Active Loops, Active Voltage Probe and Wire Antennas; A Statistical Review of the Performance of Six Antennas (Part I)

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For the last 18 months the author has been involved with Pixel Technologies in developing and producing the high-gain low-noise preamp used with the company's series of shielded magnetic loop antennas. Recently Pixel asked me to perform a series of comparative tests on the latest version of their loop antenna (Model RF PRO-1B) to determine how it performs relative to other loop antennas and other types of antennas in general. In these tests the Pixel RF PRO-1B and the Wellbrook ALA1530L loops were evaluated with four other antennas in a series of automated performance measurements, totaling more than 500,000 individual signal and noise reference measurements, comparing six antennas:

1. Wellbrook ALA1530L
2. Pixel PRO-1B
3. Pixel PRO-2 Experimental
4. Pixel PRO-3 Experimental
5. Clifton Laboratories Z1501F voltage probe antenna
6. 80 meter band inverted vee wire antenna.

The PRO-2 and PRO-3 antennas are experimental products and may or may not lead to production antennas, and their details will not be discussed. The performance of the loops against the Clifton Laboratories Z1501F voltage probe and the Inverted vee will be published in a subsequent Part II paper along with performance measurements of the antennas in various RF environments corrupted with levels of local electrical noise and RF interference.

The objective of this Part I review is to compare the two loop antennas head to head. This series of tests also confirms earlier measurements I have made with an older Wellbrook antenna that the Pixel RF PRO-1B loop, statistically speaking, provides better signal-to-noise ratio performance than the Wellbrook ALA1530L. In some frequency bands, one antenna outperforms the other, but on balance, this study gives the edge to the RF PRO-1B over the Wellbrook ALA1530L. I will also compare and evaluate other features of the two antennas including:

- Antenna pattern null depth
- Mechanical design and mounting
- Maintainability and customer support
- Intermodulation distortion in strong signal environments
- Compatibility with Transmitters
- Connectors and coaxial cable requirements

Antenna Installation

The four loop antennas are mounted on an 8 foot (2.4 meters) long cross arm of pressure treated 2” x 6” (50mm x 150mm) pine, with multiple coats of urethane spar varnish. The cross arm is supported by a length of 2” (50mm) galvanized schedule 40 steel water pipe, with a concrete footing. The cross arm is rotated by a Hy-Gain T2X “Tailtwister” rotor. The cross arm is approximately 8 feet (2.4 meters) above ground. *Figure 1* shows the completed loop installation.

Figure 1. Loop Array (from left to right) PRO-1B, PRO 2X, PRO 3X, ALA1520L

The loop antenna array is located approximately 125 feet (38 meters) from my house. Six runs of Belden “tri-shield” 75 ohm coaxial cable, model 7915A RG6/U Duobond, rated for direct burial and one run of direct burial 8-conductor rotor cable buried approximately six inches (150mm) underground connect the loop array with the test facility. Approximately 160 feet (48 meters) of cable are in each run. Belden 7915A cable employs a solid copper center conductor and has less loss than RG-58 50 ohm coaxial cable.[1] The cables are terminated with Belden “Snap-N-Seal” weatherproof connectors, either Type F or BNC, as needed for the particular antenna and DC power coupler.[2] The mis-match, if any actually exists, between the loop amplifiers, the coax cable and the test equipment, is considered negligible.

Mounting multiple antennas in close proximity requires consideration of their possible interaction. Using an HP8752B vector network analyzer, I measured the coupling between two PRO-1B loops, without amplifiers installed, spaced 2, 4, 6 and 8 feet (0.6, 1.2, 1.8 and 2.4 meters) center-to-center on the cross-arm in the configuration seen in *Figure 1*. Over the measured range of 300 KHz – 30 MHz, the worst case loop-to-loop coupling occurred at 30 MHz for 2 feet (0.6 meters) separation but was greater than -30 dB. This level of isolation is considered acceptable for the tests conducted.

The Clifton Laboratories Z1501F voltage probe active antenna *(Figure 2)* is located approximately 25 feet (7.5 meters) from the loop array. It is mounted on a short length of small diameter (1"/25mm nominal diameter) thin-wall electrical conduit approximately 5 feet (1.5 meters) above ground, with the whip portion 10 feet (3 meters) long. It is fed with 75 ohm RG-6 quad shielded coaxial cable buried 6 inches (150 mm) underground.

A voltage probe antenna has high impedance with negligible antenna current flow; hence it does not appreciably interact with the loop array.

Figure 2. Clifton Laboratories Z1501F Voltage Probe Active Antenna (Antenna length = 10 feet)

The 80 meter band inverted vee has an overall length of 130 feet (40 meters) and is suspended from a 100 foot (30 meters) tall Rohn model 45 galvanized guyed steel radio tower. The inverted vee apex is approximately 80 feet (24 meters) above ground, and the ends are approximately 40 feet (12 meters) above ground. It is fed with approximately 150 feet (45 meters) of Belden RG-8 coaxial cable. No balun is used. The tower also has a M2 7/10-30 MHz log periodic antenna at the top, along with a 20 foot (6 meters) vertical for the 144 MHz band. The tower is approximately 50 feet (15 meters) from the loop array and the Z1501F voltage probe antenna. *Figure 3* is an aerial photograph illustrating the antenna siting.

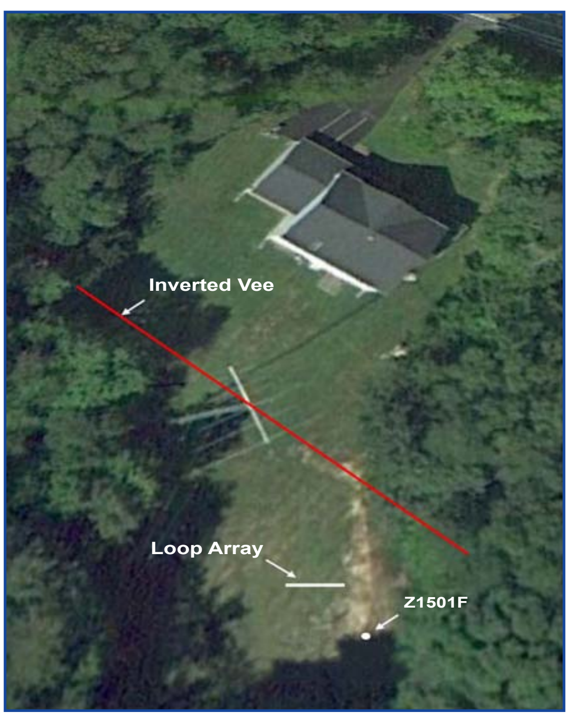

Figure 3. Aerial View of Test Site

The tower and 80 meter band inverted vee re-radiate signals and evidence of that is seen in loop null skewing and fill-in. See *Appendix 1*. To avoid re-radiation and contaminated results, antenna ranges are carefully selected to avoid significant above ground structures and, for that matter, underground conductors as well. In my case, that is impossible and, for that matter, it is rarely the case where a typical amateur operator or shortwave listener may install an antenna hundreds of feet from the nearest conducting structure, or power line. The measured results, therefore, reflect a practical installation, not untypical of real world antenna installations.

All data was taken at Clifton Laboratories, in Clifton, Virginia, located near Washington DC, between 25 August 2011 and 25 September 2011.

Latitude: 38°46'25"N
Longitude: 77°22'46"W
Elevation: 330 feet AMSL

Measurement Methodology

The traditional "A-B" antenna test - measurements are sequentially made on antenna A and then on antenna B - has a significant infirmity; fading. Fading may be viewed as either temporal or spatial. Temporal fading is what most amateurs and shortwave listeners think of when the term "fading" is used; the signal changes level over time. "Fast" fading means the signal changes in seconds; slow fading may take minutes or even hours. Spatial or geographic fading describes the difference in signal levels when simultaneously measured with identical antennas physically separated. In fact, the terms temporal and spatial fading are different ways of describing the same phenomena; signals arriving by multiple ray ionospheric reflection interact and form a diffraction pattern of radio waves on the earth's surface. As the reflection points change over time, the diffraction pattern changes. The diffraction pattern gives rise to different signal strengths at different locations and as the reflection points change, the signal strength at any given antenna location also changes.

