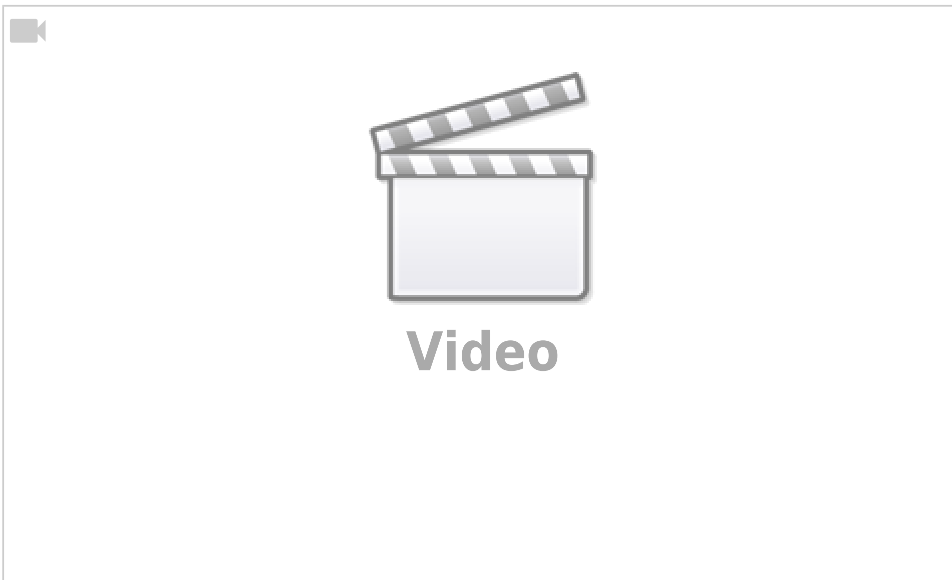
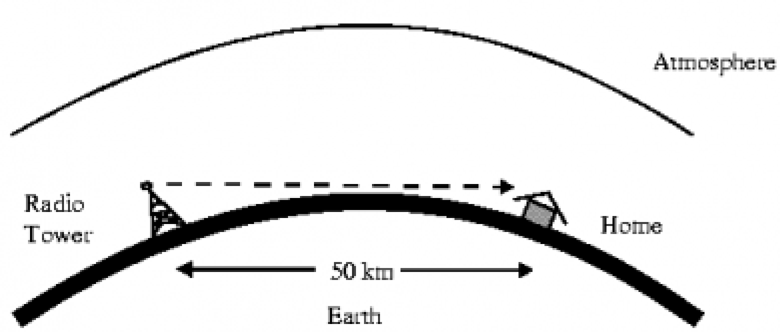
Propagation

Radio wave propagation describes the way in which radio waves travel from one point to another. As we saw in the previous page, radio waves (like light waves) have polarization and are affected by the phenomena of reflection, refraction, diffraction, and scattering. As we'll see next, these give rise to different ways that the signal can propagate through the atmosphere.



Direct Waves (Line Of Sight)

VHF radio waves (above 50 MHz) travel more or less in a straight line, and so cannot go much beyond the horizon. To increase the distance that an antenna can "see", we raise our antennas as high as possible. The *radio horizon* is given roughly by: $d = 4.12 \sqrt{h}$ where d is in kilometre and h is in meters.[1]



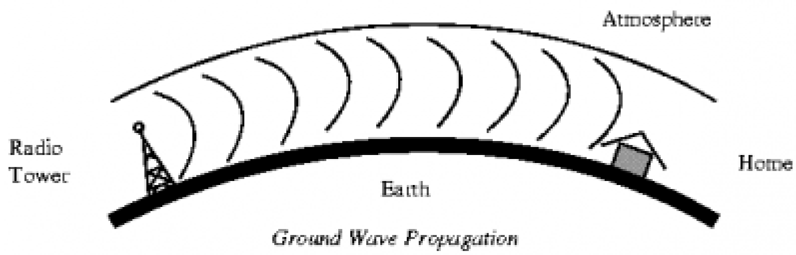
For example, VA7FI's antenna is 20m above the ground, at an elevation of 100m overlooking the water. It means that his antenna can see about 45 km in that direction.

For direct waves to occur, the height of the antenna needs to be many times greater than the wavelength of the radio wave so that the signal doesn't interact with the ground. In this example, the antenna (120m above sea level) is 60 wavelengths high on the 2 meter band, and 170 wavelengths on the 70 cm band.

