Ducting and Spotlight Propagation on 160m

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If you enjoyed reading about the issues that contribute to the unpredictability of propagation on 160m in the March and April 1998 issues of CQ, read on. Here's more information about ducting and spotlight propagation on 160m, along with some new information about the day-to-day variability of the ionosphere – the factor that makes it tough for us to predict propagation conditions on Topband.

Introduction

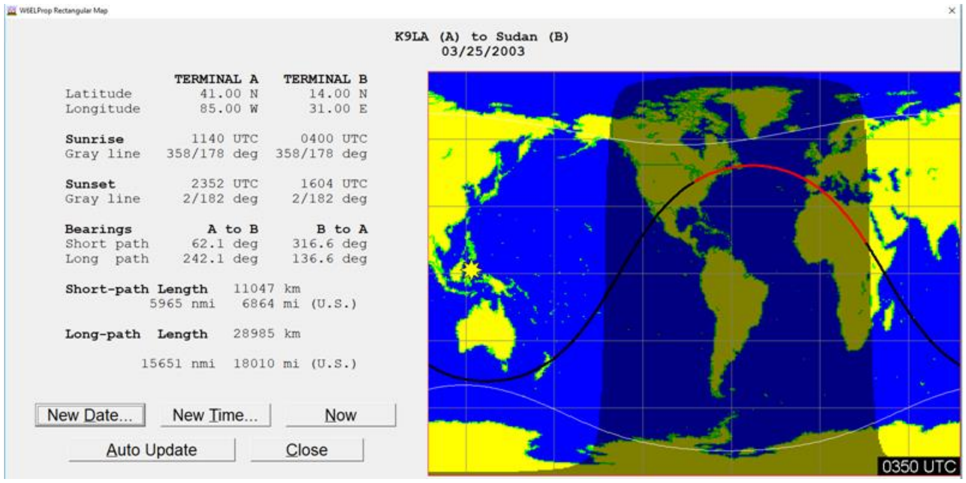
In their seminal two-part article about propagation on 160m [reference 1], Cary Oler and Ted Cohen N4XX discussed, among other topics, ducting on 160m. Figure 5 in their Part II showed a 1.8MHz electromagnetic wave propagating via a duct on a path from Washington, DC toward Hungary. They commented "a considerable number of DX openings on Topband over distances greater than 4,000 kilometers may owe their occurrence to a phenomenon known as *signal ducting*."

The purpose of this article is to expand on the Oler and Cohen article – specifically in the areas of ducting and spotlight propagation. Along the way we'll gain a good understanding of why we need to invoke ducting. We'll also look at a nighttime electron density profile to physically see the reason for ducting. Then we'll look a little closer at what gets us into a duct and what gets us out of a duct in the dark ionosphere. Finally, we'll take a very brief look at the factors that contribute to the day-to-day variability of the ionosphere – the factors that probably make or break propagation on 160m.

Multi-hop propagation

Let's start by looking at multi-hop propagation using a real-life example. In March 2003 a team of German operators put STØRY on the air. They made a big effort on 160m during their March 20 – March 31 stay. This was a new one on 160m for me, so I wanted to work them.

The short path distance from STØRY to my QTH is 11,044 km. My sunset during their stay was around 0000 UTC. Their sunrise was around 0400 UTC. This put the path in darkness for 4 hours, and it gave me high hopes of putting them in the log. Here's a picture (from the mapping feature of W6ELProp) of the short path (the red line) and the terminator. Note that this is <u>not</u> a gray line path.



If we do a ray trace using Proplab Pro [reference 2] from STØRY to my QTH at 0200 UTC (midway between my sunset and STØRY's sunrise), the best multi-hop mode (in terms of signal strength) is shown in Figure 1.

