TEST REPORT

CONTINUED INVESTIGATION OF THE FAR-FIELD RADIATION GAIN PATTERN OF THE 20-METER BACKPACKER EH ANTENNA

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Introduction

Significant claims have been made by the inventor and producers of a novel small antenna construct know as the "EH" antenna. The interested reader is directed to references [1], [2], [3], [4] and several others. Although no published references could be obtained to validate claims supported in the above references, numerous Internet postings in newsgroups [4] and personally maintained websites [2] have reported claims of performance similar to those found in the above references.

Test procedures and results documented in this report serve to provide a quantitative measure of performance of this novel EH antenna. Previous tests [7] have demonstrated that the test antenna, by itself, is not a significant source of RF radiation. In fact, these tests demonstrated an average loss of 28 dB ($1/630^{th}$ radiated power) compared to a full-size quarter-wave ground-plane reference antenna. Data collected during these previous tests indicated that the primary source of radiation was the coaxial feedline delivering power to the EH antenna device. The report concluded that the radiation characteristics of the EH antenna/coaxial feedline combination were similar to those of an end-fed longwire antenna matched by a suitable reactive loading network. The focus of the tests documented in this report is to test the above hypothesis. Additionally, an investigation is conducted which quantifies the far-field radiation pattern as a function of elevation angles up to approximately 21 degrees.

The particular version of EH antenna addressed in this report is known as the "Backpacker" antenna. It is a highly compact, portable antenna designed for amateur radio applications ranging from space-limited fixed station operation to mobile and quick-deploy field operations. Although only a very small fraction of a wavelength (approximately lambda/20) long, its proponents claim a very favorable omni-directional azimuth radiation pattern referred to "full-size" antennas.

Background

Several amateur radio station operators have attempted to illustrate the far-field gain performance of the EH antenna by performing various "on-air" comparisons against separate antennas installed within a few wavelengths of the EH antenna under study. Furthermore, the EH antennas were typically fed by various and sometimes unspecified lengths of feedline (usually coaxial). The addition of coaxial feedline cable to the EH antenna under test introduces a significant uncontrolled variable into the tests which tended to mask the performance of the EH antenna as an isolated radiator. As a result, most data reported on this type of antenna can be categorized as anecdotal reports of far-field performance.

While the above tests tended to produce qualitative measures of radiation performance when compared to installed reference antennas, the results were difficult to reproduce. Test repeatability suffered due to uncontrolled variables including feedline length, nearby interfering (parasitic) metallic objects, and unknown reference transmitting or receiving stations at the opposite end of the RF link.

To this end, controlled tests were conducted in an open-air antenna test environment [7]. These tests attempted to reduce the contamination of collected data by uncontrolled variables such as those outlined above. Tests were conducted using a factory-supplied test antenna referred against a carefully constructed, full-size quarter-wavelength ground-plane reference antenna. It was found that the test antenna radiates poorly when fed without coaxial feedline. Test results collected by feeding the test antenna with approximately one physical wavelength of coaxial feedline indicated that the antenna system (antenna and coax) radiates primarily as a function of the feeline orientation and length.

No attempt was made during previous testing to establish far-field radiation performance at other than those elevation angles parallel to the Earth (phi = 0).

Purpose

The purpose of the tests described in this document is to define the level of performance that can be expected from a typical application of the Backpacker 20-meter antenna. It is expected that the results obtained from the 20-Meter “Backpacker” variant of the EH antenna can be easily extended to other similar short-dipole EH antenna arrangements.

The tests documented by this report were designed to compare the far-field radiation performance of a factory-configured Backpacker test antenna to an equivalent height “longwire” or monopole vertical antenna. Specifically, the test antenna was placed atop an 11-foot non-conductive support mast and fed by 11 feet of high-quality 50-ohm coaxial feedline cable. The received far-field radiation was compared to that received from a well-separated reference antenna. The reference antenna was an 11-foot length of ¾-inch aluminum tubing, separated from the ground by 12 inches of non-conductive spacing material. The overall height of both antenna was 12 feet above the ground. Both the test and reference antennas were operated with a fairly effective RF ground created by connection to a 4-foot aluminum rod driven into moist ground near the base of each antenna.

Test location points were selected to simultaneously receive the signal from both the test and reference antennas, and to compare these power measurements. Locations were chosen to evaluate the far-field radiation pattern as a function of azimuth (theta) and elevation (phi). In all cases, line-of-sight was maintained between test points and both antennas.

This series of tests was conducted on 29 Mar 2003. Weather was clear and sunny, with a temperature of approximately 75 degrees. Winds were from 260 at 5-10 knots.

