DOCUMENT
GSM-AUS-CPL.028

DOCUMENT TITLE

CPL NAVIGATION 2 (AUSTRALIA)

CHAPTER 4 – PROPAGATION OF RADIO WAVES

Version 2.1
November 2017

CONTENTS .... PAGE

PROPAGATION OF RADIO WAVES

4.1 Introduction

The Earth is a sphere, and the general property of radio waves is propagation in a straight line.

These two factors would seem to indicate that the range of a transmission is limited to the visible horizon, as the surface of the Earth curves away in the distance.

Fortunately, radio waves do curve to a greater or lesser extent with the surface of the Earth and in the atmosphere, or are reflected from layers within the atmosphere.

Generally radio waves follow the great circle path over the surface of the earth and broadly two types of propagation exist, namely Ground Waves and Sky Waves. Each of these main types of radio waves have their own characteristics.

Ground Waves can also be classified into the following subtypes:

- **Ground Waves**
  - Surface waves
  - Space waves (direct waves and ground reflected waves).
- **Sky Waves**

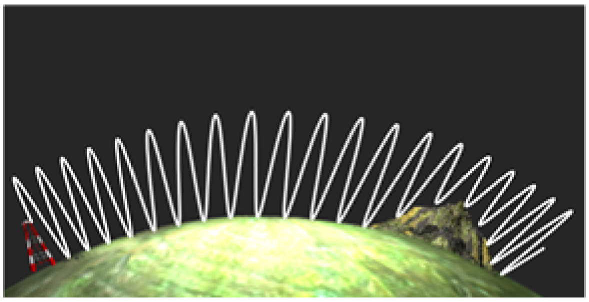
4.2 Surface Waves

As the name suggests, surface waves follow the curvature of the surface of the Earth and are a type of **ground wave**. There are two reasons for these waves following the earth's curvature, namely:

- Diffraction
- Attenuation

4.2.1 Diffraction

This phenomenon causes the radio waves to bend and go over and around most obstacles in their path.



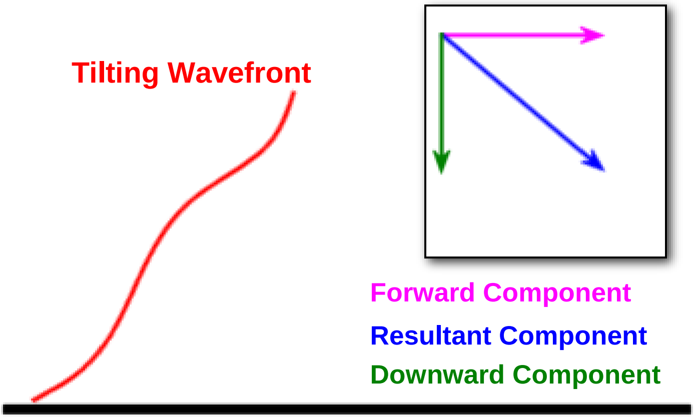
Diffraction is inversely proportional to frequency, i.e. as frequency increases diffraction decreases.

As the Earth's surface is curved, it is in itself an obstacle and the wave is continuously assisted to curve around the surface.

4.2.2 Surface Attenuation

The surface of the earth attenuates the radio wave, causing it to lose energy and slow down which, in turn, results in the wave following the Earth's surface.

As the bottom of the wave penetrates into the surface, it will slow down giving the wave a forward and downward tilt and therefore encouraging it to follow the curvature of the Earth's surface.



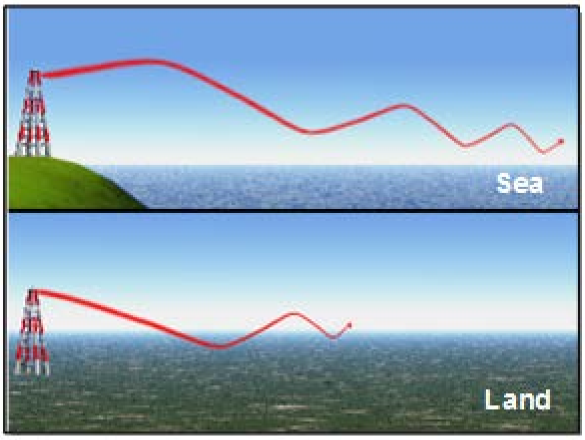
The tilted wave will continue to follow the Earth's surface until it is finally attenuated and becomes undetectable.

Surface attenuation depends on two factors:

- Type of surface
- Frequency

4.2.2.1 Type of Surface

Attenuation over different surfaces is not the same and a wave will travel almost twice as far over the sea as over land. This is due to the land absorbing more of the radio wave energy than the sea, as the radio wave travels over the surface.



4.2.2.2 Frequency

Surface attenuation is directly proportional to frequency, i.e. as frequency increases surface attenuation also increases.

As frequency increase, the range of the surface wave decreases.

