An Ionosphere-Ionosphere Mode on 20m Long Path

Carl Luetzelschwab K9LA
k9la@arrl.net

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A recent W2-to-ZS long path QSO on 20m shows how tilts in the ionosphere at dawn and dusk can help our DXing efforts.

On July 5, 2003 at 1230 UTC, Tony AA2AE (in NY) worked Edwin ZS5BBO on 20m SSB via long path. AA2AE reported that ZS5BBO's signal was around S7. Let's take a look at the MUF (maximum usable frequency) and the received signal strength on both the short and the long path. We'll see why long path was slightly favored. Then we'll look at the likely mechanism that gave long path the significant extra advantage.

The Big Picture

Figure 1 is from DXAID (Peter Oldfield) and shows the short and long paths (thick dark lines) between AA2AE and ZS5BBO.

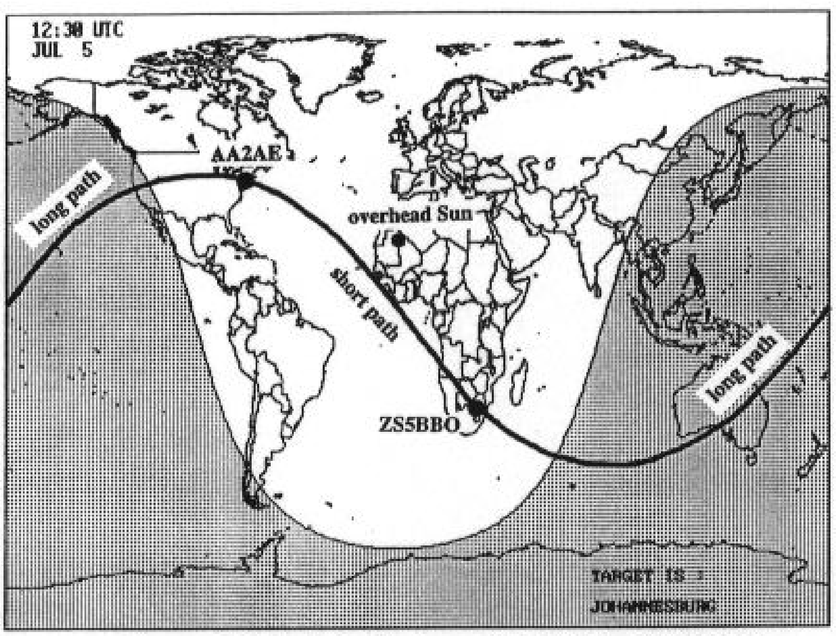

Figure 1 The Big Picture: AA2AE to ZS5BBO

The short path distance is 12,724km, and the long path distance is 27,308km. This map also includes the terminator (the line dividing night and day) on July 5 at 1230 UTC. The overhead (local noon) Sun is in northwest Africa over TZ. Note that neither path gets to the high latitudes. Thus both paths would be somewhat immune to high latitude disturbances.

A Look at Short Path

Using VOACAP (the Voice of America version of IONCAP) with 100w to a tri-bander at ZS5BBO and a monobander at AA2AE, Figure 2 plots the predicted monthly median MUF and monthly median signal strength (it's actually plotted as signal power into 50 ohms) for short path around the time of the QSO using a smoothed sunspot number of 55 (for July 2003 from sec.noaa.gov). Ideally we should address noise, too, but we'll keep it simple here and just look at signal strength.

