Online Radio & Electronics Course

Reading 28

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PROPAGATION

THE IONOSPHERE

The ionosphere is a region of the upper atmosphere extending from a height of about 60 km to greater than 500 km. Within this region some molecules of air become ionised by **ultraviolet radiation** from the sun. The ionised gas within the ionosphere is called plasma.

Ionisation is a process by which electrons, having a negative charge, are stripped from neutral atoms or molecules to form positively charged ions. It is these ions that give their name to the ionosphere. The electrons that have been stripped off are light and free to move. These electrons under the influence of an electromagnetic wave will absorb and re-radiate energy, and modify the direction of an electromagnetic wave front. If the electron density is sufficient, and the frequency of the electromagnetic wave is neither too high nor low, then total wave refraction will occur.

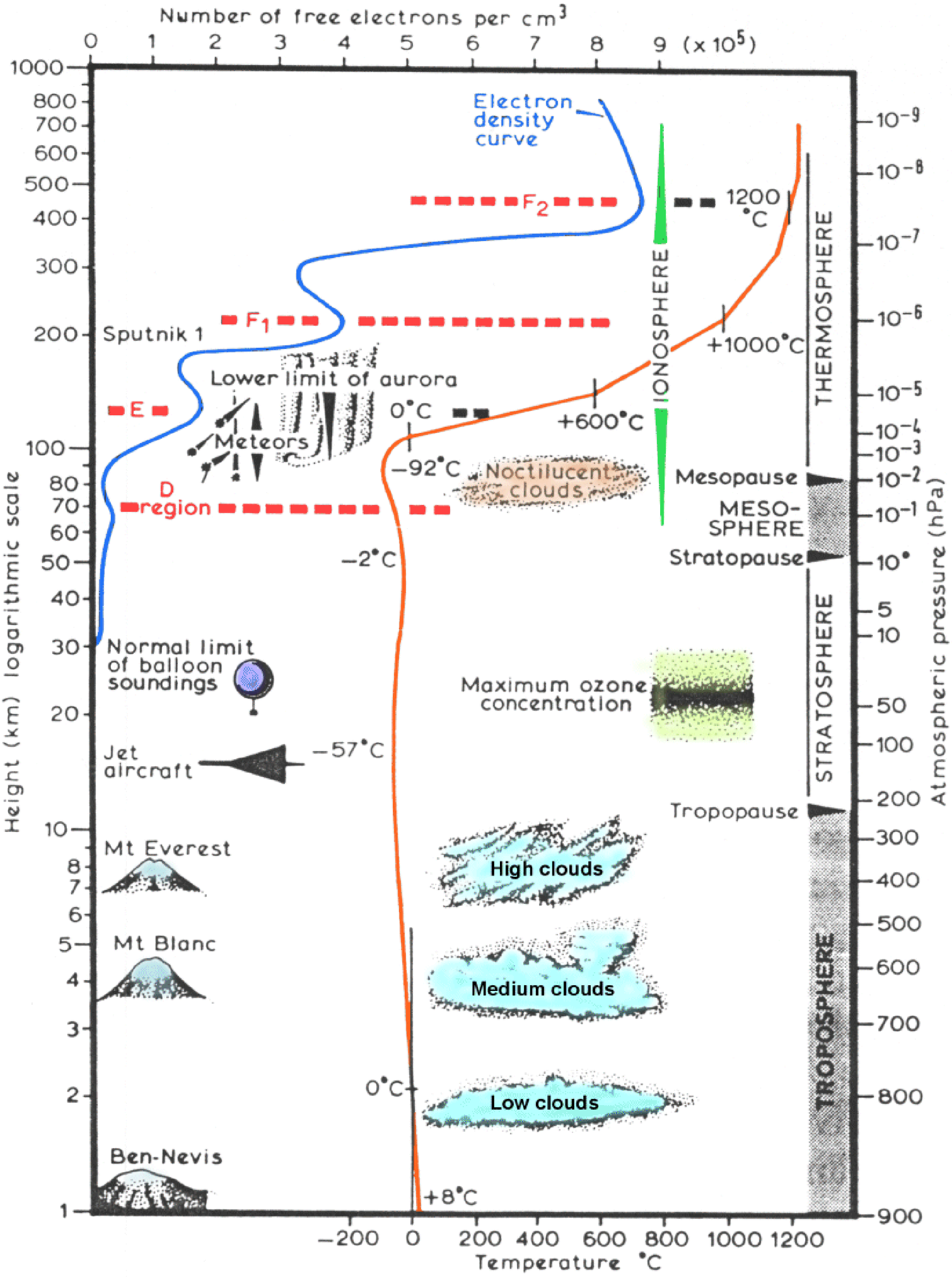
There are four regions of the ionosphere called layers.

