconi (1874-1937) the first man to communicate wirelessly over Atlantic. Jamesclark Maxwell was using (EM) wave in space for radio communication system when he became up with theory of (EM) field in 1873. He chained that EMW are subject to reflection, refraction and absorption. Rudolph Hertz in some experiment carried out in 1888.in 1896, Marconi was successful in sending signal through the wire. Edward Appleton was whose first discovered that radio wave is broad around the world after reflected back from the earth, Then wave that sent from radio transmitter to outer space Are reflected back to earth after hitting this as and plasma layer that composed of charged particle [4].

2. RADIO WAVE PROPAGATION

2.1 RADIO WAVES

Radio wave is EM wave that can be reflected, refracted, in the atmosphere like light and heat waves. Simply wave can be defined as disturbance of EM and other wave which move through medium. It is means of transferring energy from one point to another. The all leading wave has amplitude, wave length; correspond to one complete cycle, crest, trough and frequency. Wavelength-to-frequency conversions of radio waves are really quite simple because wavelength and frequency are reciprocals: Either one divided into the velocity of a radio wave yields the other. Remember, the formula for wavelength is

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

Where, λ = wave length in meters V =velocity of radio wave (speed of light) and f= frequency of radio wave (in Hz, KHz, or MHz), wavelength is measured as the distance from the top of one crest to the top of its neighboring crest. Radio waves behave like light [5]. The two fields are at right-angles to each other and the direction of propagation is at right-angles to both fields. The direction of the electric field determines what is

known as the polarization of the radio wave. Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere [6].

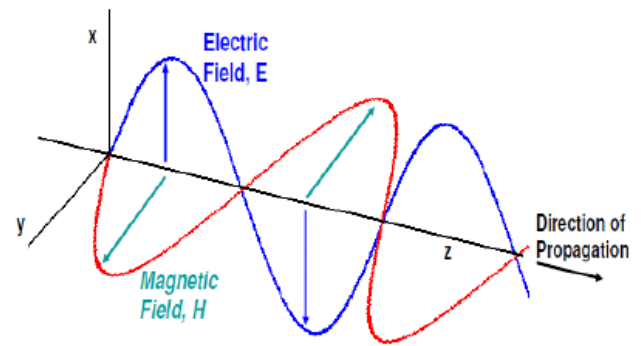


Figure 2.1: Propagation of E and B fields.

• E-FIELDS

E-field exists in the presence of charged body. Its intensity is vector quantity having magnitude and direction. The magnitude of E is proportional to the force acting on it. Positive charge at a point in the field and direction of E field is direction of force. E is represented by line of force or flux lines, D called electric displacement. $D = \epsilon E$ Where, D= electric displacement, E= electric field, and ϵ =permittivity of free space.

• B- FIELDS

B-field is associated with moving charge and electric currents. The force exerted by magnetic field on element of current I, is the vector at right angle to the plane of current I, and vector B is called magnetic induction or flux, $F=IXB$ [6]. Unit of I is ampere and of B is then, $B = H$. Where, B=magnetic field, F=the force by magnetic field, and H = magnetic induction.

2.2 Factors affect radio waves

Like light waves, radio waves are affected by the phenomena of Radio waves Such as reflection, refraction, diffraction, absorption, polarization and scattering [7].

2.2.1 Reflection

The change in direction of radio wave, striking a surface or traveling from one medium to another. EM reflection occurs when an incident wave strikes a boundary of two media. Radio waves are reflection similar to light waves traveling at the same speed.

2.2.2 Refraction

The bending of radio wave when it passes from from one medium to another in which the velocity of propagation is different. When a radio wave is transmitted into an ionized layer, refraction, or bending of the wave, occurs. The amount of refraction that occurs depends on three main factors: the density of ionization of the layer, the frequency of the radio wave, and the angle at which the wave enters the layer [8].