Frequency Range	Surface Attenuation	Diffraction	Range
VLF	Least	Bending due to diffraction is maximum	Given sufficient power, several thousand miles
LF	Less	Signals will bend with the Earth's surface	Up to 1500 nm
MF	Increasing	Slight bend with the Earth's surface	300 to 500 nm. Maximum is 1000 nm over the sea
HF	High	Bending is negligible	70 - 100 nm
VHF and above	The signals do not bend and the radio waves travel in a straight line diverging away from the surface	Limited diffraction occurs	Line of sight

4.2.3 Disadvantages of Surface Waves

The disadvantages associated with surface waves occur mainly with the lower frequencies in spite of the very long ranges they can achieve.

4.2.3.1 Low Efficiency Aerials

Ideally the length of the transmitter and receiver aerials should each be equal to half the size of the wavelength. In the lower frequency bands the wavelengths are very long (in the order of hundreds of metres) which result in very large antennas, which are expensive to build and maintain.

4.2.3.2 Static

Static is most severe at the lower frequencies. The effect of static decreases as the frequency is increased. VHF is considered to be practically static free.

In radio telephony, static interference can be heard as a background hissing or crackling noise, which at times can be so pronounced that it obscures the voice information being transmitted.

4.2.3.3 Installation and Power

The cost of initial installation of ground equipment at the lower frequencies (VLF) is high and the required power output is very large, which makes ground stations costly to run.

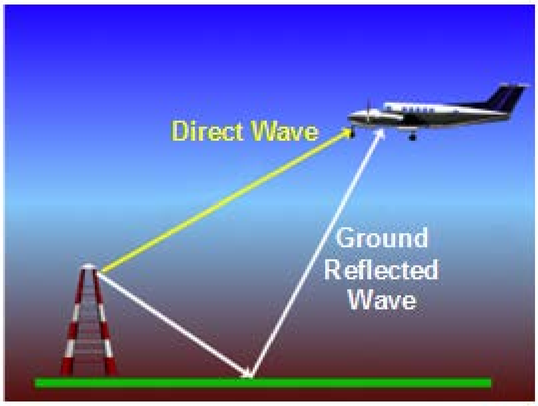
Surface waves are used with Non-Directional Beacons (NDB) in LF and MF bands.

4.3 Space Waves

Space waves are members of the family of **ground waves**.

Aircraft usually receive VHF signal from two directions - one directly from the transmitter, called the Direct Wave, and the other having first been reflected from the surface, called a Ground Reflected Wave.

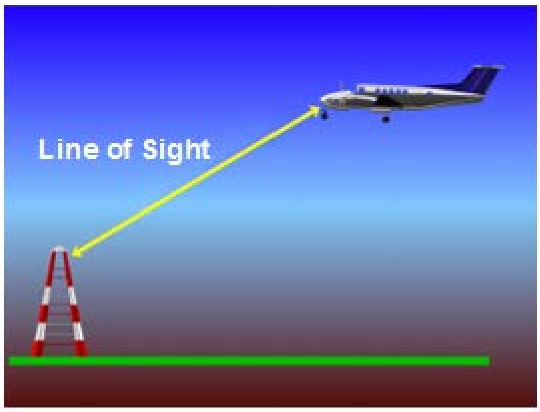
This **combination** of a Ground Reflected Wave and a Direct Wave is called a **Space Wave**.



Space waves are mostly used for **Short Range Radio Telephony**.

4.3.1 Direct Waves

Direct waves are also members of the family of **Ground Waves**, in that they are part of the two waves that make up Space Waves, and are essentially line of sight. The direct wave may undergo a certain amount of refraction due to the varying densities of the atmosphere. The maximum theoretical range for a direct wave is calculated using the formula below.



$$R = 1.25\sqrt{HT} + 1.25\sqrt{HR}$$

R = Maximum Theoretical Range in nautical miles

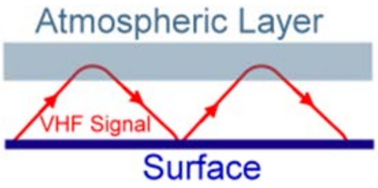
HT = Height of transmitter in feet

HR = Height of receiver in feet

Note: Both heights are above mean sea level. For the CASA CNAV examination, it will not be required to do range calculation with the formula above. Instead the ranges (called rated coverage) of any of the navigational beacons must be looked up in the AIP & ERSA of Jeppesen. The procedure is discussed later chapters.

4.3.1.1 <u>Duct Propagation – A Propagation Anomaly</u>

From time to time, certain meteorological conditions exist where radio waves in the VHF band and above, are trapped between the Earth and a layer of the atmosphere.



This causes signals to be refracted back to the Earth and then reflected back to the atmosphere with a range of several hundred miles or more.

