Propagation on 630-Meters and 2200-Meters

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This is a <u>*theoretical*</u> *look at propagation on 630-Meters and 2200-Meters using ray tracing software. It expands on the brief discussion in the ARRL Handbooks. Look for a* <u>*real-world*</u> *investigation of propagation on NDB frequencies (near 630-Meters) in a future QST article.*

The 2019 ARRL Handbook (along with several earlier editions) has a short section (Section 19.8) starting on page 19.32 titled "Propagation Below the AM Broadcast Band". I penned this section as an introduction to propagation on 630-Meters (475 KHz) and on 2200-Meters (137 KHz), and wanted to get across the concept that short hops would be prevalent on our new low frequency bands but perhaps with lower ionospheric absorption than on 160-Meters.

That material is "the truth" and "nothing but the truth", but it isn't "the whole truth". The extraordinary wave needs to be brought into the picture, as that section was only written around the ordinary wave. Also, the difference between 475 KHz and 137 KHz needs to be investigated.

As a review, when our transmitted signal enters the ionosphere down at the D region, some of the transmitted energy is coupled into the ordinary wave and some is coupled into the extraordinary wave. These are the two characteristic waves that propagate through the ionosphere [note 1]. Thus it is important to understand how both these characteristic waves propagate through the ionosphere on 475 KHz and 137 KHz compared to 160-Meters and higher.

<u>Review of HF and MF Propagation</u>

On HF (3-30 MHz), for all intents and purposes both the ordinary and extraordinary waves are circularly polarized [note 2]. Additionally, both waves essentially take the same path through the ionosphere with the same amount of ionospheric absorption. Figure 1 shows ray traces (using Proplab Pro V3) on a West-East path in the United States (32N/107W to 34N/95W) on 3.5 MHz on a December night at solar minimum with both waves launched at 15^{o} elevation angles.

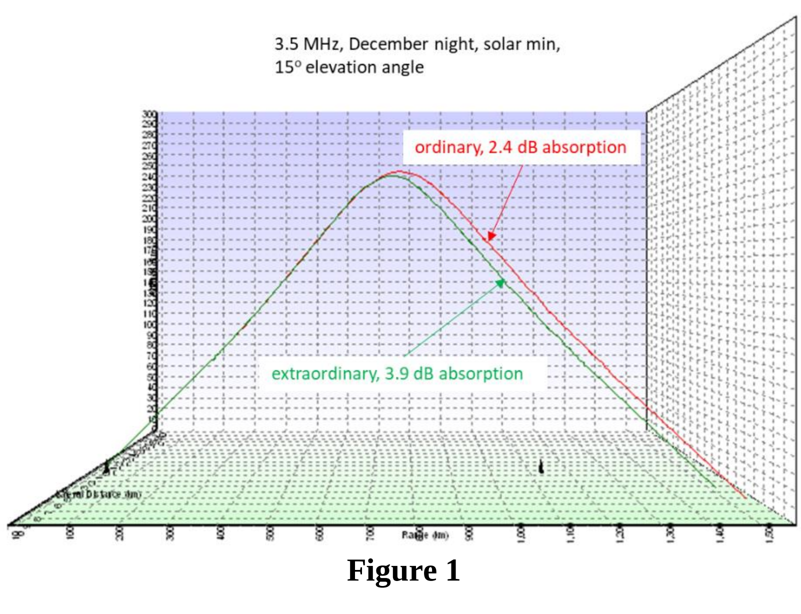


Figure 1

The ground distance is a bit different between the two waves, as is the ionospheric absorption – 2.4 dB for the ordinary wave versus 3.9 dB for the extraordinary wave. These differences would likely not be noticed. If we go up in frequency, these small differences would diminish further.

Now let's move down to 1.8 MHz under the same conditions. See Figure 2.

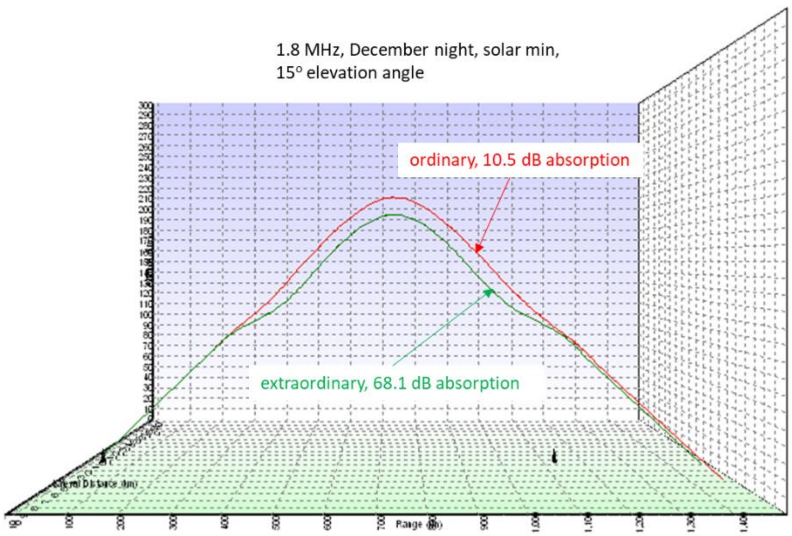


Figure 2

The paths are more different, and ionospheric absorption is much more different – 10.5 dB for the ordinary wave versus 68.1 dB for the extraordinary wave. This difference in ionospheric absorption is why only the ordinary wave is usually considered in 160-Meter propagation.