Another similar station could be reached at about 90 km.

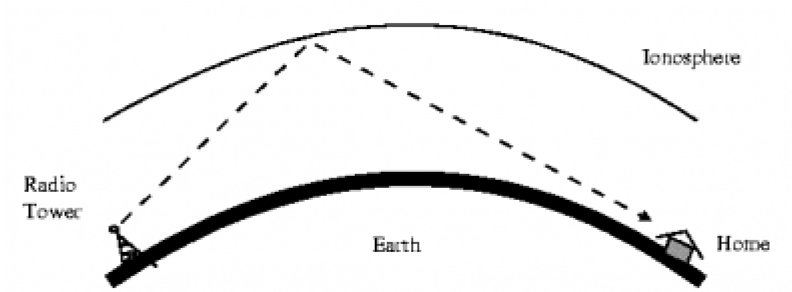
Ground Waves

Ground waves occur when the signal curves with the Earth until it becomes too weak to be detected. This phenomena happens because of diffraction for vertically polarized radio waves when the frequency is below 3 MHz. The radio wave interacts with the ground where it loses some of its energy but also curves toward it. Depending on the frequency, these waves can go beyond the horizon out to about 200 km.



Skywaves

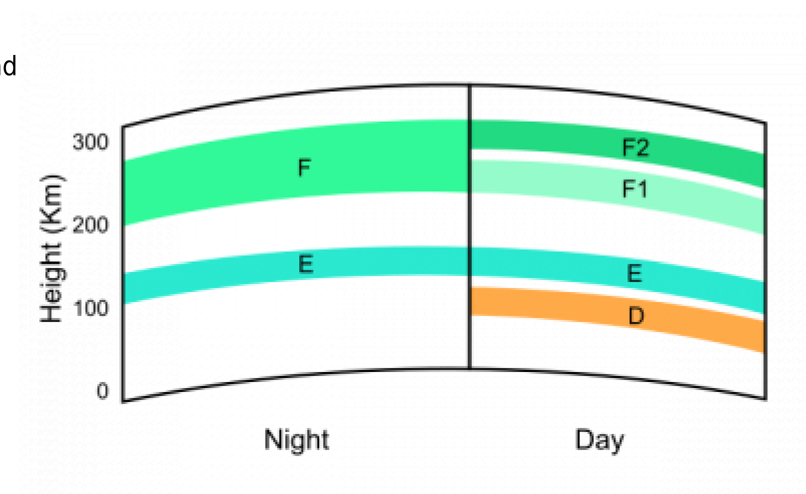
Depending on the frequency and atmospheric conditions, it's possible for radio waves going up to reflect back down to Earth. From our location in British Columbia, we can very easily talk to people in Japan using Skywaves.



This process uses Ionospheric Refraction, which we'll see next.[2)]

Ionosphere

The region of our atmosphere between 50km and 400km altitude is called the ionosphere[3)], and to radio waves, it can act like:



- a mirror that refracts and reflects a signal back to earth,
- a clear window that lets a signal escape to space,

- or a tinted window that absorbs the signal.

The reason for this complex behaviour is that the ionosphere is composed of electrons and electrically charged atoms and molecules (called *ions*) caused by the Sun's ultraviolet radiation (*solar flux*). Gas at higher altitude is more ionized because it is less dense, which makes recombination into neutral molecules more difficult. Depending on the frequency, radio waves travelling into the ionized gas can see an index of refraction that is less than that of the air below, which means that they can refract and reflect the way light does through water. Also, because ionization depends primarily on the Sun's activity, three main cycles dictate the characteristics of the ionosphere:

- The Day / Night cycle
- The Summer / Winter cycle
- 11-year Sunspot cycle

Depending on the time of day, the ionosphere separates into 3 or 4 layers (of different gas composition):