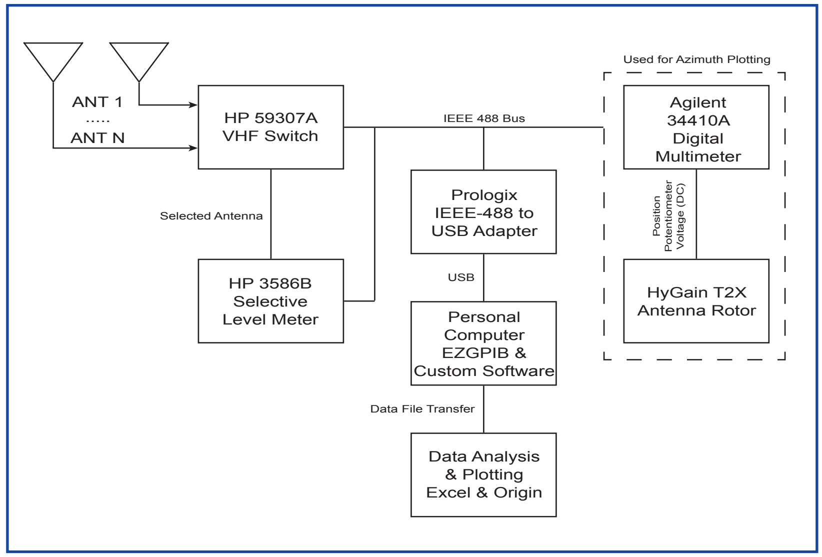

Figure 4. Test Equipment Setup

Appendix 1 provides a more thorough analysis of this effect, but for the purpose of antenna performance measurements, it means that manual measurement techniques where even a few seconds is needed to switch antennas and make a S/N measurement are fraught with error. This error is compounded if the antennas under comparison are separated by more than a small distance, roughly 0.1 to 0.2 wavelengths at the frequency of comparison.

Although it is theoretically possible to make simultaneous measurements for the six test antennas, the equipment requirements are beyond those readily available; preferably six identical measuring receivers.

A more reasonable approach is to accept the fact that signal levels may change 10 to 20 dB over a few seconds and to make many individual measurements and statistically analyze the results. A statistical approach has another advantage in that it provides a more useful understanding of the differences between antennas, as may include effects such as different arrival angles.

Figure 5. Test Equipment

Figures 4 and 5 show the data collection arrangement. Each antenna under test connects to an HP 59307A "VHF Switch." The 59307A is a dual (Sides A and B) single pole, four throw coaxial relay operated either by front panel push-button switches or remotely over an IEEE-488 bus. By series connecting side A, position 4 to side B common, up to 7 individual antennas may be selected with a single 59307A.

The 59307A connects the selected antenna to the 75 ohm input of an HP 3586B selective level meter, where the signal level is measured in dBm. Like the 59307A, the 3586B may be controlled by front panel switches or remotely over an IEEE-488 bus. For those not familiar with the 3586 series (versions A, B and C) selective level meter, it may be considered for our purposes as a wide range (50 Hz – 32.5 MHz) receiver optimized for accurate signal level measurements. Versions A, B and C are essentially identical instruments, differing only in input connector type, impedance level and bandwidth options. My measurements use 20 Hz bandwidth for carrier level measurements or 400 Hz bandwidth for data modulated signals. A Watkins Johnson WJ-8711A receiver is available for listening to signals.

The controlling software, written in EZGPIB, sequences through the antennas under test. For each antenna, it sets the 3586B to the desired signal frequency and computes the median signal level (from 5 measurements). It then tunes the 3586B to a nearby noise frequency and computes the median noise level (also from 5 measurements). The antenna ID, time of collection, the mean signal level and the mean noise level are saved to a disk file for subsequent analysis. This sequence is repeated until the operator manually intervenes to halt the program.

While data collection is underway, I monitored the signal frequency by listening to a Watkins Johnson HF-1000 receiver (not the WJ 8711A in Figure 5) connected to a different antenna, with periodic checks of the noise frequency to ensure it was free of signals. I terminated data collection when the station switched frequency or when a suitable number of measurements were made, typically one hour.

The pseudo-code sequence *(opposite)* illustrates this process.

```
Repeat Until Manual Stop
For each Antenna Do
Begin
    For the signal frequency
        Take 5 signal level measurements
        Compute median and save to disk file
    For the noise frequency
        Take 5 signal level measurements
        Compute median and save to disk file
End; {each antenna}
Operator intervention to end data collection?
```

Data Collection Software Routine

A subtle but critical point is that the five sequential level measurements are extracted as the median, not average. This is to avoid undue bias upward or downward. Downward bias is likely to come from short, deep fades, and upward bias is more often a consequence of static crashes.[3] The details supporting these conclusions are omitted. The disk file saved data is post- processed in Microsoft Excel spreadsheets to compute statistical measures of performance. Where plots were necessary, Microcal Origin is used.

The collected data represents 527,580 individual measurements.

Pixel PRO-1B versus Wellbrook ALA1530L

Table 1 shows statistical measures of (S+N)/N for the PRO-1B and ALA1530L antennas for frequencies between 24 KHz and 21 MHz. At the time the data was collected, no suitable signals above the 13 meter shortwave band (21850 KHz) were observed and hence higher frequency data was not collected. The data is grouped by frequency band, and where multiple runs were conducted for each frequency, the runs are shown separately.

For each frequency run, the table provides the percentage of time that each antenna has the best S/N and also provides the mean (average) (S+N)/N for each antenna.

	Pixel	*Wellbrook*
Number of Wins	48	26
Percentage of Wins	65%	35%
Average Margin of Victory	3.1 dB	0.8 dB

Table 2. Loop vs Loop Comparison

***Table 2* shows a summary of the results. Of the 74 loop vs. loop comparisons (opposite), each at a different frequency or time (and each consisting of hundreds or thousands of individual (S+N)/N measurements) the Pixel PRO-1B won 65% of the comparisons. The Wellbrook ALA1530L won 35% of these comparisons by an average margin of 0.8 dB, a difference virtually indiscernible to the average listener, while the PRO-1B's average margin of victory is 3.1 dB, an audibly noticeable difference.**

