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Measuring Propagation Attenuation Using a Quadcopter

These tests show that the signal strength of a local station can be many tens of decibels weaker than from a DX station.

For the last several years I have been operating *WSPR* from N6GN on the 600 m through 70 cm Amateur Radio bands. I've found the large number of geographically spaced participants combined with the round-the-clock worldwide reporting make the **WSPRnet.org** web page and database an excellent tool for investigating propagation, and also for measuring and analyzing Amateur Radio station performance.

Among several local *WSPR* stations we noticed database entries that showed stations 1,000 to 2,000 miles away spotting our transmissions with significantly larger signal to noise ratio (SNR) than did local stations as close as four miles away. Assuming that the HF ionospheric propagation path follows an inverse-square law, one where the wave front expands spherically, it would seem at first glance that there should be a greater penalty for the greater distances. Distant signals (DX) should be much *weaker* than local signals.

From previous propagation experiments at UHF I knew that foliage and slight terrain variations in the propagation path could be responsible for extremely large attenuation at shorter wavelengths. It's also clear that HF antennas are usually closer to the ground, in terms of wavelength, than they are at UHF. Perhaps the peak of the main lobe of our HF antenna patterns getting pushed well above the horizon. This increases the signal incident on the ionosphere at the expense of signal levels measured at the local horizon. The question became, "How much of this greatly increased attenuation of the local signal revealed by *WSPR* was due to foliage attenuation and how much was due to the HF antenna elevation pattern?" Our measurements using a quadcopter, see Figure 1, were designed to help answer that question.

Why is a Local Station Weaker than DX?

At my station, N6GN, I initially operated using an HF transceiver, then later with one of the Ultimate2 QRSS (U2) lower power beacon transmitters from QRP Labs.[1] On 10 m the U2 beacon delivers just 180 mW compared to the 5 W of my station HF transceiver. Even with just the lower power beacon, and a simple vertical antenna, it was very interesting to see where and when the signal can be spotted. Over several months of low power operation, I received spots from many US states and quite a few other countries.

It has been interesting to watch the reported SNRs to get an idea of propagation, and to compare them among other local stations at various distances, including several stations just 3 to 15 miles from my station. During the *WSPR* spotting activity, local stations often either could not hear my N6GN beacon at all, or reported 10 to 15 dB lower signal strength than stations 1000 to 2000 miles away. Upon discussing this over coffee with a few other local *WPSR* users one morning, we decided to see if we could determine the reasons for this.

What was limiting our signal?

From previous measurements at UHF I knew that local signals were often attenuated a great deal more than if paths to the stations were truly in a free space and line-of-sight (LOS). RF path loss models indicated that many 10s of dB of additional attenuation could be expected for a 70 cm signal between typical amateur installations in a suburban environment. This is the same type of

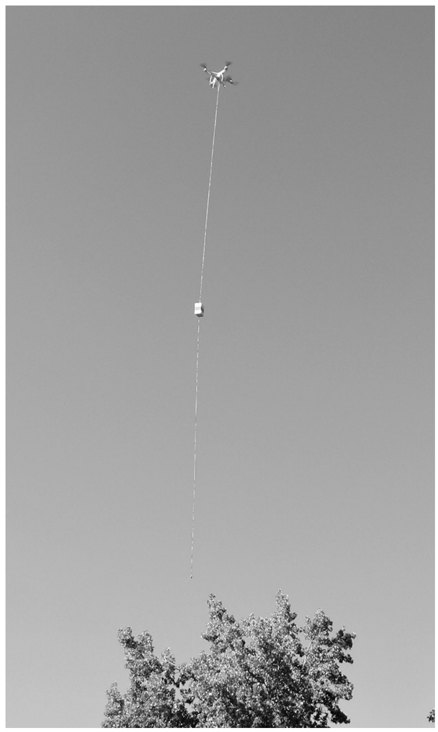

Figure 1 — Quadcopter shown towing a half-wave 10 m band vertical dipole with battery and beacon transmitter. [Photo courtesy of Glenn Elmore, N6GN].

[1]Notes appear on page 22

environment our 10 m *WSPR* signals were encountering. We had previously measured a 70 cm path using a helium balloon supporting an elevated antenna fed with a surface wave transmission line to explore the "height gain" phenomenon.