Test Antenna

The test antenna was a small, 20-meter wavelength “Backpacker” EH antenna designed for amateur radio station operation between approximately 14.0 and 14.5 MHz. The test antenna was professionally built from a commercially available kit by the producer of the “Backpacker Antenna Kit” [5]. No modifications were made to the test antenna, except for two small 1/8” diameter holes drilled in the PVC radome to allow access to both tuning capacitors in the field.

A picture of the test article is shown in Figure 1. The overall length of the antenna is approximately 23 inches. The diameter of the radome is 2.375 inches. The test antenna is constructed mainly of Poly-Vinyl Chloride (PVC) water pipe material, 7/8 inch diameter copper water pipe, and enamel-coated solid copper wire. Antenna tuning is accomplished over a range of installation conditions by means of two moderately high voltage variable capacitors located near the bottom end of the antenna.

Figure 1. Test Antenna (Radome Not Installed)

Testing was conducted with the provided PVC radome installed. The antenna was fed by 11 feet of 50-ohm shielded coaxial cable. The oscillator feeding this coaxial line was connected to an RF ground at the “bottom “end of the feedline. In this configuration, it was found that a nominal 2:1 VSWR bandwidth of approximately 250 KHz was achievable by tuning the test antenna while installed atop the non-conductive support mast. Figure 2 and 3 show the test antenna installed in the open-air test range prior to conducting radiated far-field measurements. The support mast was composed of PVC to prevent the interaction of parasitic metal elements from affecting the test results. Nylon twine was used to support the structure.

Figure 2. Installed "Backpacker" 20-Meter Test Antenna South View (Radome Installed)

Figure 3. Installed "Backpacker" 20-Meter Test Antenna North View

Reference Antenna

The reference antenna was constructed of a single 11-foot section of ¾-inch hollow aluminum tubing, supported by nylon twine and separated from the ground by a small 12 inch section of non-conductive PVC pipe. The total height of the overall structure was 12 feet measured from the top of the aluminum tube to the ground.

An RF ground point was established by driving a 4-foot aluminum rod into the ground near the base of the reference antenna, and connecting the outer shield of the short feed coax to this ground-rod. This antenna was fed by an identical RF oscillator as used for the test antenna. However, the oscillator was designed to be operated into a 50-ohm resistive load. To accomplish this, a Murch Electronics UT-2000 "Transmatch" antenna tuner was inserted between the RF oscillator and the coaxial feedline of the antenna. A very good VSWR match (1.1:1) was easily established using this system. Figure 4 shows the installed reference antenna configuration.

Figure 4. Reference Monopole Matched with Murch UT-2000 Transmatch

Test Location

A suitable open-air test range was selected to conduct the antenna comparison. Desirable features of the test location included a natural lack of nearby interfering objects, both flat surrounding landscape as well as vertical formation needed to explore elevated far-field radiation patterns, uniform surface conductivity characteristics, and accessibility by motor vehicle. An uninhabited area of desert south of California City, California provided an ideal combination of test features for this test. Figure 5 shows an aerial view of the selected test site location.

