Introduction to HF Radio Propagation

1. The Ionosphere

1.1 The Regions of the Ionosphere

In a region extending from a height of about 50 km to over 500 km, some of the molecules of the atmosphere are ionised by radiation from the Sun to produce an ionised gas. This region is called the ionosphere, figure 1.1.

Ionisation is the process in which electrons, which are negatively charged, are removed from (or attached to) neutral atoms or molecules to form positively (or negatively) charged ions and free electrons. It is the ions that give their name to the ionosphere, but it is the much lighter and more freely moving electrons which are important in terms of high frequency (HF: 3 to 30 MHz) radio propagation. Generally, the greater the number of electrons, the higher the frequencies that can be used.

During the day there may be four regions present called the D, E, F1 and F2 regions. Their approximate height ranges are:

- D region 50 to 90 km;
- E region 90 to 140 km;
- F1 region 140 to 210 km;
- F2 region over 210 km.

During the daytime, sporadic E (section 1.6) is sometimes observed in the E region, and at certain times during the solar cycle the F1 region may not be distinct from the F2 region but merge to form an F region. At night the D, E and F1 regions become very much depleted of free electrons, leaving only the F2 region available for communications; however it is not uncommon for sporadic E to occur at night.

Only the E, F1, sporadic E when present, and F2 regions refract HF waves. The D region is important though, because while it does not refract HF radio waves, it does absorb or attenuate them (section 1.5).

The F2 region is the most important region for high frequency radio propagation as:

- it is present 24 hours of the day;
- its high altitude allows the longest communication paths;
- it usually refracts the highest frequencies in the HF range.

The lifetime of electrons is greatest in the F2 region which is one reason why it is present at night. Typical lifetimes of electrons in the E, F1 and F2 regions are 20 seconds, 1 minute and 20 minutes, respectively.

Because the F1 region is not always present and often merges with the F2 region, it is not normally considered when examining possible modes of propagation. Throughout this report, discussion of the F region refers to the F2 region.

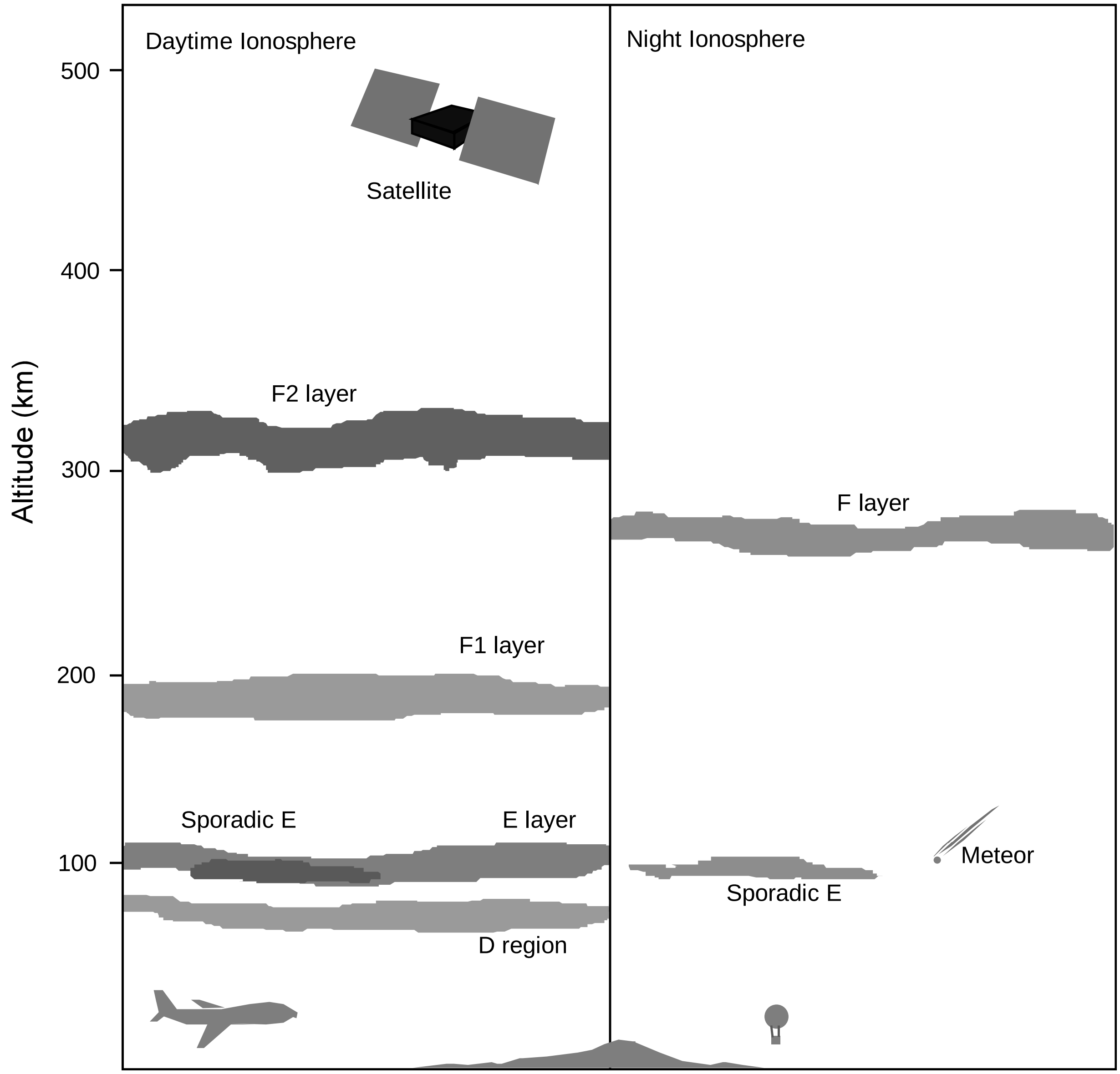


Figure 1.1 Day and night structure of the ionosphere.

1.2 Production and Loss of Electrons

Radiation from the Sun causes ionisation in the ionosphere. Electrons are produced when this radiation collides with uncharged atoms and molecules, figure 1.2. Since this process requires solar radiation, production of electrons only occurs in the daylight hemisphere of the ionosphere.

When a free electron combines with a charged ion a neutral particle is usually formed, figure 1.3. Essentially, loss is the opposite process to production. Loss of electrons occurs continually, both day and night.

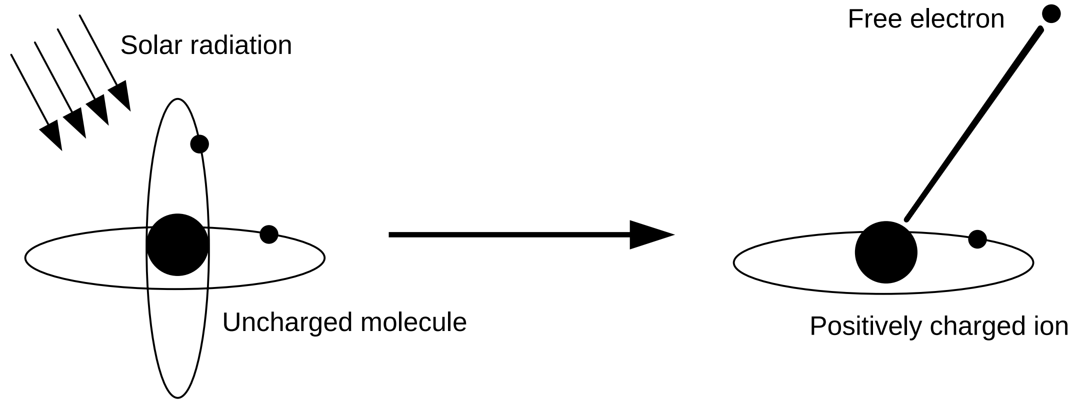


Figure 1.2 Production.

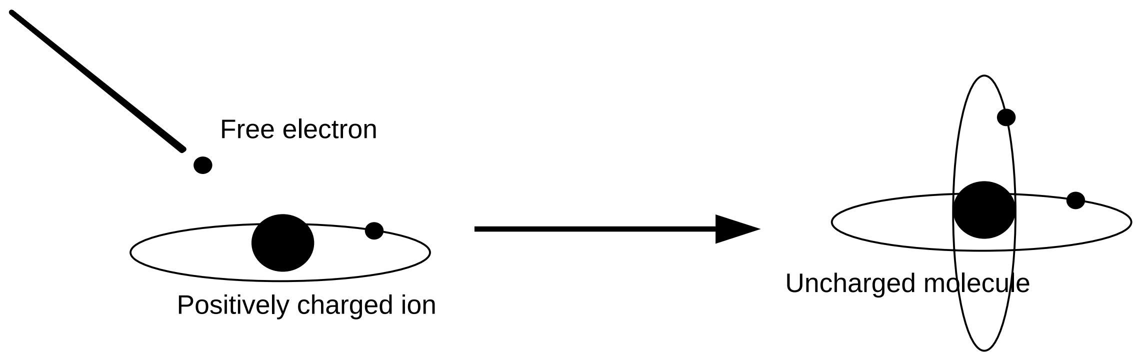


Figure 1.3 Loss.

1.3 Observing the Ionosphere

The most important feature of the ionosphere in terms of radio communications is its ability to refract radio waves. However, only those waves within a certain frequency range will be refracted. The range of frequencies refracted depends on a number of factors (section 1.4). Various methods have been used to investigate the ionosphere, and the most widely used instrument for this purpose is the ionosonde, figure 1.4. Note that many references to ionospheric communications speak of reflection of the wave. It is, however, a refraction process.

An ionosonde is a high frequency radar which sends very short pulses of radio energy vertically into the ionosphere. If the radio frequency is not too high, the pulses are refracted back towards the ground. The ionosonde records the time delay between transmission and reception of the pulses. By varying the oscillation frequency of the pulses, a record is obtained of the time delay at different frequencies.

Frequencies less than about 1.6 MHz are interfered with by AM broadcast stations. As the frequency is increased, echoes appear first from the lower E region and subsequently, with greater time delay, from the F1 and F2 regions. Of course, at night echoes are returned only from the F2 region and possibly sporadic E since the other regions have lost most of their free electrons.

