Propagation
WorldRadio October 2011
Carl Luetzelschwab K9LA

Refraction, Absorption, and Polarization

If someone asked you the question “Is propagation different on 160-Meters and 6-Meters?” I’m sure you would answer with a resounding YES. But be aware there is common ground with respect to propagation over such a wide frequency range. The common ground is that electromagnetic waves from 160-Meters to 6-Meters follow the same laws of physics. So if you understand how refraction, absorption, and polarization change over this frequency range (the three parameters that determine if a wave can get from A to B and how loud it will be), you’ll have more insight into propagation from 1.8 MHz to 50 MHz (and probably even at lower and higher frequencies).

Refraction

Most of our QSOs are via refraction. We do make QSOs via reflection and scatter at times, but we’ll focus on refraction since it is most prevalent. The underlying tenet for refraction is that for a given electron density profile the amount of refraction is inversely proportional to the square of the frequency. In other words, as the frequency is lowered the ray will bend more.

We can see this by doing ray traces. Figure 1 does ray traces on the higher frequencies for a daytime path at solar maximum at an elevation angle of 2 degrees.

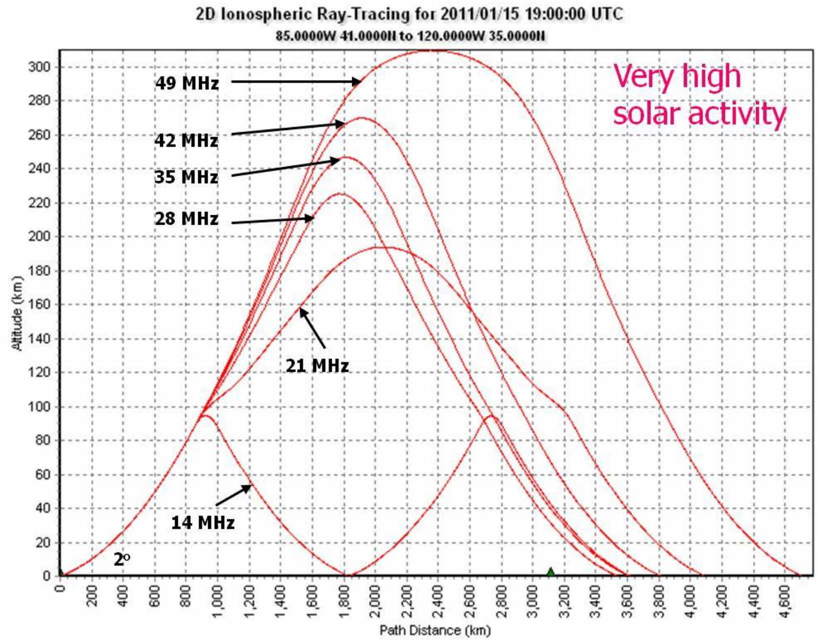


Figure 1 – Daytime Ray Traces vs Frequency

Starting with the 49 MHz ray and proceeding down to the 28 MHz ray, Figure 1 confirms that the lower the frequency the more the bending. More bending results in the ray beginning to refract sooner (at a lower altitude in the ionosphere), and thus the apogee of the ray trace decreases as the frequency is lowered. This also decreases the hop distance as the frequency is lowered.

Note what happens on 21 MHz and on 14 MHz. On 21 MHz, the E region starts coming into play by providing enough refraction to cause the ray to go farther than the 42 MHz ray. And on 14 MHz, the E region ionization is sufficient to turn the ray back to ground, resulting in much shorter hops.

Figure 2 does similar ray traces, but at night on lower frequencies. All ray traces for this case are done at a 5 degree elevation angle.

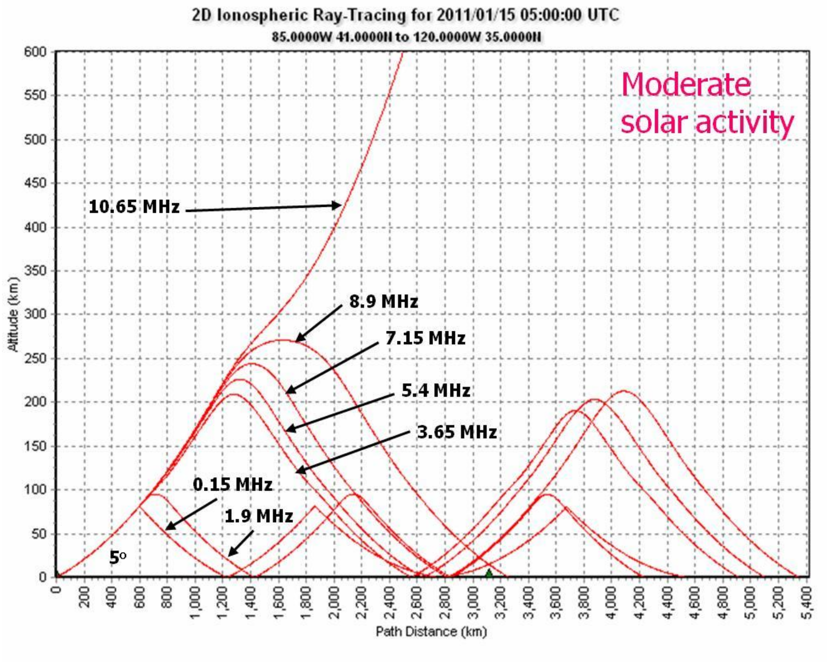


Figure 2 – Nighttime Ray Traces vs Frequency

We again see lower apogees and shorter hops as the frequency is lowered. Note that 10.65 MHz, for the conditions I've chosen (5 degree elevation angle, nighttime, and moderate solar activity), goes through the ionosphere.