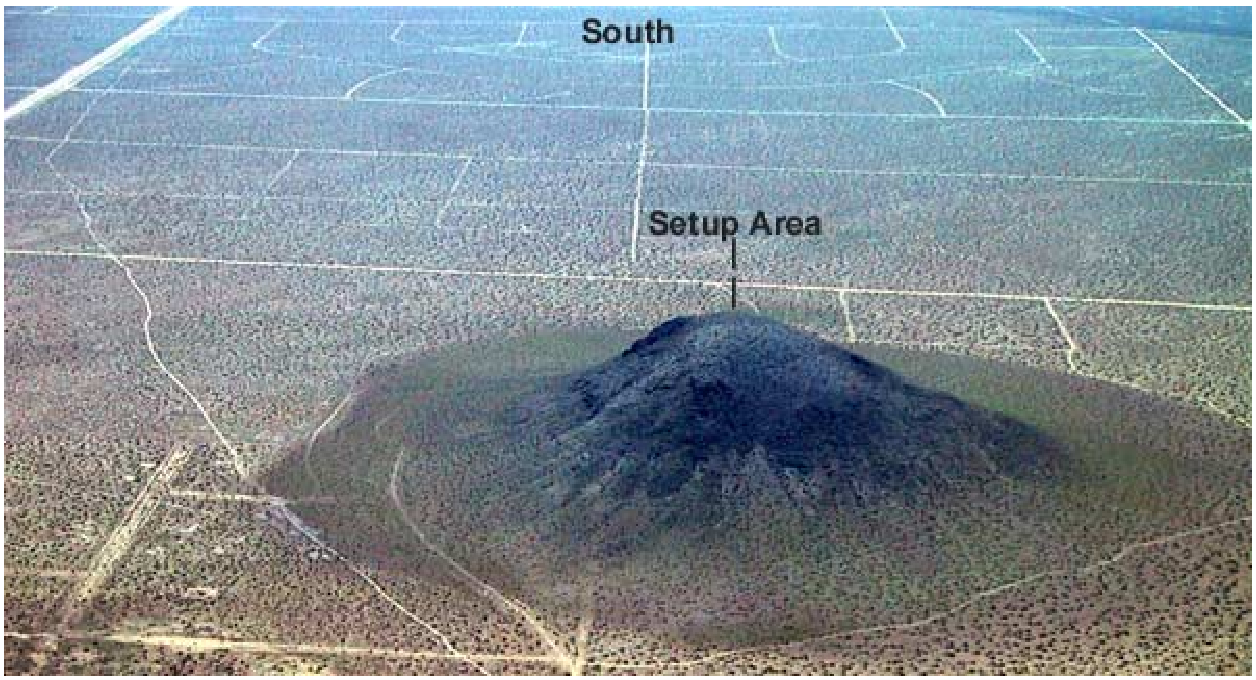

Figure 5. Antenna Test Location Site

Test Methodology

Both the test and reference antennas were placed near the base of a small (non-active) volcanic ash-mound at the North side of the test site. Test and reference antennas were placed so as to provide approximately 110 meters of separation (more than 5 wavelengths) between test and reference antenna installations.

Figure 6 depicts the azimuth far-field radiation test setup. 17 distinct test points were selected along several dirt roads located south of the antennas. These 17 points were used to evaluate the far-field radiation pattern at low (essentially zero) elevation angles over several azimuth angles (theta). A slight slope upwards towards the South allowed some small increased elevation angle far field power to be collected (notably, points 10, 14 and 15).

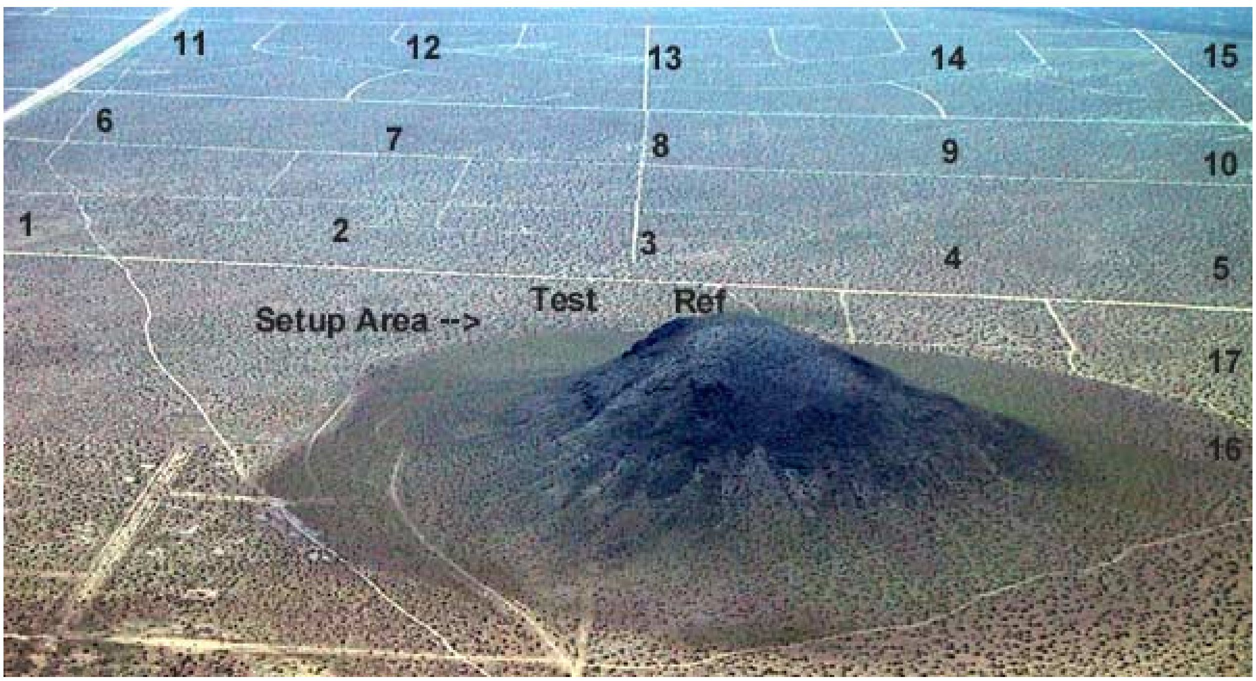

Figure 6. View of Test Setup Used to Evaluate Azimuth Far-Field Performance

Additionally, 6 points were selected along an uphill path leading to the top of the volcanic ash-mound. These 6 points were used to collect far-field data at elevated angles (phi) above the horizon up to approximately 21 degrees. Figure 7 shows the approximate location of each of these 6 points with reference to the ash-mound.