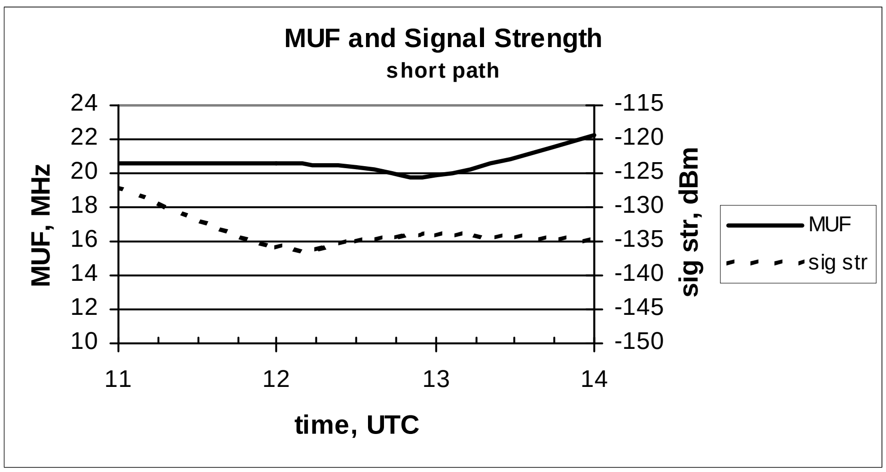

Figure 2

Note that the monthly median MUF is significantly higher than 14MHz over this 3-hour period centered on the QSO time. Thus getting 20m RF from W2 to ZS is not a problem on the short path. The MUF is that high because the short path is well illuminated by the Sun.

But this illumination is also a detriment – at the time of the QSO, the signal strength is predicted to be around –135dBm, which is right around the noise floor of a typical receiver (which is in the neighborhood of -135dBm). This low signal level is due to absorption on this full-daylight path.

Thus short path is only dependent on absorption. The MUF on most days of the month, when the daily variation of the ionosphere is taken into account, isn't an issue.

A Look at Long Path

In a like manner, Figure 3 plots the monthly median MUF and monthly median signal strength (again, it's really plotted as signal power into 50 ohms) for long path for the same time period as Figure 2.

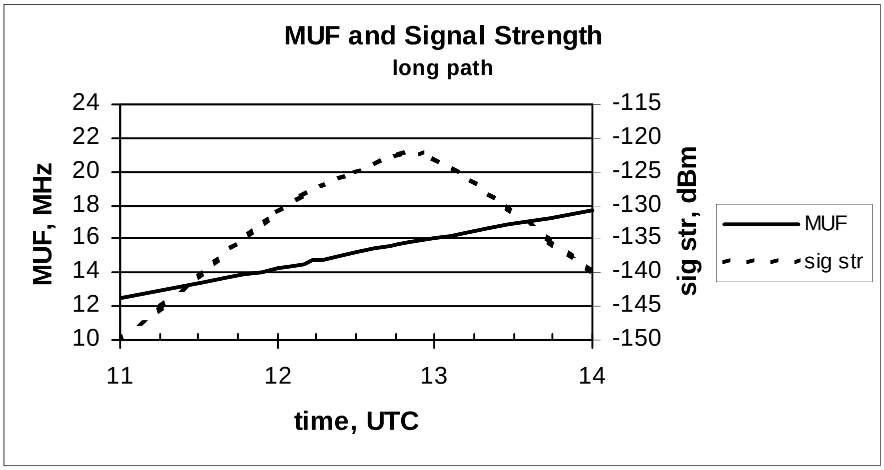

Figure 3

The long path scenario is a little more complicated. The MUF isn't predicted to get high enough on half the days of the month (since it's a median value) until 1200 UTC or so. Mentally sliding the terminator in Figure 1 to an earlier time (to the right) shows why this occurs. The long path out of W2 to the west has been in darkness all night, and needs solar illumination to get the MUF high enough for 20m.

Once the MUF is high enough, we still have a problem with signal strength. It's predicted to be about –125dBm at 1230 UTC. From the short path discussion in the previous section, this is marginally above the noise floor of a typical receiver for SSB operation (and remember we're ignoring atmospheric and man-made noise, which wouldn't help in a real-world scenario).

Thus long path is dependent on both MUF *and* signal strength.

