Propagation column
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Propagation to the Antipode Revisited

The October 1999 column looked at a 1969 paper written by researchers at Syracuse University. During 1960 and 1961 they monitored signals from Perth, Western Australia (VK6) at Bermuda (the antipode of VK6) on 5MHz, 16MHz, and 30MHz. They also monitored the Perth signals in Rome (NY) and Washington (DC) to compare reception to non-antipodal paths. They concluded that the duration of reception was longer (data in their Table III) and signal strength was higher (unfortunately no data was given) at the antipode compared to the two non-antipode sites. The middle frequency was the best, with the other two frequencies confined to several hours around sunrise and sunset.

As a refresher, the antipode of a location is that point directly opposite on the other side of the Earth. In other words, a straight line from a location to its antipode goes right through the center of the Earth. All great circle paths from the location arrive at the antipode, so there really is no short path or long path – they're all the same length at about 20,000km (ground distance). Additionally, propagation to the antipode is thought to offer enhanced signal strength due to focusing – all those signals arriving from all directions (assuming omni-directional antennas on both ends) could add to give a stronger signal. Theoretically, if the Earth was a perfect sphere and if the ionosphere was a perfect conducting shell and supported all the paths, then all the paths would indeed arrive in phase and add.

But real-world conditions temper this ideal scenario – the ionosphere is different during the day and the night, and it even varies versus latitude during the day or night. So our two familiar issues of MUF (Maximum Usable Frequency) for the higher frequencies and absorption for the lower frequencies need to be considered on all the paths. And paths that go through the auroral zones (both northern and southern) may be degraded at times. Regardless of these potential limitations, let's see if we can use propagation prediction programs to gain more insight into propagation to the antipode. Hopefully this analysis will agree with the Syracuse University results.

We'll use VOACAP to do this analysis. But VOACAP (like all our other propagation prediction programs) does not provide predictions to the antipode because it doesn't know which direction to use (since any heading from the transmitter ends up at the antipode). We can work around this by drawing a small radius circle around the antipode, and then run predictions to points on this circle. The assumption here is that if the electromagnetic wave gets to any point on the circle, then it would get to the antipode.

I set up VOACAP for Method 30 predictions from Amsterdam Island in the Indian Ocean (37.8^{o} S latitude / 77.6^{o} E longitude) to points on a circle of 100km radius around the antipode in Colorado (37.8^{o} N latitude / 102.4^{o} W longitude). I ran predictions on 20m for January at a smoothed sunspot number of 50. I further assumed 1kW for the transmit power and verticals (for omni-directional azimuth patterns) on both ends of the path. To keep this to a manageable amount of work, I only ran predictions on eight paths around the compass out of Amsterdam Island, starting at 270^o and stepping clockwise in 45^o increments. This should give us enough information to extrapolate to the "infinite number of paths" scenario. Figure 1 shows the eight paths.

