Reflections on 160 Meters:
The Joys of Salt Water and the Sorrows of Ground

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Introduction -

Signal loss occurs in many ways, from spatial attenuation or signal spreading to ionospheric absorption and reflection loss. There's nothing that can be done about any of those, save try to understand them and how they might influence DXing. All of that becomes crucial down on the 160 meter band as absorption loss is greater there than on any other band and the QRN problem can be overwhelming at times.

The question of reflection loss comes up from time to time but often in a qualitative manner, just statements to the effect that DX paths over salt water are better than those over ground. But as one trained in a quantitative science, I need some sort of confirmation to statements like that, both in numbers and with a good example that I can understand. In that regard, I think I have a good case for that truism that everyone can relate to. Let me tell you about it and how it came up in the first place.

Looking at Logs -

With my interest in propagation, I have come to focus on the results of DXpeditions, those high activity efforts that have the happy result of putting new calls in DXer's logs all over the world. In a sense, they're world-wide propagation experiments using a point source of radiation and one can then look at the DXpedition logs to learn how propagation worked on the occasion. So I spent quite a bit of time working through the logs of the Heard Island DXpedition. It proved to be something like leafing through the syllabus for a crash-course on DXing, especially for the low bands where ionospheric absorption is crucial. And after that, I worked through the 160 meter logs of the XZ1N DXpedition and was able to make some meaningful comparisons between the two efforts, even though separated by a good distance, 8,200 km.

Other DXpeditions came to my attention and I was fortunate to obtain the logs of the P29VXX, S21XX, VK9CR and VK9XY efforts. Of those operations, the '97 S21XX effort in Bangladesh is related, in space and time, with the XZ1N DXpedition in Burma while the '96 DXpeditions to Cocos-Keeling Island, VK9CR, and Christmas Island, VK9XY, are related by their proximity and dates. But the P29VXX effort in late February '96 seemed to stand alone, mainly because its location was so far to the east of the others, at 147 E longitude as compared to the operations between 90 and 105 E longitude, and it just seemed like an isolated effort that would be hard to compare with anything else when it came to propagation.

But then it could be studied by itself, one band as compared to another. In that regard, the power output was essentially the same on the two lower bands, 500 watts on 160 and 80 meters. And the antennas were both verticals, a 66 ft Titanex V80E with some elevated radials for 160 and 80 meters, but sometimes a Butternut HF6V with 32 radials on the ground was used for 80 meters if both 160 and 80 meter operations were going at the same time. And the Titanex vertical had already received rave comments from DXers for its role in the S21XX DXpedition so that was a good omen in opening the P29VXX logs for study.

But then I got an interesting letter from Luis, IV3PRK. He was interested in my efforts with regard to ducting on 160 meters but in his letter he also mentioned that he thought his contact with P29VXX was the most western contact of that DXpedition. Now if you think about it, those few words, "most western contact", are full of meaning. First, if one didn't know better, it would be possible to conclude there just aren't any 160 meter DXers west of his QTH in Udine, by the Gulf of Trieste at the top of the Adriatic Sea. But I knew that wasn't right as I'd just looked at the S21XX logs and there were almost 100 contacts in that 160 meter log from stations in Belguim, Holland, France, Germany, Spain and the British Isles, the ON, PA, F, DA, EA and G prefixes, respectively.

Rather than just dismiss the idea, I got out the P29VXX logs and went through them again for the time in question, around 2020 UTC, the time of sunrise in Papau New Guinea, when the 160 meter opening to the west was coming to an end. To my amazement, I found no ON, PA, F, EA or G prefixes in the 160 meter log; but there were a few DLs. So that would take some checking on the distances involved.