To exaggerate these differences in paths through the ionosphere and ionospheric absorption, Figure 3 looks at ray traces at 1.6 MHz.

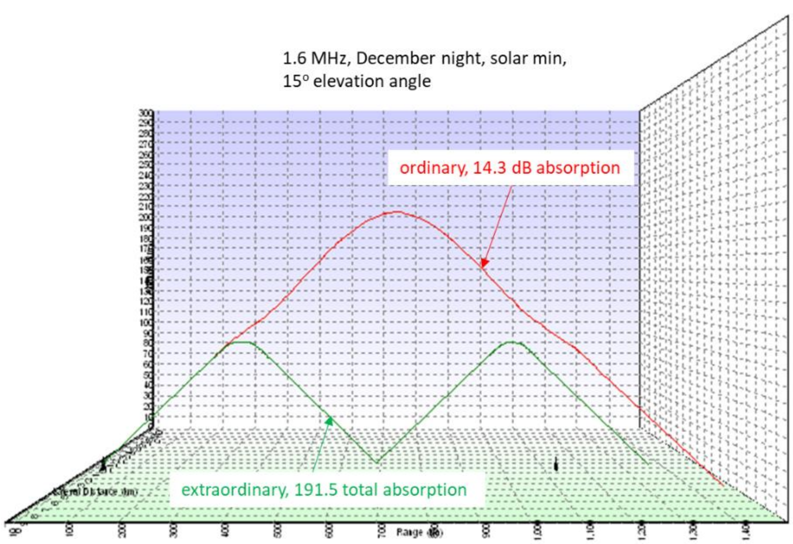


Figure 3

The paths through the ionosphere are radically different at 1.6 MHz – the extraordinary wave refracts (bends) more than the ordinary wave (as it does at 1.8 MHz and 3.5 MHz). And the ionospheric absorption of the extraordinary wave is now huge.

I should point out that the law of physics that says "the amount of ionospheric absorption is inversely proportional to the square of the frequency" only applies to frequencies that are not impacted by the Earth's magnetic field – that is, at HF and higher frequencies. At frequencies lower than HF, the Earth's magnetic field renders that law useless.

The Earth's Magnetic Field

What's causing these differences in the paths through the ionosphere and in ionospheric absorption? The electron gyro-frequency is the cause, which is a result of the ionosphere's interaction with the Earth's magnetic field. As we move down from 3.5 MHz to 1.8 MHz and finally to 1.6 MHz, the operating frequency is nearer the electron gyro-frequency.

The electron gyro-frequency is the frequency at which ionospheric electrons spiral around magnetic field lines. Worldwide, the electron gyro-frequency varies from around 700 KHz to 1.7 MHz. For our path in all the ray traces shown above, the electron gyro-frequency at the midpoint is about 1.4 MHz. Figure 4 relates 3.5 MHz, 1.8 MHz and 1.6 MHz (which are all above the electron gyro-frequency) to the electron gyro-frequency.

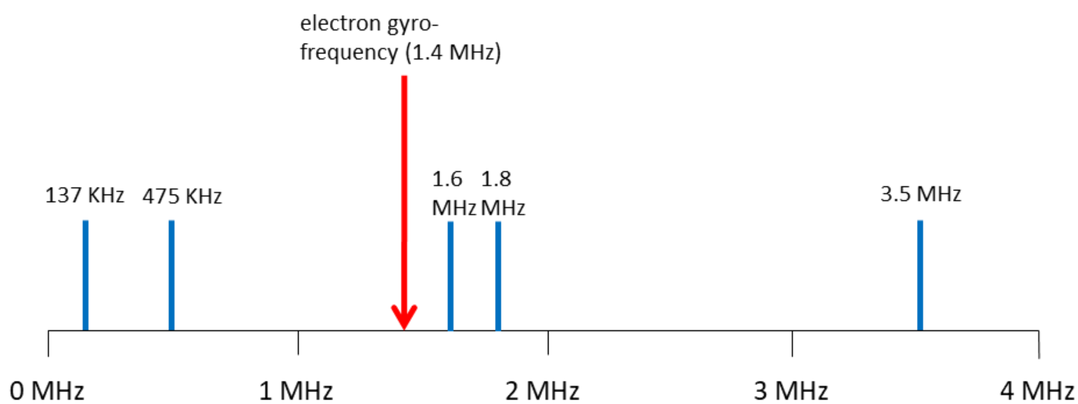


Figure 4

We note that 3.5 MHz is far enough away from the electron gyro-frequency so that the ordinary and extraordinary waves behave very similarly. But as we move down to 1.8 MHz, the effect of the electron gyro-frequency is starting to be seen – especially in ionospheric absorption [note 3].

Ray Traces on Frequencies Below the Electron Gyro-Frequency

Also annotated in Figure 4 are our two new bands – 475 KHz (630-Meters) and 137 KHz (2200-Meters). They are below the electron gyro-frequency, so we might suspect that there would be some interesting changes in propagation on our two new bands. Let's start by looking at ray traces at 475 KHz at the same 15^{o} elevation angle as all previous ray traces. See Figure 5.