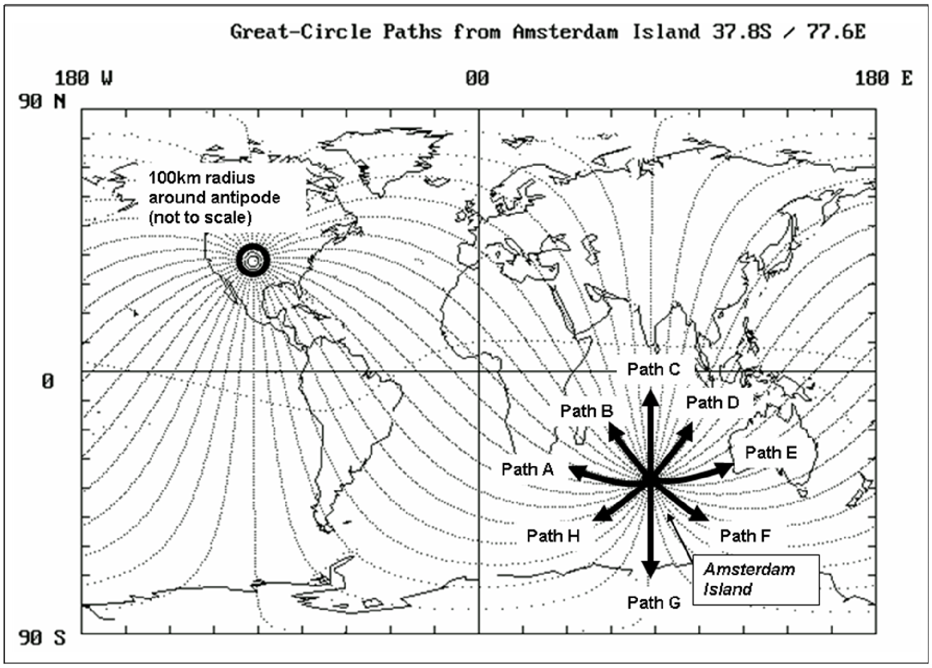

Figure 1 – The Eight Paths Evaluated With VOACAP

The predicted signal powers (in dBm) at the antipode are shown in Table 1.

Time (UTC)	Path A	Path B	Path C	Path D	Path E	Path F	Path G	Path H
01	-94	-86	-84	-100	-101	-97	-99	-94
02	-94	-101	-100	-94	-149	-128	-95	-93
03	-104	-122	-150	-130	-139	-124	-109	-105
04	-118	-131	-230	-191	-138	-122	-112	-114
05	-130	-176	-366	-330	-167	-124	-117	-123
06	-135	-185	-376	-373	-199	-129	-121	-129
07	-161	-178	-298	-360	-171	-129	-124	-135
08	-166	-188	-210	-324	-187	-123	-124	-138
09	-167	-210	-179	-162	-153	-117	-119	-139
10	-156	-230	-186	-139	-133	-111	-122	-144
11	-193	-238	-231	-116	-105	-108	-168	-161
12	-98	-152	-272	-130	-110	-146	-191	-97
13	-103	-101	-149	-163	-124	-123	-117	-103
14	-103	-111	-103	-160	-127	-94	-103	-104
15	-98	-106	-93	-111	-95	-90	-103	-101
16	-126	-105	-93	-94	-90	-99	-125	-145
17	-118	-108	-92	-90	-97	-113	-138	-146
18	-114	-105	-106	-98	-106	-137	-146	-142
19	-110	-104	-100	-102	-119	-155	-181	-131
20	-105	-94	-99	-101	-122	-149	-159	-132
21	-109	-95	-95	-98	-124	-142	-138	-128
22	-102	-91	-89	-97	-123	-134	-107	-113
23	-98	-88	-87	-98	-99	-100	-111	-104
24	-96	-86	-87	-100	-100	-99	-103	-97

Table 1 – Signal Powers in dBm at the Antipode for All Eight Paths

The signal power for each of the eight azimuths out of Amsterdam Island ranges from a maximum of -84dBm (roughly S7 on a typical S-meter) to a minimum of -376dBm (way down in the noise) – which means certain paths at certain times won't offer a readable signal. We know that anything below about -130dBm won't be heard as that's the MDS (Minimum Discernible Signal) of a typical modern-day HF receiver. We've also seen in previous columns that we're limited even further by external noise. To pin this down, let's make three assumptions: the antipode has a rural noise environment (-139dBm/Hz at 14.1MHz from Figure 10 in the document ITU-R P.372-7 titled *Radio Noise*), we've set up our receiver with a 500Hz IF filter, and we can hear a signal if the SNR (Signal-to-Noise Ratio) is greater than or equal to 0dB. This says any signal power below -112dBm (-139dBm plus 10log500) is not readable on 20m in the 500Hz bandwidth. Now let's plot signal powers greater than or equal to -112dBm for all eight paths versus time of day. This is done in Figure 2.