But There's a Problem

Although VOACAP says long path offers about 10dB more signal strength than short path at 1230 UTC, the predicted long path signal strength of –125dBm is still way too low to give the S7 signal that AA2AE reported. Assuming an S-unit equals 5dB and S9 is 50 microvolts, S7 would be –83dBm. That's a 42dB difference between predicted and measured signal strength. And more importantly, the daily variation of signal strength about its monthly median (as mentioned in "Anatomy of a 20m Gray Line QSO" in the March/April 2003 issue of The DX Magazine) could not make up for all of this difference.

The Role of Tilts in the Ionosphere

The resolution to this discrepancy between predicted signal strength and reported signal strength is most likely an ionosphere-ionosphere mode in the dark ionosphere. Figure 1 clearly shows that the fundamental requisite is met - most of the long path is indeed in the dark ionosphere.

So what's an ionosphere-ionosphere mode? It's a mode of propagation that does not involve intermediate ground reflections. Thus in addition to not incurring losses due to ground reflections, there won't be any losses due to transits through the absorbing region. This means the signal strength can be significantly higher (which we'll estimate later).

In my mind, there are three mechanisms that qualify as ionosphere-ionosphere modes: chordal hops (as in trans-equatorial propagation across the geomagnetic equator on 10m and 6m at certain times of the day and during certain seasons), ducts (successive refractions between the E and F regions), and the Pedersen ray (high angle). All three can go to long distances without intermediate ground reflections. Due to the extreme distance involved in the W2-to-ZS long path, only chordal hops and/or ducts are the likely candidates.

What instigates chordal hops and ducts in the dark ionosphere? The tilts in the ionosphere at the dawn and dusk terminator can do this. The tilts, along with the ionization at the tilt, provide just enough refraction so that the wave doesn't go into space and doesn't return to the ground. The wave either travels in a straight line from the entry tilt to another tilt (chordal hop) or is refracted at the tilt to result in extremely low angles of incidence on the E and F regions to give successive refractions (duct).

A Detailed Look at the Ionosphere

Figure 4 is from Proplab Pro (Solar Terrestrial Dispatch) and shows the ionosphere between W2 and ZS on the long path on July 5 at 1230 UTC at a smoothed sunspot number of 55.