Table 1. Pixel RF PRO-1B Loop vs. Wellbrook ALA1530L Comparison Test

Indicates Test Winner

Band	Frequency (kHz)	Best (S+N)/N Percentage of Time: Pixel	Best (S+N)/N Percentage of Time: Wellbrook	Mean (S+N)/N Pixel RFPRO-1B Loop (S+N)/N (dB)	Mean (S+N)/N Wellbrook ALA1530L Loop (S+N)/N (dB)	Pixel Wins & Margin of Victory (dB)	Wellbrook Wins & Margin of Victory (dB)	Comments
VLF/LF	24	100%	0%	20.8	5.8	15.0		24 KHz NAA Cutler ME
	40.75	82%	18%	19.0	16.2	2.8		NAU Aguada PR Navy
	73.6	100%	0%	23.2	16.4	6.8		CHF (Canadian Navy) Halifax NS
	31.6	50%	50%	5.7	5.9		0.2	DGPS Brunswick NAS ME
Medium Wave	550	32%	68%	54.3	55.0		0.7	Med.Wave Station WSVA Harrisonburg VA
	680	46%	54%	49.7	49.9		0.1	WCBM Baltimore MD
	760	42%	58%	45.5	46.6		1.1	Med.Wave Station WJR Detroit MI
	1000	46%	54%	50.1	50.2		0.1	Med.Wave Station WMVP Chicago IL
	1600	36%	64%	51.3	51.8		0.5	WLXE Rockville/Lexington Park MD, USA
90 & 120 Meters	2500	56%	45%	35.3	33.5	1.8		WWV Ft Collins & WWVH Hawaii
	3185	52%	48%	63.9	63.8	0.04		WWRB Morrison TN, USA
	3185	57%	43%	65.5	64.6	0.9		WWRB Morrison TN, USA
	3290	48%	52%	26.7	25.8	0.9		Voice of Guyana Vreed en Hoop, Guyana
	3290	51%	49%	34.8	34.3	0.5		Voice of Guyana Vreed en Hoop, Guyana
	3330	53%	47%	40.1	39.8	0.3		CHU Standard Time/Freq Ottawa ON, Canada
	3330	59%	41%	48.9	47.5	1.4		CHU Standard Time/Freq Ottawa ON, Canada
60 Meters	4840	53%	47%	73.3	73.0	0.3		WWCR Nashville TN, USA
	5025	58%	42%	63.0	62.7	0.4		Radio Cuba, Havana
	5025	43%	57%	40.5	40.8		0.2	Radio Cuba, Havana
	5040	33%	67%	57.6	59.0		1.4	Radio Cuba, Havana
49 Meters	5920	55%	45%	54.3	53.8	0.5		WHRI Cypress Creek SC, USA
	6070	29%	71%	43.6	45.8		2.1	CFRX Toronto ON, Canada
	6120	49%	51%	55.9	56.1		0.1	Radio Cuba, Havana
	6175	42%	58%	58.9	54.4	4.5		China Radio International Cerrik, Albania Relay
41 Meters	7405	55%	45%	66.0	63.9	2.1		Radio Marti Greenville SC, USA
	7490	44%	56%	63.3	64.7		1.4	WWCR Nashville TN, USA
	7850	43%	57%	51.05	51.21		0.2	CHU Standard Time/Freq Ottawa ON, Canada
	7850	51%	49%	44.8	44.9		0.1	CHU Standard Time/Freq Ottawa ON, Canada
31 Meters	9330	70%	30%	42.5	39.9	2.6		WCBQ Montecello ME, USA
	9370	70%	30%	62.9	61.2	1.7		WTJC Moorehead City NC, USA
	9445	47%	53%	54.8	55.2		0.4	All India Radio, Bangaluru, India
	9455	44%	56%	42.1	42.5		0.5	China Radio Int. Kunming-Anning, China
	9460	36%	64%	49.1	50.4		1.4	Voice of Turkey, Emirier, Turkey
	9475	70%	30%	40.3	38.4	1.9		Radio Australia, Shepparton, Australia
	9480	72%	28%	72.5	69.7	2.8		WTWW Lebanon TN, US
	9535	50%	50%	73.6	73.7		0.1	R.Exterior de Espana, Nobiejas, Spain
	9555	33%	67%	24.5	30.0		5.5	Radio Riyadh, Saudi Arabia
	9570	60%	40%	39.5	38.4	1.1		Radio China Int. via Havana, Cuba, Relay
	9625	51%	49%	42.87	42.91		0.04	CBC Radio Nord Quebec, Sackville NB, Canada

Table 1. Pixel RF PRO-1B Loop vs. Wellbrook ALA1530L Comparison Test ... Cont.

Indicates Test Winner

Band	Frequency (kHz)	Best (S+N)/N Percentage of Time Pixel	Best (S+N)/N Percentage of Time Wellbrook	Mean (S+N)/N Pixel RFPRO-1B Loop (S+N)/N (dB)	Mean (S+N)/N Wellbrook ALA1530L Loop (S+N)/N (dB)	Pixel Wins & Margin of Victory (dB)	Wellbrook Wins & Margin of Victory (dB)	Comments
31 Meters (Cont..)	9665	55%	45%	**73.7**	72.8	0.9		Voice Of Russia Kishinev-Grigoriopol, MDA
	9935	50%	50%	**59.7**	58.8	0.9		Family Radio Montsinery, GUF
	10000	61%	39%	**54.3**	53.1	1.2		WWV Ft Collins CO & WWVH Hawaii
	10000	58%	42%	**51.7**	48.2	3.5		WWV Ft Collins CO & WWVH Hawaii
25 Meters	11775	42%	58%	61.5	**62.2**		0.7	Caribbean Beacon, Anguilla
	11775	49%	51%	65.80	**65.83**		0.03	Caribbean Beacon, Anguilla
	12160	56%	44%	**63.6**	60.7	2.8		WWCR Nashville TN
22 Meters	13670	48%	52%	**64.1**	60.7	3.4		Radio Cuba (Havava)
	13700	90%	10%	**40.8**	38.5	2.3		China Radio International, Urumqi, China
19 Meters	15000	48%	52%	**44.6**	40.2	4.4		WWV Ft Collins CO & WWVH Hawaii
	15120	42%	58%	**44.3**	42.7	1.6		China Radio Int.: Havana Cuba Relay
	15230	49%	51%	57.65	**57.68**		0.03	Radio Cuba (Havana)
	15265	46%	54%	**66.2**	65.3	0.8		Radio Japan - Bonaire Relay
	15345	74%	26%	**54.8**	53.1	1.8		R Nacional Argentina General Pacheco ARG
	15400	48%	52%	32.0	**32.2**		0.2	BBC International Svc, Ascencion Island Relay
	15455	73%	27%	**68.6**	64.1	4.6		Radio Canada Int., Sackville, NB Canada
16 Meters	17505	89%	11%	**45.7**	41.1	4.5		China Radio Int., Xian, China
	17575	93%	7%	**49.6**	44.4	5.2		China Radio Int., Shijiazhuang, China
	17605	100%	0%	**63.2**	55.2	8.0		Radio Nederland Bonaire ATN
	17610	86%	14%	**58.6**	53.0	5.6		Deutsche Welle (UK Relay) Woofferton G
	17680	67%	33%	**53.8**	52.0	1.8		Radio Chile (CVC Chile) Santiago, Chile
	17715	90%	10%	**56.0**	50.9	5.1		R. Exterior De Espana, Noblejas, Spain
	17735	71%	29%	**50.3**	48.1	2.2		Radio Canada Int., Sackville, NB Canada
	17850	54%	46%	**71.2**	71.0	0.2		R. Exterior De Espana, Cariari de Pococi CTR
13 Meters	21505	44%	56%	5.0	**5.6**		0.6	Radio Riyadh, Saudi Aradia
	21540	39%	61%	57.0	**58.6**		1.6	Radio Kuwait, Sulaibiyah, Kuwait
	21580	85%	15%	**41.6**	34.5	7.2		Radio France Int., Issoudon, QB, Canada
	21610	87%	13%	**48.7**	42.5	6.3		R. Exterior De Espana, Noblejas, Spain
	21610	65%	35%	**49.0**	46.5	2.5		R. Exterior De Espana, Noblejas, Spain
	21630	38%	62%	37.2	**39.7**		2.5	WHRI Cypress Creek, SC, USA
	21690	82%	18%	**44.5**	36.2	8.3		Radio France Int., Montsinery, F Guyana
	21690	73%	27%	**50.5**	46.9	3.7		Radio France Int., Montsinery, F Guyana
	21690	87%	13%	**52.5**	46.3	6.2		Radio France Int., Montsinery, F Guyana
	21780	50%	50%	**44.9**	43.5	1.5		Deutsche Welle (Relay), Kigali, Rwanda
	21780	94%	6%	**42.8**	36.0	6.8		Deutsche Welle (Relay), Kigali, Rwanda

Loop Null Characteristics

A significant advantage of a loop antenna is its directional pattern; a “figure 8” shape with two null points separated by 180 degrees, at least for vertically polarized ground wave signals. Besides the inherent electrostatic shielding and other features that make shielded magnetic loops less susceptible to some nearby electrical interference sources, the null in reception that is located at right angles to the plane of the loop can be used to gain additional noise or interference reduction. This is accomplished by rotating the antenna on its vertical axis until the interfering noise source or strong local station is located within the null.

To compare the directional characteristics of the PRO-1B and ALA1530L, I used the test setup described earlier, but with a revised data collection program. The revised program reads the antenna azimuth and signal level, saving the data to a disk file for post collection analysis.

To obtain azimuth data, an Agilent 34410A 6½-digit multimeter measures the DC voltage across the Hy-Gain T2X antenna rotor position potentiometer, and the associated signal strength is measured by the HP 3586B selective level meter. The controlling software reads the 34410A and 3586B in fast sequence, with an estimated latency of 1 degree or less. Reference readings at -180° and +180° are measured as calibration points.

Although the 34410A and 3586B can be read effectively simultaneously, considering the rotor speed of about 6° per second, azimuth / signal data pairs can only be collected at a rate of about 50 per minute. To provide additional data points for analysis, the antenna array is rotated through six 360 degree cycles, yielding around 300 azimuth/level data pairs for plotting using Microcal Origin scientific data analysis and plotting software.