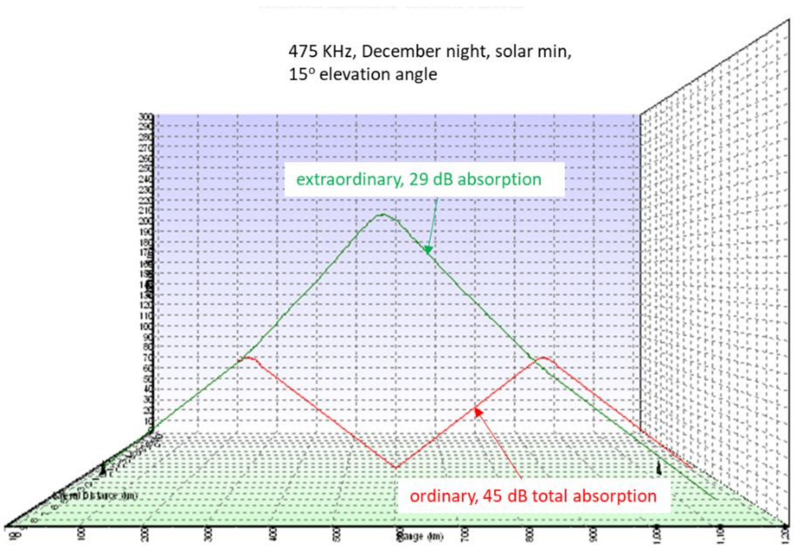


Figure 5

Indeed, the first change we note is that now the ordinary wave refracts more than the extraordinary wave [note 4]. The second change is that there is now less ionospheric absorption for the extraordinary wave for the same distance.

Now let's look at a couple different elevation angles at 475 KHz. The Figure 6 ray traces are at a 30° elevation angle.

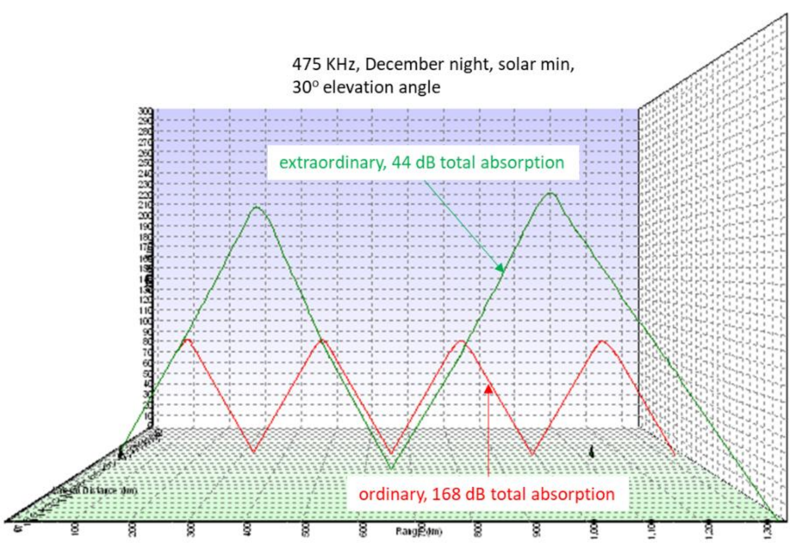


Figure 6

Again, the extraordinary wave incurs the least ionospheric absorption for the same distance. The ordinary wave at 30° elevation angle now gets up to 80 km compared to only 70 km at the 15° elevation angle – this is due to the higher elevation angle.

Next, in Figure 7, are the ray traces at a 10° elevation angle at 475 KHz.

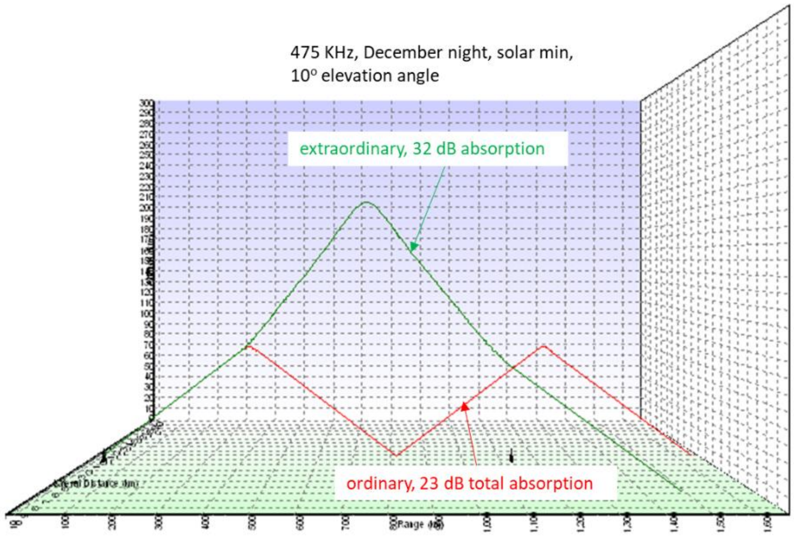


Figure 7

Now the ordinary wave has the least ionospheric absorption for the same distance. That's because at a lower elevation angle the ordinary wave only gets up to 68 km – it barely enters the D region, resulting in less ionospheric absorption.

Let's now go down to 137 KHz and do ray traces at a 15° elevation angle. See Figure 8.