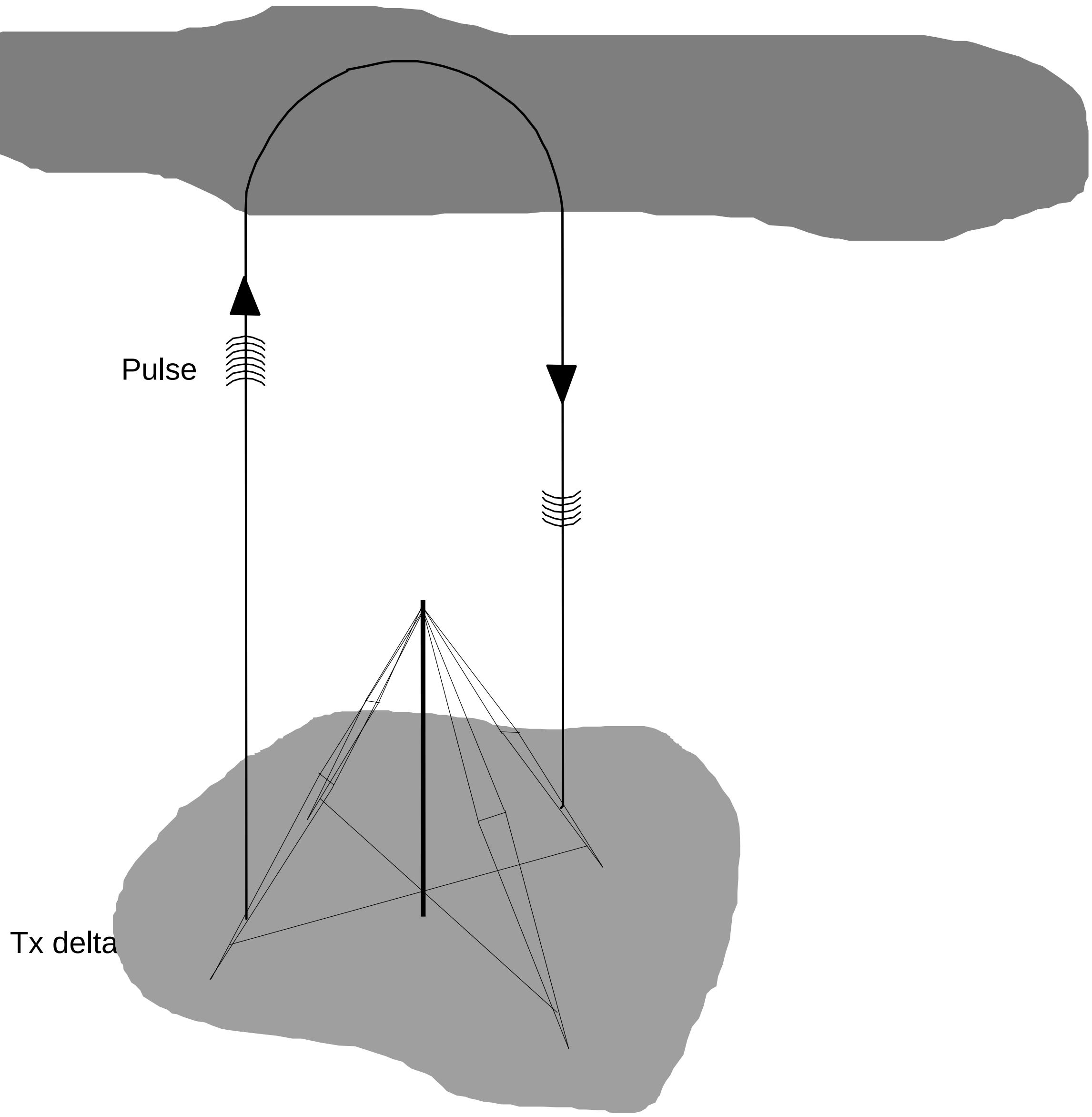


Figure 1.4 Ionosonde operation.

Today, the ionosphere is "sounded" not only by signals sent up at vertical incidence. Oblique sounders send pulses of radio energy obliquely into the ionosphere (the transmitter and receiver are separated by some distance). This type of sounder can monitor propagation on a particular circuit and observations of the various modes being supported by the ionosphere can be made. Backscatter ionosondes rely on echoes reflected from the ground and returned to the receiver, which may or may not be at the same site as the transmitter. This type of sounder is used for over-the-horizon radar.

1.4 Ionospheric Variations

The ionosphere is not a stable medium that allows the use of one frequency over the year, or even over 24 hours. The ionosphere varies with the solar cycle, the seasons, the circuit and during any given day. So, a frequency which may provide successful propagation now, may not do so an hour later.

1.4.1 Variations due to the Solar Cycle

The Sun goes through a periodic rise and fall in activity which affects HF communications; solar cycles vary in length from 9 to 14 years. At solar minimum, only the lower frequencies of the HF band will be supported by the ionosphere, while at solar maximum the higher frequencies will successfully propagate, figure 1.5. 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.

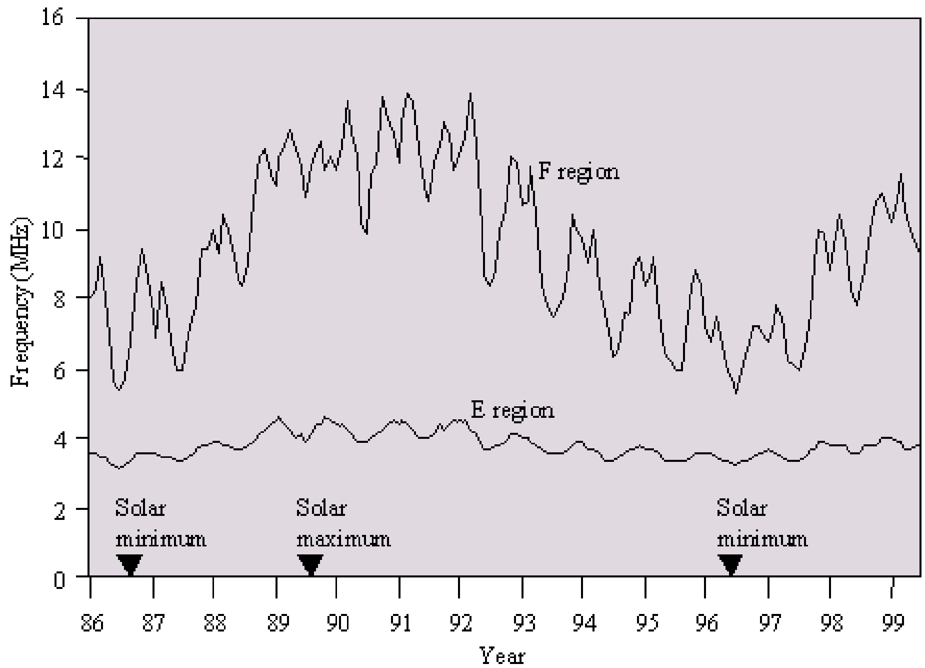


Figure 1.5 The relationship between solar cycles and E and F region frequencies at Townsville. Dotted vertical lines indicate start of each year. Note also the seasonal variations

There are other consequences of the solar cycle. Around solar maximum there is a greater likelihood of large solar flares occurring. Flares are huge explosions on the Sun which emit radiation that ionises the D region causing increased absorption of HF waves. Since the D region is present only during the day, only those communication paths which pass through daylight will be affected. The absorption of HF waves travelling via the ionosphere after a flare has occurred is called a short wave fade-out (section 3.1). Fade-outs occur instantaneously and affect lower frequencies the most. Lower frequencies are also the last to recover. If it is suspected or confirmed that a fade-out has occurred, it is advisable to try using a higher frequency, if possible. The duration of fade-outs can vary between about 10 minutes to over an hour depending on the duration and intensity of the flare.

1.4.2 Seasonal Variations

E region frequencies are greater in summer than winter, figure 1.5. However, the variation in F region frequencies is more complicated. In both hemispheres, F region noon frequencies generally peak around the equinoxes (March and September). Around solar minimum the summer noon frequencies are, as expected, generally greater than those in winter, but around solar maximum winter frequencies tend to be higher than those in summer. In addition, frequencies around the equinoxes (March and September) are higher than those in summer or winter for both solar maximum and minimum. The observation of winter frequencies often being greater than those in summer is called the seasonal anomaly (this is not observed in figure 1.5).

1.4.3 Variations with Latitude

Figure 1.6 shows the variations in the E and F region frequencies at noon and midnight from the pole to the equator. During the day, with increasing latitude, the solar radiation strikes the atmosphere more obliquely, so the intensity of radiation and the electron density production decreases with increasing latitude.