D	**60 - 80 km**
E	**80 - 160 km**
F1	**160 - 210 km**
F2	**> 210 km**

The regions of the ionosphere are not sharply defined and merge smoothly from one into the other, each region containing similar chemical and physical properties. Ionisation of the D region is weak because it is low down in the atmosphere**. The D region has the ability to refract signals at low frequencies**. High frequencies pass right through it with only partial attenuation. After sunset the D region disappears rapidly due to recombination of its ions.

The E region is also known as the Kennelly-Heaviside layer. The rate of ionic recombination is rapid after sunset, and the region has usually disappeared by midnight. The E region has the ability to refract signals of higher frequency than those refracted by the D region. In fact the E region can refract signals as high as 20 MHz.

Figure 1.


Number of free electrons per cm^3
0
1
2
3
4
5
6
7
8
9 (x 10^5)
1000
800
700
600
500
400
300
200
100
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
Height (km) logarithmic scale
Electron density curve
F$_2$
1200 °C
F$_1$
Sputnik 1
+1000°C
Lower limit of aurora
E
0°C
+600°C
Meteors
IONOSPHERE
THERMOSPHERE
–92°C
Noctilucent clouds
D region
Mesopause
MESO-SPHERE
–2°C
Stratopause
Normal limit of balloon soundings
Maximum ozone concentration
STRATOSPHERE
Jet aircraft
–57°C
Tropopause
Mt Everest
High clouds
Mt Blanc
Medium clouds
TROPOSPHERE
0°C
Low clouds
Ben-Nevis
+8°C
–200
0
200
400
600
800
1000
1200
Temperature °C
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
5
10
50
100
200
300
400
500
600
700
800
900
Atmospheric pressure (hPa)

During **daylight hours** the F region separates into two distinct regions called the F1 and F2. The ionisation levels in these regions can be quite high, and varies greatly depending upon the degree of ultraviolet radiation from the sun, which in turn is primarily determined by the altitude of the sun (ie. time of day). At the height of the F region the density of the atmosphere is low, and because of this, recombination of ions occurs slowly after sunset. **The F2 region will remain throughout the night at a fairly constant ionisation level.** The F regions are responsible for long-distance communications due to their ability to refract signals up to **30 MHz,** and also due to the long skip distance provided by refraction from such a high elevation.

CAUSES OF IONISATION

Two kinds of **solar radiation** cause ionisation in the ionosphere, namely x-rays and extreme ultraviolet (EUV). The x-ray output from the sun is irregular, increasing greatly during large **solar flares**. However by far, the most important ionisation radiation is EUV, it is generated by the chromosphere in hot plage regions that overlie sunspot groups. At any time the EUV output from the sun is approximately constant, but varies from month to month and year to year, as the number of sunspots vary.

The most important slow changing factor in high frequency (HF) propagation prediction is the **11-year sunspot cycle**. Solar activity follows a cycle, which has a period of 11 years. The best indication of solid activity is the sunspot number. Sunspots are always accompanied by plage areas, which are the source of extreme ultraviolet radiation. It has been found that the solar radio flux at a wavelength of 10.7 cm (10 cm flux) is closely related to the sunspot number, and is more easily measured. The sunspot number and the 10 cm flux may vary greatly from day to day, so that monthly or yearly averages are usually employed to show the progress of the solar cycle.