Cross-polarization loss and pointing error

It was obvious that some of the local stations providing the *WSPR* spots were cross-polarized, and encountered beam pointing errors, which attenuated their signals. Linear polarization refracted from the ionosphere results in both right and left hand circular polarized signals, so distant stations might not experience these polarization alignment issues. However, some of the locals were using vertical antennas, as I was at N6GN, so this didn't explain all of the weak *WSPR* signal reports.

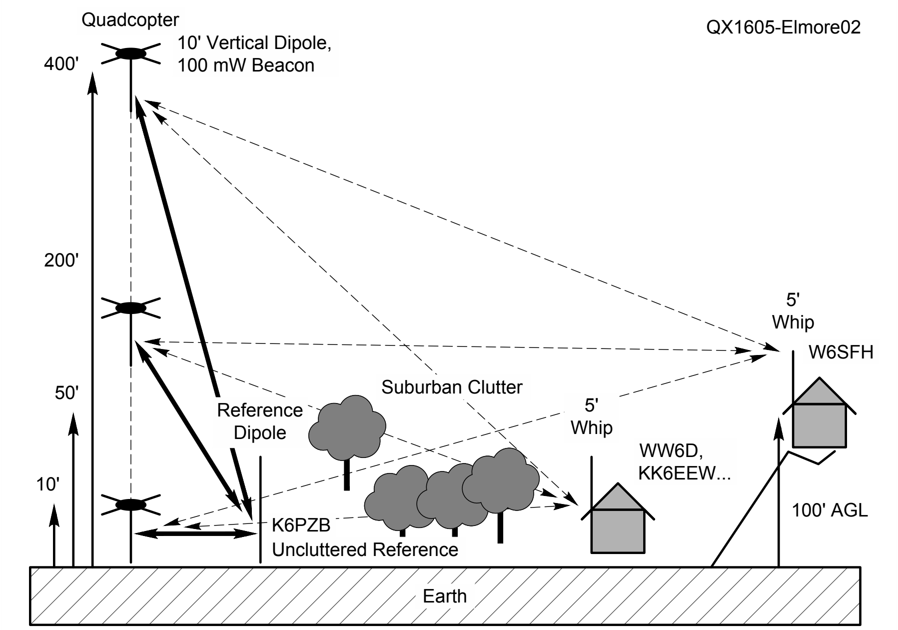

Figure 2 — Paths from various heights to a near-by station. The vertical scale is exaggerated.

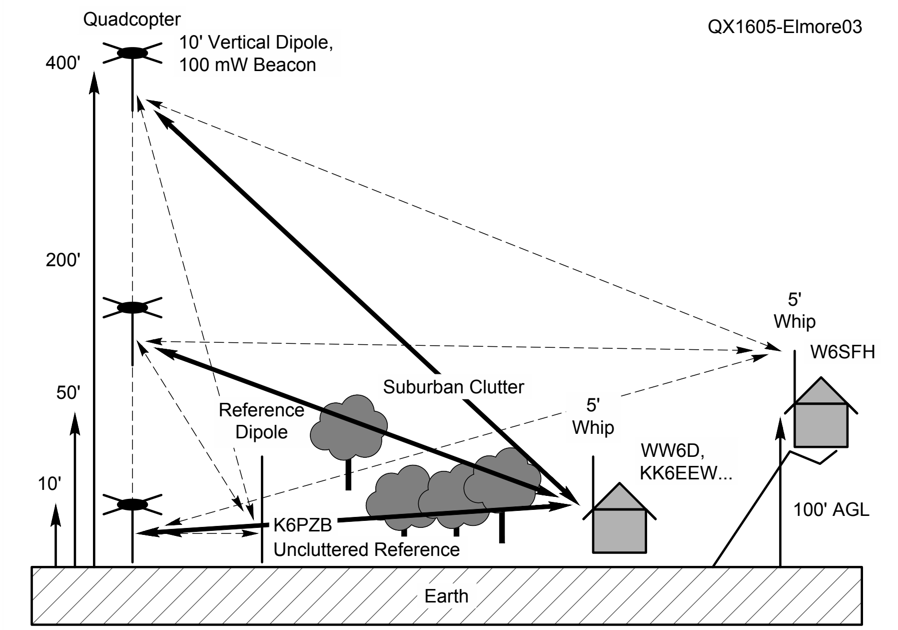

Figure 3 — Paths from various heights to mid-range stations. The vertical scale is exaggerated.