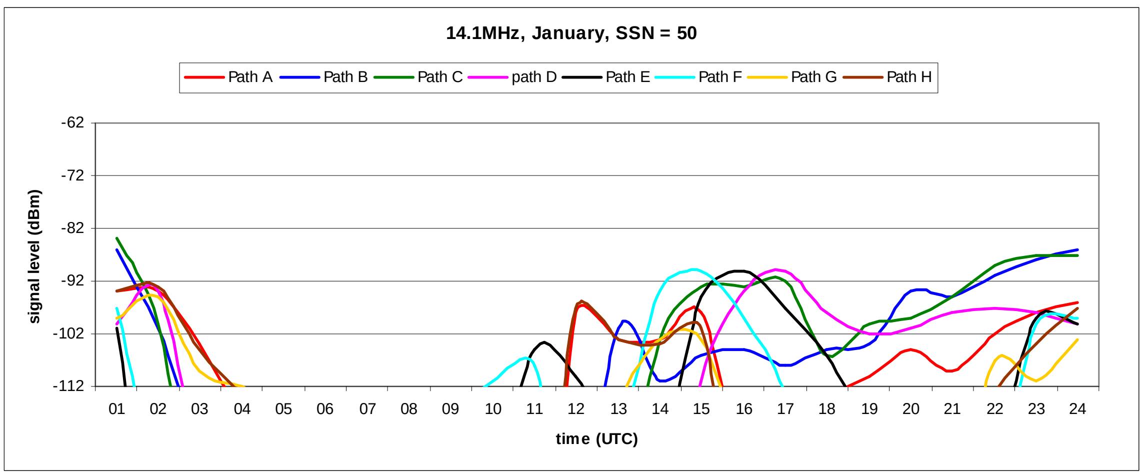

Figure 2 – 20m Signal Powers ≥ -112dBm on the Eight Paths

Figure 2 is very busy with eight curves on it. But if you stare at it long enough, two important observations surface.

#1 – Nineteen of the twenty-four hours are predicted to have a signal power level of at least -112dBm. This is 5 hours more than the best individual path (Path B at 14 hours at 315^{o} out of Amsterdam Island). Thus VOACAP predicts that propagation to the antipode offers longer duration openings by making more paths available throughout the day.

2 – Four hours (1500 UTC and from 2300-0100 UTC) offer signal powers greater than -112dBm on all eight paths. Thus VOACAP predicts the potential for a focusing enhancement. For each of those fours hours, the total signal power, assuming the electromagnetic waves all arrive in phase, is about 3dB more than the maximum individual signal power. That's not much of an enhancement, but indeed an enhancement could occur. Just think how much more signal enhancement there would be if we consider more paths out of Amsterdam Island at those times – not just the eight paths I looked at. But here's where we need to apply a dose of three "realities".

The first reality is that the signal powers predicted by VOACAP are monthly median values. On any given day during January, the signal powers could be somewhat above the predicted median to much below the predicted median – which is likely to limit the actual amount of enhancement.

The second reality is that we've ignored the MUFday parameter in VOACAP. In a like manner to the median concept of predicted signal power, on any given day during January the actual MUF may not be high enough to allow the electromagnetic wave to arrive at the antipode – which also is likely to limit the actual amount of enhancement.

The third reality is that the assumption of all electromagnetic waves arriving in phase is a mighty big assumption. Although our propagation programs say each path to the antipode is 20,000km, that's the ground distance. The real paths involve distances based on multi-hop propagation modes or perhaps even ionosphere-ionosphere propagation modes. The actual distance is always more than the ground distance and it varies depending on the hop structure along the specific path, with the phase of each electromagnetic wave at the antipode tied to this distance.

The best way to look at this third reality is to assume a random phase for each path, and statistically determine the summed signal power. Let's use the data at 0100 UTC in Table 1 to do this. What I did was randomly vary the phase of those eight power levels using a Monte Carlo analysis, and plotted the resulting probability versus total power in Figure 3 after 250 trials (I should have used a lot more trials, but the increased simulation time was not warranted to show the general concept).