GRAPH OF THE SUNSPOT CYCLES

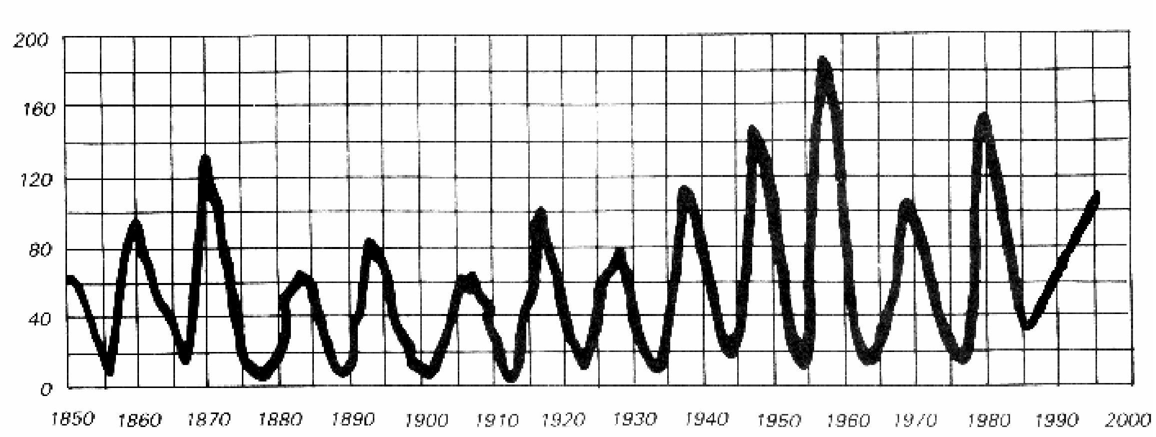


Figure 2.

SPORADIC-E

Sporadic-E layers are only a few kilometres thick and can have peak electron density comparable to the F regions maximum density. Sporadic-E layers, like the higher F Layer, are very efficient reflectors of HF signals. Sporadic-E is formed mainly by the concentration of winds of ions and electrons into a thin layer. At mid-latitudes sporadic-E is most prevalent during summer and at midday. In the equatorial zone it is nearly always present at midday.

CRITICAL FREQUENCY - MAXIMUM USABLE FREQUENCY - ABSORPTION LIMITING FREQUENCY

At vertical incidence (straight-up), the highest frequency which an ionospheric layer will reflect is called the **critical frequency** (fc).

The highest frequency which is returned to earth at a given angle of radiation is called the **maximum usable frequency** (MUF).

The **absorption limiting frequency** is the lowest frequency for reliable radio communication via the ionosphere.

Operating a radio transmitter right on the MUF will not produce the most reliable communications, as the precise MUF does fluctuate somewhat. The **optimum working frequency** is the one that provides the most consistent communications. For transmission using the F2 region, the optimum working frequency is about **85% of the MUF**. However, when the E layer is used, propagation is quite consistent if a frequency very near but less than the MUF is used. Since ionospheric attenuation of radio waves is inversely proportional to frequency, using a frequency as close to the MUF as possible results in the maximum signal strength.

VIRTUAL HEIGHT

The virtual height is the height of the ionosphere when regarded as a plane surface reflector such as a mirror.

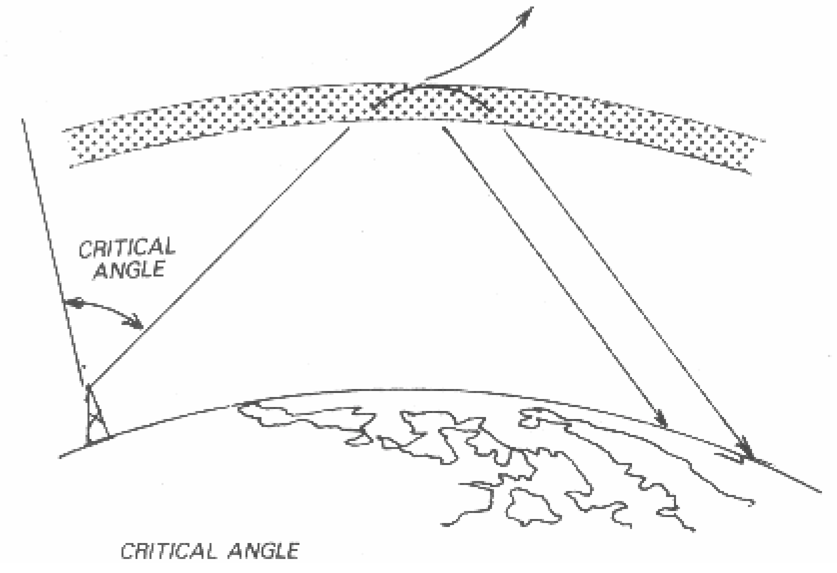
Until it reaches the ionosphere a radio wave propagates in a straight line. Once in the ionosphere it is *refracted* back to earth. **Refraction is a process whereby the wave front is slowly bent downward toward the earth**. Although a wave is actually refracted in the ionosphere, it is permissible to substitute a simple triangular path for the real ray path, as if the ray were mirror-reflected. Radio waves are often spoken of as being reflected from the ionosphere, when in fact they are refracted.