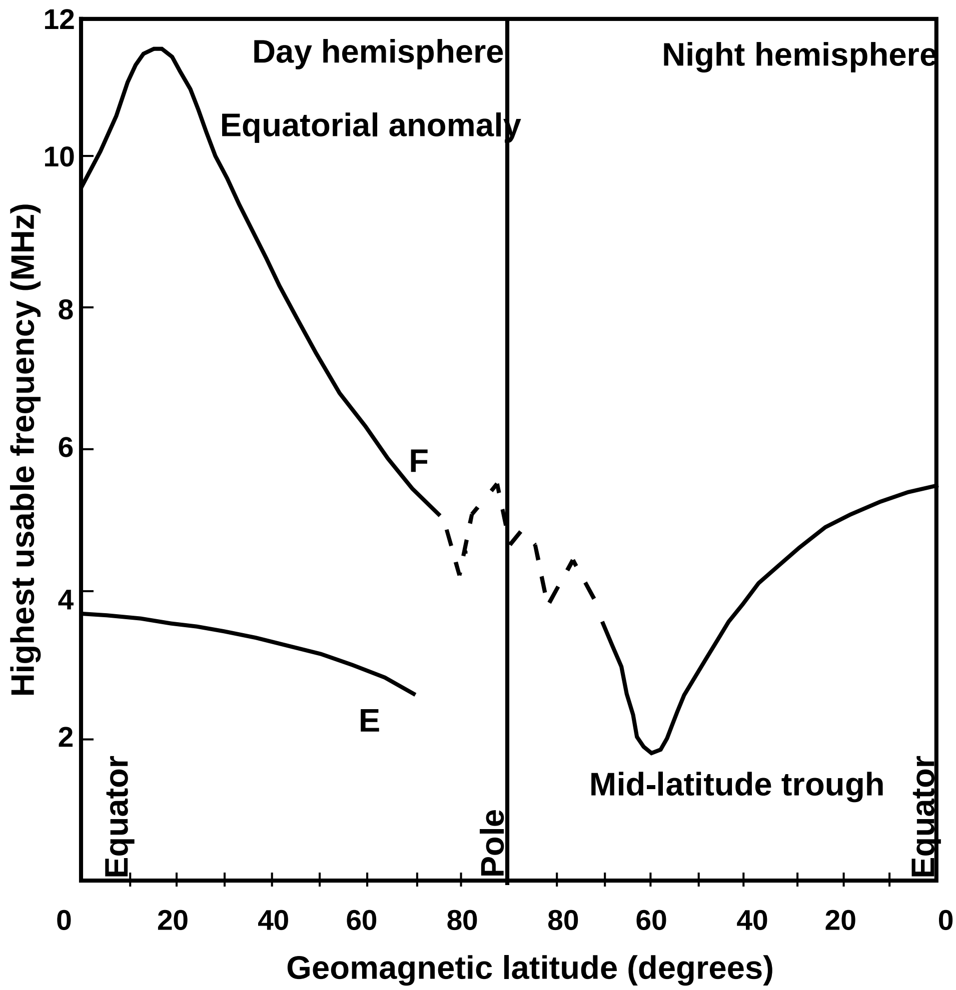


Figure 1.6 Latitudinal variations.

Note in figure 1.6 how the daytime F region frequencies peak not at the magnetic equator, but 15 to 20° north and south of it. This is called the equatorial anomaly. At night, frequencies reach a minimum around 60° latitude north and south of the geomagnetic equator. This is called the mid-latitude trough. Communicators who require communications near the equator during the day and around 60° latitude at night, should be aware of these characteristics. For example, from Figure 1.6 one can see how rapidly the frequencies can change with latitude near the mid-latitude trough and equatorial anomaly, so a variation in the refraction point near these by a few degrees may lead to quite a variation in the frequency supported.

1.4.4 Daily Variations

Frequencies are normally higher during the day and lower at night, Figure 1.7. With dawn, solar radiation causes electrons to be produced in the ionosphere and frequencies increase reaching their maximum around noon. During the afternoon, frequencies begin falling due to electron loss and with darkness the D, E and F1 regions disappear. So, communication during the night is by the F2 region and absorption of radio waves is lower. Through the night, frequencies gradually decrease, reaching their minimum just before dawn.

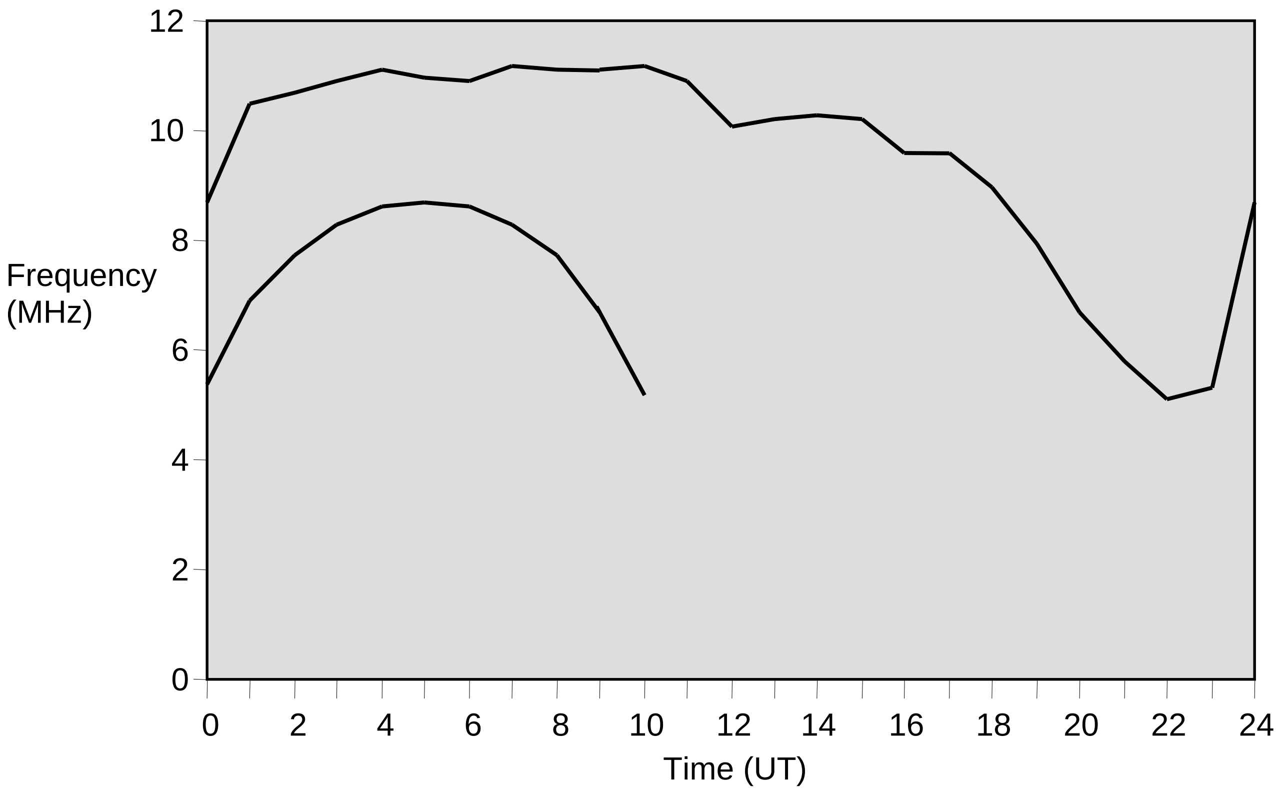


Figure 1.7 E and F layer frequencies for a Singapore to Ho Chi Minh circuit sometime in a solar cycle.

1.5 Variations in Absorption

Absorption was discussed in section 1.4.1 when describing how solar flares can cause disruptions or degradations to communication paths which pass through daylight. Absorption in the D region also varies with the solar cycle, being greatest around solar maximum. Signal absorption is also greater in summer and during the middle of the day, figure 1.8. There is a variation in absorption with latitude, with more absorption occurring near the equator and decreasing towards the poles. Lower frequencies are absorbed to a larger extent, so it is advisable to use as high a frequency as possible, particularly during the day when absorption is greatest.