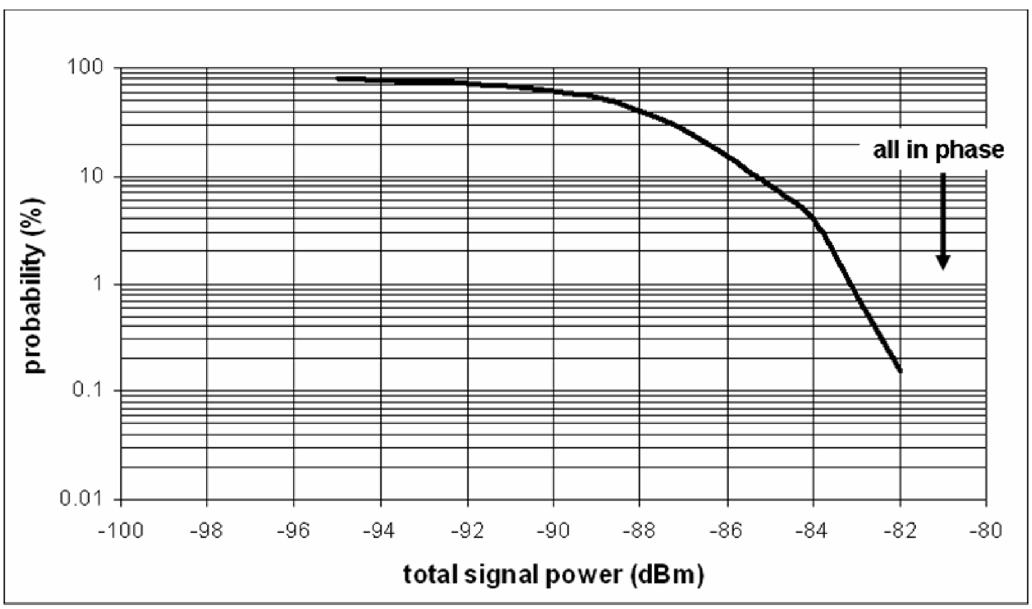

Figure 3 – The summation of the eight signals at 0100 UTC with random phase

If all the signals arrived in phase, the total signal power of the eight signals in Table 1 at 0100 UTC should end up at about -81dBm. As stated earlier, that's 3dB higher than the highest individual signal power (-84dBm on Path C). But it's at a very low probability (around 0.1% of the time) – in other words, it doesn't occur very often.

What about the scenario of more signals (paths) than just eight arriving at the antipode? And what if the signals are (optimistically) around the same level? I took a look at the statistics for thirty two signals, all at the same level. There is an enhancement of up to 15dB, but it's also at a very low probability (even less than 0.1% of the time). And taking a giant leap for this 20m example at 0100 UTC, three hundred and sixty signals (one for each degree around the compass, which assumes no detrimental impact from the auroral zones) could arrive at the antipode. Assuming they are all about the same level results in an enhancement of about 25dB, but it's at an extremely low probability (considerably less than 0.1%). Remember – if those signals can add when the phases are right, they can also subtract when the phases are wrong. More signals do guarantee more total signal power – but at lesser and lesser probability since the probability of all being in phase at the same time is extremely low.

Let's now look at predictions on 15m to see how propagation to the antipode fares on a higher frequency. With a higher frequency, the atmospheric noise is less and thus the signal power needed for greater than or equal to 0dB SNR is less than on 20m – it works out to -117dBm on 15m. Figure 4 shows the 15m results in the same fashion as the 20m results in Figure 2.