WHY THE CRITICAL ANGLE IS SO IMPORTANT

The critical angle is the angle measured between the wavefront incident on the ionosphere and a line extended to the centre of the earth. For each frequency there is a critical angle, and if the wavefront arriving at the ionosphere is less than the critical angle then wave refraction will not occur.

The shortest distance through an ionospheric region is when the wavefront strikes the region at vertical incidence. The **critical frequency is the highest frequency returned to earth when the wave is transmitted at vertical incidence**. However, if the wavefront strikes the ionosphere

Figure 3.



obliquely then the apparent depth of the region is greater, and frequencies higher than the critical frequency will be returned to the earth. For any particular frequency higher than the critical frequency there will be a minimum critical angle if refraction is to take place. A critical angle of zero corresponds to vertical incidence.

GROUND WAVE

Ground wave is the wavefront, which upon leaving the antenna, propagates close to the earth's surface. Severe signal losses due to ground conductivity limits the range of ground waves to about 100 km overland and 300 km over water for the lowest HF frequencies. The higher the frequency, the shorter the ground wave coverage of the transmitter.

SKIP DISTANCE

The skip distance is the distance from the transmitter to where sky wave first returns to the earth. Within the skip distance only ground wave communication is possible. The skip distance is shorter for lower operating frequencies. Between the point where the ground wave ends and the point where the sky wave first returns to earth, no signals will be heard. This area is called the **skip zone**. It is very important to remember, as it seems to be a favourite of the examiner to test you out on this one. The skip zone is a no signal area.

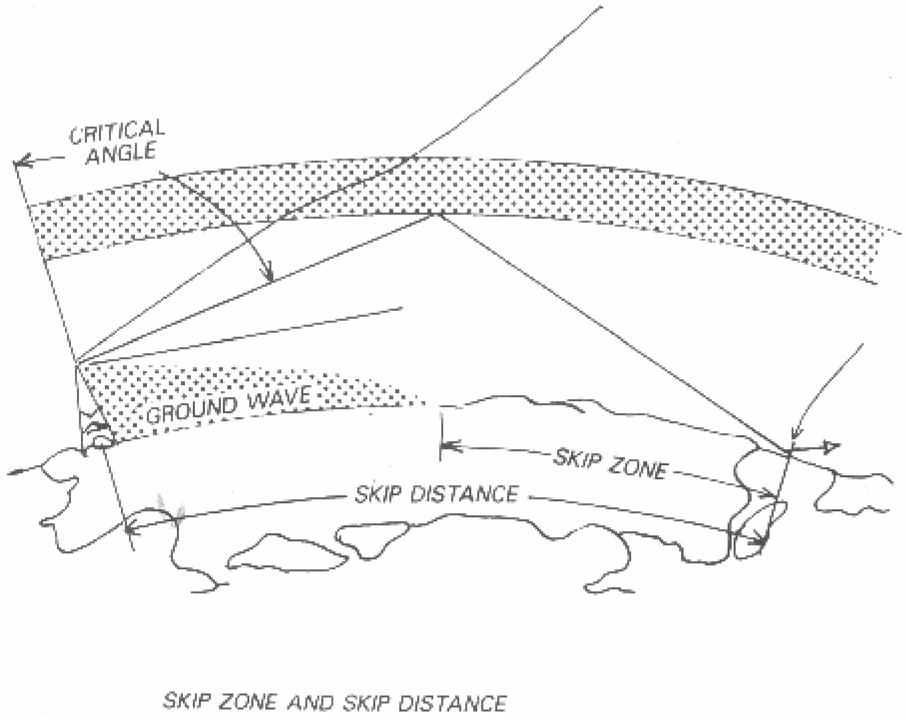


Figure 4.

