DOCUMENT

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DOCUMENT TITLE

RADIO NAVIGATION

CHAPTER 2 – PROPAGATION

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CONTENTS .... PAGE

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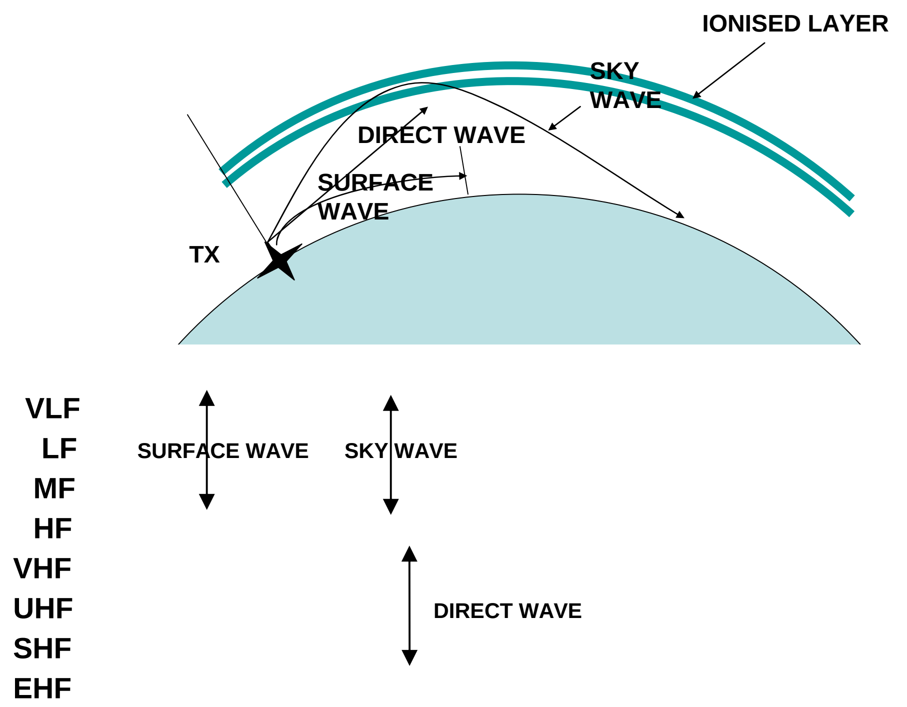
PROPAGATION

PROPAGATION PATHS

Propagation describes the means by which radio waves travel between the transmitter and the receiver. The path of the radio wave is not necessarily straight as it may be subject to refraction, reflection, diffraction and attenuation. Multiple paths for the radio waved may exist and so signals that have travelled different distances may be arriving simultaneously at the receiving aerial. The unwanted paths produce signals that interfere for they arrive from the wrong direction and are likely to be out of phase with the signal that has followed the intended propagation path. This can lead to incorrect bearing measurements and/or loss of signal strength.

To understand the limitations of radio aids, it is important to know the propagation paths in use and these can be predicted from knowledge of the frequency band. The main propagation paths are the DIRECT WAVE, the SURFACE WAVE and the SKYWAVE.



DIRECT WAVES

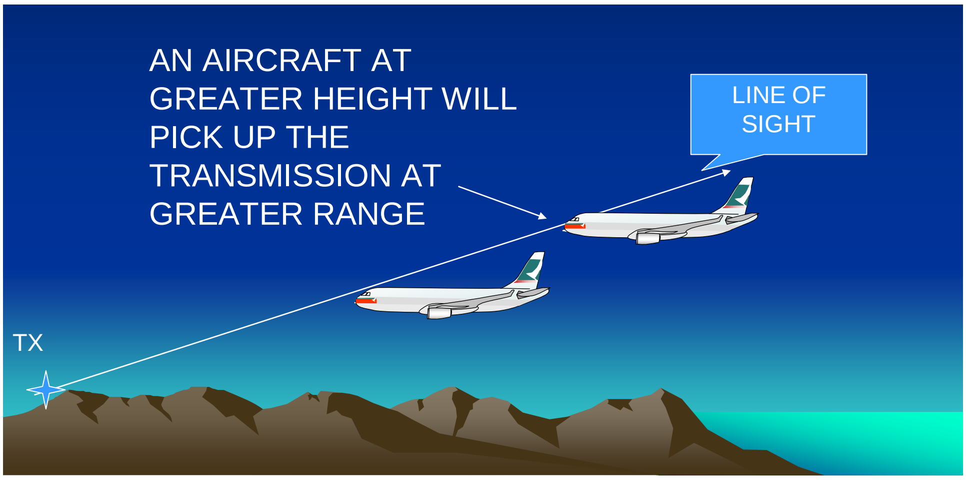
In the frequency bands of VHF and above, the only propagation path that can be used is the direct wave which travels in a straight line from the transmitter to the receiver. Radio waves