Also note that the two lowest frequencies (1.9 MHz and 0.15 MHz) don't get through the E region, resulting in extremely short hops. It's interesting to go into a bit more detail on 160-Meters, and Figure 3 does this by varying the elevation angle from 0 degrees to 20 degrees in 2 degree steps.

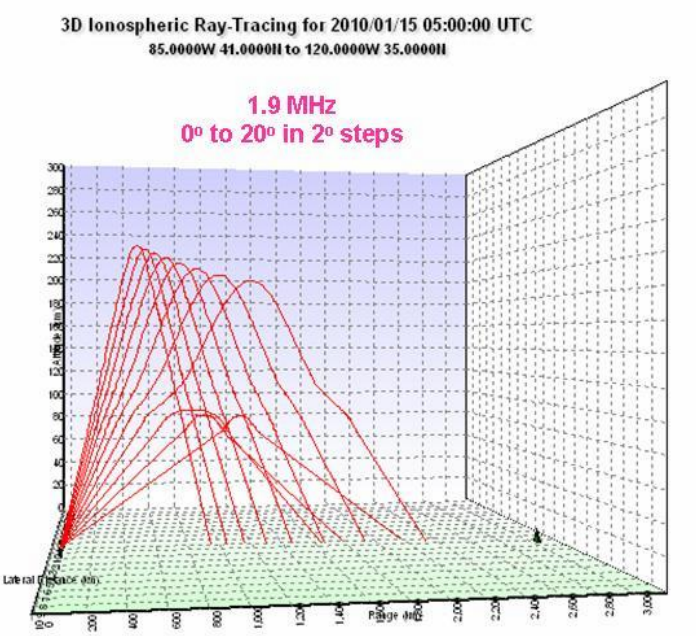


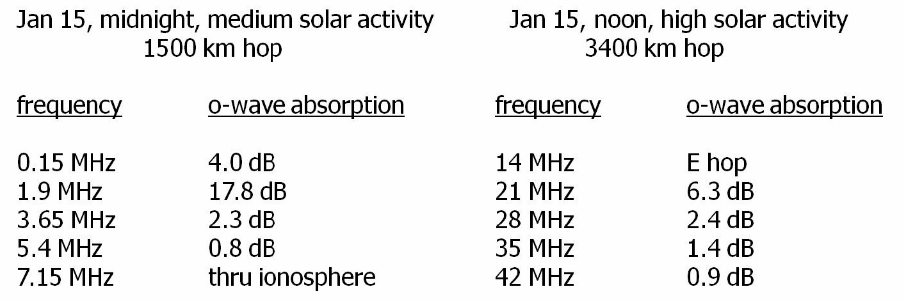
Figure 3 – Nighttime Ray Traces on 160-Meters vs Elevation Angle

For the conditions I've chosen (1.9 MHz, nighttime, and moderate solar activity), elevation angles greater than or equal to about 6 degrees make it through the E region to give F region hops. But elevation angles less than about 6 degrees are confined to E region hops. What this simply says is there is still enough nighttime E region ionization (a typical nighttime critical frequency foE is approximately 0.4 MHz) to refract low elevation angle rays on 1.8 MHz back to ground (per the secant law that relates the maximum useable frequency to the critical frequency).

Absorption

The underlying tenet for absorption is that for a given electron density profile the amount of absorption is inversely proportional to the square of the frequency. In other words, as the frequency is lowered the absorption increases.

Doing ray traces versus frequency over a 1500 km path during the night and over a 3400 km path during the day while focusing on absorption gives the results in Table 1. The data is for F hops.



Jan 15, midnight, medium solar activity 1500 km hop		Jan 15, noon, high solar activity 3400 km hop	
frequency	o-wave absorption	frequency	o-wave absorption
0.15 MHz	4.0 dB	14 MHz	E hop
1.9 MHz	17.8 dB	21 MHz	6.3 dB
3.65 MHz	2.3 dB	28 MHz	2.4 dB
5.4 MHz	0.8 dB	35 MHz	1.4 dB
7.15 MHz	thru ionosphere	42 MHz	0.9 dB

Table 1 – Absorption Results

The data in Table 1 confirms that the lower the frequency, the higher the absorption. But note the amount of absorption on 0.15 MHz (150 KHz) in the left-hand set of data. It decreases significantly compared to the absorption on 1.9 MHz. The reason for this is the 0.15 MHz ray does not get as high into the ionosphere (refer back to Figure 2) as the 1.9 MHz ray (i.e., it bends more), and in fact it hardly gets into the absorbing region (which is the lower E region at night). So when you see Amateur Radio reports of long distance QSOs on frequencies below 1.8 MHz, you'll know there's nothing magic going on – it's just the laws of physics (I don't mean to denigrate the effort that went into such a feat – you still have antenna efficiency issues to overcome and man-made noise issues to overcome below 1.8 MHz).