Data for one antenna is taken, followed by a cool-down period for the rotor, and then the data collection process is repeated for the second antenna.

In order to emphasize the pattern differences (or lack thereof) between the two antennas, the plots are normalized, so that the peak signal level is matched between the two antennas and is set to 0 dB.

301 KHz

Station information: Differential GPS correction station, Annapolis MD, 301 KHz. Distance to transmitter: 44.8 miles (72.2km), bearing to transmitter: 68 degrees.

At 301 KHz, both the PRO-1B and ALA1530L show similar characteristics, each with perhaps 5 degrees bearing error, but in opposite directions. As seen in *Figure 6*, the two null directions are not completely symmetrical, which is relatively common in loop antennas and results from small asymmetries in construction and mounting. In fact, this is common enough for a term “squint” being used to describe non-symmetrical loop nulls.

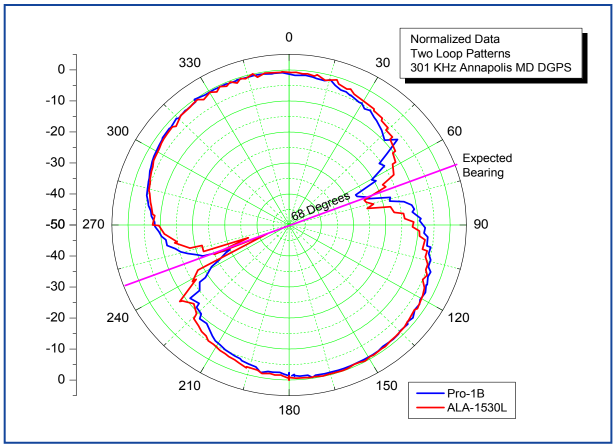

Figure 6. Normalized Two Loop Patterns 301 KHz

A further factor is the discrete data steps used to collect the bearing and signal level data. The deepest part of the null for both the PRO-1B and ALA1530L is on the order of 1 to 2 degrees wide and the deepest null may not coincide with a data collection point, thereby understating the null depth. In addition, the rapid change in signal level with azimuth around the null point creates “jaggies” or jumps in the plotted data, unlike the smooth curve expected. (The response patterns in this paper are plotted with between 300 and 350 data points, but even this relatively fine resolution is inadequate to completely characterize the antenna null performance.)

570 KHz

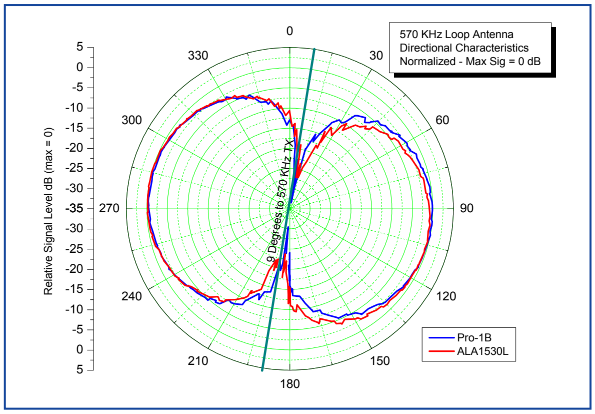

Figure 7. 570 KHz Loop Antenna Directional Characteristics Normalized

Station Information: Medium wave station WSPZ, Bethesda MD, 5 KW. Distance to transmitter 25.4 miles (40.8 km), bearing to transmitter 009 degrees.

In this case, as seen in *Figure 7*, both loops show excellent bearings, within the expected error considering the rotor potentiometer non-linearity.

The PRO-1B shows considerably greater null depth, but as discussed in the 301 KHz case, these null depth measurements should not be taken as the final word in accuracy.

Note that the two null azimuths do not demonstrate complete symmetry. This is likely a consequence of local re-radiation.

1220 KHz

Station Information: Medium wave station WFAX, Falls Church, VA, 5KW. Distance to transmitter 13.5 miles (21.7 km), bearing to transmitter 056 degrees.

Figure 8 shows obvious problems with re-radiation, as the bearing error is approximately 60 degrees for both loops.

Both loops show a similar pattern, which rules out problems with one or the other of the loops. (The two experimental loops show the same bearing skew.)

It is extremely likely that the re-radiation source is my nearby 100 ft radio tower, top loaded by the log periodic antenna.

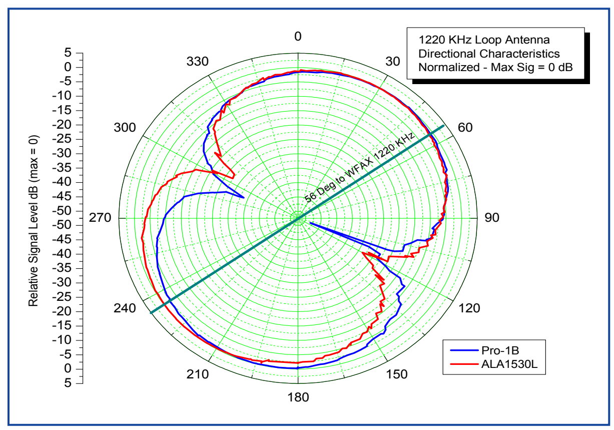

Figure 8. 1220 KHz Loop Antenna Directional Characteristics Normalized

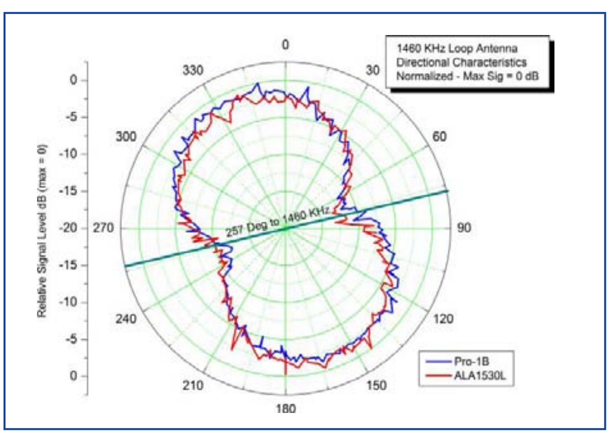

Figure 9. 1460 KHz Loop Antenna Directional Characteristics Normalized

1460 KHz

Station Information: Medium wave station WKDV, Manassas, VA, 5KW. Distance to transmitter 7.4 miles (11.9 km), bearing to transmitter 257 degrees.

Although the bearings in *Figure 9* are reasonably close to the true value, note that both loops have degraded null depth and generally distorted patterns. This again is likely a consequence of re-radiation, although it may be a more distant re-radiating structure, such as high voltage power lines, than my nearby tower.

12160 KHz

Station Information: Shortwave broadcast station WWCR, Nashville, 100KW. Distance to transmitter 545 miles (878 km), bearing to transmitter 254 degrees.

The loop antenna was invented in the early 1900's, and provided accurate bearings for low frequency, vertically polarized ground wave signals used in the early days of radio. However, when the loop was tried with ionospheric reflected signals, significant bearing errors were found, as well as for horizontally polarized signals. Where the signal does not arrive at 0 degrees, the 'figure 8' loop antenna pattern deteriorates and the null is displaced, for some arrival angles by a considerable amount.

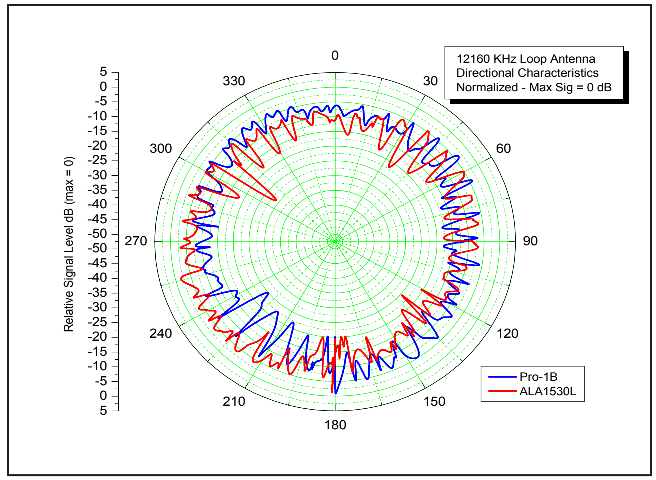

Figure 10. 12160 KHz Loop Antenna Directional Characteristics Normalized

As seen in *Figure 10*, signals at 12160 KHz from shortwave broadcast station WWCR demonstrate the difficulty in obtaining a null for skywave signals. The figure 8 pattern seen at lower frequencies no longer exists. The fine variation in signal level with azimuth is largely a consequence of time fading, as these plots are composites of data collected over the space of several minutes.