at these frequencies are not refracted in the ionosphere and their surface waves are very short due to attenuation.
The curvature of the earth limits the range available by direct waves. It is said that range is limited to the "line of sight", that is the straight line joining the transmitter and receiver. In fact, there is a small amount of refraction in the lower layers of the atmosphere due to density changes which extend the radio horizon.

The formula used to calculate direct wave range is:

$$\text{Range (nm)} = 1.25\sqrt{h_1} + 1.25\sqrt{h_2}$$

h_1 is the height of the transmitter and h_2 is the height of the receiver. Both are measured in feet AMSL.



A key variable is the height of the airborne receiver and much greater range can be expected at high altitude when using navigation aids such as VOR and DME which operate in the higher frequency bands.

Direct wave range depends on:

a. The height of the transmitter
b. The height of the receiver
c. The height of any intervening high ground
d. The power of the transmitter.

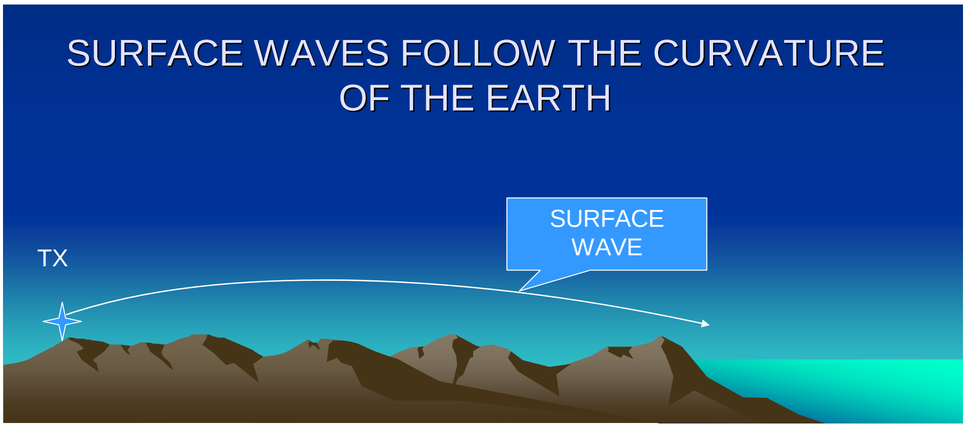
The line-of-sight limitation has the advantage of preventing interference from other transmitters which are over the horizon.

Sometimes an aircraft may pick up a signal from two directions, one having travelled direct to the aircraft and the other having first been reflected by the surface. Direct waves and ground reflected waves are collectively called space waves.