Figure 7. View of Test Setup Used to Evaluate Elevated Far-Field Performance

A pair of matched-amplitude RF oscillators located at each antenna provided sufficient power to register a strong measurement on a mobile receiver. The frequency of operation of one of the matched-amplitude oscillators was separated by approximately 3 KHz referred to the opposite oscillator. The 3 KHz separation allowed both signals to be displayed on the spectrum-analyzer display simultaneously using a narrow resolution measurement bandwidth.

Far-field radiation measurements were taken by relocating the test receiver vehicle at each of the 17 test points accessible by road. The 6 elevated test points were accessible only by foot. Measurement taken at these points were collected by using a well-calibrated portable spectrum analyzer. The Anritsu Sitemaster S332B used in this test is shown in Figure 8. At each location, absolute received power measurements were recorded for analysis. A small 10 dB amplifier, low-pass filter, and short whip antenna provided adequate signal capture capabilities for this task.

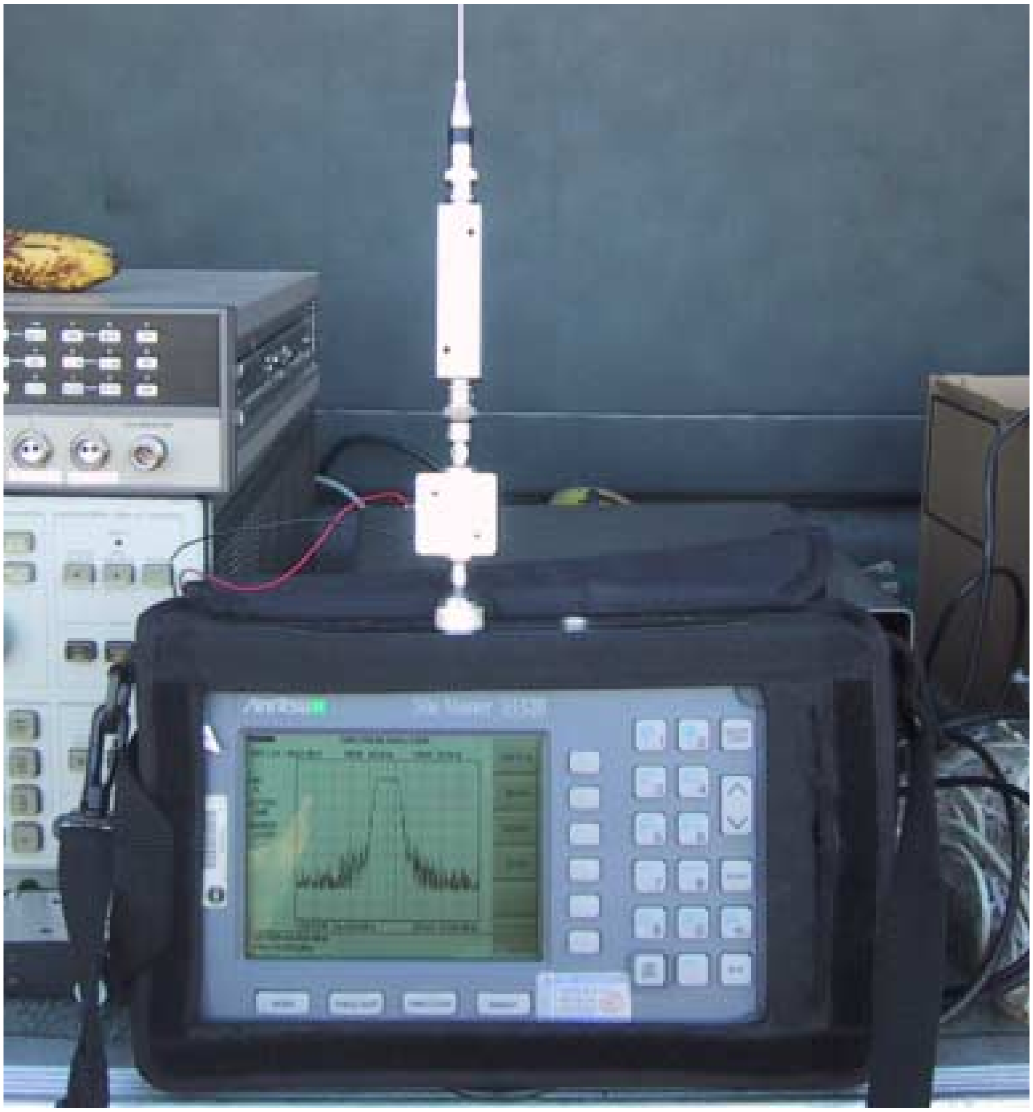

Figure 8. Anritsu S332B Sitemaster Spectrum Analyzer Used to Collect Elevated Far-Field Data

A mobile test receiver was installed in a large motor vehicle. The primary measuring equipment was a well-calibrated Hewlett-Packard Model 3585A Digital Spectrum Analyzer. The analyzer provided calibrated amplitude accuracy specified at 0.4 dB absolute. Relative accuracy between competing signals displayed on the display screen is specified to be better than the 0.4 dB absolute figure referenced above.

Figure 8 shows a representative spectrum analyzer display taken at an approximate midpoint calibration point between the test and reference antennas.

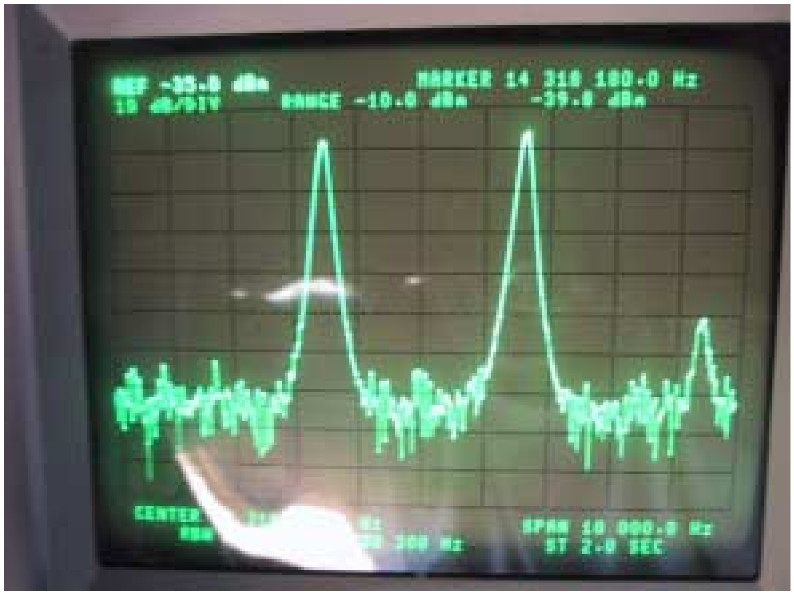

Figure 8. Representative Screen Shot of Spectrum Analyzer Used as a Calibrated Tuned Receiver