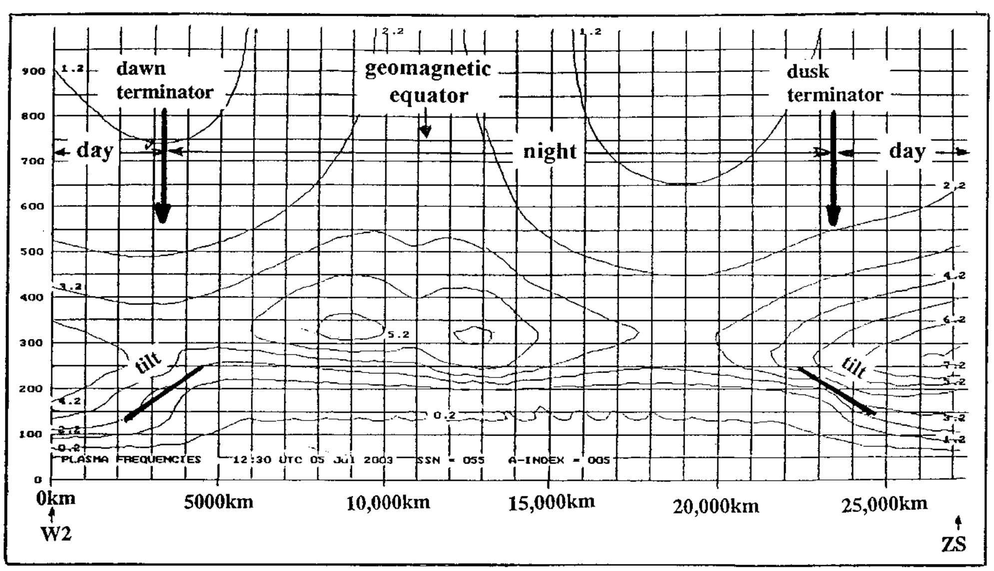

Figure 4 The Ionosphere Between W2 and ZS – Long Path

We're standing off to the side of this path, with W2 on the left at 0km and ZS on the right at 27,308km. West is to the right in this figure, with Adelaide (VK5) at about the 16,000km point (to get oriented properly with this figure, it might be helpful to refer back to Figure 1). The vertical axis is height in km. The contours are lines of equal electron density (represented by the plasma frequency). The dawn terminator is about 3200km west of W2 (just coming up on W6), and the dusk terminator is about 3700km east of ZS. Since Proplab Pro can only work out to 20,000km (halfway around the world), Figure 4 is actually two figures joined together at the 13,000km point.

The aforementioned tilts in the ionosphere at dawn and dusk are quite obvious, and are annotated and highlighted with a thick black line. In going from W2 to ZS, the tilt at the dawn terminator starts the ionosphere-ionosphere mode and the tilt at the dusk terminator ends it. In going from ZS to W2, the tilt at the dusk terminator starts this ionosphere-ionosphere mode and the tilt at the dawn terminator ends it. An excellent paper about an experiment with ionosphere-ionosphere modes appeared in the Journal of Geophysical Research (Volume 68, Number 20, pp 5659-5666). R. B. Fenwick (K6GX) and O. G. Villard, Jr. (W6QYT) wrote the paper when they were with the Radioscience Laboratory at Stanford University.

Results of Ray Tracing

Using Proplab Pro, ray traces were run to see if an ionosphere-ionosphere mode was possible under the conditions of Figure 4. Remembering that Proplab can only work out to 20,000km, two ray trace scenarios had to be looked at: one out of W2 to 20,000km and the other out of ZS to 20,000km. This provided a 13,000km overlap in the ray traces from each end, which should be more than sufficient to ascertain if an ionosphere-ionosphere mode was involved and capable of "going the distance." Ray traces for both the ordinary wave and the extraordinary wave were done from 0 degrees elevation angle to 10 degrees elevation angle in half degree steps for a total of 21 ray traces out of each end for each characteristic wave.

From W2, 11 of the 21 ray traces with the ordinary wave produced an ionosphere-ionosphere mode all the way to 20,000km, and it looks like all of them would have kept going. For the extraordinary wave, 12 of the 21 ray traces produced similar ionosphere-ionosphere modes to 20,000km (and beyond).

From ZS, only 4 of the 21 ray traces with the ordinary wave produced an ionosphere-ionosphere mode all the way to 20,000km. For the extraordinary wave, only 1 of the 21 ray traces produced a similar ionosphere-ionosphere mode all the way to 20,000km.

Thus ionosphere-ionosphere modes were readily available out of W2. They were much less frequent out of ZS. This suggests that ZS is the critical end in launching an ionosphere-ionosphere mode and is the determining factor in whether the path is working or not working at the S7 signal level. Because of the significant difference in ray trace results between the ordinary wave and extraordinary wave out of ZS, I suspect that launching an ionosphere-ionosphere mode out of ZS may be related to magneto-ionic effects – in other words, the amount of refraction necessary to get into (and out of) the ionosphere-ionosphere mode is critically dependent on the three-dimensional angle between the direction of the RF and the magnetic field at the tilt on the ZS end (since this angle would be a factor in determining the index of refraction).

Figure 5 shows a typical result from the ray trace effort.