SURFACE WAVES

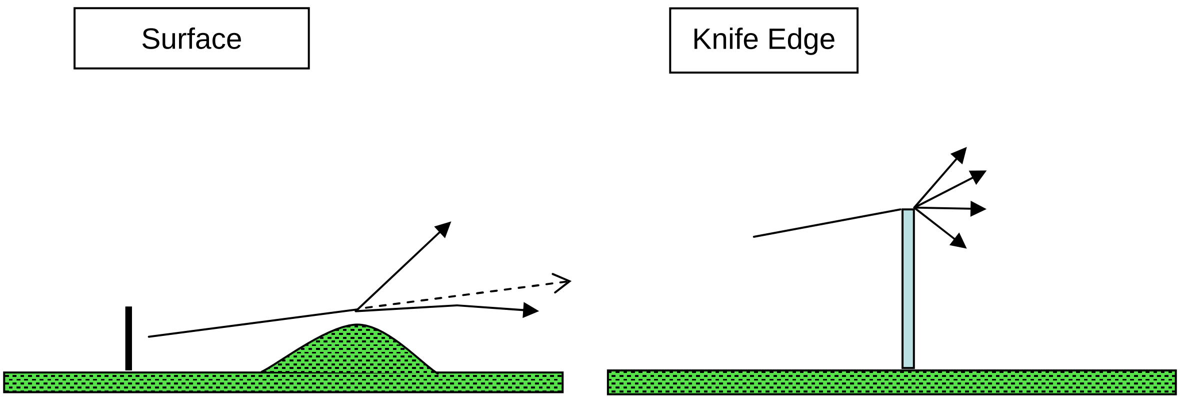
GROUND WAVES
- **SURFACE WAVES**
- **SPACE WAVES**
  - **DIRECT WAVES**
  - **GROUND REFLECTED**

It is normally expected that radio waves will travel in a straight line but in certain conditions, the waves will bend and follow the surface of the earth giving increased ranges.

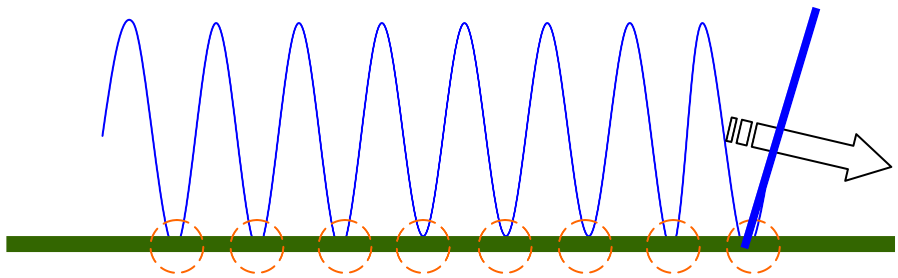


The two primary factors that cause this are diffraction and surface attenuation.

DIFFRACTION describes the scattering of the radio wave as it passes solid objects causing part of the radio wave to pass into the area of shadow. Diffraction increases with longer wavelengths (lower frequencies).



ATTENUATION is simply a loss of energy and velocity. As part of the wave comes in contact with the surface it induces a current in it, thereby losing energy and slowing down. This slowing down of the bottom of the wave gives the waveform a forward and downward tilt encouraging it to follow the curvature of the earth. Waves continue until they are finally attenuated and become undetectable.



ATTENUATION GIVES THE WAVE A DOWNWARD TILT

Attenuation depends on two factors

a. **The type of surface.** Different surfaces have different conductivities. For a given transmission power, a radio wave will give nearly double the range over the sea than over dry soil.
b. **Frequency in use.** The higher the frequency, the greater the attenuation.

As we have no control over the surface over which propagation is to be made, the main consideration in combating attenuation is the frequency. To summarise:

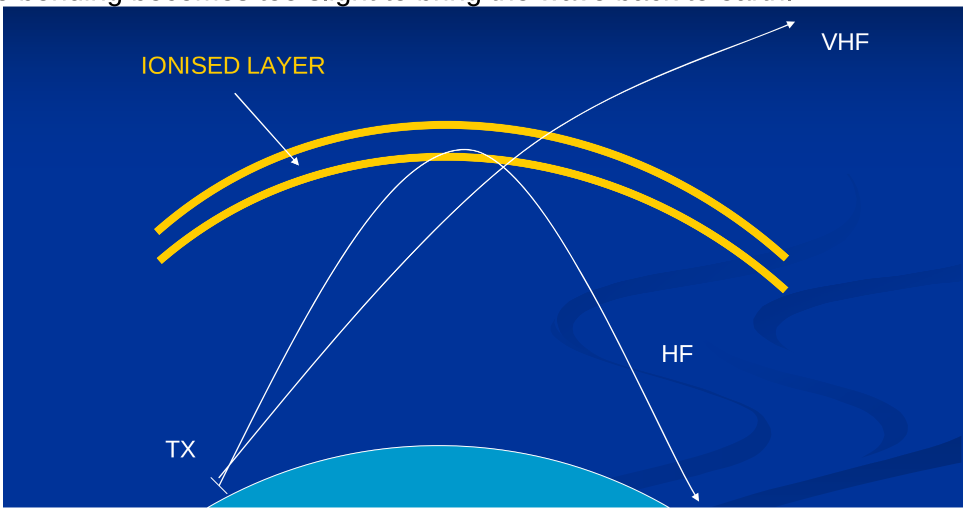
a. VLF. Attenuation is least, maximum bending is due to diffraction. With sufficient power, ranges of several thousand miles may be obtained.
b. LF Minor attenuation permits ranges up to 1500nm.
c. MF Typical ranges are 1000nm over sea and 300nm over land.
d. HF. Severe attenuation, bending is least. Maximum range by surface wave is only 70-100 nm.
e. VHF *and above*. The signals do not bend and the radio waves travel in a straight line, giving line-of-sight ranges.

Surface wave range depends on the power and the frequency. Low frequency transmissions seem ideal in respect of range but there are several disadvantages:

a. **Low efficiency aerials**. Ideally the length of the transmitter and receiver aerials should be equal to the wavelength. Half-wavelength aerials are still acceptable.
b. **Static**. Static is severe in the VLF band and can only be combated by additional power. As the frequency increases, the static decreases. VHF is considered to be practically free from static.
c. **Transmitter Power**. The power required to give satisfactory reception at long range is very large.

SKY WAVES

Sky waves are radio signals which have been bent or refracted sufficiently to return to the earth. The medium that causes such bending is the ionosphere, a region in the upper atmosphere where free ions and electrons exist in sufficient quantity to cause a marked change in the refractive index. Ultra-violet radiation from the sun is considered to be responsible for the ionization. For a given intensity of ionization, the amount of refraction becomes less as the frequency of the radio wave is increased. If the frequency is raised too much, the bending becomes too slight to bring the wave back to earth.

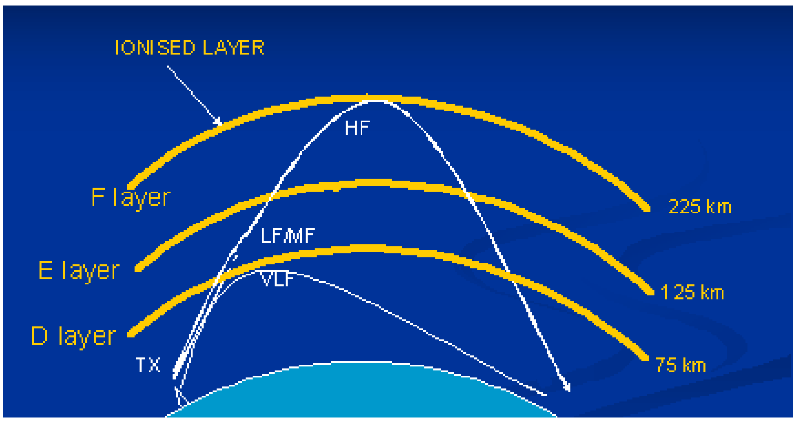


Due to uneven radiation, several distinct layers of the ionosphere have been identified:

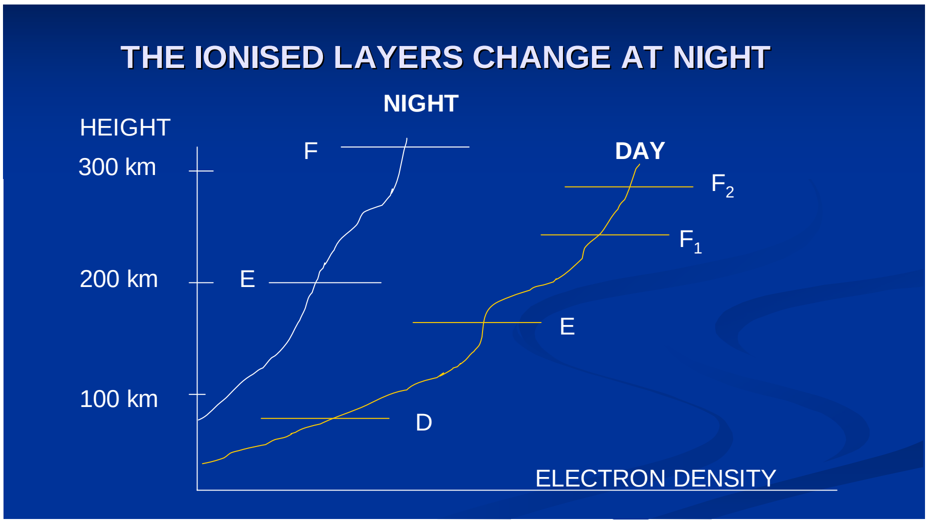
D layer. Average altitude 75 km.

E layer. Average altitude 125 km. Also known as the Kennelly-Heaviside layer. Electron density is higher than in the D layer.

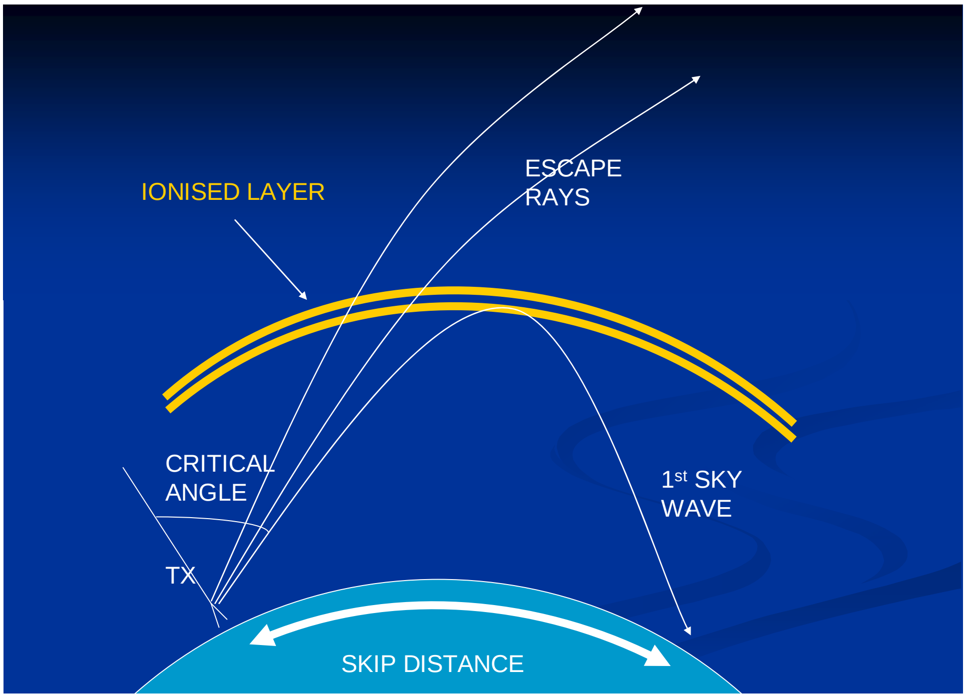
F layer. Average altitude 225 km. Also called the Appleton layer. During the day time it splits up into F1 and F2 layers. Electron density is higher than in the E layer.



During day-time solar radiation increases electron density in all the layers and the height of the refractive layers is reduced. At night the D layer disappears and there is a single F layer.