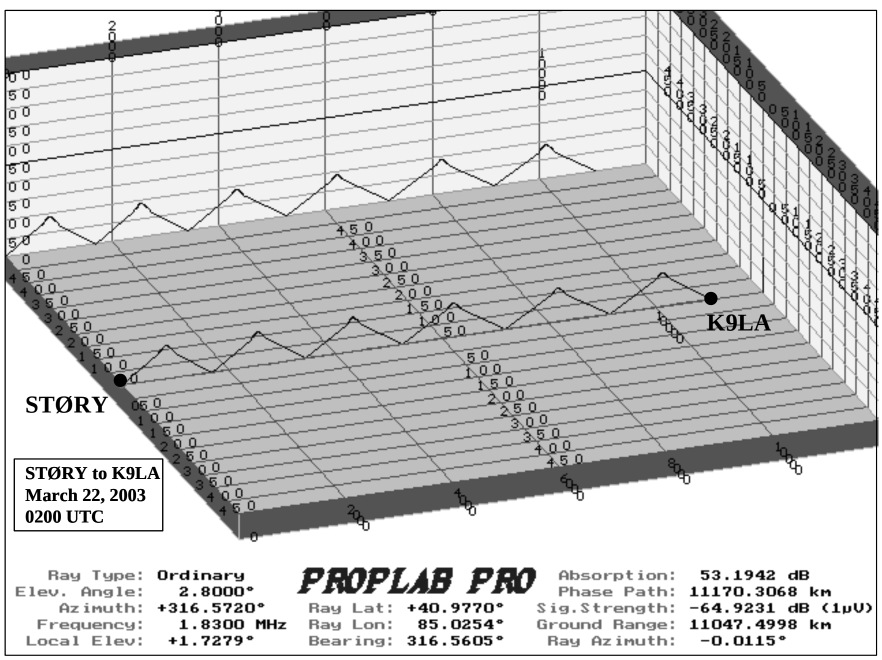


Figure 1 – The Best Multi-Hop Mode

The resulting field strength is -64.9dB referenced to 1uV/m (from the third line in the reported data in the right-most column – note that the 'per meter' annotation is omitted after 1uV in the reported data), which assumes a transmit power of 1kW at STØRY into an antenna with a maximum gain of 0dBi (about what a quarter-wave vertical will do over average ground). Translating that field strength to power in 50Ω, assuming my inverted-L has 0dBi maximum gain, gives -158dBm. This is about 25dB below the noise floor of my OMNI VI Plus, and more importantly it is many more dB below my system noise level when external noise (atmospheric and man-made) is brought into the picture.

For example, at my QTH on 160m on my inverted-L (I didn't have any Beverages at the time of the STØRY DXpedition), my noise is around -103dBm in a 500Hz bandwidth. Thus STØRY's signal was predicted to be 55dB below my system noise [note 1]. In other words, I shouldn't have heard them

And that's essentially what happened. I didn't hear them during their stay – except on two nights. On those two nights (March 22 and March 28), their signal came out of the noise around 0320 UTC and went back into the noise at 0340 UTC. Unfortunately I didn't work them on either of those two nights – I couldn't get 'K9LA' through the pile-up.

One of two things must have happened for me to hear them on those two nights. Either the amount of absorption along the 11,044km multi-hop path decreased for 20 minutes or so by at least 55dB (to take the predicted -158dBm signal power up to around my noise level of -103dBm), or a more efficient mode occurred. Coming up with a physical reason why absorption would decrease by 55dB along this 11,044km path is tough. Oler and Cohen suggested that one explanation could be due to changes in the chemical makeup and neutral wind patterns following the arrival of interplanetary disturbances causing rarefied areas of D-region electron densities – but there weren't any disturbances during the STØRY DXpedition. This suggests that a more efficient mode may be the real explanation for my observations with STØRY.

Ducting – a more efficient mode

Now let's do a ray trace along the same path, but at 0330 UTC, which is the midpoint of the signal enhancement period. Figure 2 shows this result.