Antenna elevation pattern over Earth ground

We also know that the peak of the main lobe of the 10 meter signal is not directed at the horizon as it would be if we in free space. [There is always a ground reflection contribution for antennas elevated above Earth ground. — *Ed*.]. NEC based electromagnetic solvers (4nec2, *EZNEC* and other similar programs) predict a very considerable up-tilt in the *peak* of the antenna pattern due to the presence of real ground. We didn't know precisely what our ground was like and what the ground reflections were doing to our antenna patterns. [NEC based electromagnetic solvers assume a perfectly flat and perfectly smooth ground. — *Ed*.].

Noise

Since the *WSPR* software and spotting network reports SNR referenced to an SSB bandwidth. It was possible that some of the reported differences were due to excess noise at the receiving station. We examined this possibility and found it is not always the case. Although local noise has become an increasingly serious problem everywhere, on 10 meters at least a few Amateur Radio stations can still boast about a fairly low noise floor. DX stations also often must fight local noise pollution, just as we do locally.

Excess absorptive attenuation

Referring to Figures 2, 3, and 4, one culprit for this "lost" signal was absorption by the environment. Several of the local hams were essentially at the same height above ground. They weren't behind mountains or hills so we couldn't blame obstruction losses from hills or mountains. We had a flat Earth between us. However, all of the local signals passed through trees and foliage in the propagation path to the N6GN antenna. We all live in suburban/rural areas, and there are lots of trees, with some that are well over 100 feet tall. I knew from previous measurements, as well as academic papers, that in UHF and microwave regions absorptive loss could be extremely high, with hardwood trees cited as producing excess attenuation of 0.25 dB per foot at 2.4 GHz. I had no data on what to expect from suburban California foliage at HF. Also, the wavelength in question was on the order of the height of many of the intervening trees.

When You Don't Know, Measure!

We decided to make measurements to help separate some of the potential causes of signal loss. If we had a well characterized 10 m signal and antenna, and a station with an accurately known effective radiated power (ERP), we might raise and lower the radiating antenna over a wide range of heights while measuring the field strength. This left the problem of placing the test transmitter and antenna at various heights in order to measure signal strength as a function of height.

I don't have a 400 foot variable height tower at my disposal. Furthermore, the weight of a 10 m dipole, transmitter and battery would be too much to lift with a small balloon. I then thought of the using an electric helicopter, a quadcopter that could easily lift several ounces of payload many hundreds of feet into the air. I have a DJI Phantom small quadcopter that has been modified to provide both GPS and barometric altitude telemetry data to the ground. This would allow gathering data as a function of antenna height and hopefully would help separate the potential contributors of attenuation to the signal.

Figure 2 shows the paths from various heights to a near-by station. Figure 3 shows the paths to mid-range stations. Figure 4 shows the paths to a more distant local station. The vertical dimension in the Figures is exaggerated, but you can see that at low test antenna heights, several potential contributors to attenuation were possible. The antenna lobe might be attenuated by reflections from the ground. Absorptive losses due to trees and other suburban clutter could also be involved. But as the transmitter and antenna height is increased, we thought that the effects from ground should vanish because for some stations the antennas would experience a LOS path. The path between the transmitter and receiving antenna, however, would still suffer the effects of a ground reflection.

The Tests

For the tests I chose a local park with about 1000 feet of flat ground — a completely clear sod playing field. A quadcopter lifted the payload (180 mW U2 beacon, lithium-polymer battery and a vertical dipole antenna) at one end of the park. We set the U2 to transmit a 100 Hz shift FSK-CW identifier and grid square on 28.1262 MHz. This provided us with an accurate amplitude, and an almost constant frequency carrier for measurement by the several other stations. During the tests we used UHF FM radios to coordinate and report progress, and to report the test antenna height so all receiving stations could measure and record signal strength at the various known transmitting heights. We measured signals using either calibrated test spectrum analyzers or receivers that had previously been calibrated, so we knew the absolute signal level accurately.

We ran tests on two different occasions with two receive stations common to both sets of tests. Table 1 shows the stations participating in the tests along with some details.

Test 1

For the first test, we included a reference receive measurement quite close to the transmitter and with no clutter in between. The reference station was K6PZB, located about 1000 feet away on the other side of the park. We set up a 10 m vertical dipole connected to a calibrated spectrum analyzer. The antenna was mounted on an insulating stand with the lower tip of the dipole a few feet above the ground. While the path would suffer the effects of the ground reflections, there was no other intervening clutter. Because this measurement path was so close, the effects of the two antennas beamwidths needed to be included in the calculated path loss. That is, as the test antenna was raised by the quadcopter, the broadside directions of the two antenna dipole patterns were no longer aligned. We used the known pattern of a dipole to correct for this in the final data. For more distant stations this effect was small, and we ignored it.