Looking deeper -

But before getting to that, I went through my usual routine, making a great-circle map for the P29VXX DXpedition, as shown in **Figure 1**. With a QTH at 8 S latitude, the polar axis of the great-circles was tipped 98 degrees with respect to the earth's geographic axis. That had a profound effect on the great-circle paths to areas with major concentrations of amateurs, like Western Europe and North America. In particular, the paths were all in the mid-latitude range. But IV3PRK's remark suggested a finite length to the paths over which contacts with P29VXX were possible - nothing going as far as France, the British Isles or the Iberian Peninsula.

In looking at that map, I immediately noticed that there was a certain symmetry to the paths, those to the west toward Europe being quite similar to the ones to the east toward North America. True, here was a slight difference in latitudes, a bit higher to Western Europe. But on the map, the distances looked about the same, at least for North America and Western Europe relative to the antipodal point out in the Atlantic Ocean. That would take some checking of contacts in the log.

So I sorted through the logs, identifying the 160 meter contacts with North America and looking for prefixes in Europe to the west of Italy. For the USA, I found 242 contacts, from the West Coast to the East Coast. Looking even closer, I found that contacts with P29VXX were made with 42 of the 48 states in the Continental USA and looking at the distances involved, the two extremes of the West Coast were at 10,700 km (Seattle) and 10,900 km (Los Angeles) while those on the East Coast were at 14,668 km (Maine) and 14,400 km (Florida). There was one more distant contact with North America, VE1ZZ in Nova Scotia at a distance of 15,000 km.

Turning to European contacts, the distance from Udine, Italy to P29VXX is 13,900 km. As indicated above, the logs showed only a few German contacts that might be at a greater distance. On checking, there were three contacts at greater distance, the furthest being DL0TU at 14,090 km. So IV3PRK was not far from the mark, there was an upper limit to the distance for contacts in Europe with Papau New Guinea on this occasion.

In that regard, the paths to DL0TU and IV3PRK as well as some other representative paths from P29VXX are shown in **Figure 2.** That figure is a gnomonic projection in which all great-circles are straight lines and includes the position of the terminator at 2020 UTC, sunrise in New Guinea. The paths shown are parts of the great-circles that are above 30 N latitude and clearly show the finite range to the contacts with Western Europe, paths falling short of Portugal (15,850 km to Lisbon) and Spain (15,400 km to Madrid). Paths to contacts with eastern locations in the USA, but at different times, are included for comparison.

The distance from P29VXX to the East Coast of North America is about 1,000 km shorter than that to the far reaches of Western Europe. But the paths to Western Europe ended a bit short of the limit of paths in the USA. So we now turn to the questions as to why the finite range of P29VXX signals, what factors were involved and what does this mean for DXing in general.

On finite range -

When making any sort of comparison, it should be noted that for DX contacts on 160 meters, two factors are involved - signal strength and noise or, in combination, a S/N ratio. Thus, there is a minimum S/N ratio for a successful contact and if contacts are not made, then either the noise was too great for the signal strength or the signal strength became too weak for the prevailing level of noise. Now it is difficult to determine details of the noise over an area the size of Western Europe where the contacts were made with P29VXX. So we have to assume that it was about the same over that broad region, man-made in origin as noise of atmospheric origin would seem to be minimal in February.

Turning then to signal strength, the first question is whether one group of paths or the other had any advantage or disadvantage. In that regard, the paths to the USA were over about 10,500 km of salt water and then over ground the rest of the way. It was just the opposite for the far paths to Europe, over salt water for about 3,500 km and over ground the rest of the way. If one looks at the usual reflection loss properties for salt water and ground at 1.8 MHz, shown in **Figure 3**, the reflection losses for a ground surface are about 30 times greater over ground than salt water for the typical radiation angles for DXing, thus favoring signals going toward the USA over those to Europe if a comparable number of hops were involved.

But there are other considerations beside surface reflections when it comes to signal strength. For example, there is the matter of paths which the signals follow and the degree to which they were comparable. In addition, since the frequency (1.8 MHz) on the 160 meter band is comparable to the gyro-frequencies (0.9-1.6 MHz) of ionospheric electrons in the earth's field, the entire matter should be viewed from the perspective of magneto-ionic theory (Davies, 1989). In particular, paths should be analyzed in terms of geomagnetic variables, such as geomagnetic or modified dip latitude, and how the signal directions were oriented relative to magnetic field lines along the paths. The latter point bears on matters of wave polarization, signal absorption as well as the possibility of ducting on the path, a very efficient means of propagating signals without lossy ground reflections.