Figure 9 illustrates the test receiver setup. The additional spectrum analyzer was installed as a backup to the primary analyzer. Also shown is the RF power meter used to calibrate the RF sources. Atop the vehicle roof was a compact commercial inductor-loaded vertical antenna mounted on the vehicle roof to collect RF signals at the test frequencies. This receiver antenna was manufactured by Hamstick, Inc.

Figure 9. Mobile Test Receiver Configuration

Two matched test oscillators were constructed. The circuit schematic used to construct these signal sources is documented in [7]. Both sources are crystal controlled, low-noise sources providing low harmonic distortion. Each source generated approximately 260 milliwatts of output power measured into a 50-ohm resistive load. Figure 10 illustrates one signal source.

Figure 10. Unshielded Signal Source

Figure 11 depicts both signal sources, matched to within 0.02 dBm using a Boonton Model 4300 RF power meter with type 51015 diode power head, just prior to performing radiating far-field power test measurements.

Figure 11. Matched Pair of Signal Sources

Due to concern (by the EH antenna inventor) that improper impedance matching (referred to as "Phasing" in reference [1]) might affect the operation of the EH test antenna, a small wideband transformer was employed in the test. This transformer had a minimum 3 dB bandwidth of much greater than 100 MHz. Additionally, this device provided a measurement of VSWR during the test operation. This combined VSWR/Broadband Transformer is shown in Figure 12.

Figure 12. Small VSWR Meter Combined with Broadband Transformer

Accuracy of this VSWR measuring device was confirmed by initial test antenna matching using an MFJ-269 portable VSWR/Impedance analyzer. Figures 13a and 13b show a very favorable match of the test antenna, resulting in a near perfect 50-ohm resistive match after final vertical installation.