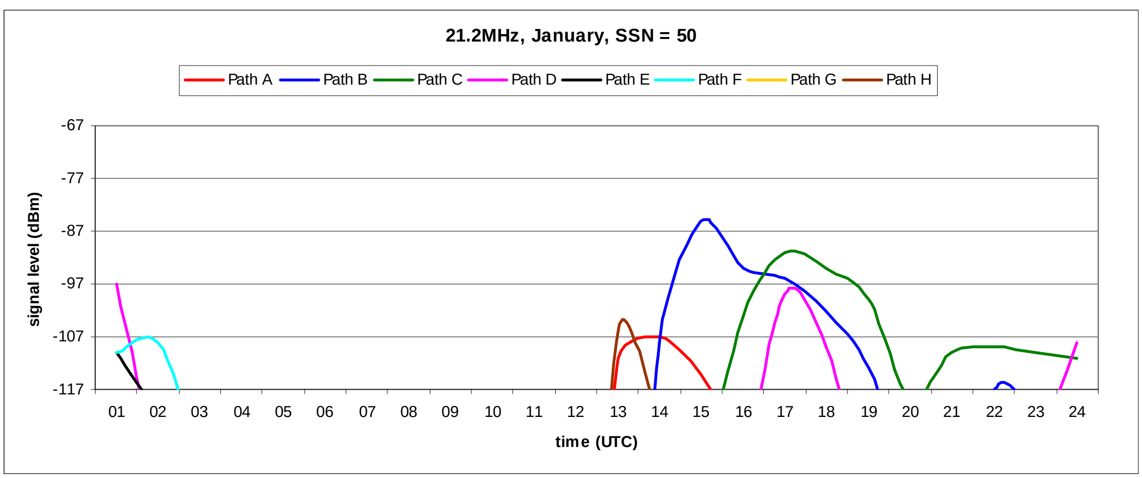

Figure 4 – 15m Signal Powers $\geq$ -117dBm on the Eight Paths

For propagation to the antipode on 15m, VOACAP predicts 13 hours of path availability, which is 5 more hours than the best individual path (Path C at 8 hours at 0^o out of Amsterdam Island). The total number of available hours is six less than on 20m, and this is due to a higher required MUF for 21.2MHz.

The best chance of signal power enhancement on 15m is at 1700 and 1800 UTC – but only three of the eight paths contribute to the total now. Again, this reduction in enhancement possibility is due to the higher MUF required for 21.2MHz. If all three paths arrived in phase, the signal powers would be from 1 to 2dB more than the maximum individual path.

And finally let's look at predictions on 40m to see how propagation to the antipode fares on a lower frequency. With a lower frequency, the atmospheric noise is more and thus the signal power needed for greater than or equal to 0dB SNR is greater than on 20m – it works out to -104dBm on 40m. Figure 5 shows the 40m results.

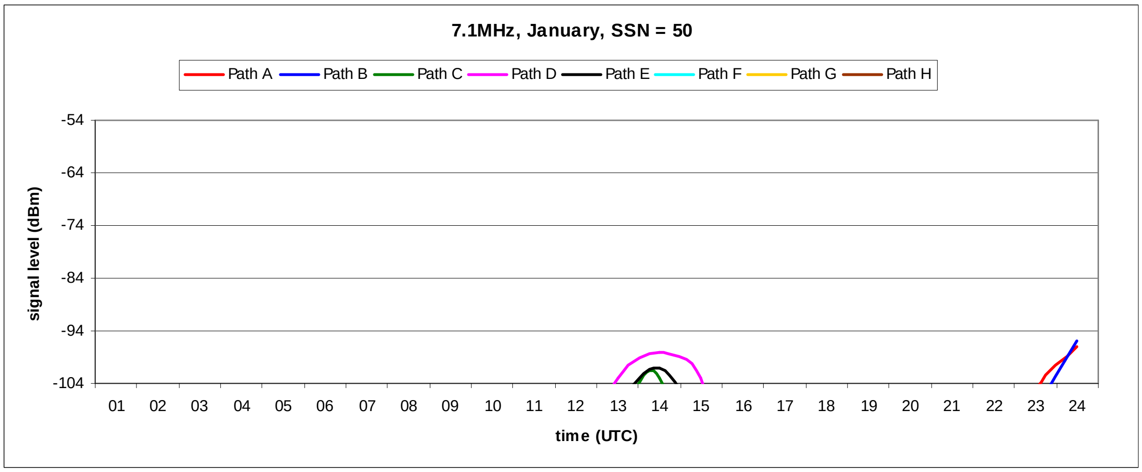

Figure 5 – 40m Signal Powers ≥ -104dBm on the Eight Paths

For propagation to the antipode on 40m, VOACAP predicts only 4 hours of path availability, which is only one hour more than the best individual path (Path D at 3 hours at 45^{o} out of Amsterdam Island). The total number of available hours is fifteen less than on 20m, and this is due to more absorption on 7.1MHz.