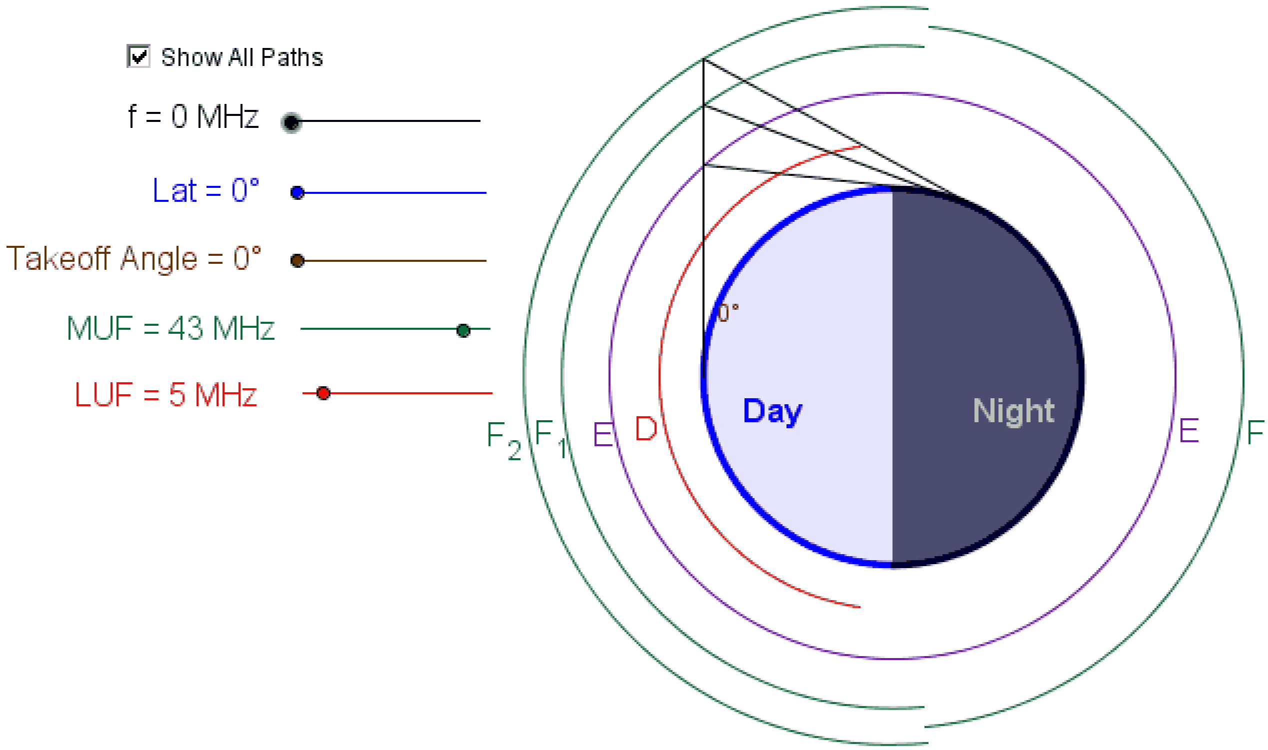
- D-Layer (50km – 90km)
- E-Layer (90km – 150km)
- F-Layer (150km – 400km)

The distance radio waves can propagate via ionospheric refraction depends on many factors:

Take Off Angle and Layer Height

A radio signal will reach further when:[4)]

- The take off angle is as low towards the horizon as possible, and
- The ionosphere layer is as high as possible.



The above animation is a gross oversimplification to illustrate the point that, all else being equal, signals sent near the horizon using the F layer will go further. For example:

- The maximum distance using one hop of the F_2 layer is around 4000 km, while
- The maximum distance using one hop of the E layer is around 2000 km.

In reality, the ionosphere is a medium with a continuously varying index of refraction rather than a series of discrete “mirrors”. As such, how much signals “curve” also depends on the takeoff angle, and just like what we saw in the previous section, there's a critical angle that must be met for *Total Internal Reflection* to occur. So the real picture is more like this one:[5]