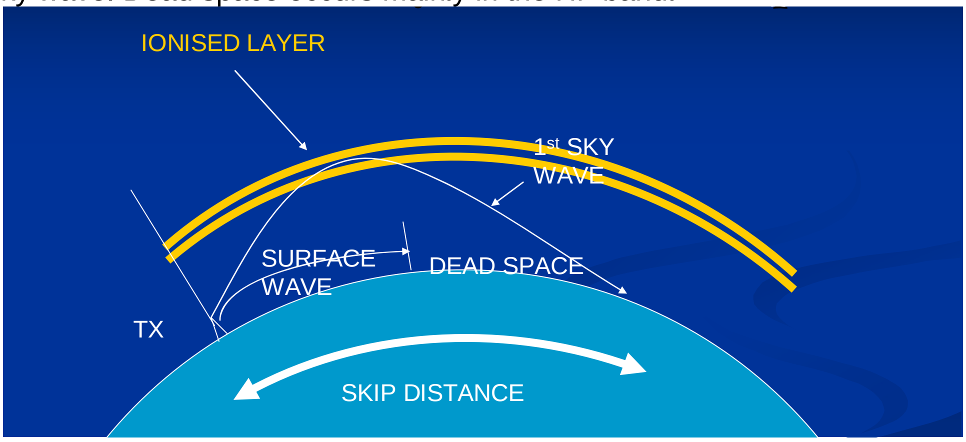
For a given state of the ionosphere, there is a minimum angle measured from the vertical at which a radio wave will refract sufficiently to return to earth. This is known as the CRITICAL ANGLE. The critical angle determines the range at which the first sky wave returns.



With increase in frequency, critical angle increases.

SKIP DISTANCE is the distance between the transmitter and the point where the first sky wave return arrives. For a given frequency this distance varies with the time of the day.

DEAD SPACE is the area between the limit of the surface wave and the point of reception of the first sky wave. Dead space occurs mainly in the HF band.



With increase in frequency, skip distance increases and surface wave range decreases. Dead space therefore increases with increase in frequency.

Skywave propagation varies according to frequency bands:-

FREQ. BAND	DAY	NIGHT
VHF and above	No skywaves	No skywaves
HF	Skywaves from or F_2 layers	Skywaves from F layers
MF and LF	No skywaves	Skywaves from the E layers
VLF	Skywaves from the D layer	Skywaves from the E layer.

HF transmissions which may reflect from the E or F layers lie in the band 3 -30 MHz.
Note that HF communication frequencies lie between 2 and 22 MHz

MAXIMUM RANGE achievable by skywaves depends on:

a. Transmitter power.

b. The state of the ionosphere

c. The frequency transmitted.

d. The quality of the receiver.

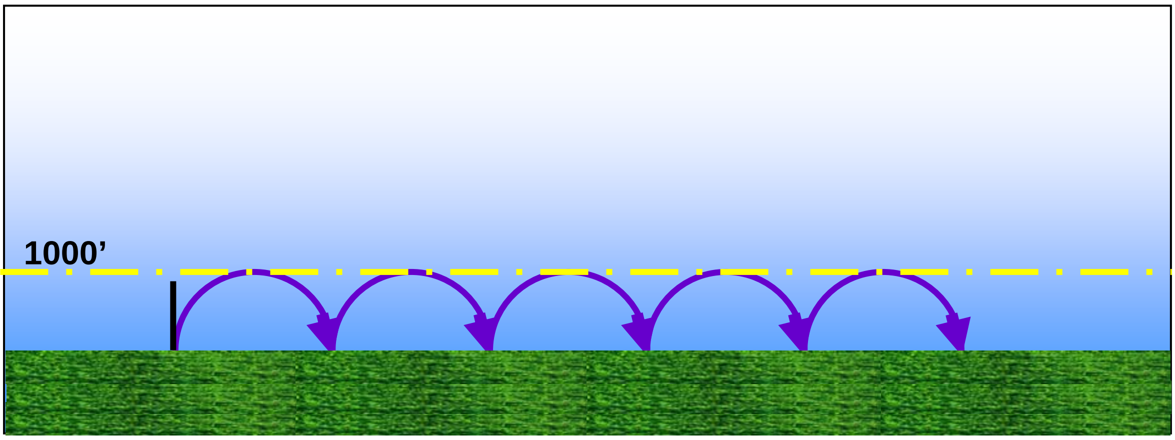
e. The angle of inclination above the horizon (max range when the wave is tangential to the surface of the earth).