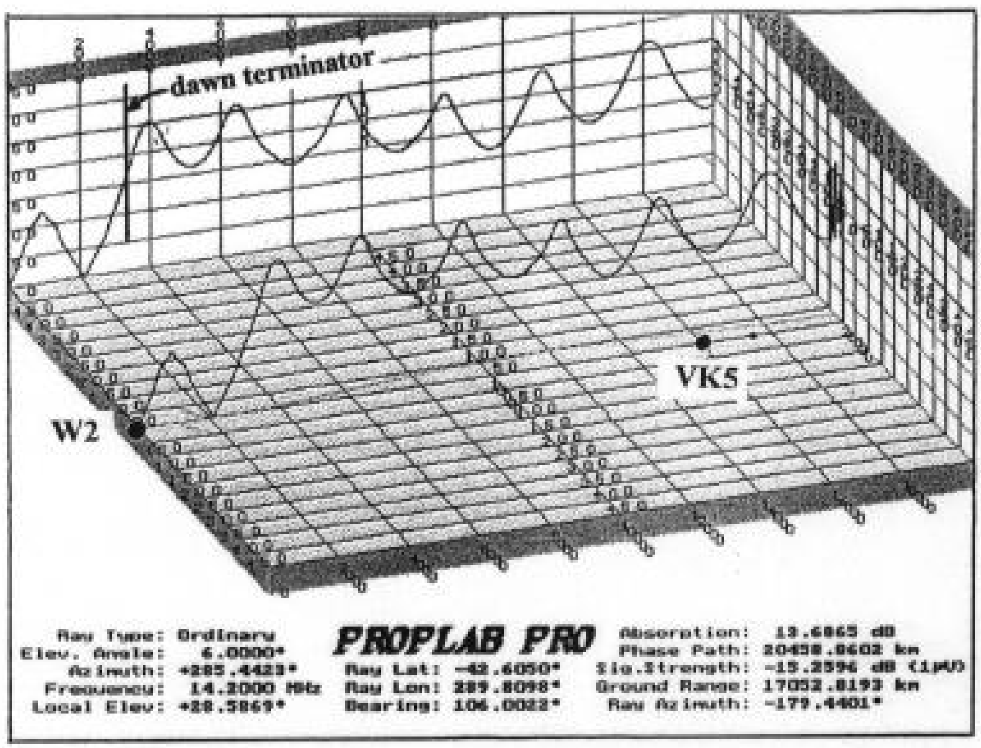

Figure 5 Ray Tracing Showing Typical Ionosphere-Ionosphere Mode

It shows one of the many ionosphere-ionosphere modes out of W2. The scale to the right is in 2000km increments out to 20,000km - ZS is another 7,300km to the right. VK5 is annotated at 16,000km for reference. Note that a conventional hop occurs prior to going into the ionosphere-ionosphere mode. This happens on both ends of the path, and is due to the solar illumination at both ends (again, refer back to Figure 1 to see this).

Upon detailed examination of the Proplab Pro data, the ionosphere-ionosphere modes appear to mostly be chordal hops. But there is some evidence of ducting in some of the ray traces, so I hesitate to say that chordal hops are the only mechanism giving ionosphere-ionosphere modes in this case. Ducting is possible because there is a valley in the nighttime electron density above the E region peak. Thus RF could be refracted back down from the higher F region, go through the valley unaffected, and then be refracted back up to the F region due to the increasing ionization on the topside of the E region peak.

Putting It All Together

Figure 5 is best described as a "proof of concept" figure. It only shows one ray trace from one end of the path out to 20,000km. Additionally, it doesn't represent the real Earth-ionosphere geometry because it's in rectangular coordinates. So what's the real ray path look like?

Figure 6 shows this in spherical coordinates – the true Earth-ionosphere geometry.