The best chance of signal power enhancement on 40m is at 1400 and 2400 UTC – but at 1400 UTC only three of the eight paths contribute to the total and at 2400 UTC only two of the eight paths contribute to the total. This reduction in enhancement availability is due to the higher absorption at 7.1MHz. If all three paths at 1400 UTC arrived in phase, the signal powers would be about 2.5dB more than the maximum individual path.

Ok – enough. Let's try to summarize all of this, and then I'll add two final comments.

First, the VOACAP results are in agreement with the Syracuse University findings – which is that propagation to the antipode offers the possibility of longer duration openings (due to more paths being available throughout the day) and the possibility of stronger signals (due to many signals arriving at the antipode).

Second, due to MUF issues on the higher frequencies and absorption issues on the lower frequencies, 20m appears to offer the best opportunity for the observation of antipodal enhancement (also in agreement with the Syracuse University findings). This makes sense, as 20m doesn't need as high a MUF as 15m, and it can withstand more absorption than 40m. Interestingly, these are the same two issues that make 20m the all-around best band for long path (as discussed in the September 2002 column). At higher smoothed sunspot numbers than the 50 value that was assumed in the VOACAP analysis, 17m and even 15m would likely to show more antipodal enhancements.

Third, Figure 5 indicates that propagation to the antipode on 40m (close to the 5MHz Syracuse frequency) only occurs around sunrise and sunset. Although the 15m results in Figure 4 indicate propagation to the antipode occurs at more times than just sunrise and sunset, looking at 10m data (close to the 30MHz Syracuse frequency) shows propagation also only occurs around sunrise and sunset. These results are in agreement with the Syracuse University findings.

Fourth, it’s tough to pin down with any certainty how much signal enhancement there might be. This is a very big statistical problem, and it’s tied to MUF, absorption, and phase (which in turn is tied to the actual distance the electromagnetic wave travels). The auroral zones are also out there with their potential to limit some azimuth sectors of antipodal propagation. On the other hand, scattering of energy into the antipode could help. The Syracuse University study didn’t settle this issue, as they didn’t include any data (as noted at the beginning of the column). I think it’s safe to say there can be a modest enhancement, but I also think reaching the theoretical limit of all signals adding is quite remote.

Fifth, the opportunity for observing antipodal paths is rather limited for North Americans. Other than the antipode of Amsterdam Island being in Colorado, the only other locations with their antipode on land in North America are Kerguelen Island (antipode in VE6) and Heard Island (antipode in VE5).

And now two final comments. One comment has to do with the necessity to use omni-directional antennas on both ends of the path (this is mostly relevant to 20m, as 20m appears to be the optimum band for observing antipodal enhancement) in order to take full advantage of antipodal propagation. But using omni-directional antennas sacrifices gain, and a study of the data in Table 1 indicates there are best directions at any given time. Thus if one knows which general directions are best at any given time, it might be better to use directional antennas on both ends of the path and turn them as necessary. The gain of a 3-element 20m Yagi at a reasonable height above ground is at least 10dB more than a ground-mounted 20m vertical over average ground, so the overall 20dB advantage in using directional antennas on each end and turning them as necessary may more than make up for any signal enhancement from signals arriving from many azimuths – especially in light of the general statistical results in Figure 3.

The other comment has to do with why I chose to analyze the Amsterdam Island-to-Colorado path. The reason for this is an e-mail exchange with Bill W4ZV about his 160m QSOs with Dany FT5ZB when Bill was W0ZV in Colorado. We’ll look at this in a column in the near future.