Two additional stations, WW6D and W6SFH, also listened and measured signals

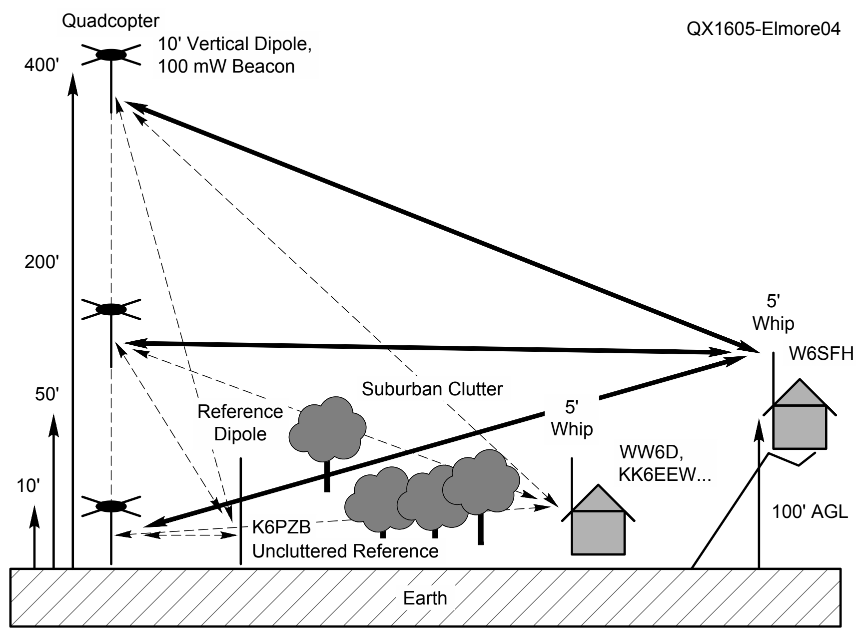

Figure 4 — Paths from various heights to a distant local station. The vertical scale is exaggerated.

Table 1.

First Test

Station	*Details*
K6PZB	Reference station, ground mounted half-wave vertical dipole, 1000 foot distant, LOS path in the same park as the transmitter.
W6SFH	About 3 miles NE, situated on a ~100 foot hill above most clutter, tri-band beam 40 feet above ground.
WW6D	About 2 miles N at same ground level height as test transmitter, tri-band beam at 40 feet above ground.

Second Test

Station	*Details*
KK6EEW	About 10 miles distant, vertical antenna and spectrum analyzer receiver, short whip with High-Z preamp.
K6PZB#2	Ground located half-wave vertical dipole about 3 miles NE, situated on a ~100 foot hill above most clutter, LOS to park.
W6SFH#2	About 3 miles NE and situated on a ~100 hill above most clutter, tri-band beam 40 feet above ground.

with either a spectrum analyzer or a calibrated SDR receiver. Both of these stations used relatively low horizontally polarized tri-band beams pointed toward the transmitting site. W6SFH was located on a ~100 foot hill above most of the intervening clutter. By the time the transmitter reached 100 to 150 foot elevation we expected to be in visual LOS of his beam. WW6D was located at the same ground level as the transmitter. This meant that there was a maximum of intervening clutter between his antenna and the test antenna at its lowest height. With the test antenna 400 feet (122 m) high, the path was still not LOS, but total clutter was reduced because only the clutter near WW6D was in the path between the transmitting and receiving antennas.

Test 2

For the second test the K6PZB reference antenna (K6PZB#2) was located at the 100 foot hill, about 1000 feet from receiving station W6SFH. Both of these stations used the same antennas and measuring systems as in the first test. K6PZB selected a location that would be LOS to the test transmitter once the test antenna was above approximately 100 feet. KK6EEW was the most distant of the reporting receiving stations. At 10 miles distance, there were very low rolling hills and very significant foliage in the path for all beacon elevations. Although still a local station, KK6EEW definitely did not have a LOS path.