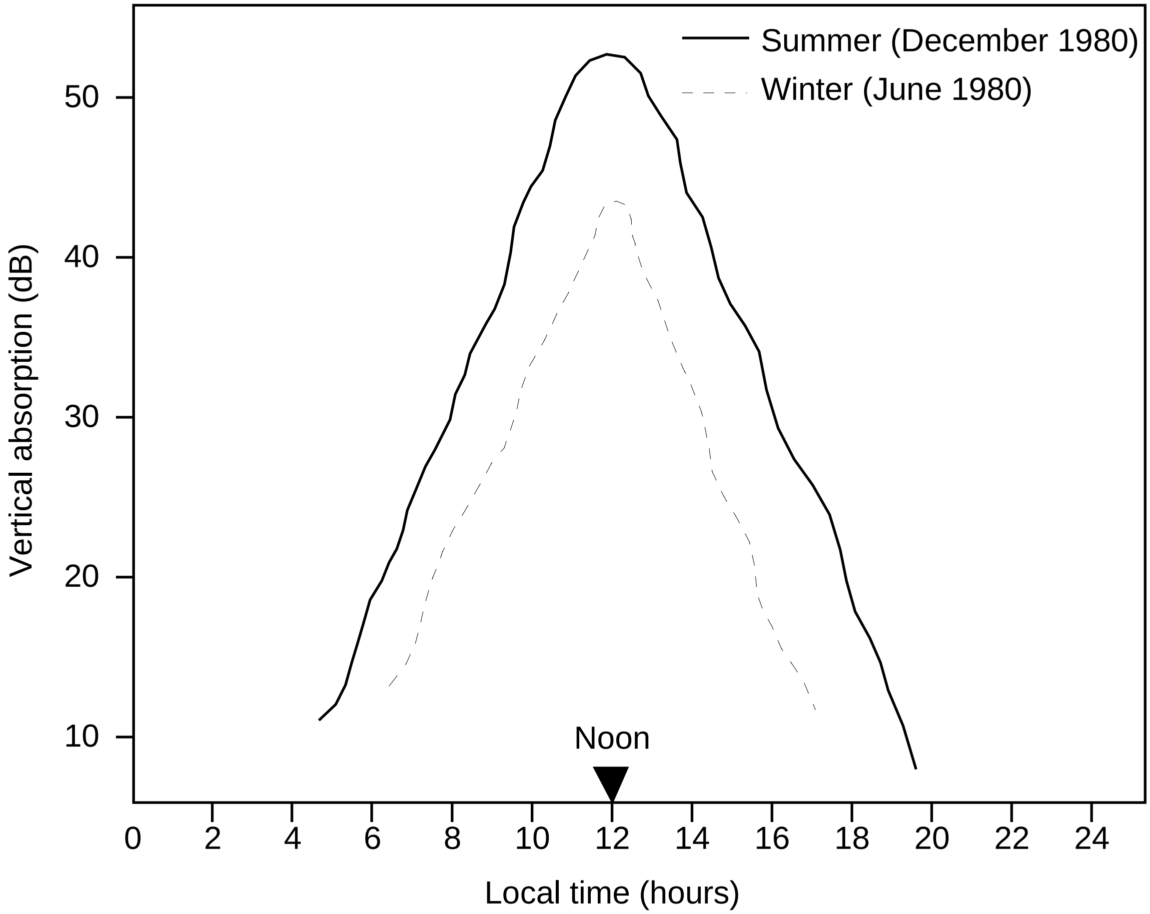


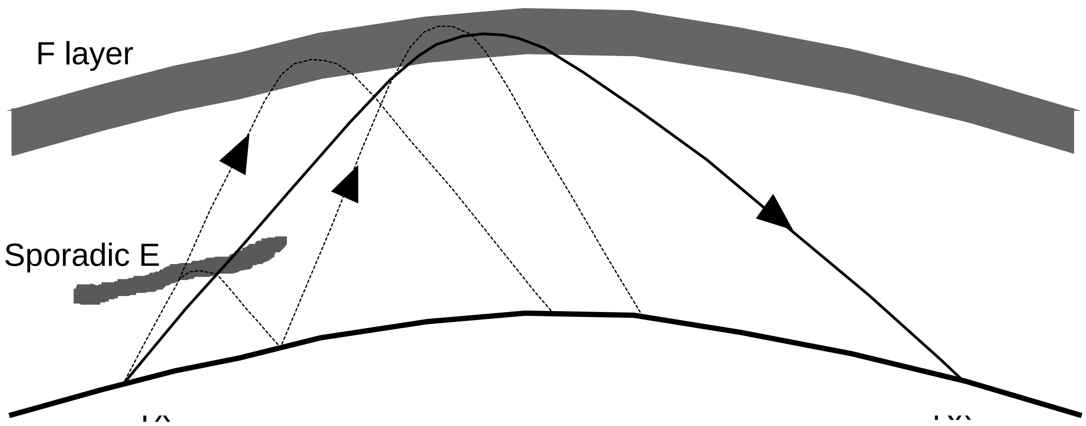
Figure 1.8 Daily and seasonal variations in absorption at Sydney, 2.2 MHz.

Around the polar regions absorption can affect communications quite dramatically at times. Sometimes high energy protons ejected from the Sun during large solar flares will move down the Earth's magnetic field lines and into the polar regions. These protons can cause increased absorption of HF radio waves as they pass through the D region. This increased absorption may last for as long as 10 days and is called a Polar Cap Absorption event (PCA), section 3.2.

1.6 Sporadic E

Sporadic E may form at any time during the day or night. It occurs at altitudes between 90 to 140 km (the E region), and may be spread over a large area or be confined to a small region. It is difficult to know where and when it will occur and how long it will persist. Sporadic E can have a comparable electron density to the F region. This implies that it can refract comparable frequencies to the F region. Sometimes a sporadic E layer is transparent and allows most of the radio wave to pass through it to the F region, however, at other times the sporadic E layer obscures the F region totally and the signal does not reach the receiver (sporadic E blanketing). If the sporadic E layer is partially transparent, the radio wave is likely to be refracted at times from the F region and at other times from the sporadic E. This may lead to partial transmission of the signal or fading, figure 1.9.

Sporadic E in the low and mid-latitudes occurs mostly during the daytime and early evening, and is more prevalent during the summer months. At high latitudes, sporadic E tends to form at night.



Signal partially transmitted by sporadic E and partially by the F layer. Any received signal may be weak or fade.

Wave passes through sporadic E and is refracted by the F layer.

Figure 1.9 Some possible paths when sporadic E is present. The ground reflection will depend on the strength of the signal and other factors such as ground type.

1.7 Spread F

Spread F occurs when the F region becomes diffuse due to irregularities in that region, which scatter the radio wave. The received signal is the superposition of a number of waves refracted from different heights and locations in the ionosphere at slightly different times. At low latitudes, spread F occurs mostly during the night hours and around the equinoxes. At mid-latitudes, spread F is less likely to occur than at low and high latitudes. Here it is more likely to occur at night and in winter. At latitudes greater than about 40°, spread F tends to be a night time phenomenon, appearing mostly around the equinoxes, while around the magnetic poles, spread F is often observed both day and night. At all latitudes there is a tendency for spread F to occur when there is a decrease in F region frequencies. That is, spread F is often associated with ionospheric storms (section 3.3).

2. HF Communications

2.1 Types of HF Propagation

High Frequency (3 to 30 MHz) radio signals can propagate to a distant receiver, Figure 2.1, via the:

- ground wave: near the ground for short distances, up to 100 km over land and 300 km over sea. Attenuation of the wave depends on antenna height, polarisation, 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 polarisation;
- sky wave: refracted by the ionosphere, all distances.

2.2 Frequency Limits of Sky Waves

Not all HF waves are refracted by the ionosphere, there are upper and lower frequency bounds for communications between two terminals. If the frequency is too high, the wave will penetrate the ionosphere, if it is too low, the strength of the signal will be lowered due to absorption in the D region. The range of usable frequencies will vary:

- throughout the day;
- with the seasons;
- with the solar cycle;
- from place to place;

depending on the ionospheric region used for communications. While the upper limit of frequencies varies mostly with these factors, the lower limit is also dependent on receiver site noise, antenna efficiency, transmitter power, E layer screening (section 2.6) and absorption by the ionosphere.

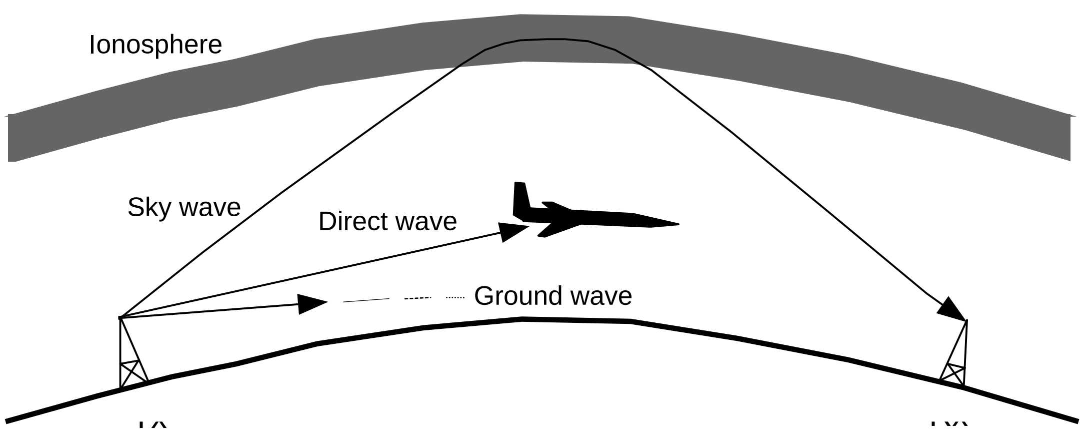


Figure 2.1 Types of HF propagation.

2.3 The Usable Frequency Range

For any circuit there is a Maximum Usable Frequency (MUF) which is determined by the state of the ionosphere in the vicinity of the refraction area(s) and the length of the circuit. The MUF is refracted from the area of maximum electron density of a region. Therefore, frequencies higher than the MUF for a particular region will penetrate that region. 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 during the day, seasonally and with the solar cycle. The data collected over the years displays a range of frequencies observed and the IPS predictions mirror this. A range of F region MUFs is provided in the predictions and this range extends from the lower decile MUF (called the Optimum Working Frequency, OWF), through the median MUF to the upper decile MUF. These MUFs have a 90%, 50% and 10% chance of being supported by the ionosphere, respectively. IPS predictions usually cover a period of one month, so the OWF should provide successful propagation 90% of the time or 27 days of the month. The median MUF should provide communications 50% or 15 days of the month and the upper decile MUF 10% or 3 days of the month. The upper decile MUF is the highest frequency of the range of MUFs and is most likely to penetrate the ionosphere, figure 2.2.

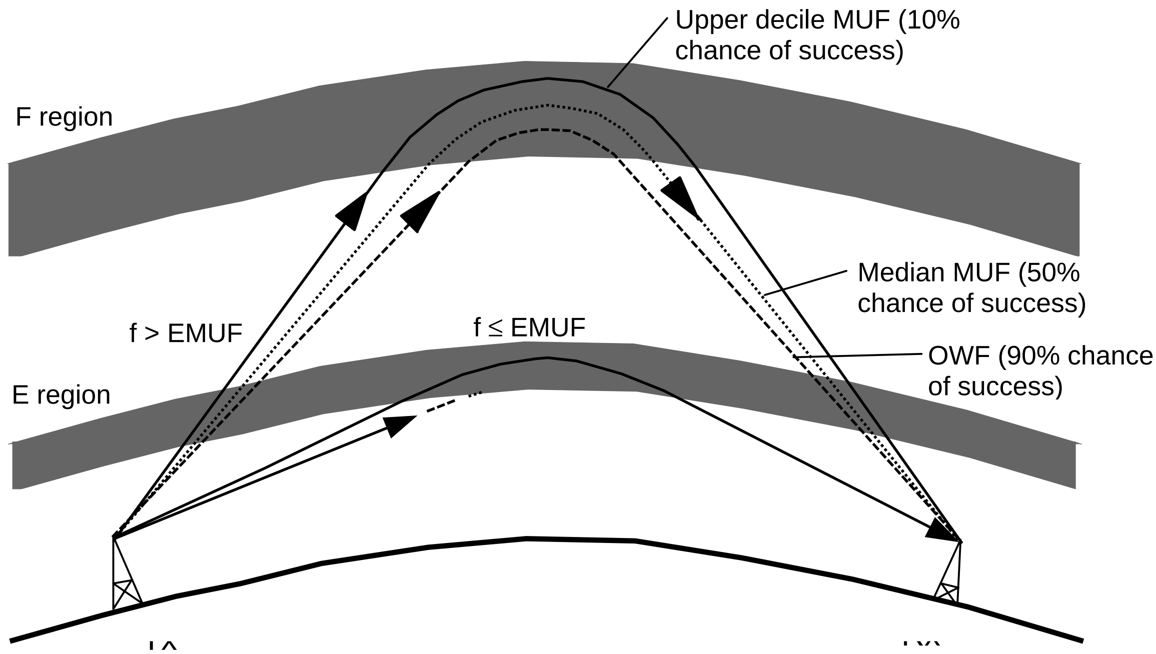


Figure 2.2 Range of usable frequencies. If the frequency, f, is close to the ALF then the wave may suffer absorption in the D region. If the frequency is above the EMUF then propagation is via the F region. Above the FMUF the wave is likely to penetrate the ionosphere.