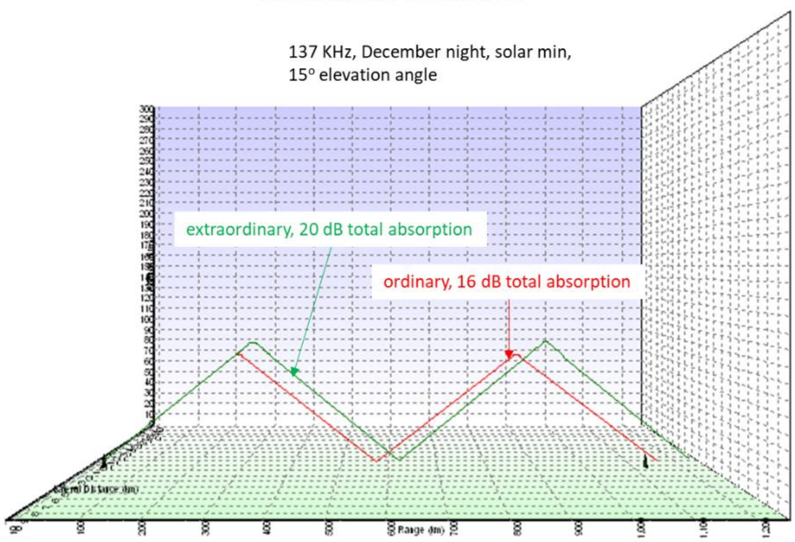


Figure 8

At an elevation angle of 15° on 137 KHz, there's still enough ionization down low during the night at solar minimum to refract both the ordinary wave (it gets to 67 km) and extraordinary wave (it gets to 77 km) from the D region. The ordinary wave has slightly less ionospheric absorption mainly because it doesn't get as high into the D region as the extraordinary wave.

On 137 KHz at an elevation angle of 10^{o}, both waves still refract from the D region, with the ordinary wave still having less ionospheric absorption compared to the extraordinary wave. At an elevation angle of 30^{o}, both waves continue to be refracted by the D region, but now the extraordinary wave has less absorption.

Summary Up to Now

Table I shows which characteristic wave has the least ionospheric absorption versus frequency and elevation angle for nighttime conditions at solar minimum.

frequency	**elevation angle**	**best wave**
137 KHz	10^{o}	ordinary
	15^{o}	ordinary
	30^{o}	extraordinary
475 KHz	10^{o}	ordinary
	15^{o}	extraordinary
	30^{o}	extraordinary

Table I

What this tells us is sometimes the ordinary wave (o-wave) will dominate and sometimes the extraordinary wave (x-wave) will dominate. It also suggests that propagation on our two new bands can be different, especially in hop distance.

Why Should We Worry about the O-Wave and the X-Wave?

As stated earlier, the polarization of the ordinary wave and extraordinary wave is circular at HF (3-30 MHz). Thus is doesn't matter whether we use a horizontal antenna or a vertical antenna at HF when just considering polarization. But be aware that vertical antennas pick up more noise and need a good ground system.

On 160-Meters, the polarization tends toward a thin ellipse due to the effect of the magnetic field – essentially linear polarization. The major axis of the ordinary wave is parallel to the magnetic field lines, while the major axis of the extraordinary wave is perpendicular to the magnetic field.

At the high latitudes, the magnetic field lines are mostly vertical. Thus if the ordinary wave has the least absorption (as it does on 160-Meters), it's major axis is parallel to the vertical magnetic field lines – which says we should transmit and receive with vertically polarized antennas. That couples the most energy from our linear antenna into the desired characteristic wave (the ordinary wave) that propagates through the ionosphere with the least ionospheric absorption.

Polarization on 630-Meters and 2200-Meters

Using Proplab Pro V2 (I used the old DOS version – I know where to find the polarization data in it!), I ran ray traces on 475 KHz and 137 KHz at a 15^{o} elevation angle during the night at solar minimum over the aforementioned West-East path.

As expected, the polarization ellipse turned out to be very thin on both frequencies. This indicates near linear polarization (as is seen on 160-Meters) [note 5]. Thus coupling the energy from your antenna to the characteristic wave with the least absorption is very important.

From the earlier table showing which characteristic wave was most important at 475 KHz and 137 KHz versus elevation angle, an antenna with both vertical and horizontal polarization would be best on our new bands since each characteristic wave might have its best time. An inverted-L would fit this requirement. I originally mentioned a T antenna, but Brian K6STI rightly advised that the two sides of the horizontal portion are out-of-phase – giving minimal horizontal polarization.

Daytime Propagation

All the previous ray traces were done during the night at solar minimum. Let's do ray traces during the day (1700 UTC – around 11:00 AM local time for the West-East path) at various elevation angles but still at solar minimum for 475 KHz and 137 KHz. There's more D region ionization during the day, so this could be a big problem with ionospheric absorption. Figure 9 shows daytime results on 475 KHz at a 15^{o} elevation angle.

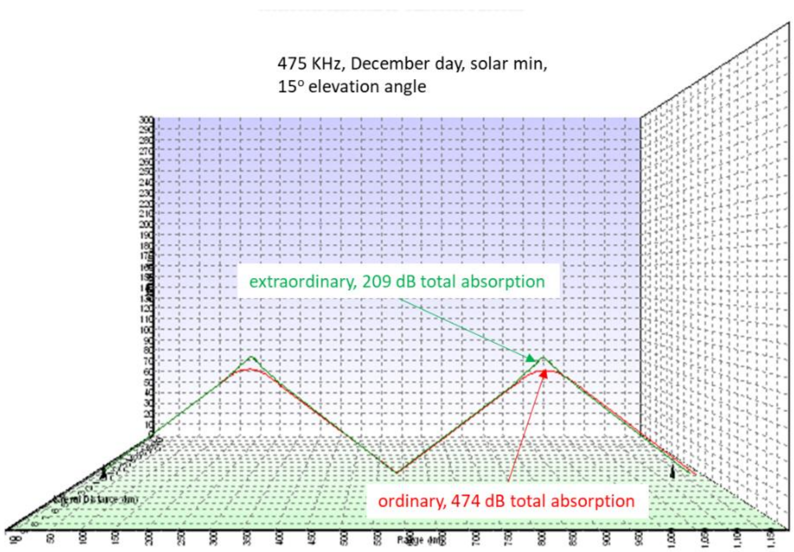


Figure 9

Neither characteristic wave gets above 80km, with high ionospheric absorption for both characteristic waves. Compare these results to Figure 5.