Test Results

Figure 5 presents the measured results from the two tests. The vertical axis is the path loss in excess of free-space loss for the distance to each of the receive sites. The horizontal axis is the altitude of the beacon transmitter. The levels for each of these curves are different because they were referenced to the calculated free space loss for the particular distance.

The data of Figure 5 shows that the reference measurement matches calculated free space values and showed no excess attenuation once the test antenna exceeds a height of 60 meters — about six wavelengths at the test frequency. Each of the more distant sites showed additional attenuation, particularly at low test antenna altitudes. At the most distant receiving site, the improvement created by altitude was most dramatic. Signals that had been lost in the noise from the test antenna when it was near ground level became quite strong by the time the test antenna reached a few wavelengths of altitude. One other monitoring station, about 8 miles distant (not included in the data), reported that although no signal was heard when the test antenna was at ground level it "...got very strong for only 200 mW" once the dipole and transmitter exceeded a 100 feet in altitude. The improvement from increasing antenna height was in excess of 50 dB. At maximum height the beacon generally became the strongest signal on the band for all receiving stations.

An Interpretation

Data from the K6PZB reference antenna seems to confirm that the ground affects the main dipole lobe and pushes the angle of peak radiation upward. This effect, 10 to 12 dB, was common to all stations and reveals a strong height dependency. There remains an additional 10 to 15 dB factor for the closer stations and at least 25 dB for the more distant receivers. This might make