2.2.3 Diffraction

The bending of radio wave as it passes the edge of the object. It the redistribution of energy with in a wave front when it passes near the edge of an opaque object and it is phenomena that allow radio wave to propagate around corners. Diffraction is the name given to the mechanism by which waves enter into the Shadow of an obstacle. The bending, called diffraction, results in a change of direction of part of the wave energy from the normal line-of-sight path. This change makes it possible to receive energy around the edges of an obstacle [9]. The lower the frequency or the longer the wavelength, the greater the bending of the wave. Therefore, radio waves are more readily diffracted than light waves.

2.2.4 Absorption

Many factors affect a radio wave in its path between the transmitting and receiving sites.

The factor that has the greatest effect on radio waves is ABSORPTION. Absorption results in the loss of energy of a radio wave and has a pronounced effect on both the strength of received signals and the ability to communicate over long distances. Most ionospheric absorption occurs in the lower regions of the ionosphere where ionization density is greatest. The highly dense D and E layers provide the greatest absorption of radio waves. Because the amount of absorption of the sky wave depends on the density of the ionosphere, which varies with seasonal and daily conditions, it is impossible to express a fixed relationship between distance and signal strength for ionospheric propagation

2.2.5 Polarization

The plane containing E- field is called the plane of polarization. The direction of the electric field determines what is known as the polarization of the radio wave The most common polarizations in use for microwave links are vertical and horizontal. A vertical half-wave dipole antenna will radiate with vertical polarization. The direction of the electric field does not necessarily remain the same as it travels forwards through space. It is possible to design an antenna that produces an electric field that rotates as it travels. This is referred to as circular polarization. Circular polarization falls into two categories, depending on the direction of rotation: 'right-hand circular' and 'left-hand circular'. The polarization of a radio wave can rotate as it propagates. Polarization may be horizontal or vertical both are used. Polarization of an antenna is the orientation of E-field with respect to the surface and determined by physical structure of antenna. Vertical antenna will be usually vertically polarized and RW from horizontal antenna are usually horizontally polarized [8].

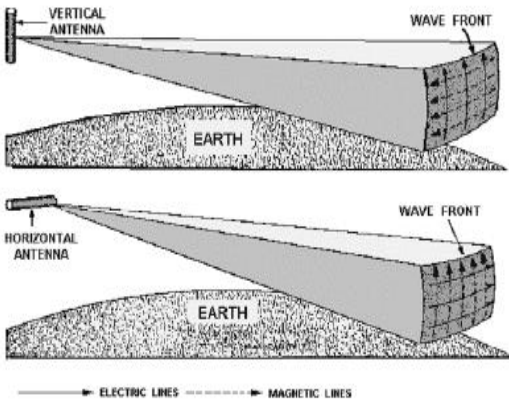


Figure 2.2: Vertical and horizontal polarization .

2.2.6 Scattering

Scattering is the process by which small particles suspended in a medium of different index of refraction diffuse a portion of the incident radiation in all directions. Scattering occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less. Characteristic of scattered signal is: - too far for ground wave and too near for sky wave. A wavering due to multiple arrivals of the signals. Sound is distorted due to this multiple path signal the usually, received signals are weak [10].

2.3 HOW SIGNALS TRAVEL

When dealing with radio signals, transmission-reception takes three forms: - line of sight, ground wave and sky wave. Line of sight is the simplest form of propagation that all frequency will function in it. The distance between transmitter and receiver is dependent on the frequency or wave length of the signal. Line of sight propagation is very useful at VHF and UHF.

2.3.1 Ground wave

This form of propagation is first most frequencies, but the distance between transmitter and receiver will vary with geography and composition of ground. Ground waves are continually in contact with the earth's Surface. They do not make use of reflection from the Ionosphere. They have a

tendency to be refracted and, in some cases, reflected into the lower atmosphere. At Frequencies above 1500 kilohertz, a ground wave is affected very little by the time of day or season. Short-distance and all UHF and upper VHF transmissions are sent by ground waves. Ground wave propagation is affected by the Earth's electrical characteristics and by the amount of diffraction (bending) of the waves along the curvature of the Earth. A ground wave is composed of two separate component waves-the surface wave and the space wave. Surface wave travels along the surface of the ground, flowing the curvature of the Earth due to the process of diffraction, where as the primary path of the space wave is directly from the transmitting antenna to the Receiving antenna [3].