At other elevation angles (5^{o}, 30^{o} and 45^{o}), the results are the same: nothing gets above the D region and the ionospheric absorption is very high. This also applies to ray traces at 137 KHz. The additional daytime ionization really takes its toll (in terms of ionospheric absorption).

Propagation at Solar Maximum of an Average Solar Cycle

Figures 10 and 11 are ray traces during the night at solar maximum of an average solar cycle (smoothed sunspot number of around 100).

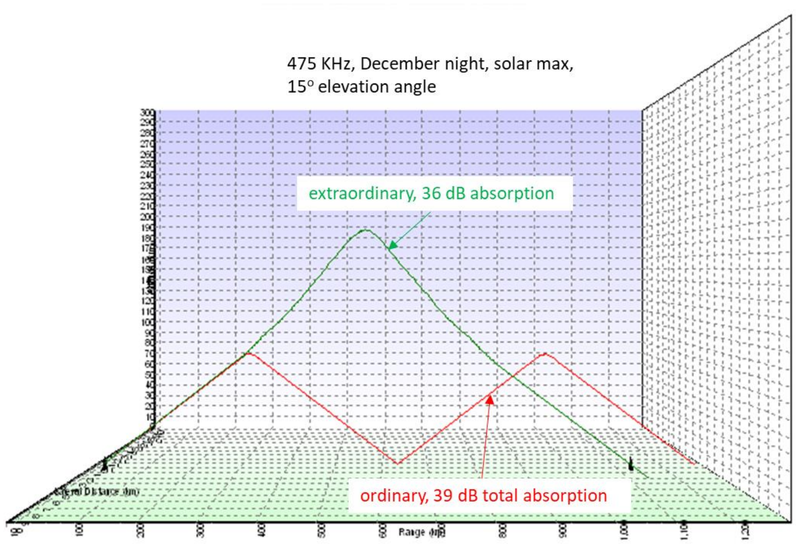


Figure 10

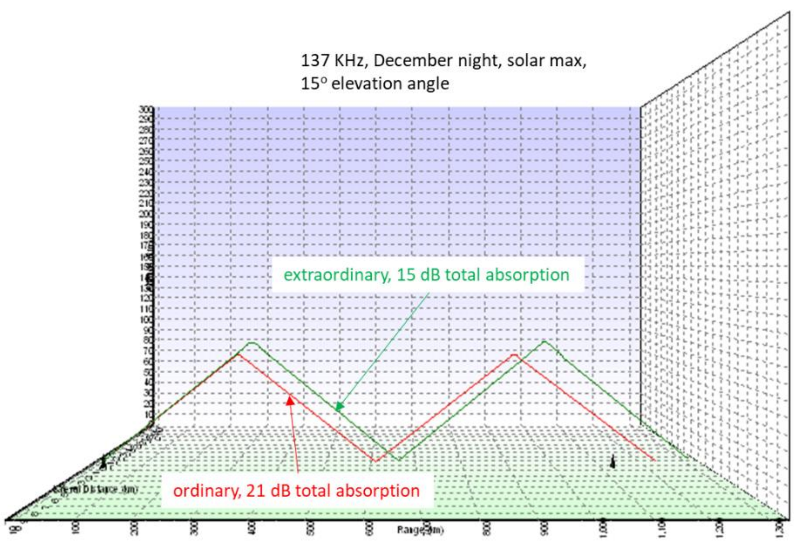


Figure 11

Comparing Figure 10 to Figure 5 and Figure 11 to Figure 8 shows there is a small difference between solar minimum and solar maximum at night. This is to be expected as there's minimal direct solar radiation at night affecting the lower ionosphere. No ray traces were done during the day at solar maximum as propagation should be worse than during the day at solar minimum.

<u>Propagation Around Sunrise and Sunset</u>

When propagation around sunrise and sunset is discussed, two different mechanisms should be reviewed. One mechanism is when the path is more perpendicular to the terminator than along the terminator. This is when we see sunrise and sunset enhancements on 160m. Figure 12 (from W6ELProp) shows a typical example of this type of path, which is discussed in the next section.