PROPAGATION ANOMALIES

In unusual conditions, the propagation of radio waves may not agree with the direct wave, surface wave and skywave models that have been outlined.
In the VHF band and above, ranges may occur which greatly exceed the expected line-of-sight limitation. These increased ranges, which rarely occur in Europe, are associated with DUCT PROPAGATION and result from SUPER-REFRACTION.

For DUCT PROPAGATION the necessary change in the refractive index is most likely:

- when there is a marked temperature inversion
- when there is a decrease in humidity with increase in height.
- at low latitudes – tropical and sub-tropical



DUCT PROPAGATION CAN EXTEND THE RANGE OF RADIO WAVES IN THE FREQUENCY BANDS VHF AND ABOVE

The height of the DUCT is usually no more than 1000 feet above the surface although elevated ducts can occur. Favourable conditions regularly occur in tropical and sub-tropical regions. An example of such conditions is the passage of warm, dry air from a desert to a cool sea.

Duct propagation can affect ground radar, as well as VHF R/T and navigation aids such as VOR and DME. It can result in greatly increased ranges but also can cause interference problems.

SCATTER PROPAGATION describes a phenomenon of minor importance that would allow radio waves in the higher frequency bands to pass between a transmitter and receiver over long distances. It is known that there are regions of turbulence in the atmosphere within which there are changes in the refractive index sufficient to cause a proportion of the radio energy to return to earth. The signal level in the returning radio wave may be very low and so to exploit this form of propagation for communication, highly directive aerials must be used, orientated to transmit or receive energy at a shallow angle. The lower of the regions in which this phenomenon occurs gives rise to TROPOSPHERIC SCATTER. The effect is marked in the UHF band, above 500 MHz and usable transmissions are possible over ranges 300 to 500 km.

WORKSHEET - PROPAGATION

1. The frequency range from 300 kHz to 3 MHz is called the _______ band. Skywave propagation in this band occurs_________.

   (a) LF by night only
   (b) HF by day and by night
   (c) MF by night only
   (d) LF by day and by night

2. In which ionised layer (or layers) will VLF waves be refracted from the base and LF/MF waves be severly attenuated without being appreciably refracted?

   (a) F_1 and F_2
   (b) E
   (c) E and D
   (d) D

3. The ionosphere lies between _____ km and ____km above the earth's surface.

   (a) 5 10
   (b) 25 75
   (c) 25 125
   (d) 50 500

4. To reduce the skip distance of a skywave, a ________ frequency should be used. The associated critical angle will _________.

   (a) higher increase
   (b) lower decrease
   (c) lower increase
   (d) higher decrease

5. Above what frequency do radio waves pass through the ionised layers to escape into space?

   (a) 30 kHz
   (b) 300 kHz
   (c) 3000 kHz
   (d) 30000 kHz

6. Duct propagation is associated with a temperature inversion and a rapid ______ of humidity with increase in height. It occurs in the frequency bands _____ and above.

(a)	increase	VHF
(b)	decrease	HF
(c)	increase	HF
(d)	decrease	VHF

7. What is the minimum altitude at which an aircraft could receive a signal from a VHF transmitter at range 300 km? The transmitter is situated at 280 feet amsl.

(a) 12700 feet
(b) 16500 feet
(c) 32300 feet
(d) 49800 feet

8. In which frequency bands is skywave propagation possible by day and by night?

(a) HF and MF
(b) HF and VLF
(c) MF and LF
(d) MF and VLF

9. The skip distance of an HF transmission depends on:

(i) the power of the transmitter.
(ii) the frequency transmitted
(iii) the time of day

Which of these statements are true?

(a) All are true
(b) (i) and (ii) only are true
(c) (ii) and (iii) only are true
(d) (ii) only is true

10. In which frequency band would you expect maximum surface range to be 70-100 nm?

(a) VLF
(b) LF
(c) MF
(d) HF