2.3.2 Sky Wave

This form of propagation is influenced by many chemical and physical phenomena. Sky wave propagation is used to communicate over long distances. Sky wave propagation allows transmitted signals to be reflected (bounced) off a portion of the Earth's ionosphere. A common example of this phenomenon is heard On the AM broadcast band, when many distant stations can be heard after sunset or in the evening hours. Usually, the HF band is used for sky wave propagation. Both the MF (300 kHz to 3 MHz) and HF bands can be used for long distance sky wave communications at night. During the night the D region disappears, so absorption falls to very low levels. This is why radio broadcast stations operating in the MF and 4 MHz bands can be heard over long distances only at night. Sky wave propagation results in communication covering our entire globe [3].

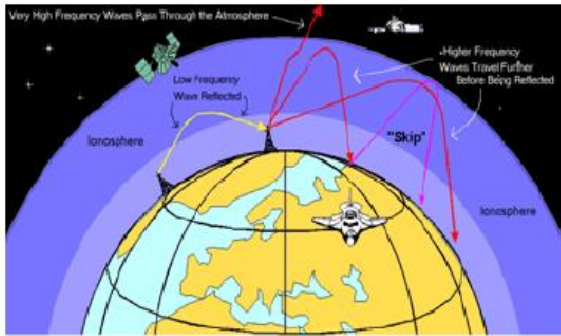


Figure 2.3: Sky wave propagation .

2.4 Application of Radio wave propagation

Radio waves are used for many things today. They broadcast, communicate with satellites, and cell phones communicate with each other, make radar systems, and allow computers to share information without wires. Today, in the age of space travel, satellites, and wireless information Networks, radio waves have become an essential element of how we communicate with one another across vast distances. These notes describe the physics and applications of radio waves and radio wave propagation within ionized gases enveloping our planet and Solar system [11].

3. Discussion on Ionospheric propagation effects

3.1. Ionosphere

3.1.1. Layers in the Ionosphere

There are primarily three distinct layers in the ionosphere namely D, E, and F [11].

• D-LAYER

The D layer is the lowest, at altitude between 50 and 80km. It is present during the day when radiation is beaming in from the sun. Because the density of the air is still high at this altitude, ions and electrons recombine relatively quickly. After sunset, when solar radiation is blocked by the Earth, electron levels fall quickly and the D layer effectively disappears. It is characterized by high electron-collision frequency, and absorption is

high. It has least amount of ionization density because it is further from the sun. This layer has greatest significance at midday when the sun's effect is greatest. Its ionization is not enough to bend the wave directions except for lower frequencies. It will only affect waves whose frequency level is 500kHz. It has a negative effect on propagation of sky waves, because it will absorb the energy from them, therefore attenuating their field as they pass through.

• E-LAYER

Above the D layer, the next ionization level is called the E layer. It can be found at altitudes between 100 and 125 km. Because electrons and ions recombine relatively quickly here, ionization levels drop quickly after sunset. Although a small amount of ionization occurs, the E layer virtually disappears at night. It is the most important for communication between 3 and 4MHz. It is positively ionized with varying amounts of free electrons. This layer also exists only during day time. Change with temperature, angle of the sun, magnetic fields, time of day and so on. It has irregular behavior, sometimes reflecting, refracting RF, in MF, and lower VHF bands.