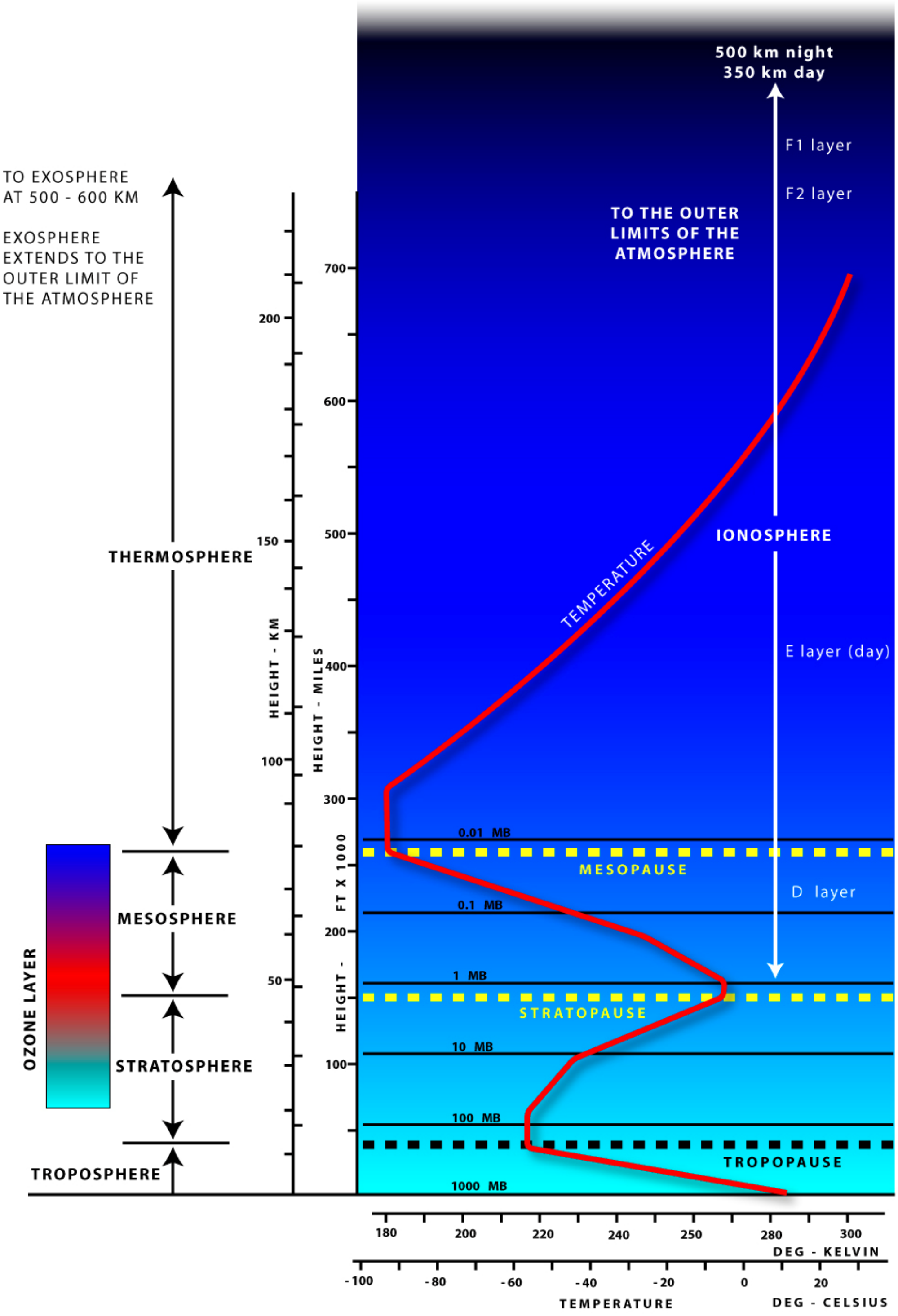
This type of propagation is known as Duct Propagation (or Super-refraction).

The meteorological conditions suitable for such propagation are temperature inversions and a decrease in humidity with an increase in height. Such conditions are caused by:

- Warm dry air blowing over a cool sea
- Subsidence
- Pronounced radiation cooling
- Temperature inversions.

4.4 Sky Waves

Sky waves are signals that have been reflected & refracted from an atmospheric layer surrounding the Earth. This layer is called the Ionosphere, and this phenomenon occurs in the VLF, LF, MF and HF bands. Sky waves are the principal mechanism for long range communication.