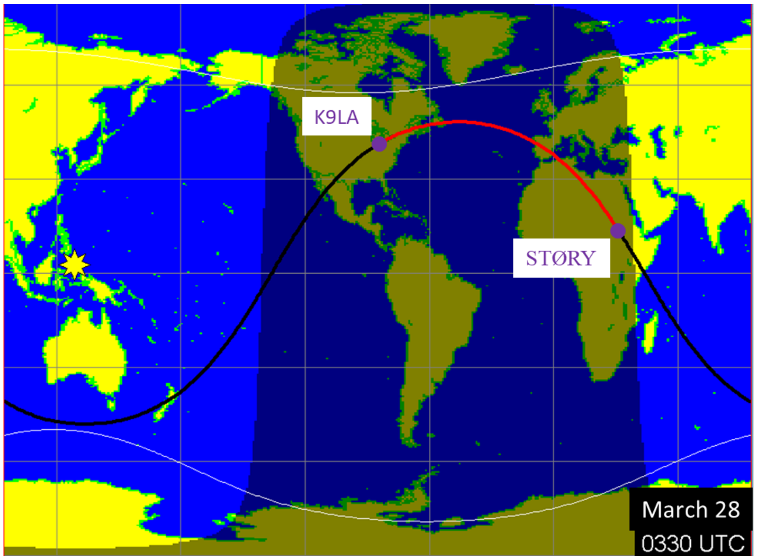


Figure 12

The other mechanism is when the path is parallel to or near parallel to the terminator. This is gray line (or grey line) propagation. Figure 13 (again from W6ELProp) shows an example of this type of path (the short red line – 1135 km) at sunrise (1320 UTC). We'll do ray traces for this scenario before, at and after sunrise. This path is from 32^{o}N/97^{o}W to 41^{o}N/91^{o}W.

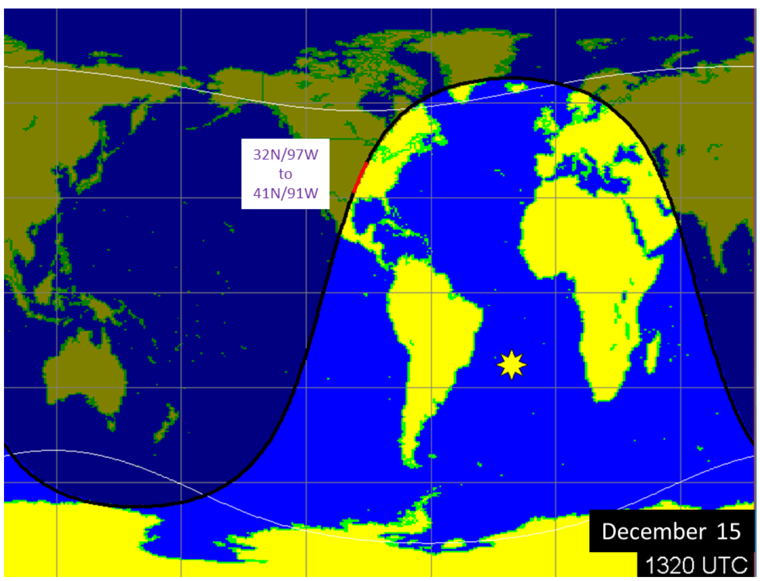


Figure 13

Table II shows the ray trace results on both 475 KHz and 137 KHz at a 15^o elevation angle around sunrise. The extraordinary wave incurs the least ionospheric absorption on this path.

		475 KHz	**137 KHz**
1220 UTC	1 hour before sunrise	69 dB	38 dB
1320 UTC	at sunrise	168 dB	105 dB
1420 UTC	1 hour after sunrise	201 dB	141 dB

Table II

Table III shows the ray trace results on both 475 KHz and 137 KHz at a 15° elevation angle around sunset on the path from 32°N/97°W to 41°N/103°W (also 1135 km). This path aligns with the sunset terminator at 1320 UTC. Again the extraordinary wave incurs the least amount of ionospheric absorption.

		475 KHz	137 KHz
1220 UTC	1 hour before sunset	195 dB	131 dB
1320 UTC	at sunset	161 dB	97 dB
1420 UTC	1 hour after sunset	60 dB	36 dB

Table III

As can be seen, our model of the ionosphere says there's nothing magical with gray line propagation. The data says there's no better place for low frequency RF than in the dark ionosphere.

But our model of the ionosphere is a monthly median model (more on this in the next section). Short-term events could happen that aren't in the model, so interesting things could still happen. The nighttime electron density valley (discussed in the next section) and D region bite-outs (discussed in the section after the nighttime electron density valley section) are known to exist and they could affect propagation on 475 KHz and 137 KHz.

Ducting and the Nighttime Electron Density Valley

Sunrise and sunset enhancements (a significant but usually short duration rise in signal strength) on long distance paths on 160-Meters are believed to be due to ducting. There is an electron density valley during the night just above the E region peak as shown in Figure 14. This figure (from Proplab Pro V2) shows the electron density profile at the midpoint of a path from STØRY (a DXpedition to Sudan in March 2003) to K9LA. The midpoint is in the dark ionosphere.

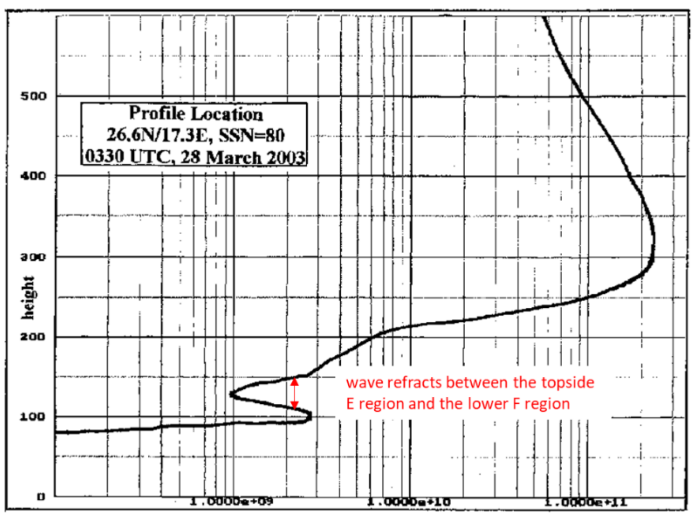


Figure 14

1.8 MHz RF can refract between the topside E region and the lower F region (kind of like the lower and upper boundary of a waveguide), avoiding ionospheric absorption in the lower ionosphere and avoiding ground reflection losses. The tilts in the ionosphere at sunrise and sunset are believed to be the major instigators of getting into the duct and out of the duct (although any irregularity in the ionosphere could also do this).