• F-LAYER

The most important layer for long-distance communication is the F layer. During the day it often splits into sub-layers we call F₁ and F₂. (At night the two layers merge back into a single F layer). F - Layer altitudes vary considerably and depend on the time of day, the season and the state of the sun. This layer is the most ionized useful layer for long distance transmission of high RF during the time of maximum ionization; F₂ layer occurs at an altitude 150 to 2590 miles, F₁ layer is lowest during the daylight hours. The F layer decreases in ionization due to recombination and increases in altitude at night. It is the primary means of reflecting or refracting MF and HF signals in sky wave propagation. At night communication distance becomes much greater than that at F₂ [12].

3.2 Effects of ionosphere density on radio waves

Energetic particle like electrons, protons, and α particles from the sun can penetrate the atmosphere and contribute to an extraordinary production of ions and electrons in the ionosphere. Thus make variation in the ionosphere, especially important in the ion production that takes place in the E and D-layer. Here, the increase in electron density, can give rise to great disturbance in the polar ionosphere can cause a total breakdown in short wave communication. The rate at which ionization occurs depends on the density of atoms in the ionosphere and the intensity of the ultraviolet light waves, both of which vary with the activity of the sun. The ultraviolet waves striking the ionosphere are of different frequencies, causing several ionized layers to be formed at different altitudes.

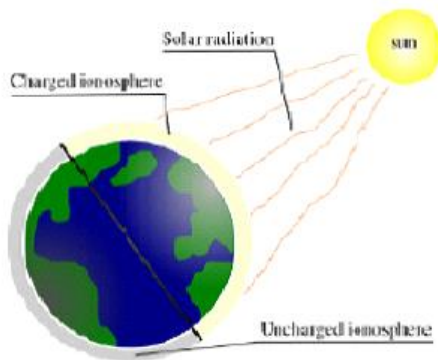


Figure 3.1: solar radiation hitting the ionosphere.

Consequently, the altitude and thickness of the ionized layers vary, depending on the time of day and even the season of the year. When free electrons and positive ions collide with each other, a reverse process called recombination occurs. Recombination depends on the time of day each ionized layer has a central region of relatively dense ionization. As a radio wave enters a region of increasing ionization, the increase in velocity of the upper part of the wave causes it to be bent back toward the Earth. While the wave is in the highly dense center portion of the layer,

however, refraction occurs more slowly because the density of ionization is almost uniform. As the wave enters into the upper part of the layer of decreasing ionization, the velocity of the upper part of the wave decreases, and the wave is bent away from the Earth. If a wave strikes a thin, very highly ionized layer, the wave may be bent back so rapidly that it will appear to have been reflected instead of refracted back to Earth. To reflect a radio wave, the highly ionized layer must be approximately no thicker than one wavelength of the radio wave. Since the ionized Layers are often several miles thick, ionosphere reflection is more likely to occur at long wavelengths (Low frequencies). Quantitatively, the propagation of a radio wave through the ionosphere plasma is described by the refractive index of the ionosphere. At high frequencies ($f > 100$ MHz), the refractive index mainly depends on the electron density. The spatial distribution of the electron density along the ray path and corresponding geomagnetic field relationships determine the ionospheric impact on the electromagnetic wave [13].

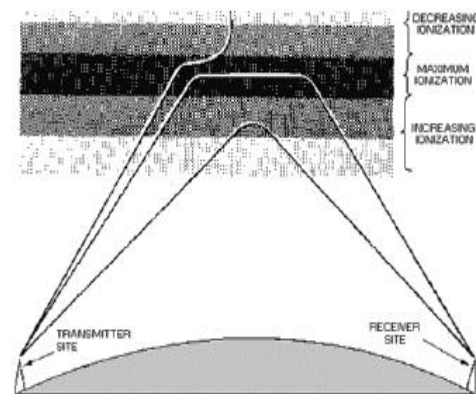


Figure 3.2: Effect of ionosphere density on radio wave propagation.