Figure 13a. MFJ-269 Showing Excellent Source Match of Test Antenna

Figure 13b. Home-Made VSWR Meter Showing Excellent Source Match of Test Antenna

Tuning of the test antenna was much improved over that experienced during earlier testing [7], most likely due to the addition of a high-quality RF ground within proximity of the oscillator end of the feedline. Local human body interaction had a minimal effect while establishing a good VSWR match.

Test Results

Table 1 lists the measured power levels collected by the vehicle mounted HP spectrum analyzer configured as a sensitive narrow-band receiver. Data were collected using a 100 Hz resolution bandwidth and a 10 KHz span, collected over a 2 second sweep time. Results were averaged over 5 consecutive sweeps.

Test Point	Latitude	Longitude	Altitude (ft)	Reference (dBm)	EH (dBm)	Uncorr Difference
1	3504.034	11755.095	2438	-63.2	-60.2	3
2	3504.034	11755.429	2426	-54.2	-49.5	4.7
3	3504.035	11755.702	2454	-39.9	-40.2	-0.3
4	3504.036	11756.054	2473	-54.1	-57.3	-3.2
5	3504.038	11756.376	2501	-65.9	-67.9	-2
6	3503.694	11755.085	2439	-72.4	-70.8	1.6
7	3503.705	11755.432	2476	-65.5	-64	1.5
8	3503.708	11755.703	2562	-62.3	-61.6	0.7
9	3503.706	11756.058	2556	-62.3	-63.5	-1.2
10	3503.712	11756.374	2597	-67.3	-68.4	-1.1
11	3503.487	11755.083	2460	-73.2	-72.7	0.5
12	3503.488	11755.428	2504	-70.9	-70.2	0.7
13	3503.488	11755.698	2555	-68.6	-68.4	0.2
14	3503.488	11756.058	2629	-70.9	-71.6	-0.7
15	3503.495	11756.377	2676	-71.7	-72.7	-1
16	3504.35	11756.384	2488	-66.5	-68.7	-2.2
17	3504.166	11756.382	2524	-65	-66.7	-1.7

Table 1. Collected Data for 17 Azimuth Locations

Table 2 lists the measured power levels collected by the hand-carried Anritsu Sitemaster spectrum analyzer configured as a sensitive narrow-band receiver. It was noted that the signal level varied slightly as a function of the tilt-angle of the antenna used with the Sitemaster. For this reason, all measurements were "peaked" over several sweeps by orienting the antenna vertically for maximum signal strength at each point.

Test Point	Latitude	Longitude	Altitude (ft)	Reference (dBm)	EH (dBm)	Uncorr Difference
1	3504.201	11755.668	2472	-47.2	-46.8	0.4
2	3504.26	11755.66	2543	-56.2	-57	-0.8
3	3504.297	11755.654	2632	-60.9	-60.2	0.7
4	3504.32	11755.64	2719	-66.4	-65.7	0.7
5	3504.339	11755.641	2775	-68.1	-67.5	0.6
6	3504.353	11755.649	2828	-68.5	-67.6	0.9

Table 2. Collected Data for 6 Elevation Locations

Analysis of Results

Due to the non-uniform distances measured between both antennas and the various test point locations, some compensation needed to be conducted on the data. This was accomplished by translating the collected latitude/longitude/altitude data to the Earth-Centered-Earth-Fixed (ECEF) Cartesian coordinate system. This reduction resulted in X,Y,Z triplets which could be directly compared to the Cartesian coordinates of both the test and reference antenna. WGS-84 Ellipsoid model data was applied to the coordinate transform to account for the ellipsoidal nature of the Earth's surface. However, that correction is minor given the small distances being measured.

The distance between each antenna and each point was then calculated by forming the 3-dimensional hypotenuse using the traditional root-sum-of-squares procedure. This radial distance is then used to compensate for the 1/r^2 power loss which occurs in any one-way RF link. Table 3 shows the normalized (compensated data) derived from the raw data of Table 1.