Figure 15 shows this ducting mode in Proplab Pro V2 on 160-Meters from STØRY to K9LA.

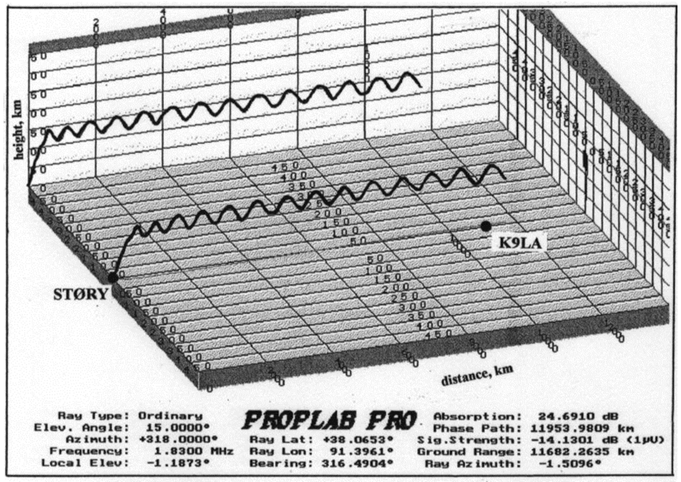


Figure 15

Going back to Figure 5 (475 KHz, December night, solar minimum, 15^{o} elevation angle) shows that the extraordinary wave goes through the nighttime E region peak. Thus ducting in the nighttime electron density valley could be a possibility on 630-Meters.

But many ray traces at many elevation angles did not produce a duct. That's not too discouraging, as we have to remember that the model of the ionosphere in Proplab Pro V3 is a monthly median model. It's kind of an average of the ionosphere over a month's time frame. The daily variation over this monthly time frame is significant, and it's possible that an electron density profile that's conducive to ducting could occasionally occur.

Ducting in the nighttime electron density valley on 137 KHz is likely out of the picture, as 137 KHz doesn't get through the E region.

D-Region Bite-Outs

The nighttime electron density valley may not be the only mechanism for ducting on our new bands. Although the D region is usually modeled as a monotonic decrease in electron density from about 90 km down to about 60 km, it can be different in the real world. Figure 16 shows some measurements on the high latitude D region.

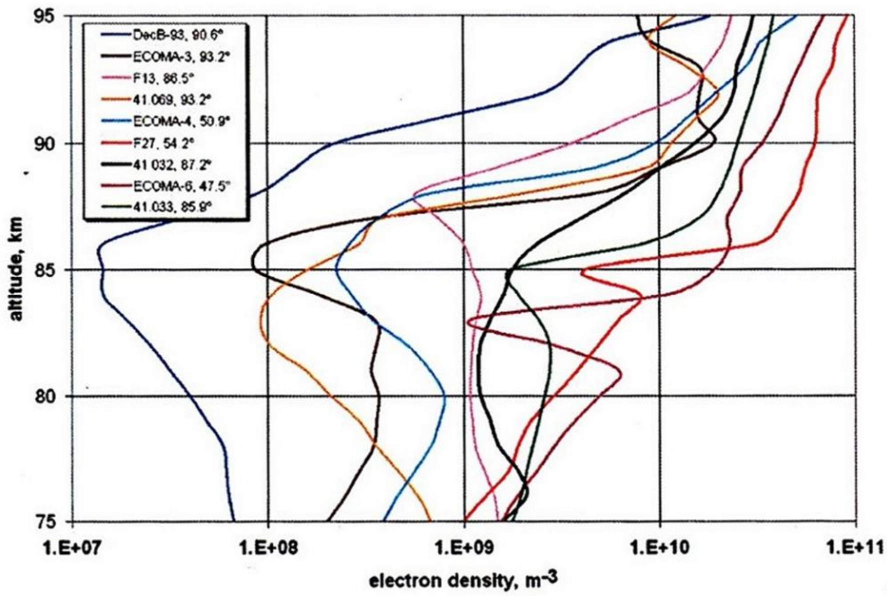


Figure 16

The various colors indicate the source of the data and the solar zenith angle [note 6] at the time of the measurement.

What's important to notice are the largest bite-outs in the electron density when the Sun is on the horizon (solar zenith angles around 90°). These bite-outs look somewhat like the nighttime electron density valley above the E region peak in Figure 14. Thus ducting on both 475 KHz and 137 KHz could be possible. Obviously more work is needed in this area.

Even if ducting doesn't occur with these bite-outs, the significant drop in electron density would cause a significant decrease in ionospheric absorption [note 7].

The Role of Negative Ions

When the Sun sets, free electrons start recombining to reduce the D region and lower E region electron density to its small (but finite) nighttime value – which decreases ionospheric absorption.

Electrons that don't recombine may also attach to neutral constituents to make negative ions. Since these negative ions are much heavier than an electron, the electrons that attached to the neutrals are now out of the picture for the ionospheric absorption process.

Thus there could be enhanced propagation on our new bands due to negative ions. Here's another area where more work is needed.