With regards to paths, **Figure 1** shows that there is a greater spread in latitudes over the USA than in Europe and this is borne out by the paths, in modified dip latitudes, shown in **Figures 4 and 5**. But the more important point is that the upper latitude limits of the two sets of paths are essentially the same, 60 degrees, and below auroral latitudes, out of harm's way.

The path-field angles for the signals to Europe and the USA were obtained from the International Geomagnetic Reference Field (IGRF, 1995) and are shown in **Figures 6 and 7**. The spread in initial path-field directions is greater for paths to the USA because of the wider range of latitudes at the far end-points. The path-field angles increased steadily toward the final points, meaning that the waves changed over from being nearly circularly-polarized in the early, quasi-longitudinal part of the paths to elliptical polarization and finally becoming linearly-polarized at the ends of the paths as the path-field angle approached 90 degrees, the quasi-transverse condition in magneto-ionic theory.

As for reflection losses, until the waves became linearly-polarized in the last third of their paths, they can be considered as being randomly polarized, with essentially equal intensities in the horizontal and vertical components of their fields. That would justify using the reflection loss curves in **Figure 3** in considering signal losses along the first two-thirds of the path, thus making losses much greater on the path to Europe over ground than the one to the USA over salt water.

In regard to signal ducting, there is a greater probability of that happening for paths with small angles with the field, the quasi-longitudinal approximation, and **Figure 7** shows that would be the case for the locations (ME and MA) at higher latitudes in the USA. While not shown in **Figure 7**, path-field angles for the path to VE1ZZ in Nova Scotia were about 1 degree lower at the start of the path. Thus, there would be a significant chance for ducting at the start of the paths toward the upper latitudes in the North America.

It is not clear whether any significant fraction of the signals were still trapped within the ducts overhead on reaching the East Coast area. But since the P29VXX logs showed that stations in the USA were making their contacts as the sunrise terminator was sweeping westward, there is the possibility of a dawn enhancement, signals dumped out of the ducts by F-region tilts from solar heating at sunrise. If that were the case, it would make contacts more likely and thus increase the distances reached by P29VXX signals in the USA because of greater field strengths.

In Europe, there was no such advantage as **Figure 2** shows the sunset terminator is well-removed from the paths and there would be no F-region tilts to affect any signals that happened to be ducted toward Europe. Thus, no signal enhancement would be expected in the European area.

The last point to check is whether the limit to the path lengths was caused by an auroral disturbance. In that regard, the magnetic activity reported at the time was low (Kp=1), arguing against such a disruption. In addition, the P29VXX logs showed over a dozen contacts to higher latitudes, from 60-65 degrees in Sweden and Finland but at somewhat shorter (12,000 km) distances. As a result, one could conclude auroral activity did not play a role in on how far the P29VXX signals reached into Europe. So, everything considered, the limited range of P29VXX signals was an due to surface reflections gradually reducing the S/N ratio as the signals passed over 10,000 of ground. Right? Not exactly.

Another band -

One can look at the matter using the contacts that P29VXX made on another band, notably 80 meters. But the question comes down to what order should be followed, looking first at how the frequency-dependent variables change to see how propagation would be expected to differ in going to the higher frequency or go to the logs to see what the contacts showed, particularly in regard to the finite range of signals?