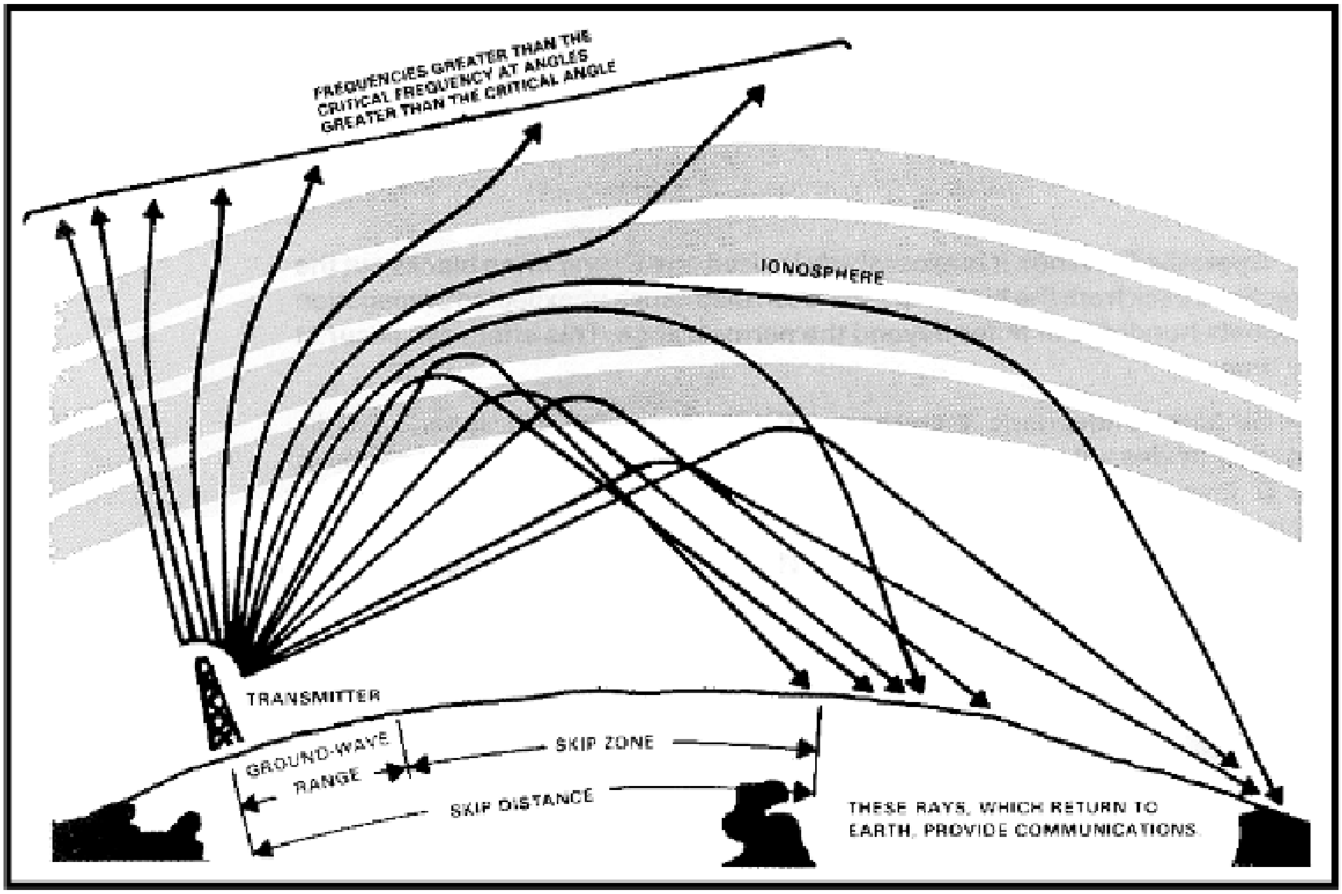
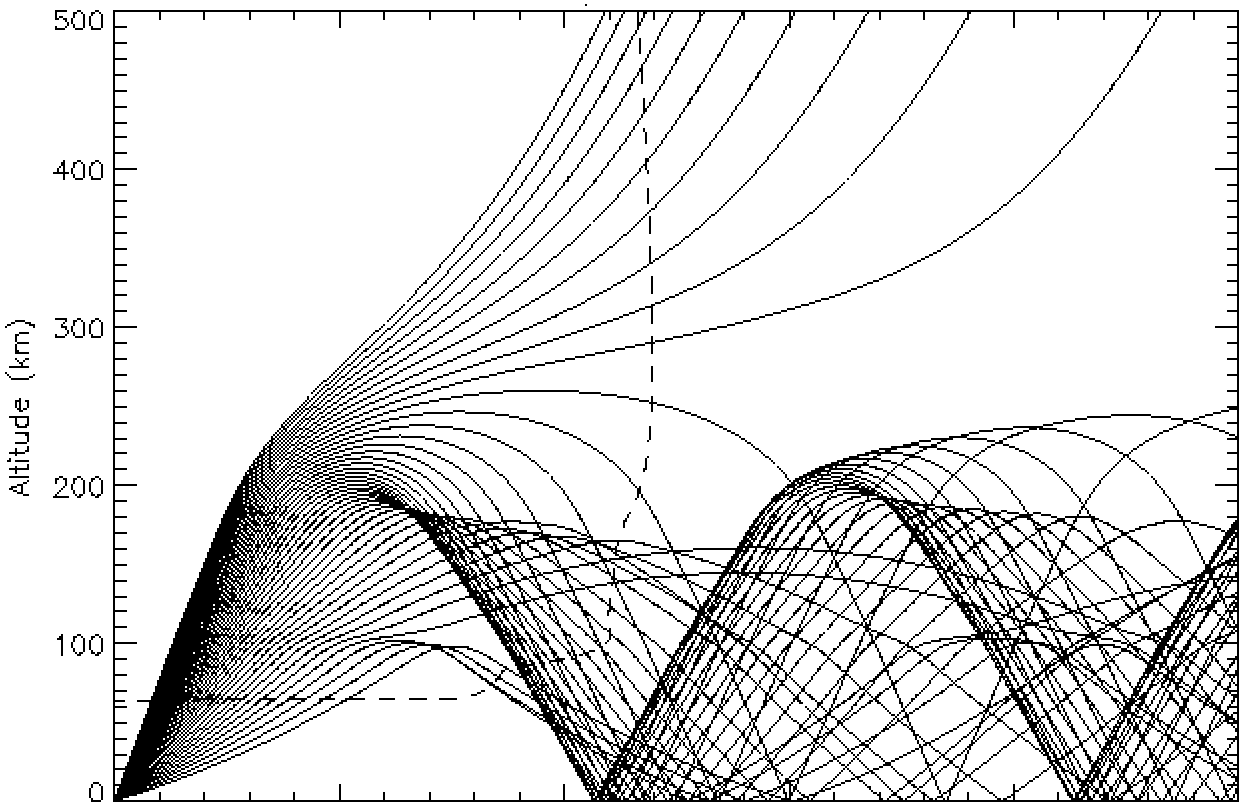