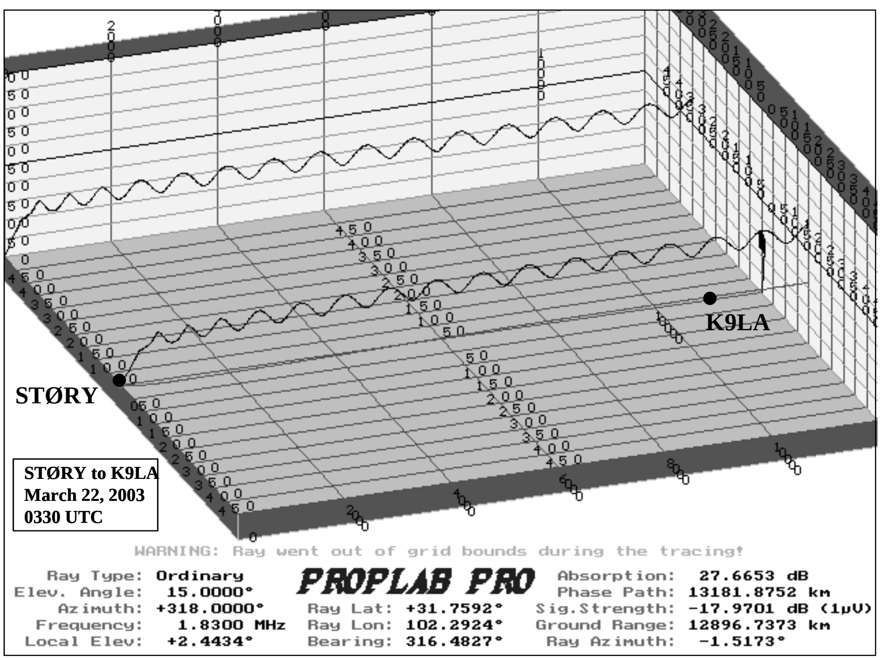


Figure 2 – A Ducting Mode

The electromagnetic wave immediately goes into a duct. The resulting field strength of the ray in the duct above K9LA is about -17dB referenced to 1uV/m. Translating that field strength to power in 50Ω, again assuming my inverted-L, gives -99dBm. Assuming several dB for absorption for a high-angle down-coming ray at my end of the path gives a signal power that is comparable to my -103dBm noise. This is a readable signal, and is in the ballpark of my observation of STØRY's signal strength during my enhancement period.

The physical mechanism for ducting

As Oler and Cohen mentioned in their article, there is a good reason for ducting to occur on 160m. To see this, let's look at the electron density versus altitude at the midpoint of the path at 0330 UTC. Figure 3 shows what an electromagnetic wave would see along the path as it travels from STØRY to my QTH. The horizontal axis in Figure 3 is electron density (per cubic meter) and the vertical axis is height above ground in km.