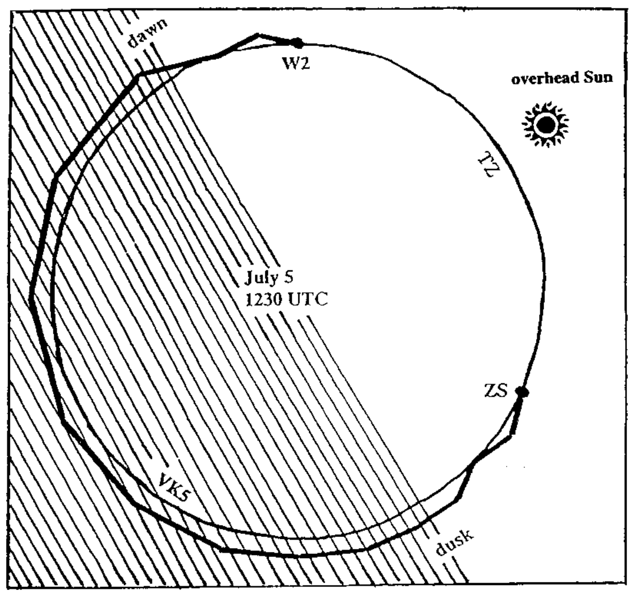

Figure 6 Ionosphere-Ionosphere Mode Between W2 and ZS on 20m Long Path

This is a best-guess sketch that is based on the results of the ray tracing effort. To make this drawing easy for me, I took the liberty of using straight lines between successive apogees. That may not be correct if ducting was occurring in lieu of chordal hops - but the intent of this figure is to show the "big picture" and not the nitty-gritty details.

Estimating Signal Strength

Since VOACAP assumes conventional hops, can we estimate ZS5BBO's long path signal strength if indeed an ionosphere-ionosphere mode occurred? We can make a pretty good estimate of this using the VOACAP data that generated Figure 3, the ground reflection loss data from Figure 12.6 of Ionospheric Radio (Kenneth Davies, Peter Peregrinus Ltd, 1990), and the absorption data from the Proplab Pro ray trace of Figure 5.

VOACAP says the total loss on the long path at 1230 UTC is 175dB. Backing out the estimated antenna gains (13dBi at ZS5BBO and 16dBi at AA2AE, which includes ground reflections gains) and the free space path loss (144dB for 27,308km on 14.2MHz) gives 60dB. This is the ground reflection loss plus the loss due to absorption for seven conventional F2 hops (seven F2 hops comes from the VOACAP mode data).

If we assume an ionosphere-ionosphere mode, we'll only have two conventional hops: one still over the USA on the W2 end and one over the sea on the ZS end. Figure 12.6 in Ionospheric Radio indicates we'll have about 2dB total ground reflection loss for low elevation angles. Adding an absorption value of 22dB (from the ray trace in Figure 5, plus 8 more dB to go the extra 7300km and for the conventional hop on the ZS end) says the ground reflection loss plus the loss due to absorption for the ionosphere-ionosphere mode is now only 24dB.

Thus the ionosphere-ionosphere mode gives us a signal that is roughly 60dB – 24dB = 36dB stronger than the conventional hops from the VOACAP prediction. The –125dBm signal strength cited earlier now goes to –89dBm, which is in the ballpark of the –83dBm S7 signal strength reported by AA2AE (and it would be even closer if we assume July 5 was a "better than average" day with respect to signal strength). This strongly suggests that the ionosphere-ionosphere mode scenario is believable.

Summary

This QSO appears to be a classical example of an ionosphere-ionosphere mode helping our DXing efforts on 20m long path. AA2AE also checked PacketCluster spots and found at least three other stations (one in NY, one in NC, and one in TX) that took advantage of this mode in July to work ZS5BBO. Some quick ray traces with Proplab Pro indeed showed that these other stateside locations could have been helped by an ionosphere-ionosphere mode to and from ZS.

And now's the time to ask my favorite question – can I prove any of this? The answer is "no", because we'll never really know what *exactly* is going on up there in the ionosphere. But the fact that the actual long path signal strength was significantly higher than the predicted signal strength, the fact that the ionosphere along the long path had the necessary tilts at dawn and dusk to give ionosphere-ionosphere modes, the fact that ray tracing showed the possibility of ionosphere-ionosphere modes, and the fact that an estimate of signal strength for an ionosphere-ionosphere mode was very close to what was measured says it is highly likely that this is what really happened.

Do ionosphere-ionosphere modes occur on other long paths and on other frequencies? I think the best answer to that question is 'could be.' For each specific path, you'd have to determine if the necessary tilts are present, and then assess (more than likely based on ray tracing) that the ionization along the path is what is needed based on the frequency, the time, the day, the month, and where we are in the solar cycle.