Figure 2-14. Sky wave transmission paths.

Note the following important terms on the above image:

- The **Skip Distance** is the distance between the transmitter and the first hop of the reflected sky-wave.
- The **Skip Zone** is the zone where no signal reaches. It's too far for the ground wave can reach, but too close for the first reflected sky-wave hop.

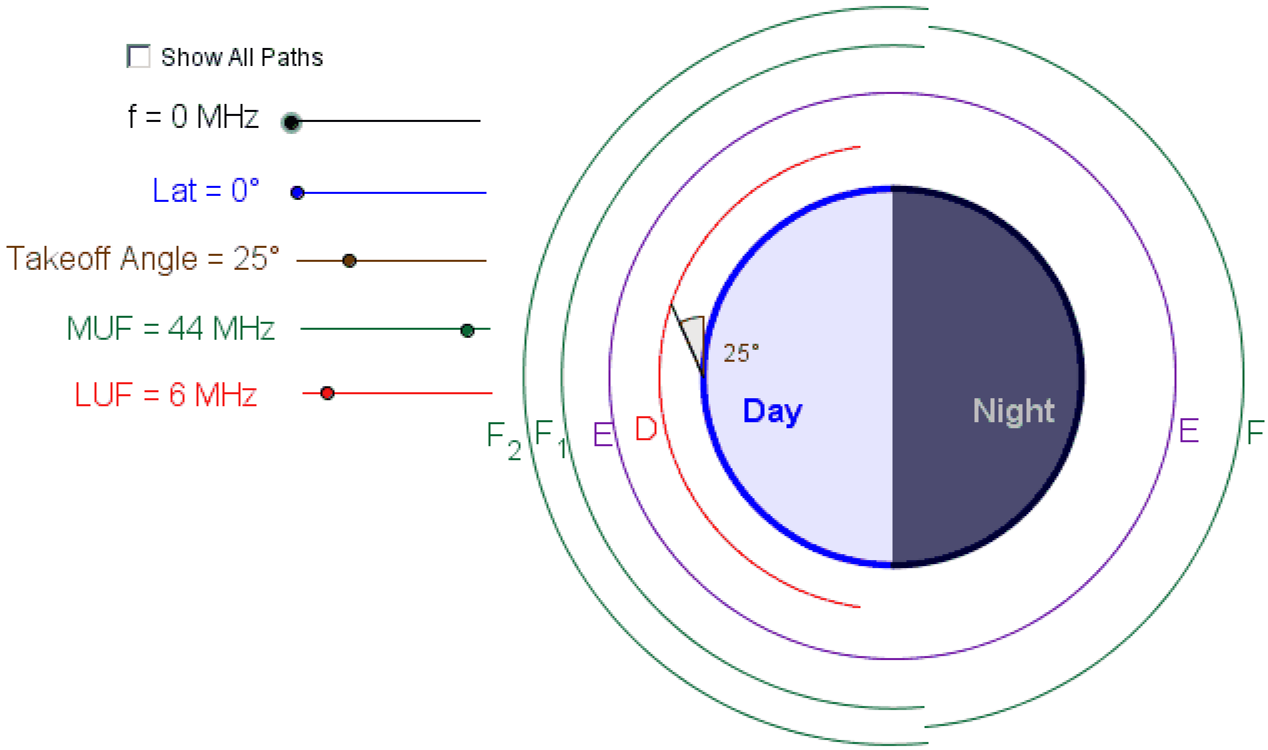
And finally, real antennas do NOT transmit their signal at a single take off angle but over a range of them, which can vary depending on the antenna type and how high it is over the ground. So in reality, many of these paths are used at the same time and even reflect off the ground and go back for a second or third hop. Communications exceeding 5000 km uses *multihop* propagation, which looks like this:[6)]