In many ways it is more instructive to look first at the variables, starting with ground reflection loss. Thus, one can look at the reflection loss curves for 3.5 MHz in **Figure 8** and those for 1.8 MHz in **Figure 3** to compare reflection loss per hop on the two bands. Now given the path lengths under consideration, up to 14,000 km or so, one could expect 6-7 F-layer hops over the distance. In that regard, using typical radiation angles for DXing, one sees that the reflection loss per hop on 3.5 MHz is about about 0.2 dB greater than on 1.8 MHz in the range around 12 degrees radiation angle. That makes the total reflection loss on 3.5 MHz greater than on 1.8 MHz by about 1.5 dB, a small but finite amount.

Thus, with a slight increase in reflection loss, one would not expect any significant change, the finite range of the paths from P29VXX remaining on 3.5 MHz as it was on 1.8 MHz. In particular, the 3.5 MHz log for P29VXX should continue to lack prefixes like EA, F, PA, ON and G, as was the case on 1.8 MHz. But the 3.5 MHz logs did not agree with that notion. Instead, they contained over 70 contacts with stations further along into Western Europe, with prefixes like ON, PA, F, EA, G, IT9 and even to a distance of 15,400 km to Madrid, as in **Figure 9**. So how does one account for the difference? Simple, one has to finish the signal loss calculations by looking at ionospheric absorption and seeing how it differs on the two bands. That's the answer.

First, it should be noted that ionospheric absorption does not go to zero even though a path may be in darkness; there is residual ionization in the lower ionosphere along a path and when RF excites motions of ionospheric electrons, their collisions with neutral constituents result in some signal loss. In darkness, however, the ionization is not as far down as D-region heights in daytime hours where the collision frequency would be very high. Instead, it is up somewhat higher, around E- and lower F-regions, and where the collision frequencies would be small compared to the operating frequency of the signals.

That results in a simplification of the expression used in calculating absorption along a path. Thus, the numerator would be the usual term which contains the product of the electron density at a point along the path and the local collision frequency but the denominator would not contain the collision frequency, only the factor which involves the operating frequency, the electron gyro-frequency and the path-field angle. Thus, ionospheric absorption could be calculated by summing terms like:

$$\frac{AN\nu}{(\varpi+|\cos(\theta)|\varpi_B)^2}$$

all along a path, hop by hop. In that expression, N is the electron density per cubic meter, ν is the electron-neutral collision frequency per second, the ϖs are angular frequencies for the RF and electron gyration, θ is the path- field angle and A is a constant that brings the units of the expression to dB/km.

Further simplification is possible since the travel of a wave in the ionosphere is essentially the same, hop by hop. Thus, the radiation angle does not change appreciably with the surface reflections and the vertical excursion of hops is limited to heights set by the critical frequency limit for hops on the operating frequency. While ray-tracing with the PropLab Pro program (Oler, 1994) shows there may be changes of 20-30 km in the heights reached on hops with a change in frequency, there would be little change in absorption due to the additional ionization encountered on the hops. That is the case as the wave absorption all takes place at lower heights where the electron collision frequency is much higher.

Thus, the absorption calculation can be taken as a sum of terms, hop by hop, and the only things that change appreciably from one hop to the next are in the denominator, the electron gyro-frequency and the path-field angle. That being the case, the effect of the denominator may be averaged over the path, making it possible to see how absorption would vary from one path to another and more importantly, for different frequencies on the same path.

For the sake of completeness, it should be noted that the above discussion is within the framework of magneto-ionic theory and applies just to the ordinary or O-wave. There is also the extra-ordinary or X-wave to consider and its absorption is treated the same way except that the denominator has a minus sign, instead of the plus sign for the O-wave. Now since the minus sign makes the denominator smaller for X-wave absorption, that means the whole expression for signal absorption would be much greater. In fact, it would be so much greater, especially if the electron gyro-frequency were close to the wave frequency, that the X-wave would be heavily absorbed on the 1.8 MHz band and only O-waves survive to reach great distances along paths, as discussed here.