FACTORS EFFECTING SKIP DISTANCE

The main factors affecting range are: frequency, radiation angle, and the height of the reflecting region.

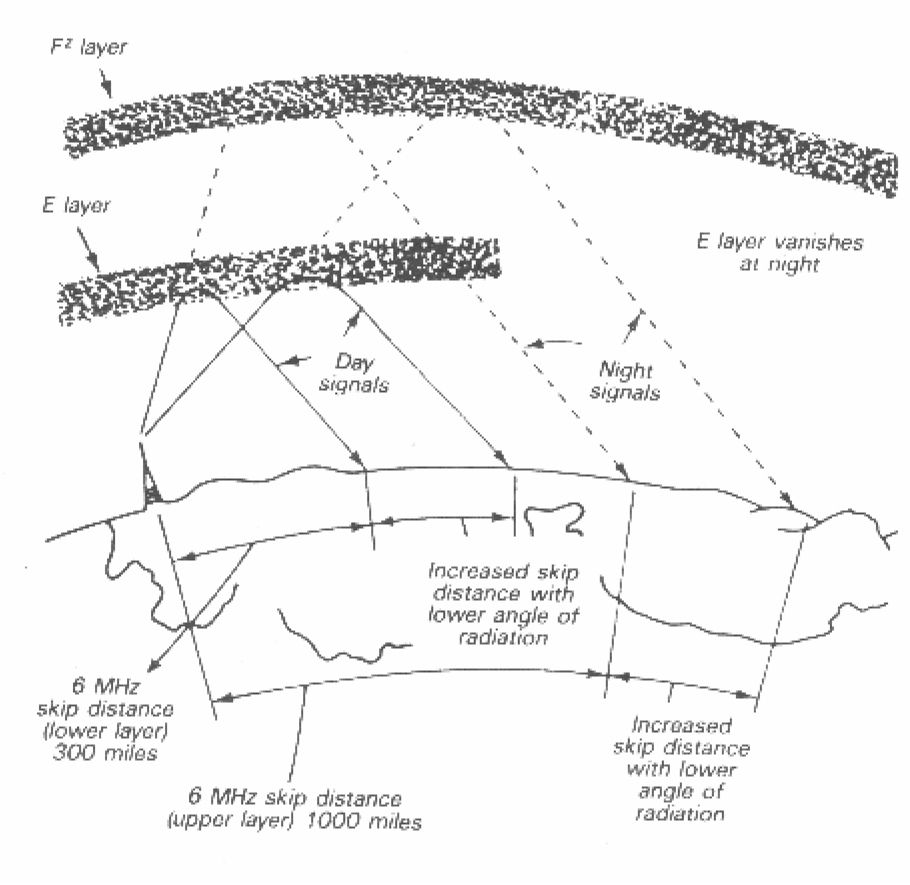


Figure 5.

If the height of the reflecting region is increased then the skip distance will increase. As the frequency of the transmission is increased the skip distance will increase until the frequency exceeds the MUF, above which the signal is not refracted back to earth.

If the angle of radiation above the earth's surface is increased, then the skip distance is decreased. If the transmission frequency is greater than the critical frequency, then making the angle of radiation too high will cause the wave front to penetrate the refracting region.

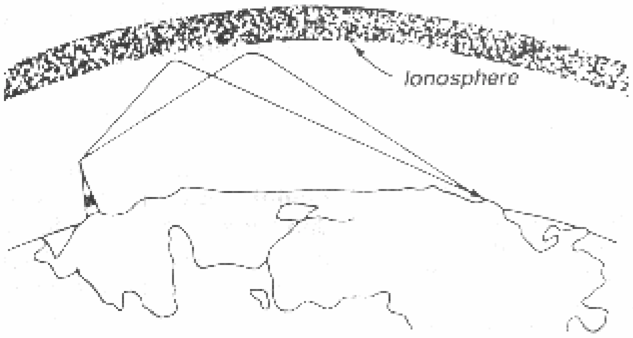
LONG-DISTANCE COMMUNICATIONS ABOVE THE HF

Temperature inversions in the earth's troposphere make it possible for radio waves to be ducted or guided over large distances. This mode of propagation is called **tropospheric ducting**.