The chances of successful propagation discussed above rely on the monthly prediction of solar activity being correct. Sometimes unforeseen events occur on the Sun resulting in the monthly predictions being inaccurate. The role of the Australian Space Forecast Centre (ASFC) at IPS is to provide corrections to the monthly predictions, warning customers of changes in communication conditions.

The D region does not allow all frequencies to be used since the lower the frequency the more likely it is to be absorbed. The Absorption Limiting Frequency (ALF) is provided as a guide to the lower limit of the usable frequency band. The ALF is significant only for circuits with refraction points in the sunlit hemisphere. At night, the ALF falls to zero, allowing frequencies which are not usable during the day to successfully propagate.

2.4 Hop Lengths

The hop length is the ground distance covered by a radio signal after it has been refracted once from the ionosphere and returned to Earth, figure 2.3. The upper limit of the hop length is set by the height of the ionosphere and the curvature of the Earth. For E and F region heights of 100 km and 300 km, the maximum hop lengths with an elevation angle of 4°, are 1800 km and 3200 km, respectively. Distances greater than these will require more than one hop. For example, a distance of 6100 km will require a minimum of 4 hops by the E region and 2 hops via the F region. More hops would be required with larger antenna elevation angles.

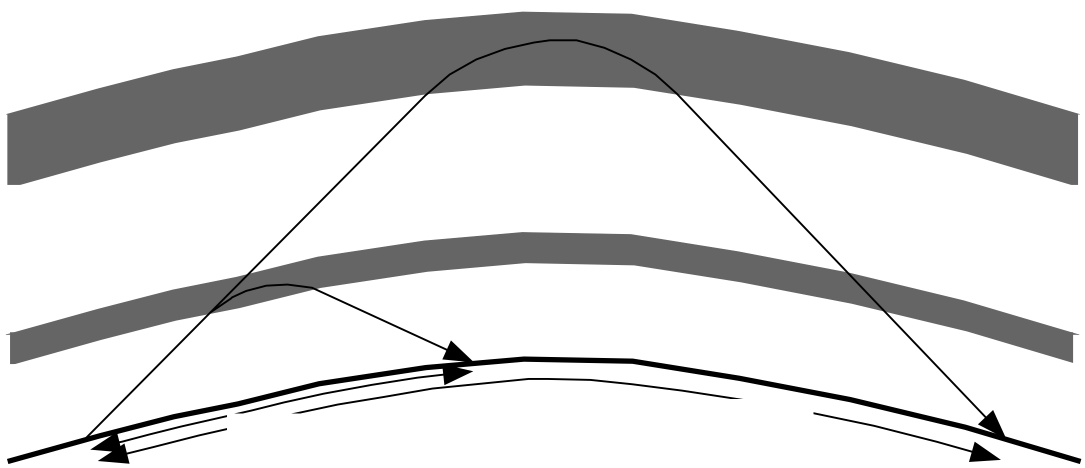


Figure 2.3 Hop lengths based upon an antenna elevation angle of 4° and heights for the E and F layers of 100 km and 300 km, respectively.

If the elevation angle of the antenna is able to be altered easily or there is a choice of antennas, it may be possible to use a certain number of hops such that an opponent's position does not coincide with a reflection point on the Earth. This will however, be affected also by the time of day and what frequencies are available. However, in most cases the directional properties of the antenna are such that this is not possible.

2.5 Propagation Modes

There are many paths by which a sky wave may travel from a transmitter to a receiver. The mode by a particular layer which requires the least number of hops between the transmitter and receiver is called the first order mode. The mode that requires one extra hop is called the second order mode. For a circuit with a path length of 5000 km, the first order F mode has two hops (2F), while the second order F mode has three hops (3F). The first order E mode has the same number of hops as the first order F mode. If this results in a hop length of greater than 2050 km, which corresponds to an elevation angle of 0°, then the E mode is not possible. This also applies to the second order E mode. Of course, the E region modes will only be available on daylight circuits.

Simple modes are those propagated by one region, say the F region. IPS predictions are made only for these simple modes, Figure 2.4. More complicated modes consisting of combinations of refractions from the E and F regions, ducting and chordal modes are also possible, figure 2.5.

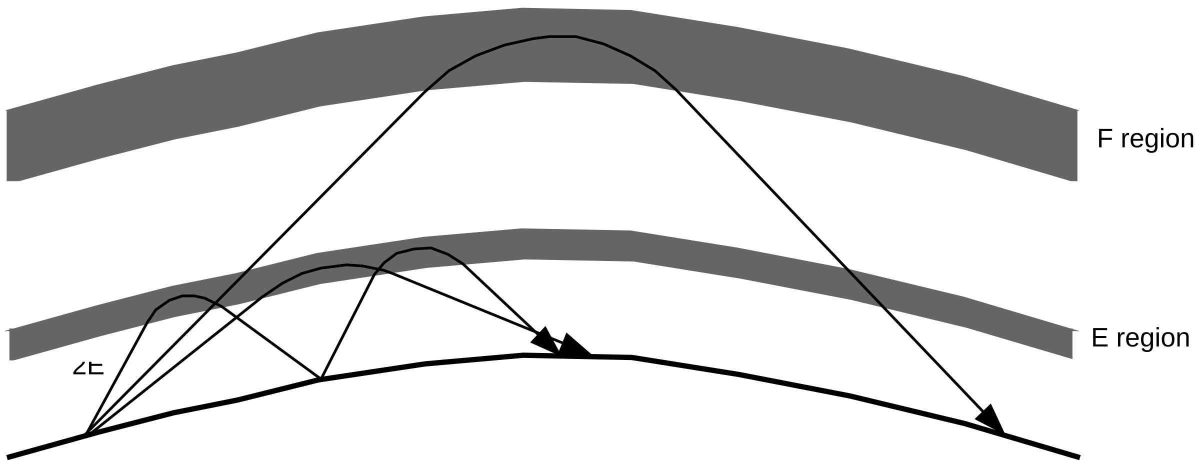


Figure 2.4 Examples of simple propagation modes.

Chordal modes and ducting involve a number of refractions from the ionosphere without intermediate reflections from the Earth. There is a tendency to think of the regions of the ionosphere as being smooth, however, the ionosphere undulates and moves, with waves passing through it which may affect the refraction of the signal. The ionospheric regions may tilt and when this happens chordal and ducted modes may occur. Ionospheric tilting is more likely near the equatorial anomaly, the mid-latitude trough and in the sunrise and sunset sectors. When these types of modes do occur, signals can be strong since the wave spends less time traversing the D region and being attenuated during ground reflections.

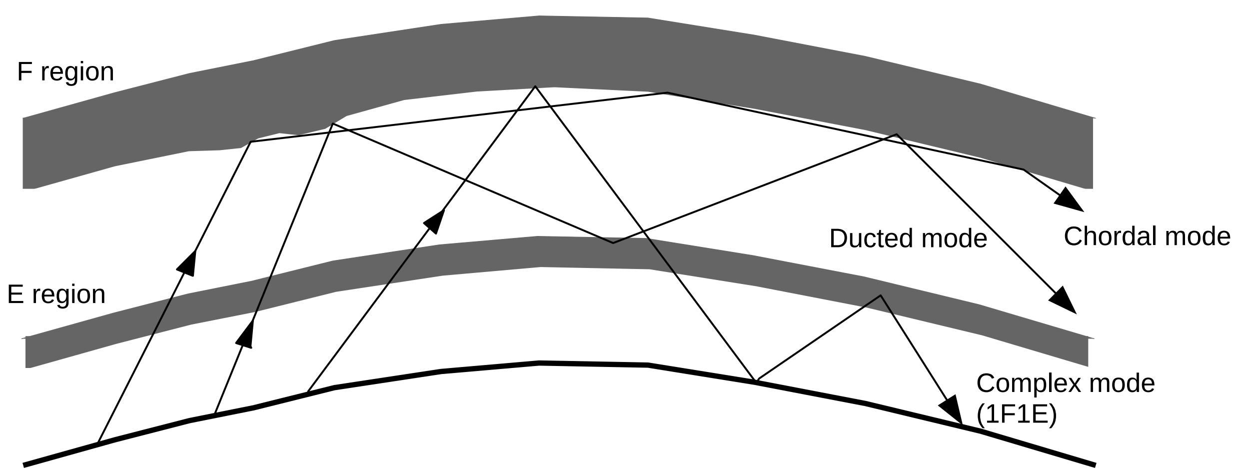


Figure 2.5 Other propagation modes.

Because of the high electron density of the daytime ionosphere in the vicinity of 15° of the magnetic equator (near the equatorial anomaly), transequatorial paths can use these enhancements to propagate on higher frequencies. Any tilting of the ionosphere may result in chordal modes, producing good signal strength over long distances.

Ducting may result if tilting occurs and the wave becomes trapped between refracting regions of the ionosphere. This is most likely to occur in the equatorial ionosphere, near the auroral zone and mid-latitude trough. Disturbances to the ionosphere, such as travelling ionospheric disturbances (section 2.9), may also account for ducting and chordal mode propagation.

2.6 E Layer Screening

For daytime communications via the F region, the lowest usable frequency via the one hop F mode is dependent upon the presence of the E region. If the operating frequency for the 1F mode is below the two hop EMUF, then the signal is unlikely to propagate via the F region due to screening by the E region, figure 2.6. This is also because the antenna elevation angles of the 1F and 2E modes are similar.