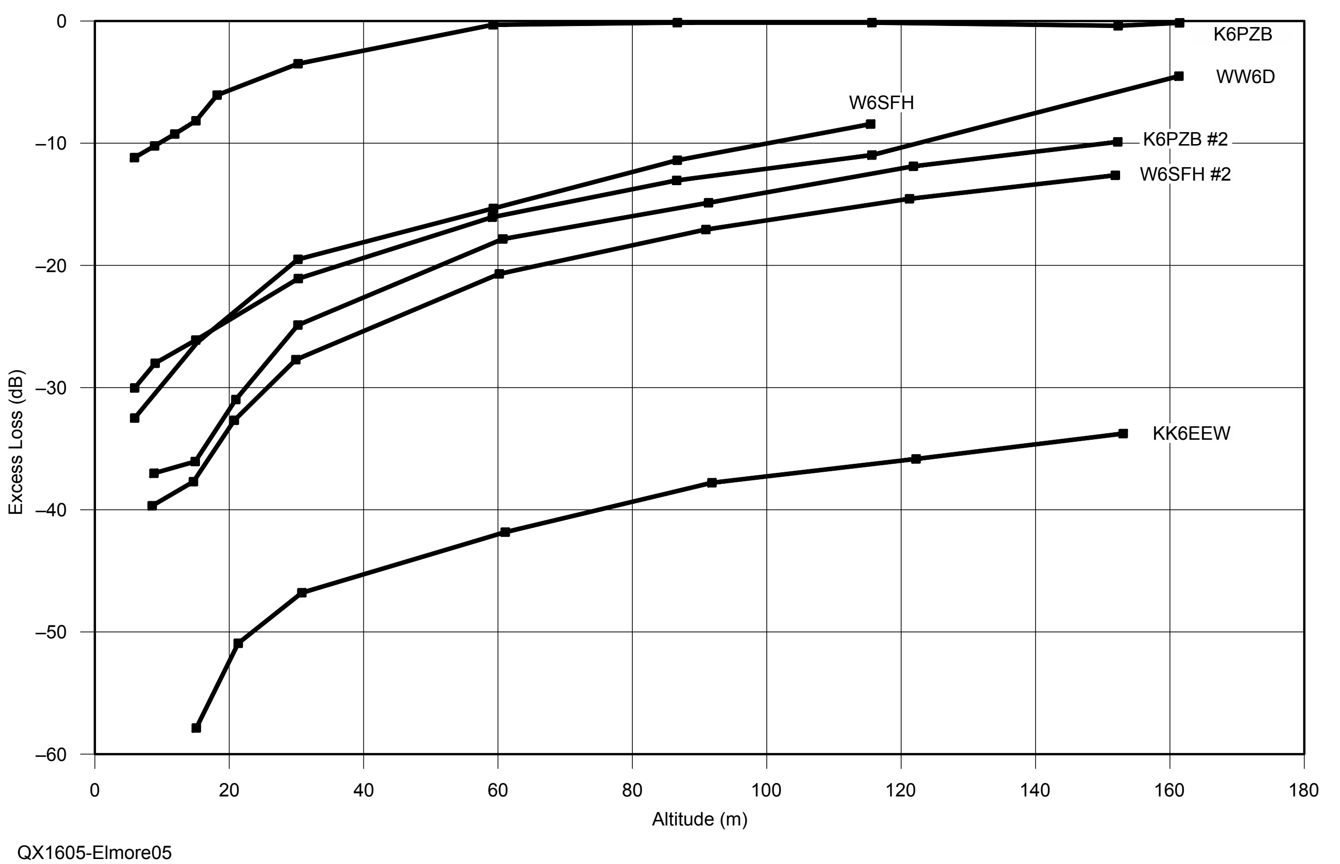

Figure 5 — Measurements of signals as a function of height using a quadcopter to support a "flying" 10 m transmitter and dipole.

intuitive sense. For closer stations, see Figure 2, the angle of the antenna increases more than for distant stations, Figures 3 and 4, and the proportional amount of intervening absorbers from trees, terrain and buildings decreases. The amount of intervening absorbers, however, decreases the most for elevation angles appropriate to DX station paths.

In a recent 432 MHz measurement, each doubling of height produced about 7 dB of improvement of SNR in a suburban/urban environment. Although that RF path attenuation model was not intended for HF, our data also follows this trend in the 10 meter band.

Conclusion

Our tests were not definitive. They could be improved, and they leave open questions. We investigated a single locale with one type of ground and generally similar foliage and terrain. Some of the data involved cross-polarized antennas. We did not investigate any "Brewster angle absorption" effects. Even so, all receiving sites reported a generally similar experience. Our data provided evidence that long distance contacts on 10 m by way of the ionosphere along paths involving elevation angles above 10 to15 degrees can have considerably lower attenuation than some local contacts. We speculate that one reason is that when station antennas lower than a few wavelengths are used, there is on the order of 10 dB penalty due to the effect of ground reflection pushing the peak of the antenna lobes upward, and putting the local station at a disadvantage. A second reason is that there is greater attenuation due to absorption by the local environment just as there is at VHF and above. The combination of these two effects can easily exceed 40 dB and serves to explain the differences we see in reported SNRs on *WSPR*.

These results add emphasis to the value of antenna height when working stations at or very near the local horizon, rather than via higher angle ionospheric propagation paths. As an HF band is just opening or closing, when the angle of the ionospheric path is extremely low, and the skip distance is long, the improvements possible from increasing antenna height may dominate other improvements that you can make to an Amateur Radio station. Height may have even more effect than antenna size — height gain may exceed the gains possible for practical HF antennas. Investments in tower height probably provides much greater return than investment in antenna size or number, since an antenna with a gain in excess of about 30 dB is not generally feasible below the microwave bands. The benefits of antenna height are perhaps most dramatic on VHF and higher frequencies as demonstrated in online videos.[2]

Next Steps

Our local 10 m band data seems to agree with the findings of previous 70 cm tests. Following our 10 m test, we have performed 2 m band test with *WSPR* on 2 m. We used a balloon rather than a quadcopter. We would like to make similar height gain measurements out to several hundred miles using *WSPR*. We plan to report our progress on *QEX*.

Glenn Elmore, N6GN, has been a licensed Amateur Radio operator for 50 years. He's held the call signs WV6STS, WA6STS, and now N6GN. He holds the Amateur Extra class license since 1972. Glenn was an electrical engineer involved with the design of RF and microwave test and measurement equipment, notably scalar, vector network and spectrum analyzers. His Amateur Radio interests include weak signal VHF-microwave operation, meteor scatter, EME, terrestrial DX as well as higher speed amateur TCP/IP radios and networks. Glenn has been using WSPR for more than five years to examine VHF/UHF propagation. He operates a largely homebrew station using OpenHPSDR SDR hardware and software.

Over the years Glenn has authored professional papers and articles, Amateur Radio microwave hardware projects and more recently, several papers and articles on surface wave transmission line theory and applications, including a three-part series in QEX in 2012. Glenn is semi-retired and able to devote more time to applications and theory of SWTL and integrating these with an understanding of theoretical physics.

Notes

[1]QRP Labs, **www.qrp-labs.com**.
[2]See the several videos at **https://youtu.be/-VWBUDJv2n0**.
[3]**https://www.dropbox.com/s/jkpyxkpci50hb4q/HaloTest.pdf?dl=0**