Antennas and Man-Made Noise

Two of the problem areas on our new bands that we have some control over are antennas and man-made noise.

The purpose of an antenna is to put the most radiation at the azimuth dictated by the ionosphere (usually a short or long great circle path), at the elevation angle dictated by the ionosphere and at the polarization dictated by the ionosphere. As stated earlier, due to the apparent variability of propagation on our new bands, an antenna with both vertical and horizontal polarization with somewhat of an omni-directional azimuth pattern appears to be best. An inverted-L or a T might be the best choice within real-world implementation issues.

That leaves man-made noise. Our job is reduce man-made noise as much as possible. Living in a quiet rural area certainly helps compared to a residential area. You made need to do some sleuthing to find noise sources. Then the tough part may begin – resolving these noise sources (especially if they are not on your property).

Per the ITU noise document [note 8], man-made noise increases as frequency is lowered (see Figure 10 in the referenced document). When you get to 475 KHz, the median man-made noise in a 500 Hz bandwidth (a typical CW bandwidth) in a quiet rural area is -85 dBm. That's about S7 assuming S9 = -73 dBm.

Unfortunately the man-made noise curves only go down to 300 KHz. If we extrapolate the curves to 137 KHz, the median noise in the 500 Hz bandwidth in a quiet rural area would be -72 dBm. That's S9. It should be noted that the variability of the noise is around +/- 8 dB. On both bands there will be "good" days and "not so good" days with respect to man-made noise.

Your antenna pattern (in both azimuth and elevation) may provide some SNR (signal-to-noise ratio) improvement due to not picking up noise from all around the compass. You can also use a separate receive antenna – for example, I have used my SAL-20 Shared Apex Loop to listen to the Non-Directional Beacon band (roughly 200 – 415 KHz) with good success.

Finally, the new digital modes will likely out-perform our ear-brain interface. So go digital on our new bands!

Ground Wave Propagation

Using ITU ground wave curves [note 9], the distance at which the transmitted power at the receive site equals the aforementioned noise powers can be estimated (this gives an SNR of 0 dB). Assuming 25 Watts radiated and -10 dBi gain antennas and average ground conditions (dielectric constant = 22 and conductivity = 0.003 S/m from Figure 6 in the referenced ITU document), this distance is about 300 km on 475 KHz and about 900 km on 137 KHz.

Remember the above distances are estimates for decoding by ear. Digital modes will increase these distances. Thus ground wave propagation will be a factor on our new bands – especially on 137 KHz. Again, go digital on our new bands!

Conclusions

A. The Earth's magnetic field has a profound effect on propagation at 630-Meters and 2200-Meters (as it does on 160-Meters). It appears that both the ordinary wave and the extraordinary wave could be important on our new bands, which suggests using an antenna with both horizontal and vertical polarization.

B. On low frequencies, usually more ionization is not needed. To reduce ionospheric absorption, less ionization in the lower ionosphere is the enabler for good propagation.

C. Propagation on 630-Meters and 2200-Meters can be different.

D. Sky-wave propagation during the day on both bands appears to be very limited in distance.

E. Propagation around sunrise and sunset can give good results, but we don't fully understand the mechanisms that enable this.

F. Ducting might be possible on 630-Meters in the nighttime electron density valley and in D region bite-outs.

G. Ducting might be possible on 2200-Meters in D region bite-outs.

H. Ionospheric absorption may be decreased in D region bite-outs.

I. Negative ions may help propagation on 630-Meters and 2200-Meters.

J. Antennas are inefficient on both bands.

K. Man-made noise on both bands will likely be very high.

L. Groundwave propagation can be a big factor on 2200-Meters

Notes

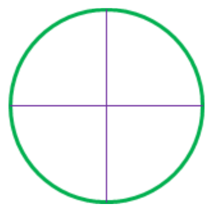
1. How much of the transmitted energy is coupled into each characteristic wave depends on the originating polarization (which is usually horizontal or vertical) and where you are on Earth.

2. The polarization vectors of the ordinary and extraordinary waves rotate in opposite directions.

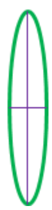
3. There are other gyro-frequencies. For example, the proton gyro-frequency is 762 Hz. It is much lower in frequency because a proton is much heavier than an electron.

4. We have to watch it here. Is the increased refraction by the ordinary wave due solely to the Earth's magnetic field? Or is some of it due to the law of physics that says "the amount of refraction is inversely proportional to the square of the frequency"? I think some of it is due to this law of physics, and we'll see more of its impact at 137 KHz.

5. Proplab Pro V2 reports the real and imaginary parts of the polarization ellipse. Converting those rectangular coordinates to a magnitude and phase gives us R, which is the ratio of the major axis to the minor axis in the polarization ellipse. An R value of 1 or near 1 indicates circular polarization (major and minor axis lengths are equal) as shown below.

   A small R value or large R value indicates a thin ellipse (major and minor axis lengths are radically different) – which is tending towards linear polarization as shown below.

6. The solar zenith angle is the angle between overhead at your location and the position of the Sun. If the Sun is directly overhead, the solar zenith angle is 0^{o}. If the Sun is on the horizon (sunrise or sunset), the solar zenith angle is 90^{o}.

7. To a first-order approximation, ionospheric absorption is proportional to the number of electrons.

8. Recommendation ITU-R P.372 titled "Radio Noise".

9. Recommendation ITU-R P.368 titled "Ground-Wave Propagation Curves for Frequencies Between 10 KHz and 30 MHz.