Frequency

Whether a layer lets a radio signal through, reflects it back, or absorbs it depends on the frequency. In general:

- The D-Layer forms about half an hour after sunrise and disappears half an hour before sunset. It tends to absorb frequencies below 5 MHz and lets others through. At our HF frequencies, it acts either like a tinted window, or a clear window, and so it never really does anything good for us.
- The E-Layer can reflect high angle 160m and 80m signals that made it through the D-Layer during daylight hours.
- The F-Layer splits into two layers about half an hour before sunrise and recombines into one layer about half an hour after sunset. It refracts higher frequency HF bands (40m, 20m, 10m), but VHF frequencies (above 50 MHz) go straight through it, acting either like a mirror or a clear window.

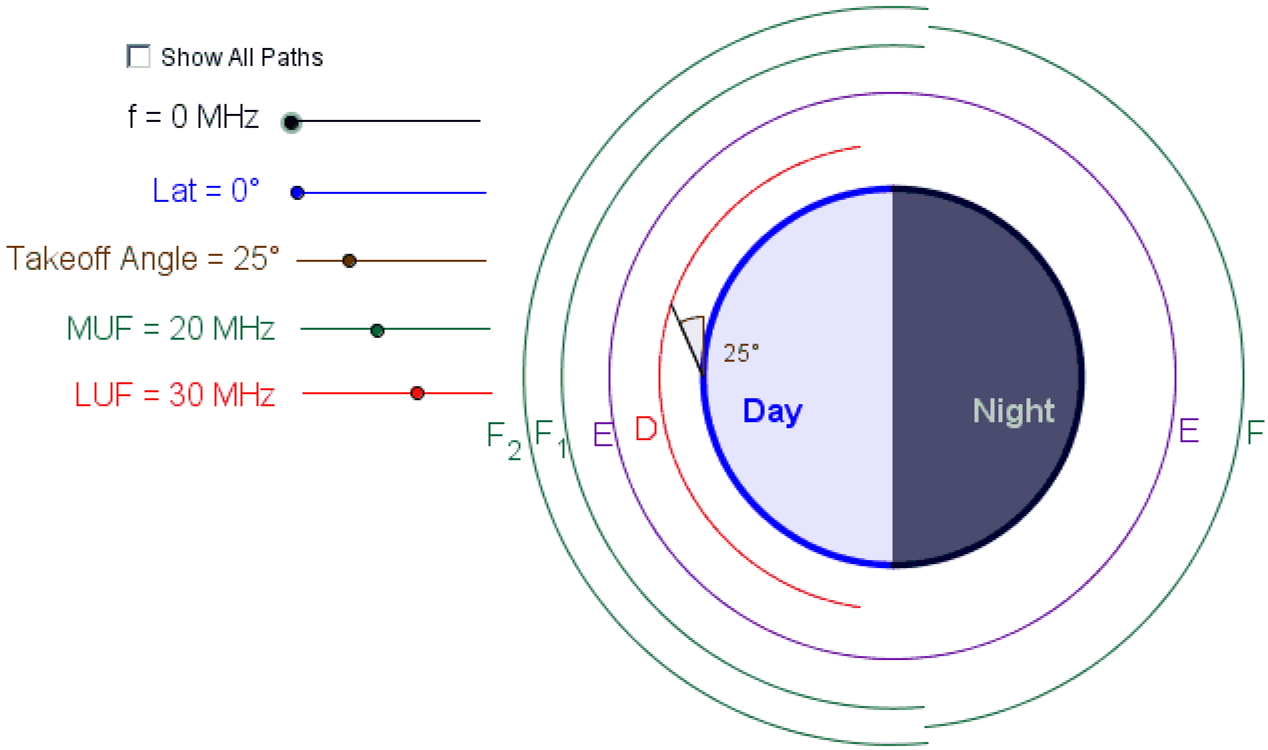


If the goal is to get our signal to travel as far as possible, there's a kind of Goldilocks range of frequencies that we can use. If the frequency is too high, the signal will travel straight through the ionosphere as if it was a clear window. If the frequency is too low, the signal will get absorbed by the ionosphere as if it was a tinted window. The game is to find the frequency that will get reflected by the ionosphere as if it were a mirror, and not only that but we also would like to use the F layer because the higher the point of reflection, the further the signal will travel.