The troposphere is the layer of the atmosphere that lies directly above the surface of the earth, it extends to a height of about 10.5 km. Under normal conditions the density of the troposphere is higher near the surface of the earth and becomes progressively lower at higher altitudes. **A temperature inversion occurs when a pocket of warm air is trapped above cool air**. Instead of a gradual changing density, abrupt changes occur, making complete refraction possible. The refracted wave does not travel back to earth; it is refracted back and forth by both boundaries on each side of the layer of warm air. The trapping medium is called a **tropospheric duct**. In order to use the duct both transmitting and receiving antennas must be within the duct.

FADING

Fading can be broken down into two main categories: **multiple path reception and selective fading**. Multiple path reception occurs when signals arrive at the receiving antenna by more than one path. No path length is exactly the same from one moment to the next due to the dynamic nature of the ionosphere.

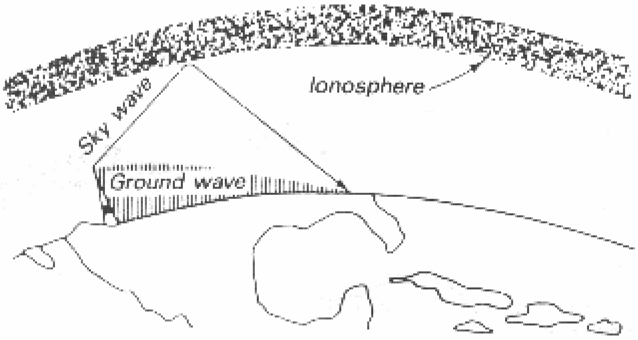


Fading caused by two sky waves.

Figure 6.

Multi-path signals may arrive in-phase one moment and produce signal enhancement, and the next moment may arrive out-of-phase and produce, at times, total cancellation. Under such conditions the received signal may fluctuate wildly. **Selective fading occurs when individual frequency components undergo different amounts of refraction at the ionosphere** to such an extent that some of the frequency components may not arrive at the receiving antenna.

Multiple path reception occurs when the sky wave returns to the earth within the ground wave region of the transmitter. Since ground wave coverage does not extend far, this type of fading only occurs when the skip distance is short. This effect is most noticeable in the 160 metre amateur band. AM broadcasts stations frequently employ 5/9 wavelength antennas. Antennas of this wavelength have a radiation angle which provides a skip distance that falls outside the ground wave coverage area, thus avoiding fade at the ground wave/sky wave boundary.



Fading when ground wave meets sky wave.

Figure 7.

Fading due to multiple path reception can occur when the signals arriving at the receiving antenna travel by different ionospheric regions, or when signal reflection from a large object such as a man-made structure or a mountain range is involved.

Because a **single** radio transmission consists of a band of frequencies, then it is possible for a group of frequencies **within the signal bandwidth** to be refracted by a greater or lesser amount. This can result in some signal components not arriving at the receiving antenna - this phenomena is called selective fading. Expectedly, the signals of wider bandwidth are more susceptible to selective fading. A double side band signal (AM) is more likely to suffer selective fading than a single side band signal (SSB) due to it wider bandwidth. An unmodulated telegraphy signal will not experienced any selective fading. One classic example of this phenomenon is the well known high school physics experiment using a light beam from a torch and a prism; the different colours (frequencies) are seen to be refracted by different amounts. Sunlight through water droplets undergoes selective refraction and creates a rainbow.

There is much more to propagation than has been covered in this reading, however you have all you need here for examination purposes. Radio wave propagation is a fascinating subject and a bit of a science in itself.

We are now (at time of writing) going into a time of high sunspot activity, a great time for HF radio communication. The peak should occur around the year 2000 and stay with us for quite a while.

I have written a more in-depth article about sunspots and their history and prediction, or should I say unpredictability! There are mysterious coincidences in earth's history, which have been associated with sunspot activity, drought, ice ages, and the like. If I am able I will make the reading available as an optional reading. There have also been some potentially environmentally disastrous attempts to alter the ionosphere by the military using extremely high power ionising energy to create an ionised layer. The most notable experiment was the exploding at high altitude of a bomb, which released billions of small metal particles in the hope of engineering the ionosphere.

HF (ionospheric) propagation is crucial and will always be so. In the event of war, communication satellites and submarine cables would be one of the first things to go, leaving nothing but HF communications.

End of Reading 28.
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