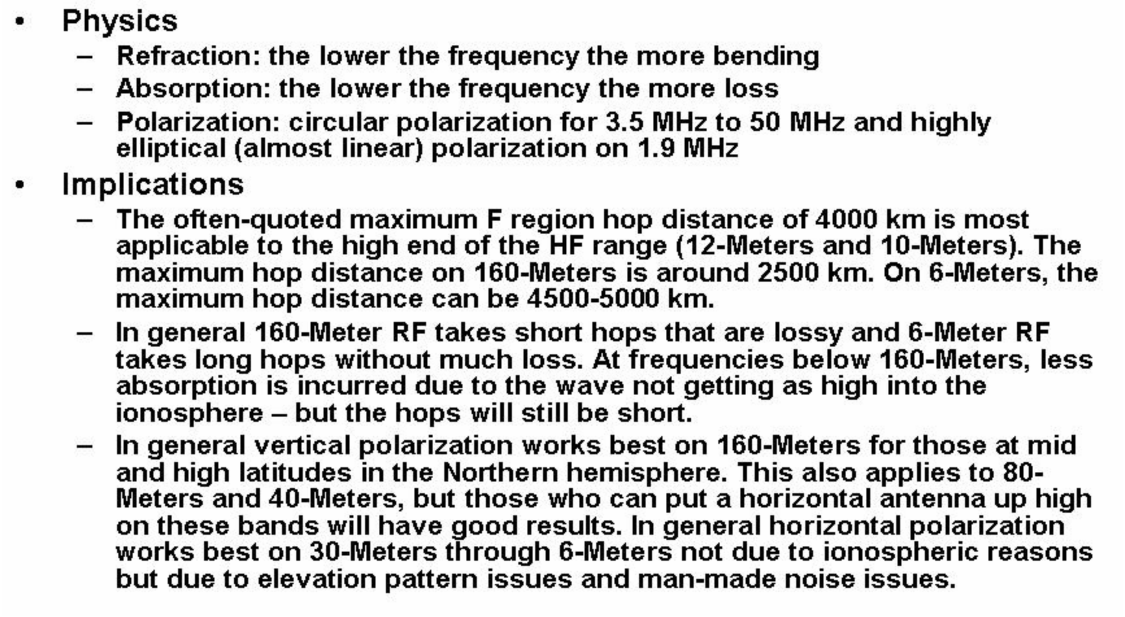
Polarization

When we send a signal on its way from our transmit antenna, it enters the ionosphere and couples into the two characteristic waves that propagate through the ionosphere – the ordinary wave and the extraordinary wave. The polarization of these two waves progresses from circular on 50 MHz to highly elliptical (approaching linear) on 1.8 MHz. It's a gradual trend, and for all intents and purposes we can consider that these waves are circularly polarized all the way down to 3.5 MHz. When these two waves exit the ionosphere, the polarization at the exit point is what's presented to our receiving antenna.

Both waves propagate similarly through the ionosphere down to 3.5 MHz. But on 1.8 MHz the extraordinary wave incurs significantly more absorption than the ordinary wave due to being near the electron gyro-frequency (from 0.7 MHz to 1.7 MHz depending on where you are in the world), and as such it is usually considered out of the picture on 160-Meters (that's only half the story – the extraordinary wave on 1.8 MHz also see a significantly different index of refraction, and it takes a significantly different path through the ionosphere).

Summary and Implications

The Summary Box highlights the main points of the physics of refraction, absorption, and polarization, along with some pertinent implications. Please realize these are generalities for the F region for a given electron density profile. The fact that we have two major players (the F region and the E region) and disturbances to propagation adds intracasies to these generalities.



- Physics
  - Refraction: the lower the frequency the more bending
  - Absorption: the lower the frequency the more loss
  - Polarization: circular polarization for 3.5 MHz to 50 MHz and highly elliptical (almost linear) polarization on 1.9 MHz
- Implications
  - The often-quoted maximum F region hop distance of 4000 km is most applicable to the high end of the HF range (12-Meters and 10-Meters). The maximum hop distance on 160-Meters is around 2500 km. On 6-Meters, the maximum hop distance can be 4500-5000 km.
  - In general 160-Meter RF takes short hops that are lossy and 6-Meter RF takes long hops without much loss. At frequencies below 160-Meters, less absorption is incurred due to the wave not getting as high into the ionosphere – but the hops will still be short.
  - In general vertical polarization works best on 160-Meters for those at mid and high latitudes in the Northern hemisphere. This also applies to 80-Meters and 40-Meters, but those who can put a horizontal antenna up high on these bands will have good results. In general horizontal polarization works best on 30-Meters through 6-Meters not due to ionospheric reasons but due to elevation pattern issues and man-made noise issues.

Summary Box