- The *Maximum Usable Frequency* (MUF) is the maximum frequency that the F layer will reflect before it turns transparent and lets the signal escape into space.
- The *Lowest Usable Frequency* (LUF) is the lowest frequency that the D layer will let through before it turns opaque and absorbs the signal.

In the previous animation, frequencies below 6 MHz don't get through the D layer, and frequencies above 44 Mhz escape into space. Only frequencies between the LUF and MUF get reflected back down to Earth by different layers.

Sometimes, depending on the atmospheric and/or solar conditions, the LUF, is greater than the MUF. In that case, no reflection is possible. Signals either get absorbed by the D layer, or get through all of them and escape into space:



In general, during the day:

- The *Maximum Usable Frequency* (MUF) is around 50 MHz, which means the 6m, 2m, and 70cm bands are all direct waves.
- The *Lowest Usable Frequency* (LUF) is around 15 Mhz, Which means that the 40m, 80m, and 160m bands are all ground waves.
- Only frequencies between the 20m and 10m bands will be skywaves.

At night:

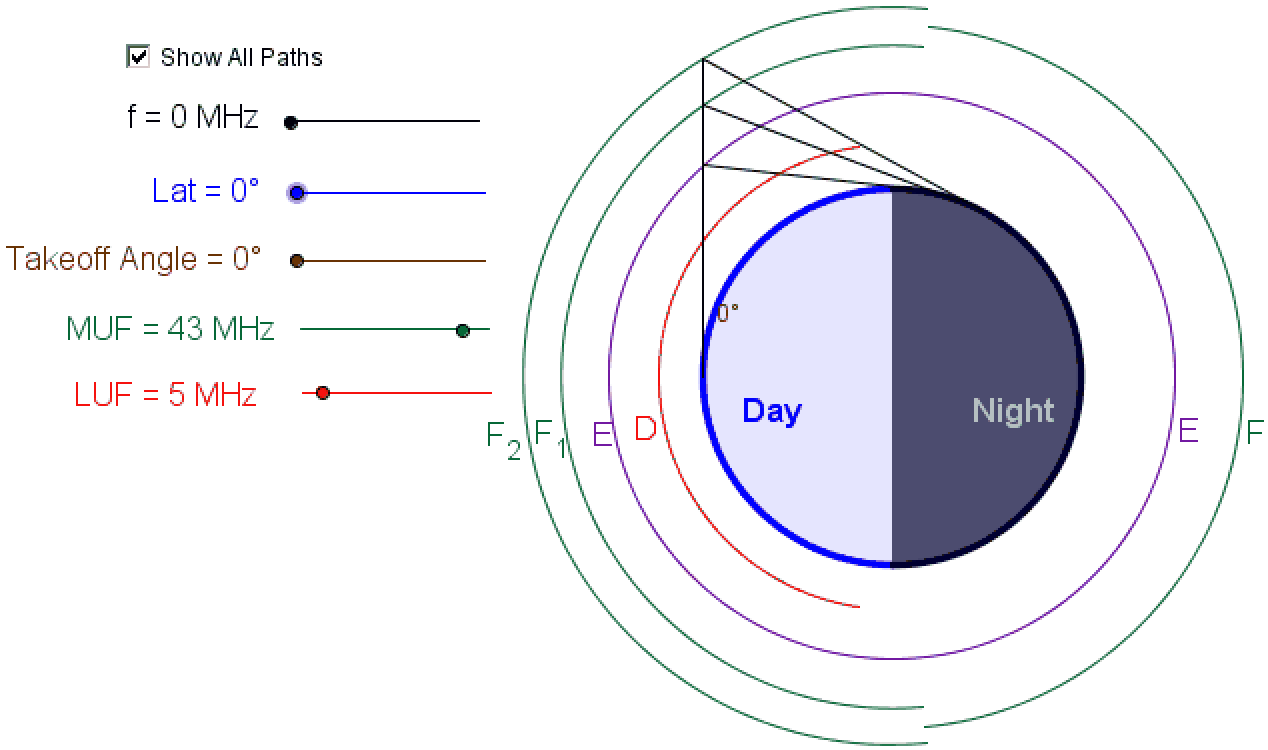
- The D-Layer recombined into neutral molecules.
- The MUF lowers to around 10 MHz, which means that even the 10m and 20m band escape into space.
- The LUF also lowers so that the 160m and 80m band can be skywaves.