Test Point	R(EH)	R(Ref)	Loss dB (EH)	Loss dB (Ref)	Corr EH Pwr	Corr Ref Pwr	Corr Diff (dB)
1	886.8905613	993.550453	58.95740	59.94380	-1.24260	-3.25620	2.01360
2	421.1803951	518.1033716	52.48936	54.28833	2.98936	0.08833	2.90103
3	246.0684916	248.9547821	47.82112	47.92241	7.62112	8.02241	-0.40129
4	647.0944666	551.9521811	56.21935	54.83803	-1.08065	0.73803	-1.81868
5	1116.557978	1013.363134	60.95763	60.11530	-6.94237	-5.78470	-1.15768
6	1233.406405	1318.019325	61.82212	62.39844	-8.97788	-10.00156	1.02369
7	918.7389334	972.4782897	59.26384	59.75760	-4.73616	-5.74240	1.00624
8	846.7466236	854.1133753	58.55507	58.63031	-3.04493	-3.66969	0.62476
9	1044.117754	993.1517883	60.37499	59.94031	-3.12501	-2.35969	-0.76532
10	1373.017192	1295.157149	62.75352	62.24645	-5.64648	-5.05355	-0.59293
11	1533.541439	1604.864324	63.71391	64.10877	-8.98609	-9.09123	0.10514
12	1304.704218	1346.41732	62.31024	62.58359	-7.88976	-8.31641	0.42665
13	1256.911177	1265.616407	61.98609	62.04604	-6.41391	-6.55396	0.14005
14	1393.101585	1358.128391	62.87966	62.65882	-8.72034	-8.24118	-0.47916
15	1652.431353	1590.398179	64.36247	64.03012	-8.33753	-7.66988	-0.66765
16	1160.621177	1055.276956	61.29381	60.46733	-7.40619	-6.03267	-1.37352
17	1102.307562	994.3658966	60.84606	59.95092	-5.85394	-5.04908	-0.80487

Table 3. Radial Distance Compensated Data for 17 Azimuth Locations

All distances are displayed in Meters. Note that the corrected powers were calculated by adding the path loss back to the raw collected data. A positive value in the Corrected Difference column indicates an improvement of the EH antenna over the reference antenna.

The mean difference between the EH test antenna and the reference "matched long-wire" was 0.011 dB, with a Standard Deviation of 1.226 dB over the 17 collected data points. The mean difference is well within the measurement accuracy of the equipment and is not significant.

However, points 1, 2, 3 and perhaps 16 may be significant, since the total measuring uncertainty was calculated as 1.2 dB.

Table 4 shows similar data for elevation data as presented for azimuth data in Table 3. Here, only 6 points are normalized and compared.

Test Point	R(EH)	R(Ref)	Loss dB (EH)	Loss dB (Ref)	Corr EH Pwr	Corr Ref Pwr	Corr Diff (dB)
1	78.47975268	113.3266473	37.89515	41.08664	-8.90485	-6.11336	-2.79149
2	192.5722095	210.269738	45.69187	46.45554	-11.30813	-9.74446	-1.56366
3	270.1082027	283.958912	48.63076	49.06511	-11.56924	-11.83489	0.26565
4	323.4732934	340.5521924	50.19677	50.64367	-15.50323	-15.75633	0.25309
5	364.7314644	378.5472705	51.23946	51.56240	-16.26054	-16.53760	0.27706
6	396.3303178	405.166466	51.96115	52.15267	-15.63885	-16.34733	0.70848

Table 4. Radial Distance Compensated Data for 6 Elevation Locations

The mean Corrected Difference in received signal power was -0.475 dB, with a standard deviation of 1.385 dB. A positive value in the Corrected Difference column indicates an improvement of the EH antenna over the reference antenna.

As in the case for data collected for the study of Azimuth radiation, no significant difference in elevation far-field patterns between the test and reference antennas is indicated in these data.

A Microsoft Excel spreadsheet is included with this document to allow inspection of the data reduction methods. However, it is evident from casual observation of the raw data that no significant field strength differences were noted, except for those points where the orientation of the closer test points led to larger power measurements due to the proximate antenna.

No further attempt was made to reduce these data in order to display far-field gain as a function of azimuth (theta) or elevation (phi) angles, as such gain patterns are clearly established in the great body of literature. Note however that the maximum elevation angle corresponds to roughly 21 degrees elevation (using .866 NM per longitudinal degree at 35 degrees latitude).

Conclusions

The data indicate that the EH Backpacker antenna, tested as delivered from the factory, works quite well when fed by a suitable length of coaxial feedline. In fact, these data indicate that the combination of EH Backpacker and coaxial feedline radiates precisely as well as a well-matched, end-fed monopole vertical antenna of the same overall system length. This conclusion is accurate to within the measuring tolerance of the instrumentation used.

From these data, as well as background testing documented in [7], it can be reasoned with a high degree of certainty that the Backpacker EH antenna acts as a type of reactive network that allows the outer braid of the coaxial feedline to radiate efficiently. It is not clear from data obtained within this report how the RF currents are distributed along the radiating feedline. However, the user is cautioned that significant RF current should be expected at various points along the feedline, dependant on feedline length, and is cautioned to take appropriate measures to avoid excessive exposure to potentially hazardous RF radiation. This may possibly be accomplished by the use of baluns or RF chokes along the feedline cable. However, the data collected during this study do not indicate the effectiveness or specific procedure needed to apply such devices.