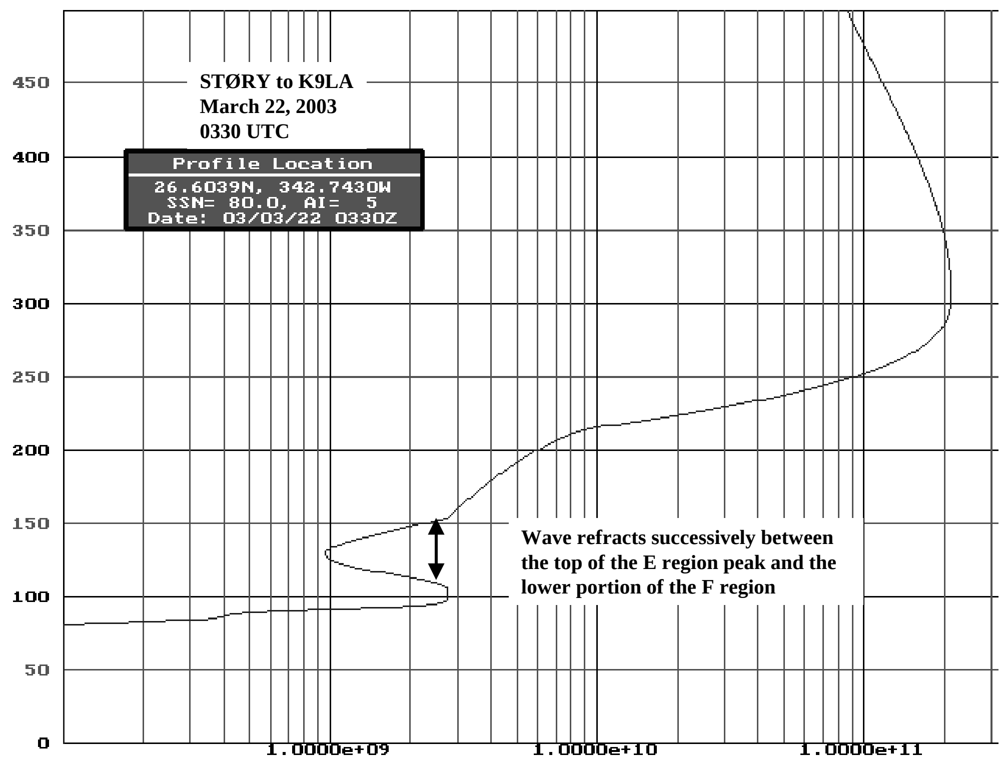


Figure 3 – Electron Density versus Altitude in the Dark Ionosphere

The nighttime ionosphere, under quiet geomagnetic field conditions, has an electron density valley above the E region peak [note 2]. This forms a natural upper and lower boundary for an electromagnetic ray to duct in. Going back to Figure 2 and noting the apogee (about 155km) and the perigee (about 110km) of the ray trace when in the duct indicates that it successively refracts between the topside of the E region peak and the lower portion of the F region.

Getting into the duct

Since the enhancement in signal strength (from 0320 – 0340 UTC) occurred as sunrise approached STØRY (which was around 0400 UTC), it is reasonable to assume that sunrise was responsible for getting into the duct [reference 3] – or at least sunrise helped.

Proplab Pro shows that the range of elevation angles for getting into the duct in Figure 2 is quite small. This makes sense, since two conditions with respect to elevation angle have to be met to get into a duct. The elevation angle must be high enough to get through the E region peak. But it can't be too high, or it will also go through the F region. What makes this complicated is the index of refraction – it determines how much the electromagnetic wave is refracted. The amount of refraction depends on two critical factors: how close the signal frequency is to the electron gyro-frequency, and the angle between the Earth's magnetic field and the direction of travel of the electromagnetic wave. Even though the ducting mechanism (the electron density valley) may be present worldwide in the nighttime ionosphere, getting into the duct may be easier on certain paths compared to other paths – even from the same QTH – due to these considerations.

It's also interesting to do a ray trace at the time of Figure 1 – at 0200 UTC, which puts STØRY well away from sunrise. Proplab Pro also shows ducting at this time. This is why I earlier commented that sunrise might be more of a helper than an instigator in getting into a duct. The help could be the tilt in the ionosphere that develops as sunrise approaches (there's also a tilt in the ionosphere at sunset). This could favorably impact the critical mechanics of refraction to get into the duct.

Staying in the duct

Once the electromagnetic wave gets into the duct, it has to stay in it – sometimes for very long distances. That requires the nighttime ionosphere to be stable so that the electron density valley retains its necessary characteristics. Generally this is the case, except as cited in note 2 – when electron precipitation from auroral activity can fill in the valley along the high latitude portion of a path.

Getting out of the duct

The ray trace in Oler and Cohen's article came out of the duct because "about 6,500 kilometers from Washington, D.C. the E-region is no longer ionized sufficiently to refract the signal back up to the base of the F-region." Obviously this isn't the case for the STØRY ray trace in Figure 2.

The ray trace in Figure 2 is still in the duct over my QTH. What brought the ray down into my QTH around 0330 UTC on those two nights? It's not likely that the tilt in the ionosphere at my sunset is the answer, as sunset at my end was three and a half hours earlier. And it's not likely that the tilt in the ionosphere at my sunrise is the answer, either, as sunrise at my end is still eight hours away.

The most plausible explanation for bringing the ray down in the dark ionosphere is an irregularity in the ionosphere. These irregularities are the result of the day-to-day variability of the ionosphere. We know that these irregularities exist, but we don't have a good handle on them (or on the day-to-day variability of the ionosphere, for that matter) because they are so dynamic [note 3]. The model of the ionosphere in Proplab Pro (the 1995 version of the International Reference Ionosphere) is, for all intents and purposes, smooth and homogeneous in the dark ionosphere, and does not reflect the real-world ionosphere. Thus for the STØRY ray trace, the wave does not come out of the duct.

I think a very good analogy for irregularities in the ionosphere is a stratus cloud layer. When viewed from afar, a stratus cloud layer looks very homogeneous – like a solid overcast.

Figure 4 – Close-up of a Stratus Cloud Layer

But upon closer examination (Figure 4), there are small valleys in the stratus layer, small clumps in the stratus layer, and even possibly some small holes in the stratus layer.