One method of at least partially offsetting skywave loop error is to tilt the loop so that reflected signals arrive perpendicular to the loop plane. In addition to requiring a dual azimuth/elevation rotor, it does not compensate for polarization tilt, however.

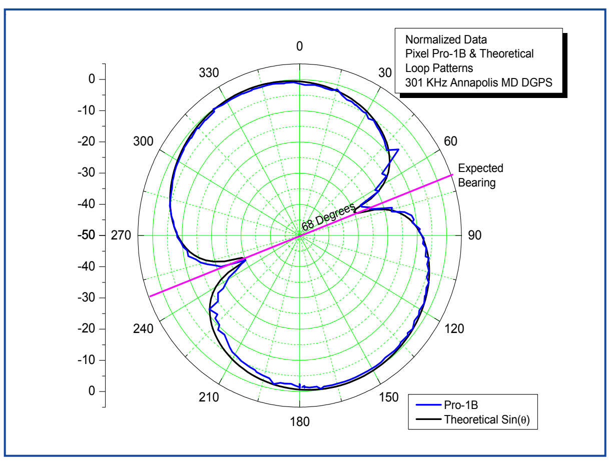

Figure 11. Normalized Data Pixel PRO-1B & Theoretical Loop Patterns 301 KHz

Loop Pattern Compared with Theoretical Pattern

For a vertically polarized ground wave signal, a small loop antenna's signal voltage response can be shown to be proportional to the sine of the angle between the loop's vertical plane and the transmitter.[4] *Figure 11* compares the measured response of the PRO-1B at 301 KHz and the theoretical sin(φ) response.

Figure 11 and other antenna pattern plots are, by convention, plotted in dB on a polar grid, *Figure 12* shows the same data, but replotted in a more familiar formant; that of voltage on an X-Y axis. (To remove some of the jagged response in *Figure 11, Figure 12* uses adjacent averaging to smooth the measured data.) The close agreement between measured and theoretical patterns is striking in both *Figures 11 and 12*.

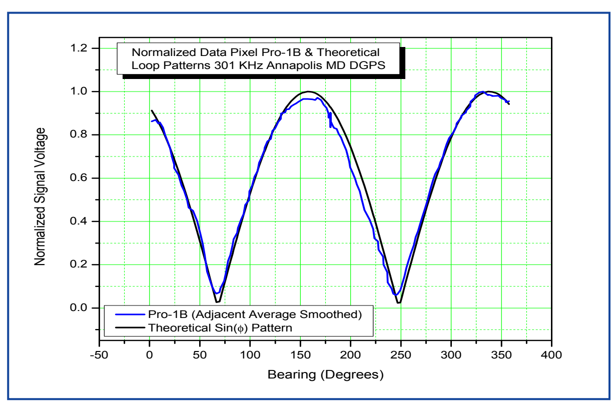

Figure 12. Normalized Data Pixel PRO-1B & Theoretical Loop Patterns 301 KHz

Loop Pattern Conclusion

There is no material difference between the PRO-1B and ALA1530L. Both provide excellent nulls for ground wave, vertically polarized signals and both are subject to the same errors from local re-radiation, skywave error and polarization error.

Mechanical and Equipment Support Considerations

Both the PRO-1B and ALA1530L use an aluminum loop, approximately 3/4 inch (18 mm) diameter. The PRO-1B has a second vertical support element to enhance structural strength; the ALA1530L does not.

The ALA1530's loop amplifier is contained within the small plastic housing at the base and is mounted via a short (approximately 8" or 200mm) length of aluminum tubing about ¾ inch (18 mm) diameter, as illustrated below. The PRO-1B loop assembly mounts with a 1/8" (3mm) thick steel, powder coated "L" bracket punched for two U-bolts (provided with the loop) and may be installed on any mast from about 1" (25 mm) to 2" (50 mm) diameter.

The electronics module, containing the loop amplifier, is in a separate die cast, powder coated enclosure painted white to reduce thermal heating, with mounting flanges. It connects to the loop element with a supplied 1 ft (300mm) long RG-6 cable, with waterproof F connectors and mounts on the lower end of the L bracket.

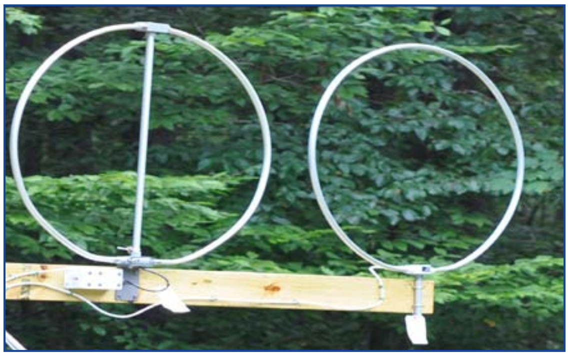

Figure 13. Loops under test (Pixel PRO-1B left, Wellbrook ALA1530L right)

For my multi-loop installation, I used a different mounting approach. The ALA1530L "spigot" is clamped to the wood cross arm with two U-bolts. The PRO-1B's L bracket is attached with four bolts and the loop amplifier is attached with four wood screws. *Figure 13* shows a PRO-1B (left side) and ALA1530L (right side).

In my opinion, Pixel's loop construction and L bracket mounting hardware arrangement *(Figure 15)* is mechanically superior to Wellbrook's mounting spigot *(Figure 14)* that requires additional work and fixtures not supplied to mount to a mast. Also the Wellbrook PVC plastic enclosure provides no shielding from external noise and may be susceptible to long term mechanical degradation from UV rays.[5]

Fitting the electronics into the loop housing, as in the ALA1530L, versus a separate amplifier assembly is a design choice with both pluses and minuses.

To Wellbrook's credit, the result is a smaller footprint, with two fewer connectors as possible failure points and less hardware to fiddle with during installation. However, Wellbrook decided (to improve weatherproofing and increase mechanical strength or to prevent reverse engineering of its design, or both) to pot the electronics module in epoxy. In the event of a failure, therefore, either the entire loop must be replaced or the aluminum tubing cut away from the base and then reattached (possibly with an aluminum sleeve?) to a replacement amplifier module.

Pixel followed a different philosophy; the loop amplifier is in a separate enclosure and in the event of a failure just the loop amplifier module requires removal and return for repair. The amplifier is not potted and is repairable down to the component level by Pixel. (For weatherproofing, Pixel conformal coats the amplifier PCB after assembly.) The larger enclosure also provides better heat dissipation which improves component life. If, as a compromise solution, Pixel mounted the loop amplifier printed circuit board in an integrated enclosure that also provides mechanical support to the loop structure, a failure would require partial disassembly of the loop package, removing the printed circuit board for repair or exchange and then reversing the process. This is not necessarily a good design choice as it may require more work and electronics experience of the owner than he possesses. A simple enclosure swap, with the amplifier inside, can be handled by anyone who installed the loop antenna.

On balance, therefore, Pixel's approach offers better long term support.

Loop Mounting Configurations

Figure 14. Wellbrook

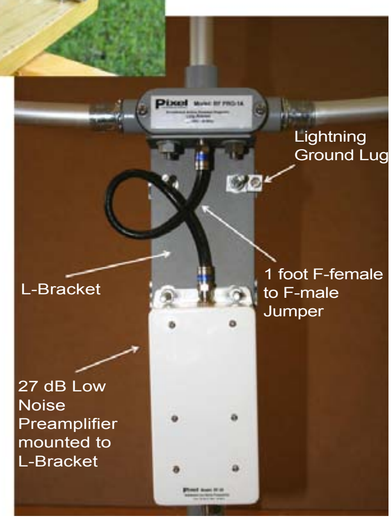

Figure 15. Pixel

Connectors and Coaxial Cable

The ALA1530L is equipped with a 50 ohm female BNC connector, mounted on the side of the plastic amplifier housing. The PRO-1B uses 75 ohm “F” connectors of the type commonly used in cable television and satellite direct broadcast TV applications.