Having noted that point, the next step is simply to look at how absorption varies along paths on the two bands, taking into account how the path-field angles differ and how the electron gyro-frequency changes along the path. In that regard, **Figure 6** shows how the path-field angles vary for paths to Europe. Over that range, the electron gyro-frequency increases by about a factor of 1.5, from 0.9 MHz to 1.4 MHz, and with the changes in path-field angles, the ratio of O-wave absorption on 1.8 MHz to that on 3.5 MHz averages to about 3.0.

So, while reflection loss on one of the paths increases by about 1.5 dB in going from 1.8 MHz to 3.5 MHz, the ionospheric absorption, expressed in dB, decreases by a factor of 3. The absolute values of the absorption values are not calculated here but clearly, the presence of contacts in the 80 meter logs with the British Isles, the Low Lands, France and Spain where there were none in the 160 meter logs indicates that the absorption decrease was more than enough to overcome the 1.5 dB increase in reflection loss.

That argument can be reversed to say that the limited range of P29VXX contacts with Western Europe on the 160 meter band was more due to ionospheric absorption, not ground reflection losses. Indeed, if one looks at the details of the absorption calculation, the range of contacts would have been even shorter were it not for magneto-ionic effects. Those effects reduced the absorption on the hops around P29VXX, the smaller path-field angles serving to keep contributions from the gyro-frequency term in the denominator of the absorption calculation. On the other hand, at the European ends of the paths, the path-angle was close to 90 degrees and essentially removed the gyro-frequency term from the denominator. thus increasing the absorption in that region. Indeed, without the gyro-frequency term, absorption (in dB) on 1.8 MHz would have been about 50% greater, 15 dB for each 10 dB, and resulted in a shorter penetration of P29VXX signals into Europe.

Discussion -

By an accident of geological evolution, Papua New Guinea is located so that the geometries of great-circle signal paths in the eastern and western directions are essentially symmetrical toward North America and Western Europe, two centers of amateur radio activity. But the paths differ in an interesting way, those toward North America going over about 10,000 km of salt water and then 4,000 km over a ground while those to Europe are just the opposite, first over about 4,000 km of salt water and then 10,000 km of ground.

It was in that sort of setting that the P29VXX DXpedition was conducted and the reflecting properties of those surfaces produced some interesting results. Thus, 1.8 MHz signals going over salt water toward North America went right to the Atlantic Coast while signals toward Europe stopped short of its west coast, suggesting a finite range of signals from losses in that direction. But the 80 meter logs of P29VXX showed that 3.5 MHz signals did reach further, on to the British Isles, the Low Countries, France and Spain. When analyzed using magneto-ionic theory, it was found that ionospheric absorption was the more important of the two contributions to signal loss, lower ionospheric absorption on 3.5 MHz overcoming a greater reflection loss at the higher frequency.

Physically, the role of the geomagnetic field in absorption is to effectively increase the time between electron-neutral collisions in a dark ionosphere, thereby raising the probability of re-radiation by ionospheric electrons between energy transfers to the atmosphere. While the observation of a finite range of radio signals is an interesting matter in its own right, it is important to note that it represents a magneto-ionic effect as far as signal absorption is concerned and without the earth's field, even greater absorption would have made the finite range of Top Band signals from P29VXX even shorter.

The magneto-ionic aspects of signal absorption deserve a few additional comments with regard to Top Band DXing. First, with the signal frequency so close to electron gyro-frequencies, the extra-ordinary or X-wave is heavily absorbed in regions where the path-field angle is small or quasi-longitudinal propagation is in effect. Thus, for the P29VXX DXpedition, both O- and X-waves were formed with equal intensity at the outset but as signals entered the ionosphere over New Guinea, heavy X-wave absorption meant that in the final analysis half the radiated power was not effective in making DX contacts with North America and Europe.

For those paths, even O-wave absorption rose to high levels as the path-field angles increased on going from low latitude regions, where the earth's field is nearly horizontal, to high latitudes, where the magnetic dip angle is over 60 degrees. While these remarks are in connection with a DXpedition from a low latitude, the magneto-ionic aspect of ionospheric absorption deserves consideration for other locations and paths as well.

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