3.2.1 Ionosphere refractive index

For high frequency (HF) radio waves with frequencies $f > 100$ MHz the phase refractive index can be derived from the Appleton - Harte formula as [15],

$$n = 1 - \frac{f_p^2}{2f^2} \pm \frac{f_p^2 f_g \cos \theta}{2f^3} - \frac{f_p^2}{4f^4} \left[\frac{f_p^2}{2} + f_g^2 (1 + \cos^2 \theta) \right] \quad (3.1)$$

in which

$$f_p^2 = \frac{n_e e^2}{4\pi \epsilon_0 m}, \quad f_g^2 = \frac{eB}{2m}$$

where f_p is the plasma frequency, f_g is the gyro frequency, ϵ_0 is the free space permittivity,

B is the geomagnetic induction, θ is the angle between the wave propagation direction and

e , n_e , m are the electron charge, density and mass, respectively. All of the propagation

effects, which are depend on the reflection of radio waves from the ionosphere, are limited to those frequencies that can be reflected. As a result the term MUF is used often is ionosphere propagation. The MUF highest frequency at which signals will be reflected by F2 layer of greatest ionization [14].

3.2.2 Types of HF Propagation

The Usable Frequency Range In radio communications, not all HF waves are reflected by the ionosphere; there are upper and lower frequency bounds for communications between two terminals. If the frequency is too high, the wave will pass straight through the ionosphere. If it is too low, the strength of the signal will be very low due to absorption in the D region. The definition of the frequency to be used for radio communication is an important parameter for healthy of propagation. For this, the Maximum Usable Frequency (MUF), and the Lowest Usable Frequency (LUF) are determined. Frequencies over MUF penetrate the ionosphere shooting right through the ionosphere and going out into space, whereas frequencies below MUF are reflected. LUF is the lowest frequency that is completely absorbed in the D layer. To conduct good communication, a frequency, calculated as MUF, should be used. This frequency may be lower at

night and higher during the day. During the day it is possible to communicate via both the E and F layers using different frequencies. The highest frequency supported by the E layer is the EMUF, while that supported by the F layer is the FMUF. The F region MUF in particular varies greatly throughout the day, seasonally and with the solar cycle. D region absorption of HF radio waves increases rapidly with decreasing frequency. The angle at which the radio waves enter the atmosphere (angle of incidence) defines the path that will be covered by the waves on their way to Earth. The angle of incidence should be small enough for the waves to be reflected back to Earth and large enough so that the waves will not penetrate the ionosphere layer. Smaller critical angles should be used for smaller frequencies and larger critical angles should be used for larger frequencies so that they will not penetrate through the ionosphere layer and be lost in space. The range of usable frequencies will vary:

- a) Throughout the day
- b) With the seasons;
- c) With the solar cycle;
- d) From place to place

The upper limit of frequencies varies mostly with the above factors, while the lower limit also depends on receiver site noise, antenna efficiency and transmitter power [15].

3.3 IONOSPHERIC VARIATION

The ionosphere is not stable medium that allows the use of frequency over 24 hours. It is varies with solar cycle, season, day to night, latitude and so on [1].

• VARIATION DUE TO SOLAR CYCLE

The sun goes through a periodic rise and fall in activity which affects HF communication. At solar minimum, only the lower frequencies of the HF band will be reflected by the ionosphere, whereas, at solar maximum the higher frequencies will successfully propagation. This is because there is more radiation being emitted from the sun at solar maximum, producing more electrons in

the ionosphere which allows the use of higher frequencies.

• SEASONAL VARIATION

E-region frequencies are greater in summer than winter. But; the variation in F region frequencies is more complicated. Around solar minimum the summer noon frequencies are generally greater than those in winter, but around solar maximum winter frequencies tend to be higher than those in summer.