Structure of the Atmosphere

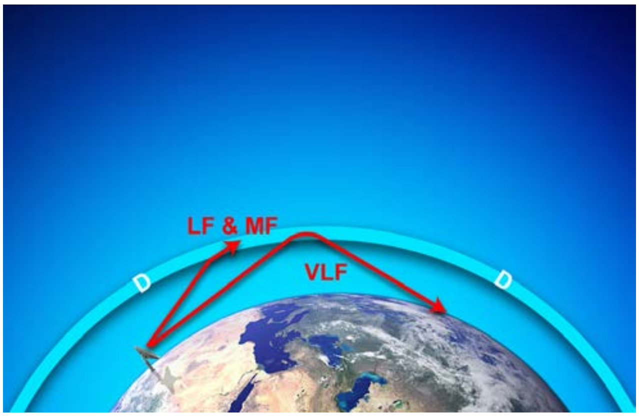
4.4.1 The Ionosphere

The Ionosphere is an electrically conducting sphere, completely surrounding the Earth. As ultra-violet rays from the Sun strike the upper atmosphere, electrons are released from gas molecules, forming an ionised layer.

Due to uneven absorption of radiation at different levels in the upper atmosphere, two to four separate layers are formed in the Ionosphere depending on time of day. The Ionosphere layers are:

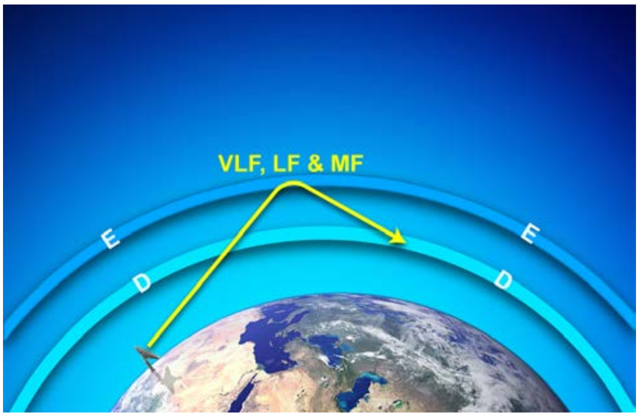
4.4.1.1 D-Layer

- Found between 50 km and 100 km, this layer is normally only present during daytime and disappears at night
- Refracts VLF waves back to the Earth but absorbs LF and MF waves.



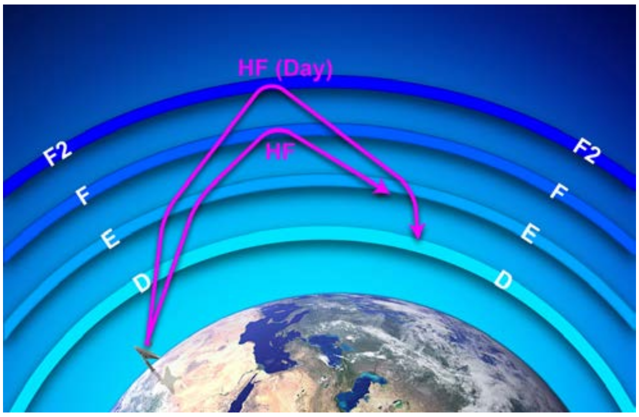
4.4.1.2 E-Layer

- Found between 100 km and 200 km
- Refracts frequencies up to 2 MHz but only at night
- Also called Kenelly-Heaviside layer.



4.4.1.3 F-Layer

- Situated between 200 km and 400 km.
- Refracts HF frequencies
- Also called the Appleton layer
- Splits into a F1 and F2 layer during daytime
- HF refracts from F2 layer by day.

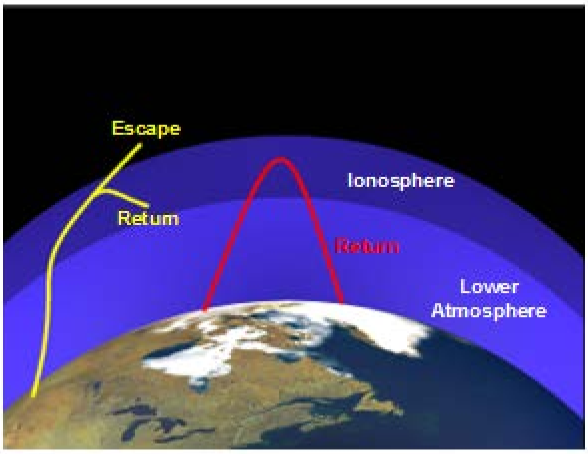


These ionospheric layers cause refraction, reflection and attenuation of radio waves.

4.4.1.4 Characteristics of the Ionosphere

- Electron density increases with height
- Refractive index decreases with height
- Radio waves travel at a higher velocity in the upper levels, i.e. where the refractive index is less and the electron density is higher.
- Attenuation increases as electron density increases and therefore refraction also increases.

4.4.2 Ionospheric Refraction



Refraction is the bending or change in direction of a radio wave on entering a different medium. As the atmosphere and ionosphere constitute different media, a radio wave travelling upwards will be refracted, i.e. bent.

In suitable conditions, a radio wave may bend sufficiently in order to be returned to the Earth.

A radio wave may also be refracted by a lower layer and then be further refracted by a higher layer. The wave may then return or escape.

The degree of refraction varies in accordance with the intensity of the atmospheric ionisation.