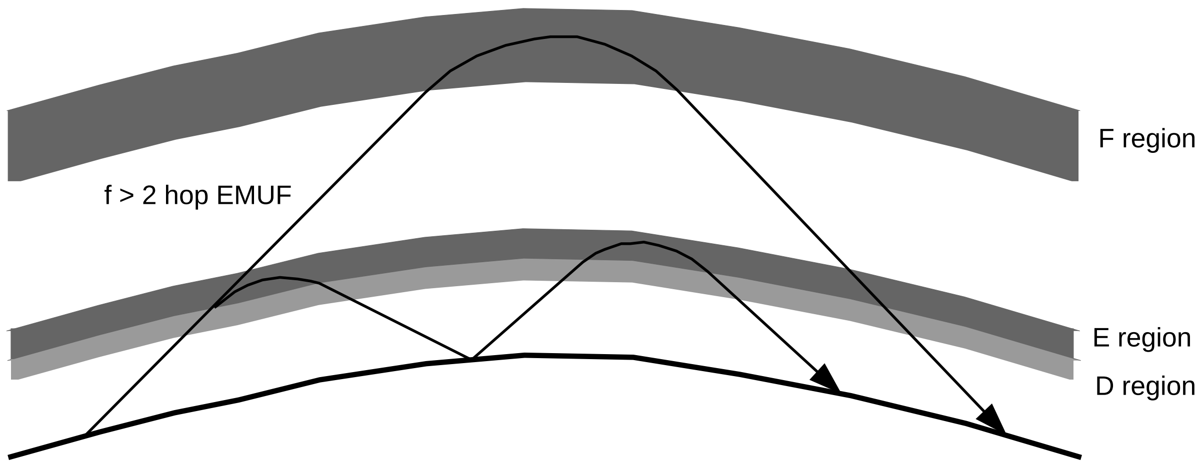


Figure 2.6 E layer screening occurs if communications are required by the 1F mode and the operating frequency is close to or below the EMUF for the 2E mode. Note the paths through the D region for each wave.

A sporadic E layer may also screen a wave from the F region. Sometimes sporadic E can be quite transparent, allowing most of the wave to pass through it. At other times it will partially screen the F region leading to a weak or fading signal, while at other times sporadic E can totally obscure the F region with the possible result that the signal does not arrive at the receiver, figure 1.9 (section 1.6).

2.7 Frequency, Range and Elevation Angle

For oblique propagation, there are three dependent variables:

- frequency;
- range or path length;
- antenna elevation angle.

The diagrams below illustrate the changes to the ray paths when each of these is fixed in turn.

Figure 2.7: Elevation angle fixed:

- As the frequency is increased toward the MUF, the wave is refracted higher in the ionosphere and the range increases, paths 1 and 2;
- At the MUF for that elevation angle, the maximum range is reached, path 3;
- Above the MUF, the wave penetrates the ionosphere, path 4.

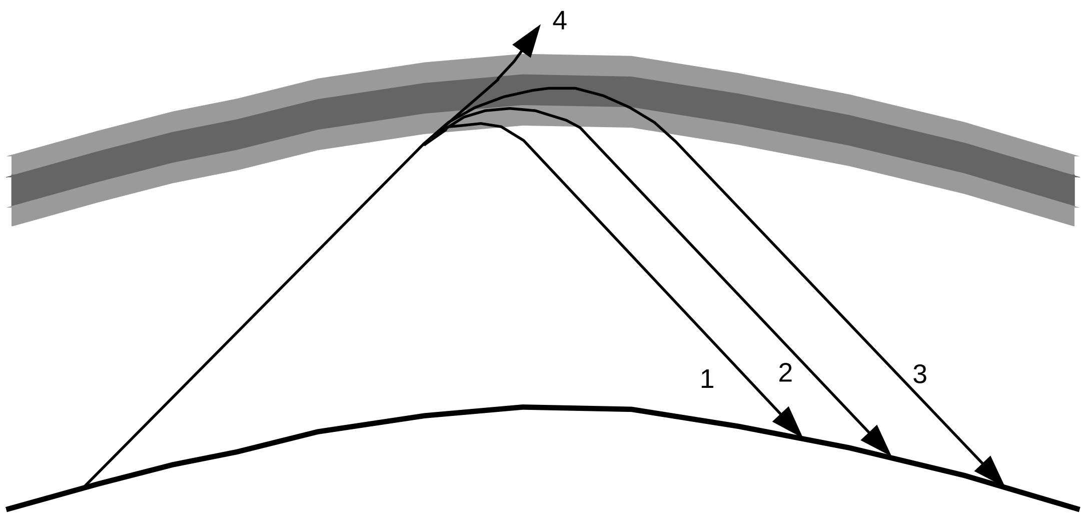


Figure 2.7 Elevation angle fixed.

Figure 2.8: Path length fixed (point-to-point circuit):

- As the frequency is increased towards the MUF, the wave is refracted from higher in the ionosphere. To maintain a circuit of fixed length, the elevation angle must therefore be increased, paths 1 and 2;
- At the MUF, the critical elevation angle is reached, path 3. The critical elevation angle is the elevation angle for a particular frequency, which if increased, would cause penetration of the ionosphere;
- Above the MUF, the ray penetrates the ionosphere, path 4.

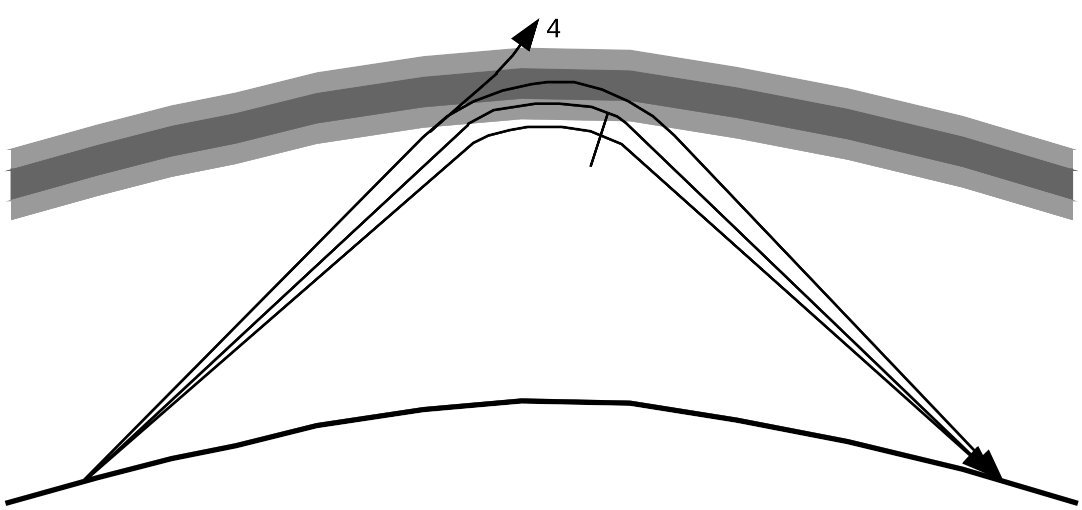


Figure 2.8 Path length fixed.

<u>Figure 2.9: Frequency fixed</u>:

- At low elevation angles the path length is greatest, path 1;
- As the elevation angle is increased, the path length decreases and the ray is refracted from higher in the ionosphere, paths 2 and 3;
- If the frequency will return when sent vertically up into the ionosphere, then the skip distance is zero. However, if this is not the case, then as the elevation angle is increased, the range decreases. If the elevation angle is increased beyond the critical elevation angle for that frequency then the wave penetrates the ionosphere and there is an area around the transmitter within which no sky wave communications can be received, path 4. To communicate within the skip zone, the frequency must be lowered.

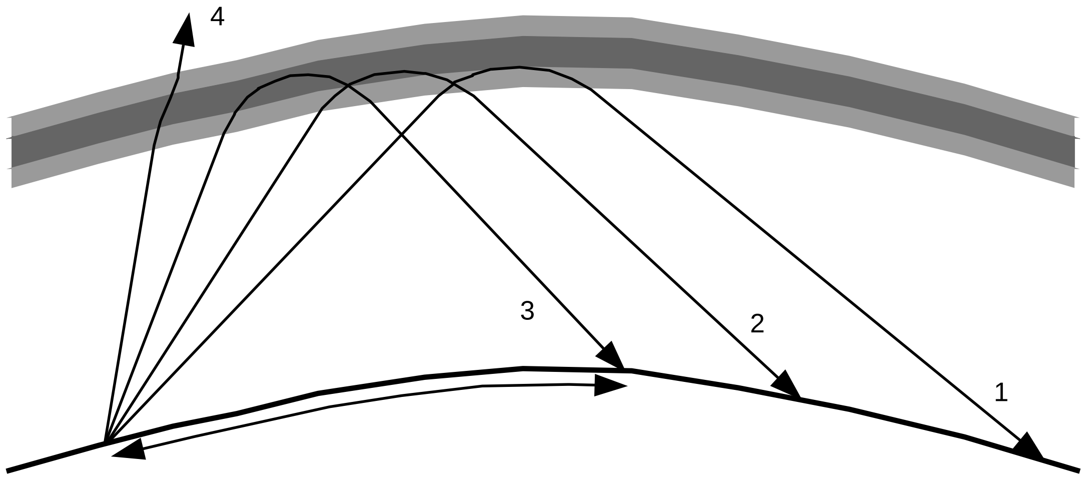


Figure 2.9 Frequency fixed.

2.8 Skip Zones

A propagation path will consist of high and low angle rays corresponding to the wave propagating from the transmit antenna at a range of angles. The high ray is transmitted at a high angle from the antenna. These rays may travel by different paths through the ionosphere. The edge of the skip zone corresponds to the high and low rays taking the same path through the ionosphere, with the resulting signal often being stronger. Within the skip zone the signal fades due to the waves penetrating the ionosphere.

In figure 2.9, path 3 corresponds to the high and low rays taking the same path through the ionosphere, this corresponds to the MUF. As the frequency is increased toward the MUF, the height of refraction of the low angle ray increases and the height of refraction of the high angle ray decreases until they are both refracted at the same point in the ionosphere.

Skip zones can often be used to advantage if it is desired that communications are not heard by a particular receiver. Selecting a different frequency will alter the size of the skip zone and if the receiver is within the skip zone and out of reach of the ground wave, then it is unlikely that it will receive the communications. However, factors such as sidescatter, where reflection from the Earth outside the skip zone results in the wave transmitting into the skip zone may affect the reliability of this.

Skip zones vary in size during the day, with the seasons, and with solar activity. During the day, solar maximum and around the equinoxes, skip zones generally are smaller in area. The ionosphere during these times has increased electron density and so is able to support higher frequencies.