From the author’s prospective, the choice between the connector types is a matter more of cost and mechanics than electrical performance.

Before discussing the connector issues, it should be stated that there is no need to be concerned about “matching” the antenna and feed line impedance to the receiver for these antennas. No significant difference will be observed if 50 or 75 ohm impedance coaxial cable and connectors are used for either antenna. (And, yes there are 75 ohm BNC connectors, but no 50 ohm F connectors.) In the absolute worst case, where the loop amplifier output operates with exactly 50 ohms output impedance and the receiver has 50 ohms input impedance, and 75 ohm cable is used, a trivial increase in cable loss would be seen, amounting to a tenth or two of a dB in the typical case. Since 75 ohm RG-6 cable has lower loss than an equivalent 50 ohm RG-58 type cable, the net would be that the 75 ohm cable would still have lower loss. The output impedance of typical loop amplifiers is not necessarily constant over the frequency range 20 KHz – 30 MHz, nor is the input impedance of a receiver constant over its frequency range.

Of real concern are the practical problems associated with coaxial cable and connectors, particularly if they are to be buried and exposed to weather.

Direct Burial Cable

Some coaxial cables are constructed to be safely buried without conduit. In general, there are two types of direct burial cable, “flooded” and “non-flooded.”

Cable rated for direct burial has a different outer jacket material than normal cable, and is more or less impervious to water ingress over time. Normal coaxial cable is waterproof originally, but if exposed to standing water will degrade over time and allow leaks. As the water corrodes the braid, losses increase, and over time the cable may become unusable. Normal RG-58 is not rated as direct burial cable and should not be used as such.

Even direct burial cable can develop pinholes (and holes can be chewed in the cable by animals) over time, and water can enter. Flooded cable has an injected silicon compound filling voids between the outer jacket and inner conductor insulation, and braid. Water entering at a pinhole is blocked from spreading by the flooding compound so braid damage is confined to the area of the pinhole and degradation minimized.

Far more RG-6 type cable is manufactured in direct burial and flooded ratings than is the case for RG-58 type cable, although prices for flooded cable are similar for RG-58 and RG-6 type. For example, Times Microwave LMR-195 DB is an RG-58 type, direct burial flooded cable and sells for $0.55 to $0.65 cents/foot. Belden 9066 is a RG-6 type, direct burial flooded cable and is in the same price range. Non-flooded direct burial RG-6 type cable, on the other hand, runs about 50% of these prices.

Some flooded cable has a larger jacket diameter than un-flooded cable, which may be an issue for connector fit.

BNC versus F Connectors

Along with cable selection, connectors must be considered.

Traditional wire antennas do not require DC power over the coax but active loops and active voltage probe antennas do. A traditional wire antenna fed with coax cable and a less than waterproof connector may not pose much of a problem for a receive-only application for years. Eventually, the center conductor or the braid will corrode and the connector (and probably a section of the coax cable as well) must be replaced, of course. However, if DC voltage is carried over the coax, current will flow through the water and galvanic corrosion will occur rather quickly, to the point where the center conductor can be completely eaten away in a matter of days or weeks.

Direct Burial Cable ... cont.

Standard BNC connectors are not inherently waterproof and must be sealed with tape after installation to prevent water entry. Certain F connectors, in contrast, are waterproof and require no additional sealing when used outdoors. (Of course, it's even better to seal waterproof connectors and Pixel includes a length of "Coax Seal" waterproof sealing tape as part of the installation hardware.)

Belden Snap-N-Seal connectors, designed for RG-6 type cables, are one example of a waterproof connector. (The short jumper provided with the PRO-1B uses a similar weatherproof connector from a different supplier.) An O-ring seals the jacket to connector joint to prevent water entry. Snap-N-Seal connectors are available as F, BNC and RCA connectors. Their main drawbacks are that a special application tool is required; these are not crimp connectors in the normal sense of the term and that a different model Snap-N-Seal connector is required for each type (standard shield, double shielded, tri-shield and quad-shield RG-6) cable, as the jacket diameters differ . A similar line of weatherproof connectors for RG-58 type cable may exist, but the author is not aware of it. Certainly the great bulk of low price weatherproof coaxial connectors developed in the last decades has been for RG-6 type cables.

How Many Shields and Center Conductor Type?

RG-6 cable is available in almost bewildering varieties of shielding – with single braid, tri-shield, quad-shield being the most common. RG-58 cable, in its traditional form, is a single braided shield cable, although some RG-58 variants now exist with multiple combination shields.

Multi-shielded RG-6 combines conventional braid-type shielding with conductive foil shields, with quad-shielded cable having two braid and two foil shields, and tri-shield cable having two foil shields and one braid shield.

In general, the more shields, the greater the shielding effectiveness and less signal leakage. As a practical matter, for coax cable runs of a couple hundred feet or so (75 meters) in the 20 KHz – 30 MHz range, little difference will be observed amongst a high quality single braid (90% or greater coverage) and tri-shield or quad-shield cable, particularly if buried.

Most RG-6 cable is manufactured with a copper plated steel center conductor. This has two drawbacks for HF powered loop operation. First, the DC resistance is greater which limits the length of cable permitted before excessive voltage drop occurs. Second, at frequencies below about 5 MHz, copper clad steel center conductor coax cable shows greater loss than solid copper center conductor cable. Unless very short runs are contemplated, solid copper center conductor RG-6 is preferred. (It's also easier to work with as it's more flexible.)

For these reasons, therefore, Pixel's design decision to go with DBS / CATV-style connectors and recommended cable is preferable to Wellbrook's BNC choice.

Performance in High Level Signal Environments, IMD and Compatibility with Transmitters

Since each antenna includes a wideband high gain low noise amplifier, intermodulation distortion in high level signal environments is an important performance parameter. Close-by high power transmitters particularly in the AM and FM broadcast band can cause severe overloading of the preamp which results in spurious signals all across the pass band. (The PRO-1B includes a 6th order low pass input filter to reduce the potential of interference from nearby high power FM or TV broadcast transmitters.) The table below shows the second and third order intercept specifications for each company's preamplifier.

Typical IMD Specifications	Pixel RF PRO-1B	Wellbrook ALA1530L
OIP3	48 dBm	49 dBm
OIP2	110 dBm	90 dBm

Performance in High Level Signal Environments, IMD and Compatibility with Transmitters ... Cont.

Both amps provide similar 3rd order performance but Pixel's Norton architecture provides far superior 2nd order performance by 20 dB.

To avoid damage to the amplifier in situations when a transmitting antenna is located on the same tower (and also to prevent high level, potentially damaging RF from getting to the input of a receiver) each company has a different approach. The Wellbrook approach is to use protection diodes at the input and output of their amplifier. The disadvantage of this is that diodes always introduce a level of degradation to intermodulation performance. The positive side of this approach is that it does not add much cost to the product. Pixel takes a more conservative approach that does not compromise intermodulation performance. They provide an interface to the transceivers' "Key" output normally used to turn on or off an external linear amplifier. An input on Pixel's power coupler removes power from the preamp when the transceiver is transmitting and also shorts the coupler's Antenna Out port so no RF can get into the receiver during transmission. Pixel includes a cable for this and also a Y-adapter to daisy chain the "Key" signal to an external linear amp if one is used. The result is a more expensive approach, but one that does not compromise performance.

Packaging

Pixel ships its antenna in a custom-designed container composed of high strength composite foam to protect it from damage in shipping. The antenna comes fully assembled, ready to mount and with all accessories. See *Figure 16*. Wellbrook ships its loop bareback with two bamboo poles lashed to the loop to provide ridgidity and some foam padding around the aluminum tubing. The accessories are in a small box attached to the loop with wire ties. Both companies claim that their shipping methods provide adequate protection, but I give the edge to Pixel in this respect.