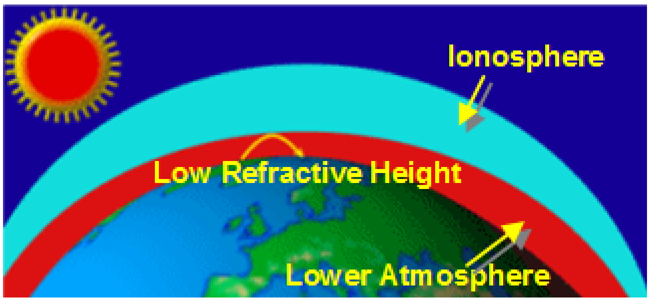
The higher the altitude the thinner the atmosphere, and at high-altitudes the solar radiation has a greater effect in breaking down the gas molecules than at lower altitudes - where the atmosphere is denser.

Due to this greater breaking down of gas molecules at higher altitudes, the F-layer of the Ionosphere will have the highest electron density and the lowest refractive index. Variations in the density occur due to:

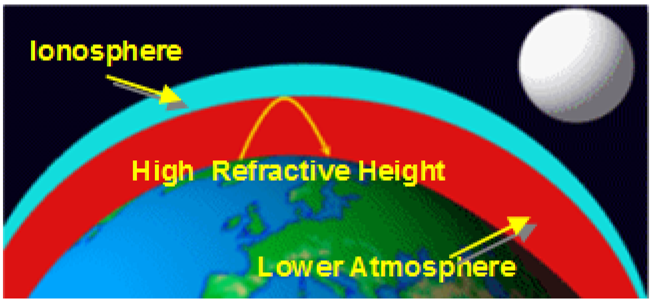
- Diurnal activity
- Seasonal activity
- 11 year sunspot activity.

4.4.2.1 Diurnal Activity

During the day solar radiation increases ionic density in all the layers and the refractive height moves down (closer to the Earth's surface).



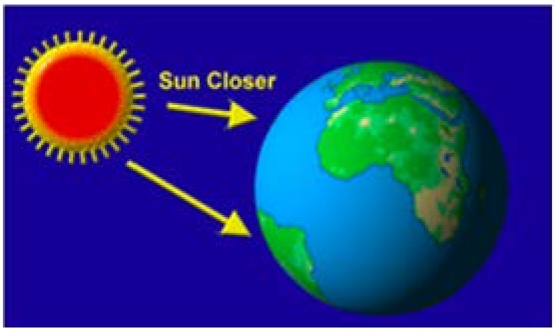
At night the reverse takes place and the D-layer disappears. The refractive height rises.



Sunrise and sunset produce unstable conditions in the Ionosphere as the layers start falling or rising. These are critical periods for the operation of radio equipment operating in LF, MF and HF bands such as HF radios and NDB.

4.4.2.2 Seasonal Activity

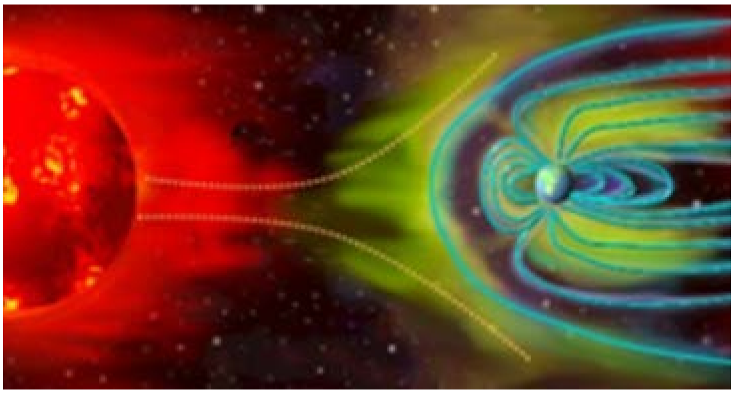
The amount of intensity depends on where the sun is with regards to the position under consideration. There is maximum activity when the sun is closest and sporadic ionisation occurs in the E-layer in summer.



During sporadic ionization events of the E-Layer the refracted frequencies can increase to as high as 150 MHz, which is in the VHF range. In these conditions long range VHF communications may be possible meanwhile the short range VHF communications may be effected by these long range VHF signals.

4.4.2.3 11 Year Sunspot Activity

Very marked changes in ionisation occur during this sun-spot activity period. This is due to enhanced ultra-violet and X-radiation from the sun. At this time, ionisation in the D and E layers cause an increase in absorption, disrupting communication - and signals at VHF frequencies may return back to earth.