2.9 Fading

Multipath fading results from dispersion of the signal by the transmitting antenna. A number of modes propagate which have variations in phase and amplitude. These waves may interfere with each other if they reach the receiver, figure 2.10.

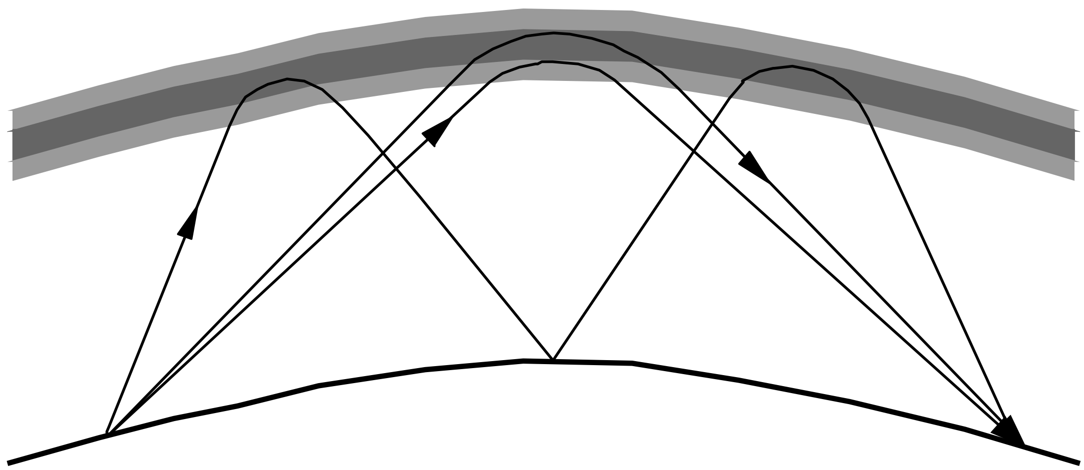


Figure 2.10 Multipath fading. The signal may travel by a number of paths which, if they arrive at the receiver and are of similar amplitude, may interfere and cause fading.

Disturbances known as Travelling Ionospheric Disturbances, TIDs, may cause a region to be tilted, resulting in the signal being focussed or defocussed, figure 2.11. Fading periods of the order of 10 minutes or more can be associated with these structures. TIDs travel horizontally at 5 to 10 km/minute with a well defined direction of travel affecting higher frequencies first. Some originate in auroral zones following an event on the Sun and these may travel large distances. Others originate in weather disturbances. TIDs may cause variations in phase, amplitude, polarisation and angle of arrival of a wave.

Polarisation fading results from changes to the polarisation of the wave along the propagation path. The receiving antenna is unable to receive parts of the signal; this type of fading can last for a fraction of a second to a few seconds.

Skip fading can be observed around sunrise and sunset particularly, when the operating frequency is close to the MUF, or when the receiving antenna is positioned close to the boundary of the skip zone. At these times of the day, the ionosphere is unstable and the frequency may oscillate above and below the MUF causing the signal to fade in and out. If the receiver site is close to the skip zone boundary, as the ionosphere fluctuates, the skip zone boundary also fluctuates.

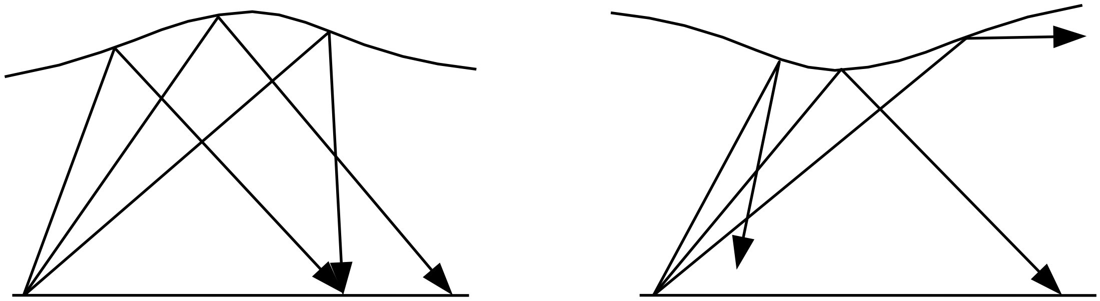


Figure 2.11 Focussing and defocussing effects caused by tilting and travelling ionospheric disturbances (TIDs).

2.10 Noise

Radio noise arises from internal and external origins. Internal or thermal noise is generated in the receiving system and is usually negligent when compared to external sources of noise. External radio noise originates from natural (atmospheric and galactic) and man-made (environmental) sources.

Atmospheric noise, which is caused by thunderstorms, is normally the major contributor to radio noise in the HF band and will especially degrade circuits passing through the day-night terminator. Atmospheric noise is greatest in the equatorial regions of the world and decreases with increasing latitude. Its effect is also greater on lower frequencies, hence it is usually more of a problem around solar minimum and at night when lower frequencies are needed.

Galactic noise arises from our galaxy. Receive antennas with higher frequencies more likely to be affected by this type of noise.

Man-made noise includes ignition noise, neon signs, electrical cables, power transmission lines and welding machines. This type of noise depends on the technology used by the society and its population. Interference may be intentional, such as jamming, due to propagation conditions or the result of others working on the same frequency.

Man-made noise tends to be vertically polarised, so selecting a horizontally polarised antenna may help in reducing noise. Using a narrower bandwidth, or a directional receiving antenna (with a lobe in the direction of the transmitting source and a null in the direction of the unwanted noise source), will also aid in reducing the effects of noise. Selecting a site with a low noise level and determining the major noise sources are important factors in establishing a successful communications system.

2.11 VHF and 27 MHz Propagation

VHF and 27 MHz are used for line-of-sight or direct wave communication, for example, ship-to-ship or ship-to-shore. The frequency bands are divided into channels and one channel is usually as good as the next. This is in contrast to medium frequency (MF: 300 kHz to 3 MHz) and HF where the choice of a frequency channel may be crucial for good communications.

Because VHF and 27 MHz operate mainly by line-of-sight, it is important to mount the antenna as high as possible and free from obstructions. Shore stations are usually on the tops of hills to provide maximum range, but even the highest hills do not provide coverage much beyond about 45 nautical miles (80 km) because of the Earth's curvature.

Antennas for VHF and 27 MHz should concentrate radiation at low angles (towards the horizon) as radiation directed at high angles will usually pass over the receiving antenna, except when communicating with aircraft. VHF and 27 MHz do not usually suffer from noise except during severe electrical storms. Interference results from many users wishing to use the limited number of channels, and this can be a significant problem in densely populated areas.

27 MHz and the lower frequencies in the VHF band can, at times, propagate over large distances, well beyond the normal line-of-sight limitations. There are three ways that this can take place:

- around solar maximum and during the day, the ionospheric F region will often support long range sky wave communications on 27 MHz and above;
- sporadic E layers can often support 27 MHz and lower frequency VHF propagation over circuits of about 500 to 1000 nautical miles (1000 to 2000 km) in length. This kind of propagation is most likely to occur at mid-latitudes, during the daytime in summer;
- 27 MHz and VHF can also propagate by means of temperature inversions (ducting) at altitudes of a few kilometres. Under these conditions, the waves are gradually bent by the temperature inversion to follow the curvature of the Earth. Distances of several hundred nautical miles can be covered in this way.

2.12 Medium Frequency (MF) 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 at night.

2.13 Ground Wave MF and HF Propagation

It is possible to communicate up to distances of several hundred nautical miles on MF/HF bands at sea by using ground wave propagation.

The ground wave follows the curvature of the Earth and its range does not depend upon the height of the antenna. However, the range does depend upon the transmitter power and also upon the operating frequency. Low frequencies travel further than high frequencies. Thus under ideal (midday, during winter) low noise conditions, it is possible to communicate over distances of about 500 nautical miles at 2 MHz by using a 100 W transmitter. At 8 MHz, under the same conditions and using the same transmitter power, the maximum range is reduced to about 150 nautical miles.

Note that ground wave propagation is much less efficient over land than it is over sea because of the much lower conductivity of the ground and other factors. Consequently, ranges over land are greatly reduced compared to ranges over sea water.

Ground wave communications vary daily and with the seasons. Greatest communication ranges are achieved during the daytime in winter because background noise levels are lowest during these hours.

Successful ground wave communications over hundreds of nautical miles can only be achieved if the transmitting and receiving antennas are chosen to direct and receive radiation at low angles. Tall whips are ideal for this purpose.

2.14 Universal Time

Unless communications are always with another communicator on the same time standard, it is considered more convenient to work in universal (UT) or Zulu (Z) time since in many cases the transmitter and receiver are operating in different local time zones. Universal time is the same as the Greenwich Mean Time (GMT) and 0000 UT (0000 Z) is midnight at Greenwich, UK. For eastern Australia, operating on Eastern Standard Time (EST), 10 am EST equals 0000 UT. Western Australia is 8 hours ahead of Greenwich, UK, so 0800 WST = 0000 UT, and central Australia is 9.5 hours ahead of Greenwich (0930 CST = 0000 UT).

3. Summary of the Effects of Solar Disturbances

3.1 Short Wave Fade-outs (SWFs)

Also called daylight fade-outs or sudden ionospheric disturbances (SIDs). Radiation from the Sun during large solar flares causes increased ionisation in the D region which results in higher absorption of HF radio waves, figure 3.1. If the flare is large enough, the whole of the HF spectrum can be rendered unusable for a period of time. Fade-outs are more likely to occur around solar maximum than at solar minimum. The main features of SWFs are:

- Only circuits with daylight sectors will be affected;
- Fade-outs usually last from a few minutes to sometimes two hours, with a fast onset and a slower recovery. The duration of the fade-out will depend on the duration of the flare;
- The magnitude of the fade-out will depend on the size of the flare and the position of the Sun relative to the point where the radio wave passes through the D region. The higher the Sun with respect to that point, the greater the amount of absorption;
- Absorption is greatest at lower frequencies, which are the first to be affected and the last to recover. Higher frequencies are normally less affected and may still be usable, figure 3.2.