So normally, higher frequencies are better during the day (up to about 6m), and lower frequencies are better at night.

Here's a map of MUF that's updated regularly. You can think of this as a “weather map” for ham radio.

The Gray Zone

Finally, because the D-Layer disappears before the F-Layer recombines, and reappears after the F-Layer splits, the propagation can be interesting around sunrise and sunset. This is called the *gray zone*.



Meteor Scattering

When meteors enter the ionosphere, they create intensely ionized columns of air that can scatter radio waves for very short periods of time (from a fraction of a second to a couple seconds per event). This mode can be used on VHF frequencies between 30 MHz and 100 MHz but is most effective on the 6m band (50 MHz).

Auroral backscatter

Auroral activity creates strong ionization of the E-region. HF (and sometimes VHF) radio waves can backscatter and be heard up to 2000 km in the east-west direction. CW is the best mode to use to take advantage of this mode.

Sporadic-E propagation

Sporadic-E propagation (not to be confused with ordinary E-layer propagation) takes advantage of ionization patches in the E-layer that drift westwards at speeds of a few hundreds of kilometres per hour. You can think of it as invisible clouds of ionized gases that move in the E-layer. If your signal is lucky enough to enter one of these clouds, it can bounce between 1000 and 2000 km in a single hop. Sporadic-E is most often observed on the 6m band.

Troposphere

In the previous section, we discussed how the Ionosphere (the region of our atmosphere between 50km and 400km altitude) can, reflect and refract radio waves, let them pass straight through, or absorbed them completely mostly due to the sun's ionization of the gas in these layers.

Here we discuss how the troposphere (the lowest region of our atmosphere below 20km altitude) can also affect radio waves because of variation in temperature, pressure, or water vapour content. Normal VHF tropospheric propagation can have a range of roughly 800 km.

Tropospheric Ducting

The index of refraction of air is lower when the air is warmer. So during a temperature inversion, the air on the ground is colder than the air above, which means that radio waves go from a high to a low index of refraction medium (that is, from a slow to a fast medium). This causes the radio wave to refract back down toward the Earth. Tropospheric ducting is when the radio wave follows the curve of that inversion layer until it exits back to the Earth after travelling several hundreds of kilometres (up to 2000 kilometers).

Unlike Ionospheric refraction, Tropospheric ducting is observed at VHF frequencies as opposed to HF frequencies.

Scattering

At VHF frequencies, small variations in the density of the troposphere (around 10 km) can scatter some of the radio waves back toward the ground to distances of 800 km.

Scattering can also allow HF signals from the skipzone to be heard. Scatter is most likely involved when weak or distorted signals near or above the maximum usable frequency (ie, they should escape into space) are heard over unusual paths.

References

- https://www.voacap.com/
- http://prop.hfradio.org/

Questions

- B-007-001-001 → B-007-004-002
- B-007-005-001 → B-007-008-001
- B-007-008-006 → B-007-008-011

[1]
See Wikipedia: Line Of Sight Propagation for more details

[2]
The previous three images were taken from Milo Carroll's *Satellite Time Transfer* presentation: http://slideplayer.com/slide/5941869/

[3]
Picture from Wikipedia: Ionosphere

[4]
The animations that follow are not to scale.

[5]
Picture is from Fig. 2-14 at https://www.globalsecurity.org/intell/library/policy/army/fm/24-18/fm24-18_3.htm

[6]
Picture from http://www.ferzkopp.net/Personal/Thesis/node8.html