The user of such a combined “antenna” and feedline system must anticipate RF energy radiation from the coaxial feedline. Thus, for effective operation, it is advised that the operator use as much feedline as possible to allow a greater antenna aperture. This will minimize the amount of energy that must be dissipated in the loading coils found within the Backpacker antenna. Additionally, the long feedline should be oriented in such a way as to produce maximum gain along a particular direction, if so desired.

In particular, if a user desires an “omni-directional” azimuth far-field radiation pattern, it is advised that the operator install the antenna as high as possible, while orienting the feeline vertically at as great a distance as possible from metallic objects which will serve to distort the field pattern, or even induce losses by coupling RF energy to ground.

The operator is advised to model the feedline orientation using one of several free or low-cost computer aided antenna modeling software packages based on Numerical Electromagnetic Code (NEC) developed for the US governments. Such tools will allow the user to predict the effectiveness of individual installations to a fairly high degree of accuracy, depending on the fidelity of included parasitic conductors and loss mechanisms such as nearby grounds.

No data were collected during these tests which indicate physical phenomena other than those processes already described in detail by the common body of electromagnetic propagation and antenna literature.

The operator is reminded that equal far-field propagation was achieved during this test by simply loading a short monopole (length < lambda) using a standard amateur radio “transmatch”. Such a familiar configuration may be preferred due to the ease of tuning required when using the antenna system at other than a single operating band. The use of a good RF ground cannot be under-emphasized, although this point was not well studied during the course of this test. A poor (non-existent) RF ground as documented in [7] may preclude the efficient tuning of the Backpacker.

For installations where a long length (significantly greater than 1 wavelength) vertical coaxial cable is used to feed the Backpacker, operators may anticipate enhanced gain over a vertical dipole at fairly low radiation angles. Such a far-field gain pattern is well documented for monopole radiators of sufficiently long length. For best results, it may be best to install the Backpacker from the tallest tree or other low-conductivity structure available. Longer lengths of coaxial feedline will have the direct and potentially desirable effect of lowering the elevation angle at which maximum gain occurs. Operators which desire a higher “radiation angle” for short-skip propagation may enjoy the gain pattern typical of a relatively low-mounted Backpacker.

The curious reader is directed to the numerous texts and open literature, which describe the far-field radiation patterns of long-wire (vertical) antennas, for example [6] or [8].

Summary

The far-field radiation of a novel small antenna fed by a moderate length of coaxial feed line was compared to similar height reactively matched monopole reference antenna. Testing was conducted in an open-air antenna test range due to the relatively large wavelength of the test frequency. Far-field received power measurement data was collected for both the reference and test antenna over a total of 23 test positions, 6 of which were locations which provided an opportunity to explore the elevated gain pattern at angles up to approximately 21 degrees above the horizon. The collected data were corrected for range differential from each of the two antennas. Far-field radiation of the small test antenna fed by an 11-foot length of coaxial cable was measured and found to be essentially indistinguishable from the far-field gain pattern of a loaded monopole reference antenna of the same overall height.

References

[1] http://www.eh-antenna.com Inventor Ted Hart's seminal website concerning EH antenna theory, construction and other activity

[2] http://www.qsl.net/w0kph Jack Arnold, W0KPH, avid experimenter and explanation of how the EH antenna works.

[3] http://www.qsl.net/vk5br/EHAntennaTheory.htm SOME NEW THOUGHTS ON HOW THE EH DIPOLE WORKS (THE H FIELD GENERATED BY THE LONGITUDINAL E FIELD) Lloyd Butler VK5BR (Original Feb 7, 2003) (Amended Feb 24, 2003)

[4] http://groups.yahoo.com/group/eh-antenna Yahoo ISP hosted newsgroups related to the EH antenna concept

[5] http://www.eh-antenna.com/20-Meter_Kit.htm George Jones 366 S. Steel Bridge Rd. Eatonton, GA 31024. Produces and distributes the EH Antenna Backpacker Kit.

[6] *Antenna Theory Analysis and Design.* Second Edition. Constantine A. Balanis. Wiley and Sons, Inc. 1997. Pages 133-142.

[7] *Investigation of the Far-Field Radiation Gain Pattern of the 20-Meter Backpacker Antenna*, Adam MacDonald N1GX and Kevin Prosser WA1ZEB, 23 March 2003.

[8] *The ARRL Handbook*, Eightieth Edition, 2003. American Radio and Relay League.