This translates to possible irregularities in the valley mechanism shown in Figure 3. Remember that the amount of refraction incurred by a wave by a given electron density gradient is inversely proportional to the square of the frequency. Thus of all our HF bands, 160m needs the least gradient (smallest irregularity) to have an impact on refraction [note 4]

For example, looking back at Figure 3, there might be too much ionization in the upper boundary at some point, which would refract an up-going wave down at a steeper angle so that it would go through the E region to ground instead of continuing along in the duct.

Or there might not be enough ionization in the lower boundary at some point, which would not refract a down-coming wave back up to continue ducting.

To summarize the three sections "getting into the duct", "staying in the duct", and "getting out of a duct", I think it's best to say that the entire process of ducting can be a fragile affair – which implies a low probability.

Spotlight propagation

Spotlight propagation is defined as a small geographic area that is favored with good propagation at any given time. Oler and Cohen suggested that spotlight propagation is simply the unpredictable result of coming out of a duct. I agree wholeheartedly with this, and further I believe that irregularities in the ionosphere are generally the cause.

This is an interesting concept to ponder. It very well could be that there's lots of RF rattling around up there in the duct (based on many Proplab Pro ray traces that indicate getting into a duct and staying in the duct is easier than getting out of the duct), but the luck of the draw in terms of an irregularity to bring the wave down at your QTH in the dark ionosphere determines if you have a QSO or not.

The day-to-day variability of the ionosphere

Earlier I mentioned that irregularities in the ionosphere are the result of the day-to-day variability of the ionosphere. It's interesting to dig into this deeper to understand what causes these day-to-day variations.

Two scientists with the Center for Space Physics at Boston University did just this. They analyzed 34 years (1957 – 1990) of F2 region critical frequency data [reference 4]. Although this was a study about the F2 region, the results are very relevant to propagation on 160m in the lower ionospheric regions.

The two scientists started by listing the causes of F-layer variability, which fell into three broad categories as listed in Table 1.

Solar ionizing radiation	Solar wind/geomagnetic activity/electrodynamics	Neutral atmosphere (note 5)
Solar flares	Day-to-day 'low level' variability	Solar and lunar tides
Solar rotation (27 day) variations	Substorms	Acoustic and gravity waves
Formation and decay of active regions	Magnetic storms	Planetary waves
Seasonal variation of Sun's declination	IMF/Solar wind sector structure	Quasi-biennial oscillation
Annual variation of Sun-Earth distance	Energetic particle precipitation	Lower atmosphere coupling
Solar cycle variation (11 and 22 yrs)	Fountain effect at low latitudes	Surface phenomena (earthquakes)
Longer period solar epochs	Magnetospheric electric fields	Surface phenomena (volcanoes)
	Plasma convection at high latitudes	
	Field-aligned plasma flows	
	Electric fields from lightning	

Table 1 – Three Broad Categories of Day-to-Day F Region Variability

They then determined that the day-to-day variability of the daytime F region averaged over 13 ionospheric stations over the 34 years was 20%. They defined variability as a percentage calculated by dividing the standard deviation of the F2 region critical frequency (foF2) by the monthly mean value of foF2 and multiplying by 100.

Next they dug down into the 34 years of data. The result was they determined the contribution of each of the three broad categories to the total variability: solar ionizing radiation came in at around 3%, solar wind/geomagnetic activity/electrodynamics came in at around 13%, and neutral atmosphere came in at around 15% [note 6].

Think about these results. The category that we probably understand the best, solar ionization radiation, contributes the least to the day-to-day variability of the F2 region. The other two categories are significantly greater than the solar ionizing radiation category, and are about equal in contribution. We're learning more and more each day about the contribution of solar wind/geomagnetic activity/electrodynamics category, but I think we still have a long way to go to understand the processes involved in the contribution of the neutral atmosphere category.

Let me reiterate that the analysis by the two Boston University scientists was done for the F2 region. But the three broad categories should be very relevant to the day-to-day variability of the lower ionospheric regions, too, where our 160m RF propagates. In fact, I would guess that the neutral atmosphere category plays an even more important role on 160m than it does on our higher HF bands (where the F2 region is very important). In other words, for propagation on 160m in the lower ionospheric regions the neutral atmosphere category may be a bigger contributor to the total variability than the 15% cited in reference 4 for the F2 region.