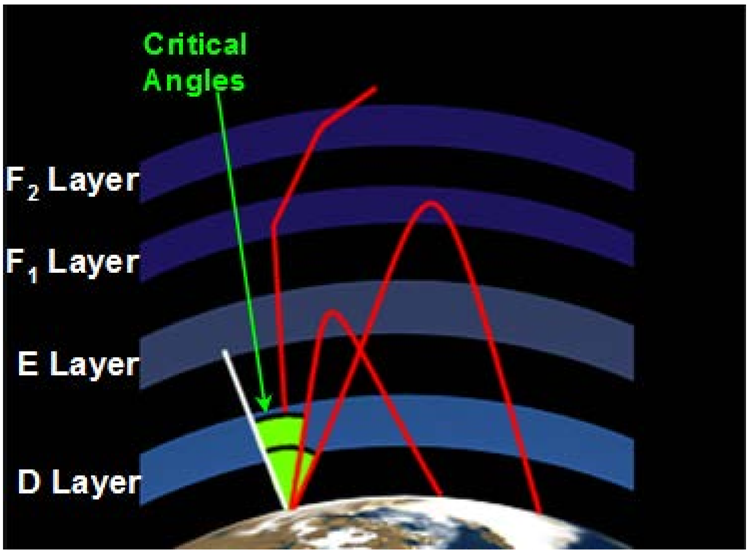


4.4.3 Factors Affecting Refraction

4.4.3.1 Critical angle

If the angle that a radio wave makes with the vertical is too small, the radio wave will not be refracted sufficiently to return.

As this angle from the vertical is progressively increased, the signals will bend (i.e. refract) progressively more until an angle is reached (for a given frequency and ionospheric distribution), when the first radio wave will return to earth.



This angle is called the **critical angle**. The returned wave, when the radio wave is transmitted at the critical angle, is called the critical ray or first sky return, also called the first skip or the first hop. At the critical angle and higher, there will be an uninterrupted flow of sky waves.

4.4.3.2 Critical Frequency

In radio wave propagation the term critical frequency has the following meanings:

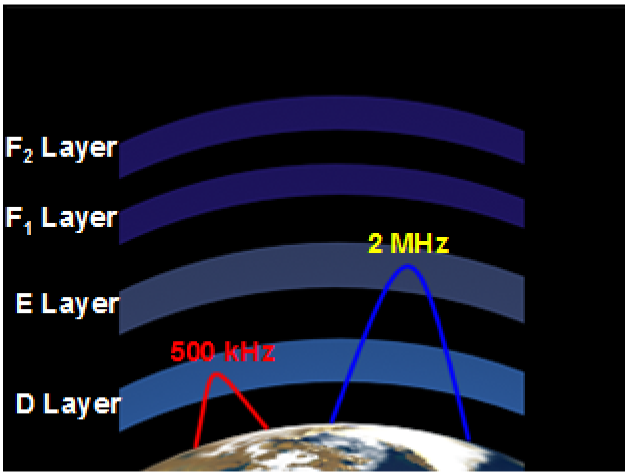
- In radio propagation by way of the ionosphere, the limiting frequency at or below which a wave component is reflected by, and above which it penetrates through, an ionospheric layer.
- At vertical incidence, the limiting frequency at or below which incidence, the wave component is reflected by, and above which it penetrates through, an ionospheric layer.

4.4.3.3 Frequency in Use

A higher frequency requires a higher electron density to refract it. As density increases with height, higher frequencies will penetrate more deeply into the layer than lower frequencies before returning. The higher a signal penetrates the Ionosphere, the greater the range of the first hop.

The D-layer is not heavily ionised and it will refract only low frequencies up to around 500 kHz.

The E-layer is relatively more heavily ionised and will reflect frequencies up to around 2 MHz.



In the F-Layer, frequencies higher than 2 MHz will not be sufficiently refracted in the E layer to return. It will travel to the F-layer before returning, thus giving very long ranges. Above 30 MHz (VHF and above), the refraction in the layers is insufficient and the signals escape into free space.

The UHF band is used for communication with astronauts in the outer space, due to the ability of these very high frequencies being able to penetrate through the Ionosphere. An exception arises however in the case of VHF and UHF during the high solar activity period - when the ionisation is extremely dense.

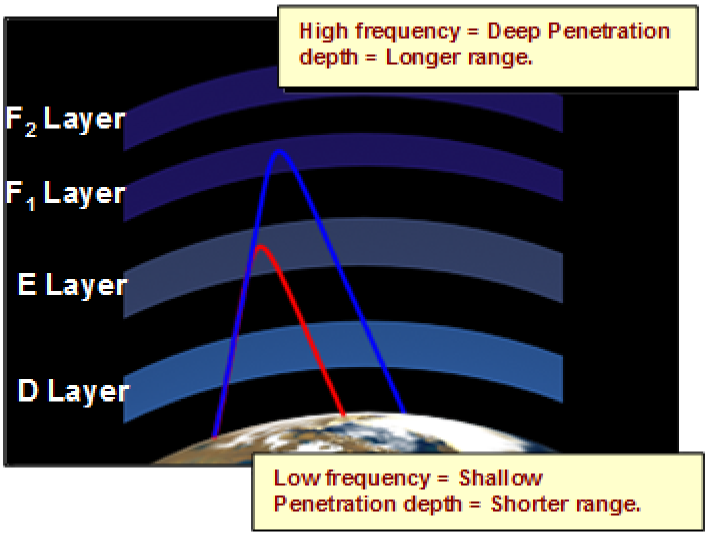
4.4.4 Ionospheric Attenuation

Radio energy is absorbed in the Ionosphere and the extent of this ionospheric attenuation depends on the following factors:

- Density of the Layer. The greater the density, the greater the attenuation. Maximum attenuation occurs around mid-day.
- Penetration Depth. The deeper the signal penetrates into the layer, the greater the loss of energy due to attenuation.
- Frequency in use. The lower the frequency, the greater the attenuation. This is one of the reasons why a higher frequency is used for communication in the HF band during the day.

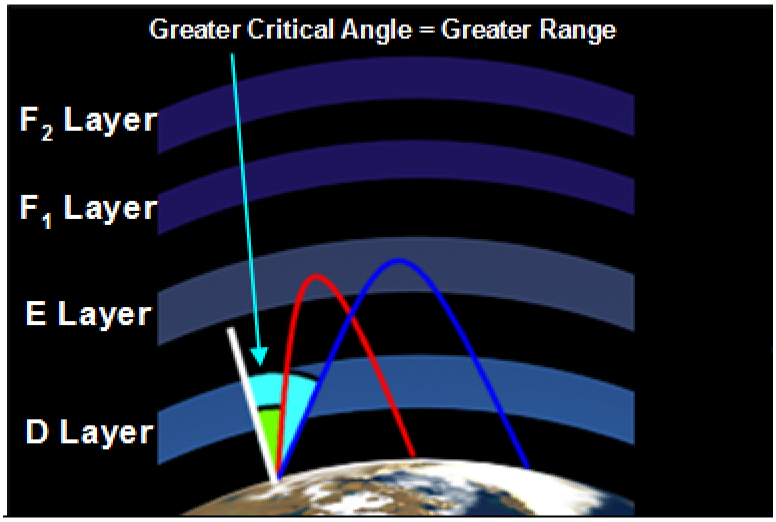
4.4.5 Factors Affecting the Range of a Sky Wave

- Transmission Power. The range of sky waves will increase as the transmission power is increased.
- Depth of Penetration. Penetration depth depends on the frequency in use and the ionospheric distribution. Deeper penetration means greater attenuation.



The deeper a signal travels before being refracted, the larger the range it produces for the first hop. Higher frequencies require a higher density to refract it.

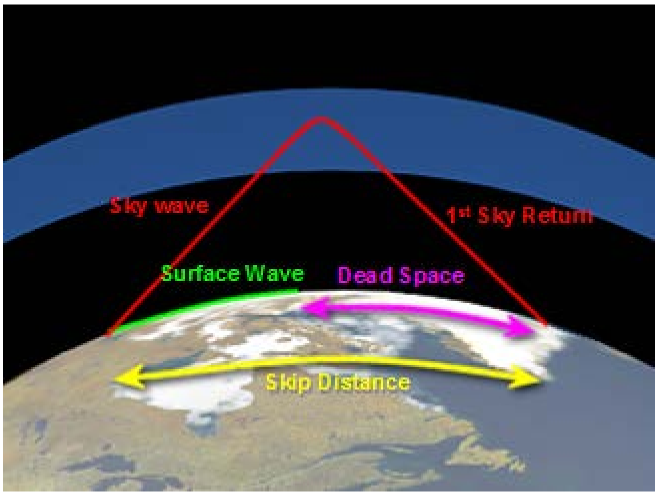
- Critical angle and Angle of Incidence. The critical angle will determine the range at which the first sky return occurs.



4.4.6 Characteristics of Sky Waves

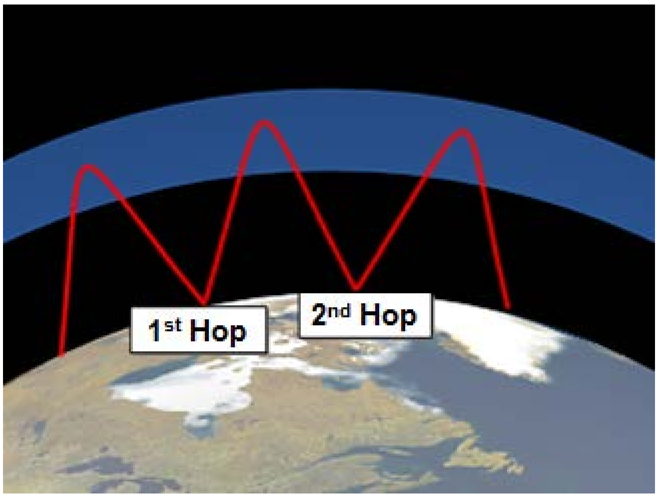
Certain terms are associated with sky waves, such as skip distance, dead space and multi-hopping.