• DAILY VARIATION

The most important factor that affects sky wave is ionosphere. Sky wave propagation is used to communicate over long distances. During the night the D region disappears, so absorption falls to very low levels. This is why radio broadcast stations operating in the MF and 4 MHz bands can be heard over long distances only at night. Frequencies are normally higher during the day and lower at night. After dawn, solar radiation causes electrons to be produced in the ionosphere and frequencies increase rapidly to a maximum around noon. During the afternoon, frequencies begin falling due to electron loss and with darkness the D, E and F₁ regions disappear. Communication during the night is by the F₂ (or just F) region only and attenuation is very low. Through the night, maximum frequencies gradually decrease, reaching their minimum just before dawn.

FIG4. Daily variation of layers of ionosphere [16].

• LATITUDINAL VARIATIONS

During the day, with increasing latitude, the solar radiation strikes the atmosphere more obliquely, so the intensity of radiation and the daily production of free electrons decrease with increasing latitude.

• VARIATION IN ABSORPTION

Absorption is extremely high a solar flare, a certain amount of D region absorption occurs all the time. Absorption in the D region varies with the solar cycle, being greatest around solar maximum. Signal absorption is also greater in summer and during the middle of the day. Lower frequencies are absorbed the most so it is always advisable to use the highest frequency possible, particularly during the day when absorption is greatest.

3.4 HOW DOES RADIO WORK?

A radio transmitter used to move electric charges up and down its antenna sets the signal that is to be propagated in motion. These waves that are propagated carry signals that are received by antenna on our radio or television set. Antennas are used both to transmit or and receive signals).The movement of the electric charges produces a changing electric field—a structure in space that pushes on electric charges—and a changing magnetic field—a structure in space that pushes on magnetic poles. Because the electric field changes with time, it creates the magnetic field and because the magnetic field changes with time, it creates the electric field. The two travel off across space as a pair, endlessly recreating one another in an electromagnetic wave that will continue to the ends of the universe. However, when this wave encounters the antenna of our radio, its electric field begins to push electric charges up and down on that antenna. Our radio senses this motion of electric charges and thus detects the passing radio wave. These movements of the speaker are what cause our radio to emit sound. A transformer modulates or adjusts the strength of the radio wave. The modulator changes the strength of the radio waves to match the loudness of the music or voice we want to transmit. When we connect our transmitter to a transmitting antenna an electric charge travels up and down the wire antenna (at the rate of the oscillator), causing radio waves to be emitted from the wire. An electric field exerts forces on

electric charges and a magnetic field exerts forces on magnetic poles. Both electric and magnetic fields contain energy. In a radio wave, this energy moves along with the fields. Our transmitter uses electric power to create the radio wave and the radio wave delivers that power to your crystal radios via the antenna. To understand radio transmission our may want to think of a radio wave like a swing [17].

4. Conclusion

In this paper, radio wave propagation had been looked at under three headings: the explanation of

radio waves, the ionosphere and its layers, and finally the propagation of radio waves through the ionosphere. In the explanation of radio waves, it was mentioned about the discovery of the existence of radio waves. The ionosphere and its layers were explained. The propagation of radio waves depends on the frequency. Such that, decreasing wave length is result in increasing frequency, $\lambda=v/f$. Finally ionospheric propagation is possible because of the ionized region of the upper reaches of the earth's atmosphere as a result of receiving ultraviolet radiation from the sun.

ACRONYMS

<u>Abbreviations</u>	<u>Definitions</u>
UV	Ultraviolet
Hz	Hertz
MHz	Mega Hertz
KHz	Kilohertz
GHz	Gigahertz
BEC	Bose-Einstein Condensation
BHM	Bose-Hubbard Model
EMW	Electromagnetic wave
RW	Radio Wave
EM	Electro Magnetic
UF	Usable Frequency
MUF	Maximum Usable Frequency
LUF	Lowest usable Frequency
UHF	Ultra High frequency
VHF	Very High Frequency
MF	Medium Frequency
HF	High Frequency
EMI	Electromagnetic interference
RF	Radio Frequency
EMUF	E-layer Maximum usable frequency
FMUF	F-layer Maximum Usable Frequency



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