Summary

This article has shown why ducting is needed to explain long distance QSOs on 160m. It also hypothesized that the general cause of spotlight propagation is an irregularity in the ionosphere dumping the signal out of a duct. This article also reviewed some new information about the pertinent day-to-day variability of the ionosphere. Finally, this article suggests, as have others, that complicated processes in the neutral atmosphere are likely to play a very important role in our 160m DX QSOs. Unfortunately we don't have a good handle on these processes yet, so being on 160m every night is the only real way to make sure you take advantage of those 'good' nights.

For more information on ducting on 160m, I strongly suggest reading Brown's article [reference 5]. Bob NM7M discusses in detail, among other topics, the role of the Earth's magnetic field in ducting.

Notes:

1. Based on our present model of the ionosphere, this result says multi-hop propagation on 160m at night is limited to much less than 11,000km with 1kW and 0dBi antennas under optimum real-world conditions. A rough estimate indicates that ducting could be the dominant mode for paths longer than 4000km (as cited by Oler and Cohen) under less than optimum conditions – more external noise at the receive end of a path and less transmit power and antenna gain at the other end of the path. This result may come as a surprise to

many – that there's so much absorption on 160m at night when the D region is, for all intents and purposes, non-existent. The answer to this is two-fold. First, absorption is proportional to the electron density times the electron-neutral collision frequency, which results in the absorption process moving up to the lower E region at night. Second, absorption is inversely proportional to the square of the frequency, which means of all our HF bands 160m will suffer the most.

2. The valley develops in the dark ionosphere. The valley is essentially non-existent during the day. During disturbed geomagnetic field conditions, the valley (especially at the higher latitudes) can fill in with precipitating electrons, thus negating the ducting mechanism.

3. This is why Proplab Pro and our other propagation prediction programs use a monthly median model of the ionosphere. After years of data collection, when 'what the Sun was doing' was compared to 'what the ionosphere was doing', the best correlation was found to be between the smoothed sunspot number (or smoothed solar flux) and monthly median parameters of the ionosphere. This simply says we do not yet have an acceptable daily model of the ionosphere.

4. This is also the reason why 160m RF does not get too high into the ionosphere – essentially up to 200km or so. So when you see someone invoking the F2 region (300-400km) for propagation on 160m, treat it with some skepticism.

5. The term 'neutral atmosphere' refers to the fact that only about one of every one million atoms and molecules in the atmosphere is ionized. Thus the bulk of the atmosphere consists of neutral (not ionized) particles, and its motion can be influenced by those items in Table 1 under the 'Neutral atmosphere' column. Since positive ions have the same mass as neutral particles and collide with them at a high rate, positive ions are carried along by the motions of the neutral particles. Electrons then follow the positive ions to maintain charge neutrality. The bottom line is that electrons are tied to the neutral particles, and therefore the ionosphere is subject to the same motions as the rest of the atmosphere.

6. If you're wondering how 3%, 13%, and 15% can add up to 20%, note from the definition of variability that it is a standard deviation. Thus the sum of squares of the individual standard deviations equals the square of the total standard deviation. Indeed $(3\%)^2 + (13\%)^2 + (15\%)^2 = (20\%)^2$.

References:

1. Cary Oler and Dr. Theodore J. Cohen N4XX; *The 160 Meter Band – An Enigma Shrouded in a Mystery – Part I*; CQ, March 1998, pp 9-14 and *The 160 Meter Band – An Enigma Shrouded in a Mystery – Part II*; *CQ*, April 1998, pp 11-16.

2. Proplab-Pro Version 2.0; Solar Terrestrial Dispatch; Stirling, Canada; **www.spacew.com/proplab/index.html**.

3. Nick Hall-Patch VE7DXR; *Medium-Frequency Sunrise Enhancements*; QEX, July/August 2001, pp 1-8.

4. H. Rishbeth and M. Mendillo; *Patterns of F2-layer variability*; Journal of Atmospheric and Solar-Terrestrial Physics, Volume 63, 2001, pp 1661-1680.

5. Brown, Robert R. NM7M; *Signal Ducting on the 160-Meter Band*, Communications Quarterly, Spring 1998, pp 65-82.