The distance between the transmitter and the point on the surface where the first sky return arrives is called the **skip distance**.



Where a signal produces both surface waves and sky waves, there may be an area where no reception is possible. This is due to the surface wave's limit been reached and the sky waves have not started returning. The area between the limit of the surface wave and the point of reception of the first sky wave is termed **dead space**.

If the returning sky waves are sufficiently strong, it will be reflected from the Earth's surface back to the Ionosphere - where it will be refracted and returned again. This is known as **multi-hopping**.



This process may continue several times, producing very long signal ranges until the signals are finally attenuated by passage through the Ionosphere and contact with the Earth's surface at the point of reflection.

When multi-hop propagation is taking place, the first return is called the 1st hop or skip and its subsequent reflections are called 2nd hop and so on. If the angle of incidence is right, the signals can travel around the Earth and an 'echo' of the previous reception may arrive 1/7th second later.

4.4.7 Fading

Fading is always present to a greater or lesser extent in sky wave reception due to continuous fluctuations in the Ionosphere.

The relative phases of the sky waves arriving at a receiver vary in random fashion affecting the amplitude of the output.

It is also possible to receive two sky waves which have travelled different routes or to receive both 1st hop and 2nd hop signals. Since it has not travelled the same distance, there will be a phase difference between the sky waves.

When two incoming signals are in phase it augments each other resulting in a stronger reception. When the signals are directly in opposition (180° out of phase) it will cancel out.

4.4.8 Scatter Propagation

Another form of propagation is Scatter Propagation or Sporadic-E Reception.

The E-layer sometimes has patches of intense ionisation. This is most pronounced in summer. Signals are scattered by these patches and may be received as much as 1500 nm away.

A scattering effect is also present in the Troposphere in regions where air turbulence prevails. This causes a discontinuous refractive index resulting in abnormally strong signals on one occasion and equally strong interference on another.

4.4.9 Maximum Usable Frequency (MUF)

If the frequency is too low, excessive ionospheric attenuation will weaken the signal. If the frequency is too high, the skip distance will exceed the distance between the aircraft and the transmitter and the signal will not be received. The MAXIMUM USABLE FREQUENCY (MUF) is the highest frequency available for a given distance and state of the ionosphere. At the MUF, skip distance is just short of the distance from the transmitter to the aircraft.

4.4.10 Operational Working Frequency (OWF)

The operator is normally supplied with the MUF. In practice, the frequency that the operator selects is the next lowest available frequency with respect to the MUF. For example, if the MUF is 15 kHz the operator would select 14 kHz or whatever is the next lowest channel available on the transmitting equipment. This frequency is known as the Operational Working Frequency (OWF) and its selection ensures that the aircraft stays within radio coverage.

4.4.11 Uses of Sky Waves

- Sky waves are used for long-range communication.
- It occurs in all bands up to (but not including VHF) and long ranges are achieved in the HF frequency band.

Sky Waves should not be used in navigation aids such as the NDB and ADF. If received can cause some of the major errors associated with this equipment.

4.5 Worksheet – Propagation of Radio Waves

1. Which type of radio wave is refracted by the Ionosphere and can return to earth?
   a. Direct Waves
   b. Space Waves
   c. Sky Waves
   d. Ground reflected waves.

2. Which one of the following statements is correct?
   a. When frequency increases, diffraction increases.
   b. When frequency decreases, surface attenuation increases.
   c. When frequency increases, surface attenuation decreases.
   d. When frequency decreases, static interference increases.

3. Which one of the following is a use of Sky Waves?
   a. Long range radio communication
   b. NDB
   c. VOR
   d. DME.

4. Which one of the following frequency ranges has the least diffraction?
   a. LF band
   b. MF band
   c. HF band
   d. VHF band.

5. Which one of the following frequency ranges has the highest surface attenuation?
   a. LF band
   b. MF band
   c. HF band
   d. VHF band.

6. Which statement below best describes Space Waves?
   a. Space waves are refracted by the Ionosphere if conditions are just right.
   b. Space Waves propagate along the earth's surface, bending over obstacles.
   c. Space Waves are the combination of a Ground Reflected Wave and a Direct Wave.
   d. Space Waves is the term used to describe radio waves that have left the earth's atmosphere, radiating out into space.

7. Which one of the following statements is true regarding radio waves?
   a. Direct Waves are the main type of radio wave used in long distance communication systems.
   b. Direct Waves are a subtype of Sky Wave, travelling in a straight line, between the transmitter and receiver.
   c. Sky Waves diffract and follow the curvature of the Earth.
   d. Space Waves are a combination of a Ground Reflected Wave and a Sky Wave.

4.5.1 Worksheet Answers

1C	2D	3A	4D
5D	6C	7B	