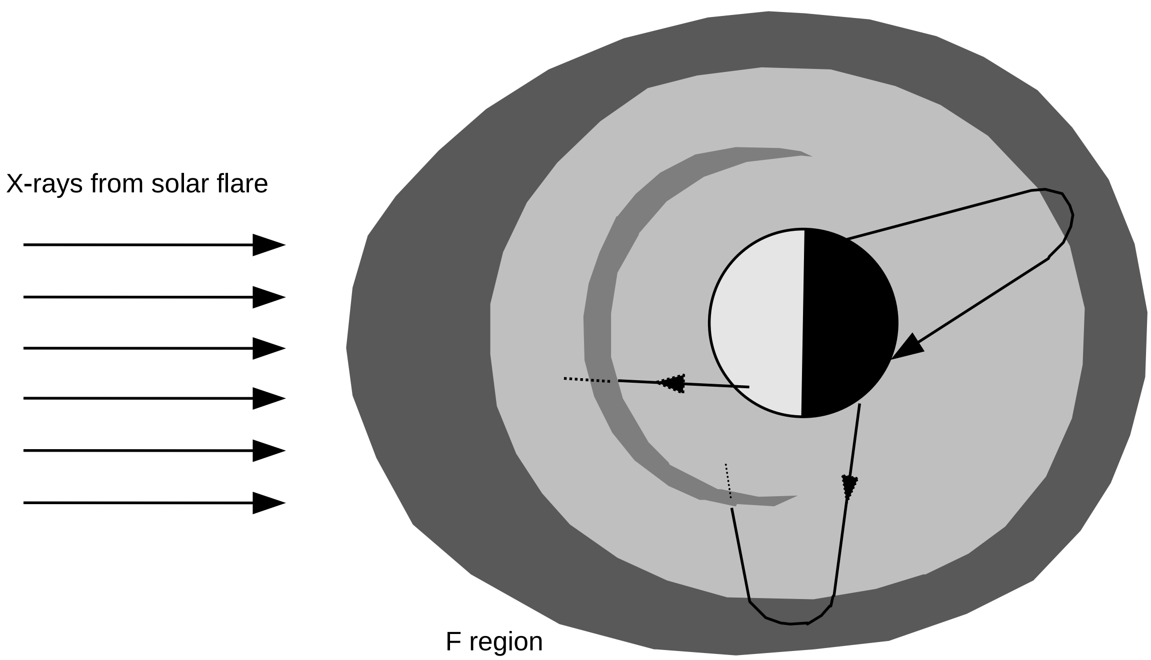


Figure 3.1 Fade-outs affect only those circuits where the wave passes through the D region. That is, circuits with daytime sectors. Night circuits are unaffected by fade-outs.

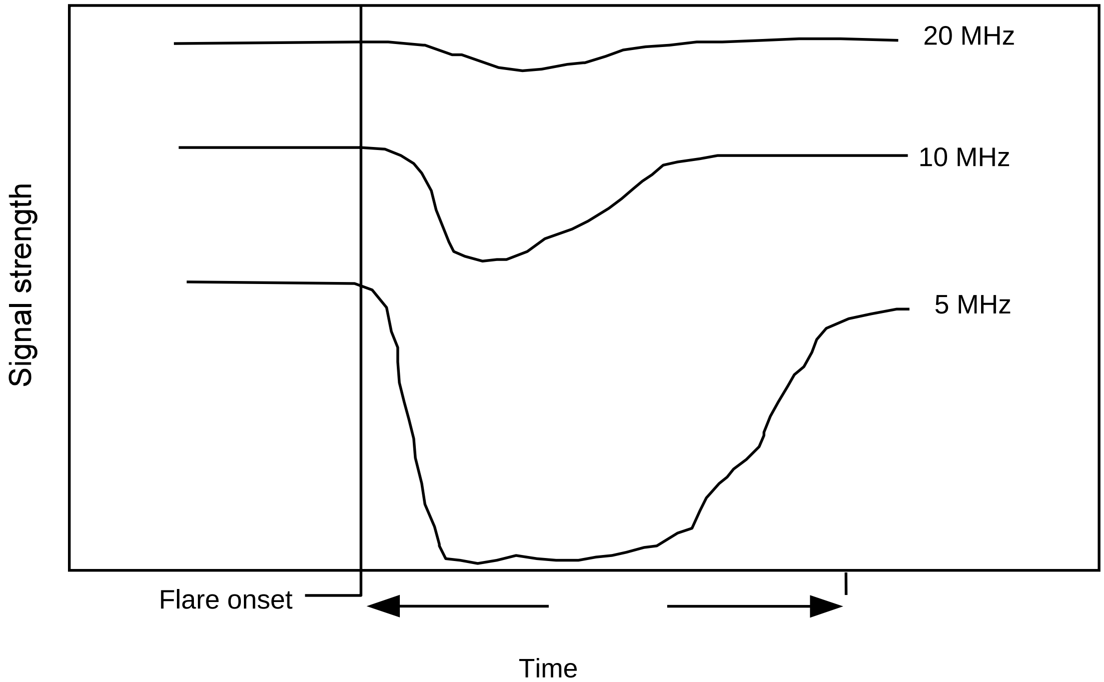


Figure 3.2 Fade-outs affect lower frequencies first and these are the last to recover. Higher frequencies are least affected and with many fade-outs will be unaffected.

3.2 Polar Cap Absorption Events (PCAs)

PCAs are attributed to high energy protons which escape from the Sun when large flares occur and move along the Earth's magnetic field lines to the polar regions. There they ionise the D region, causing absorption of HF waves passing through the polar D region. PCAs are most likely to occur around solar maximum, however, they are not as frequent as fade-outs.

PCAs may commence as soon as 10 minutes after the flare and last for up to 10 days;

The effects of PCAs can sometimes be overcome by relaying messages on circuits which do not require polar refraction points;

Even the winter polar zone (a region of darkness) can suffer the effects of PCAs. The particles from the Sun may actually produce a night D region.

3.3 Ionospheric Storms

Due to events on the Sun, sometimes the Earth's magnetic field becomes disturbed. The geomagnetic field and the ionosphere are linked in complex ways and a disturbance in the geomagnetic field can often cause a disturbance in the ionosphere.

These ionospheric storms sometimes begin with increased electron density allowing higher frequencies to be supported, followed by a decreased in the electron density leading to the successful use of only lower than normal frequencies of the F region. An enhancement will not usually concern the HF communicator, but the depression may cause frequencies normally used for communication to be too high with the result that the wave penetrates the ionosphere.

Ionospheric storms may last a number of days and higher latitudes are affected more than low latitudes, generally. Unlike fade-outs, higher frequencies are most affected by ionospheric storms. To reduce storm effects, a lower frequency should be used where possible.

Ionospheric storms can occur throughout the solar cycle and related to coronal mass ejections (CMEs) and coronal holes on the Sun. Figure 3.3 shows how an ionospheric storm has caused frequencies in the main to be depressed at Canberra, Australia (a mid-latitude station) from the 24th to 28th. Higher frequencies would probably have been unsuccessful over this time.

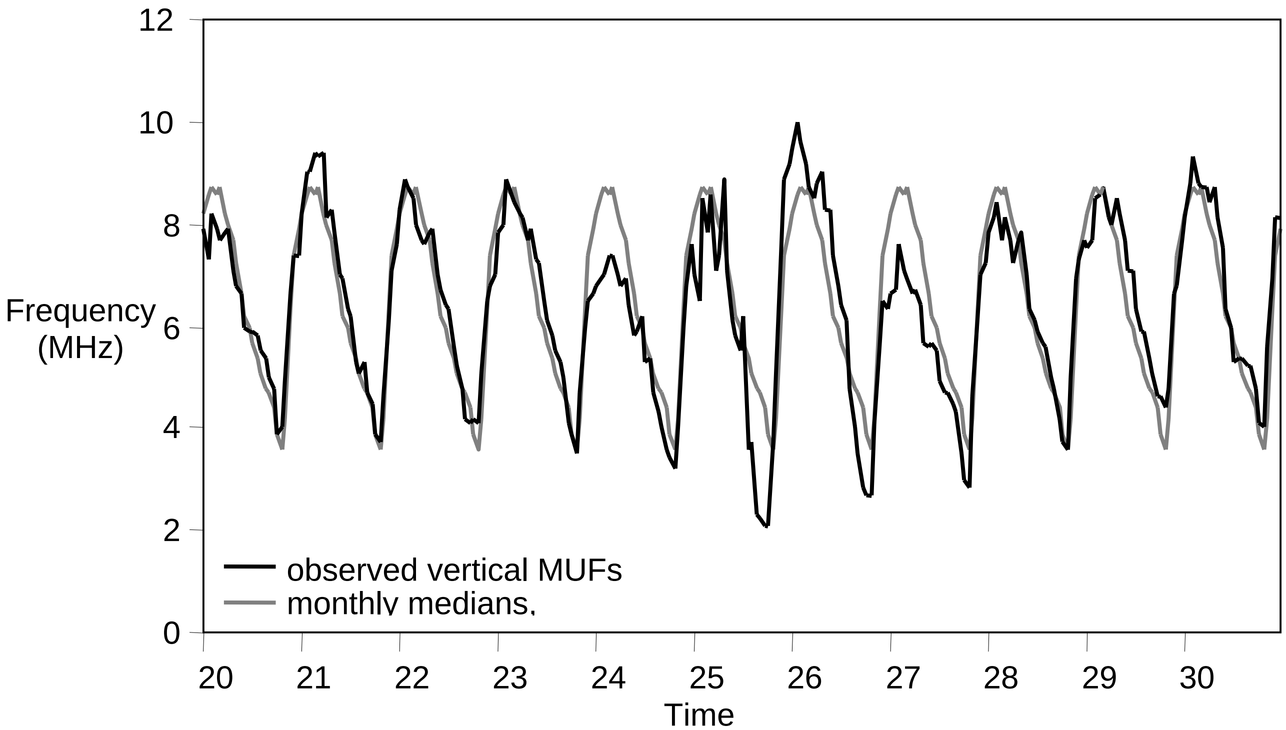


Figure 3.3 Canberra, Australia observed and median vertical MUFs for the latter part of September 1998. Significant depressions in F region frequencies occurred between 24 to 28 September due to solar activity.