Figure 16. Pixel PRO-1B Custom Shipping Container

Comparison	PRO-1B	ALA1530L	Comments
S/N Ratio Performance	√		PRO-1B wins 65% of direct comparisons and its wins are by a larger margin (3.2 dB).
Null depth	√	√	No significant difference between the two antennas
Intermodulation Performance	√		PRO-1B has far superior OIP2 by 20 dB
Delivered Price to USA		√	With current exchange rates the price for the ALA1530L (including shipping to the US from the UK)) is $385. The price for the RF PRO-1B is $399.99 + shipping from Denver which ranges between $20-25 to most parts of the US.
Mechanical Quality	√		PRO-1B mounting arrangement and hardware provide superior strength and ease of installation on a typical mast.
Repair Possibility and Support in USA	√		PRO-1B is repairable at the component level. ALA1530L is potted and the entire loop, or at least the loop amplifier, must be replaced in the event of damage.
Compatibility with Transmit Operations	√		PRO-1B has provisions for automatically removing DC power from the loop electronics upon entering transmit mode, thereby reducing the risk of loop amplifier damage without compromising IMD performance.

Appendix 1. Temporal and Spatial Fading

A useful antenna comparison methodology must recognize and account for fading, both short term and long term. Fading can be categorized as “short term fading” – where the signal changes over the space of seconds or minutes – and “long term” or “slow” fading, over the space of hours or between day and night.

Since human senses do not enable us to “see” high frequency radio waves, we are, to a degree, in the position of the six blind men and the elephant in the Indian fable. The observer with but one antenna will say short term fading is caused by changes in the ionospheric path between the transmitter and his antenna. An observer with two antennas separated by an appreciable fraction of a wavelength may describe it as geographical changes in signal. An observer with both a horizontally polarized antenna and a vertically polarized antenna may believe short term fading results from changes in wave front polarization.

Like the six blind men’s descriptions of the elephant, each of these descriptions has an element of truth, but individually fails to provide a coherent description of short term fading.

Davies describes ionospheric fading as:

> In general, the signal strength is a function of the relative positions of the transmitter and receiver. Now suppose that the ionosphere changes with time, either as a result of horizontal bodily movement (drift), a random motion of ionospheric inhomogeneties, or because of a change in the electron density profile. The received power fluctuates with time as the signal-strength pattern on the ground moves past the receiver. (Emphasis in original.) [6]

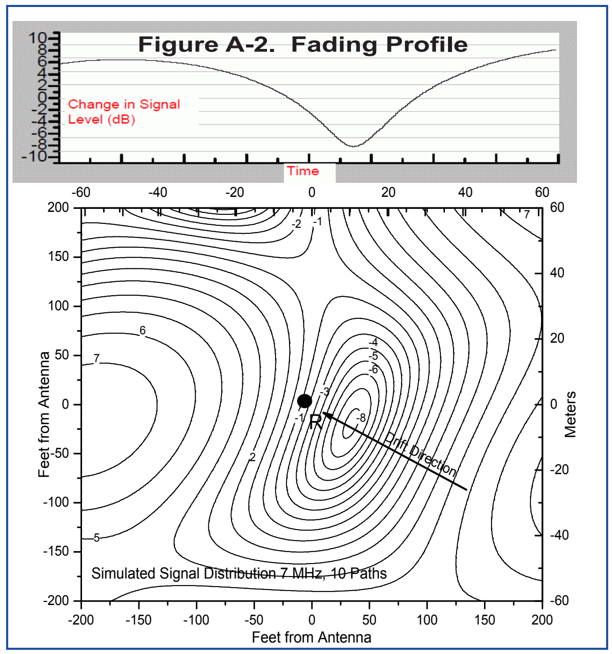

Figure A-1. Signal Strength Pattern

The signal strength pattern on the ground is the vector sum of the signal as propagated by various paths through the ionosphere, neglecting for simplicity the possibility of a direct, ground wave path. Thus, signals from the various paths reinforce and cancel in a complex pattern that changes with time.

Figure A-1 illustrates a hypothetical signal strength pattern for a 7 MHz signal with 10 simultaneous ionospheric reflection points, with the receiving antenna at point R in the center, and the pattern drifting in the direction shown by the arrow.[7] If we look at the signal level at Point R versus time as the signal strength pattern moves along the path identified by the arrow, the result is typical fading profile, illustrated in *Figure A-2*. The duration of the fade depends upon how fast the factors mentioned by Davies change.

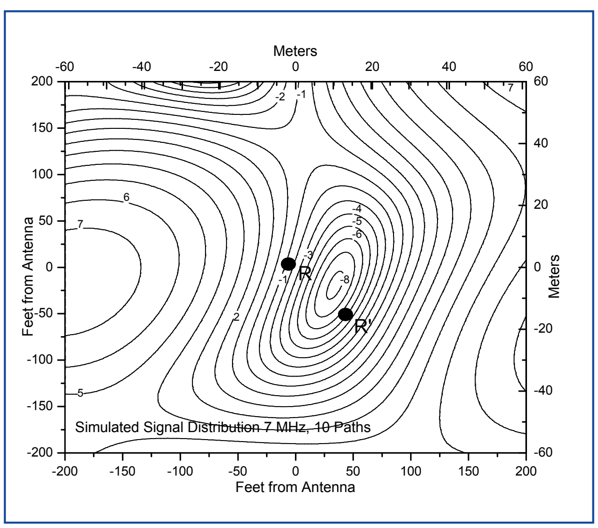

Figure A-3. Signal Strength Pattern (Two Antenna Locations)

If we instead make instantaneous signal strength measurements with two antenna locations, R and R' as in *Figure A-3,* we see a fixed difference in signal strength. Of course, if we plot the received signal strength at R and R' over time, we see fades on both, as each sees a different part of the horizontal signal distribution at any particular instant. If, for example, the pattern happens to put both R and R' in locations where, say, R is moving up the signal strength contour and R' is moving down the contour, their fades will be in opposite directions and, of course, not necessarily equal in change. Or, it is also possible for both to be on the same side of the contour and both could rise or fall in some degree of synchronization.

Figure A-4 shows the signal strength at two antennas separated by approximately 20 meters or 0.5 wavelengths during 100 seconds of observation of standard time and frequency station CHU, operating at 7850 KHz at Ottawa Ontario, as observed at Clifton, Virginia in April 2010, a distance of approximately 450 miles (730km). The data is taken with two Advantest R3463 spectrum analyzers, 200 Hz bandwidth, sampling at one measurement every 100 ms, or 10 measurements per second, synchronously triggered for simultaneous measurements from each antenna. The plot shows periods where the two antennas have identical fading characteristics (high correlation) and periods where the fading characteristics do not track or even move in opposite directions (low correlation).

It is possible to mentally fit the measurement set of *Figure A-4* with a signal strength pattern analogous to that simulated in *Figure A-1*; periods of little change in signals from either antenna corresponds to either a period of static signal strength pattern or a shift along a shallow valley or plateau where the signal strength is more or less constant. Periods of high correlation may relate to times where the pattern shift brings both antennas across rising or falling contours and periods of low correlation correspond to a pattern shift such that one antenna is on a rising contour and the other on a falling contour. If one were equipped with a test range with hundreds of non-interacting test antennas,[8] spaced on a grid of a few feet raster, and a method of simultaneously reading the signal strength from each antenna, it should be possible to produce "real" versions of *Figure A-1*.

Noise Pattern and S/N Ratio

If one or more of the antennas under comparison is a rotatable loop antenna, some special considerations apply to performance measurements.

At the risk of over-simplification, commonly used HF amateur antennas, such as dipoles, inverted vees and Yagi style antennas have a similar horizontal pattern shape for nearby noise and for distant skywave signals. A well-built balanced broadband loop antenna, in contrast, will exhibit a different pattern for vertically polarized signals with a low angle of arrival, such as ground wave signals or nearby noise sources, and for high angle of arrival signals. Indeed, the inability of a loop to provide accurate null bearings for skywave signals was discovered early and lead to alternative antennas, such as the Adcock, for HF direction finding.

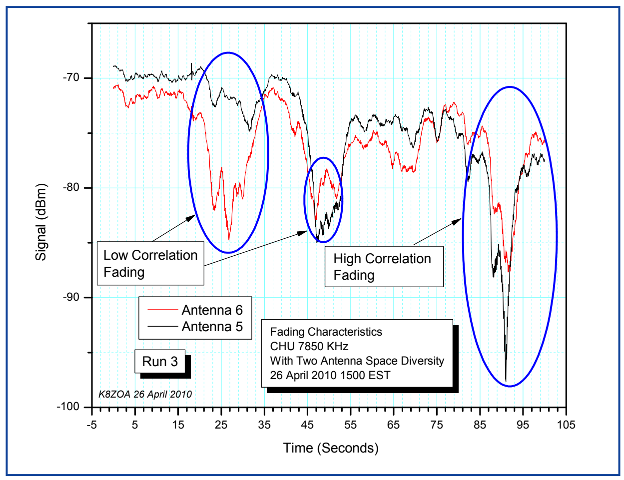

Figure A-4. Signal strength at two antennas separated by 20 meters

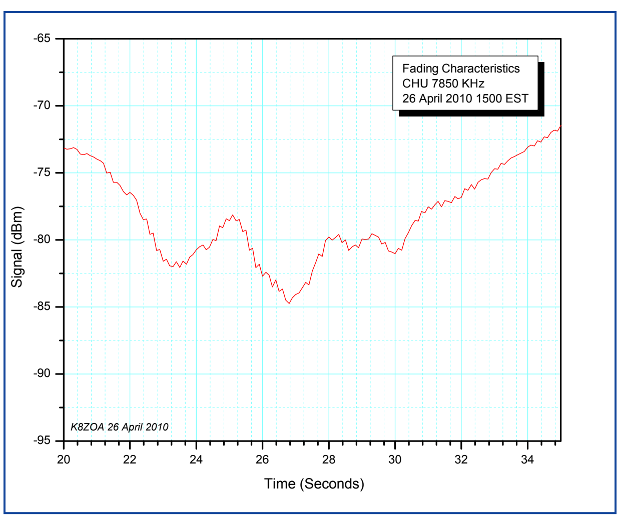

Figure A-5. Fading vs Time

Implications for Antenna Comparisons

From *Figures A-1* and *A-4* it should be apparent that no single measurement, either sequential or simultaneous, can accurately determine relative antenna performance.

If it requires 5 seconds to switch antennas and make a manual measurement, fading can account for nearly 15 dB difference between the two measurements. Even if faster switching and measurements are possible, fading may still result in significant errors, as seen in *Figure A-5*, where the data set of *Figure A-4* is expanded over a 15 second interval. Even one second of switching and measurement time can, with this fading characteristic, introduce several dB errors.

Implications for Antenna Comparisons ... cont.

Spatial fading is perhaps less familiar to radio amateurs. It represents the difference in signal level, measured at the same exact time, in two antennas separated by a finite distance. Small differences in ionospheric reflection points mean that signal strength is not uniform even over relatively short distances. This phenomenon is behind diversity reception; fading may be reduced by automatically selecting between two antennas, with fade reduction increasing with antenna separation measured in wavelengths. (Although uncommon in amateur radio, diversity reception is widely used in cellular telephone base station design. At least one new amateur radio transceiver, Elecraft's K3, makes diversity reception an optional feature.)

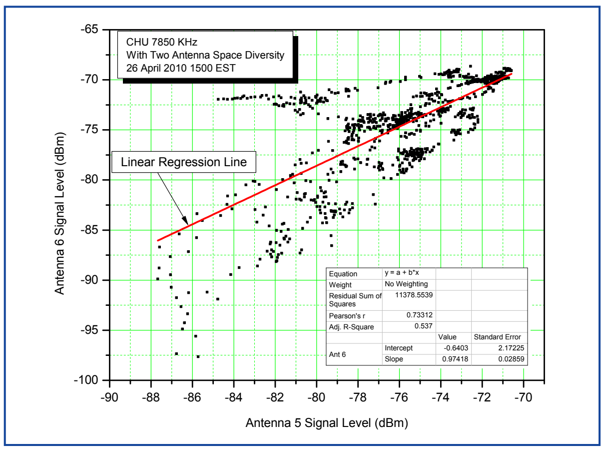

Figure A-6. Scatter Plot

Figure A-6 is a scatter plot, together with a linear regression fit and statistics for the data set of *Figure A-4*. Each data point represents the signal level measured at two antennas at the same instant. In the absence of spatial fading, the data points would cluster into a straight line, with an offset representing the difference in signal level observed between the two antennas, i.e., the observed signal levels would move up and down in synchronization, differing by a constant offset. As *Figure A-4* shows, there are areas of the plot where the two signal levels are highly correlated, forming a cluster nearly matching the linear regression line. However, and particularly where signal levels are well below the maximum, the scatter plot shows low correlation.

Even if time and spatial fading problems are overcome, an ideal antenna comparison methodology will consider other factors, such as the vertical angle of signal arrival, which will change with ionospheric conditions, the distance between the transmission and reception points and the transmitting antenna vertical characteristics, amongst others. These considerations can be partially addressed with the methodology proposed in this article, although disentangling these effects from others may be difficult.

If we compute S/N, or more accurately, (S+N)/N since the signal cannot be measured without noise, short term changes in noise must also be considered.

Data Collection

One obvious solution to the effects of time and spatial fading upon antenna comparisons is data averaging. Although any particular instantaneous measurement may be at risk, a number of measurements, made over an extended time, will provide a meaningful result.

Thus, the method used in this article has been developed to compensate for the difficulties created by measuring antenna performance in a fading environment.

About the Author

Jack Smith, K8ZOA, has been licensed since 1961, first as KN8ZOA, and has held the Amateur Extra Class license since 1963. He received the BSEE degree from Wayne State University in Detroit in 1968 and a JD degree magna cum laude from Wayne State University School of Law in 1976. He has enjoyed a career involving both engineering and telecommunications law. He is a co-founder of the telecommunications consulting firm TeleworX and is the author of Programming the PIC Microcontroller with MBasic (Newnes Publishing, 2005), as well as many articles published in QEX and 73 Amateur Radio magazine. After retirement, he established Clifton Laboratories to make available high performance analog radio equipment of interest to radio amateurs and shortwave listeners. His web site is http://www.cliftonlaboratories.com.

He is the designer of the loop amplifier used in Pixel's Pro-1A and Pro-1B active loops as well as other Clifton Laboratories products, including the Z1501F Active Voltage Probe Antenna.

Footnotes:

1. Compare Belden 7915A www.belden.com/techdatas/english/7915A.pdf and RG-58 http://www.belden.com/techdatas/english/9201.pdf. At 50 MHz, for example, RG-58 has a loss of 2.5 dB/100 ft compared with 1.4 dB at 55 MHz for type 7915A cable. This is not unexpected, of course, because minimum coaxial cable loss occurs for impedance greater than 50 ohms for most practical dielectrics.

2. Thomas & Betts recently sold its Snap-N-Seal connector line to Belden. http://www.belden.com/docs/upload/Belden_SNS_Catalog_2011.pdf

3. A simple example illustrates the advantage of median over mean statistics. Suppose a steady signal at -100 dBm is received, but a static crash occurs during the measurement interval, such that the five level readings are -100, -70, -100, -100, -100 dBm. The mean (average) received signal level is -94 dBm. The median value is -100 dBm. (The sorted level readings are -70, -100, -100, -100, -100 and the median is the center value, or -100 dBm.)

4. Herndon Jenkins, Small-Aperature Radio Direction-Finding (1991), Artech House, Boston MA, equation 2.1 at p. 13

5. Unless a UV-stabilizer is added during manufacture, many plastics become brittle and subject to cracking after extended exposure to sunlight's UV radiation. It is not known for certain that Wellbrook's amplifier housing uses UV-stable material, but most UV-stabilized plastic has a black or gray color imparted from the stabilizing agent. Wellbrook's amplifier housing is white.

6. Kenneth Davies, "Ionospheric Radio Waves" (1968), Blaisdell Publishing Co, Waltham MA, §13.61, p. 365.

7. *Figure A-1* is based upon a propagation simulation program I wrote. The particular simulation is with 10 Rayleigh distributed paths, ionospheric reflection point 125 miles high, with transmitter to receiver distance set at 1000 miles.

8. An array of voltage probe active antennas might be suitable as they have negligible antenna current and effectively zero radiation resistance, they have no appreciable re-radiation and hence demonstrate minimum mutual coupling.