TEST REPORT

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

23 March 2003

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. A well understood antenna construct is used as a reference antenna, against which all test antenna results are compared. The quarter-wave resonant ground-plane reference antenna is a vertically polarized antenna commonly employed in many transmitting and receiving locations. It is a familiar, highly documented resonant antenna, which provides moderate far-filed radiation performance at a broad value of elevation angles above the horizon. Additionally, the reference antenna is known to have an omni-directional gain pattern in the azimuth plane.

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

A high level of controversy surrounds claims made by the inventors, producers and distributors of EH antennas. Various reported signal strength measurements reported by the amateur radio community seem to deny the applicability of classical electromagnetic physics to this particular type of antenna. Unfortunately, measured data confirming the performance of these antennas relative to well-studied reference antennas is extremely limited.

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.

Purpose

The purpose of the tests described in this document is to define a baseline level of performance that can be expected from this construct of 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 in this report attempt to reduce measurement variability by removing parasitic metallic interfering objects, employing calibrated RF measuring equipment, and performing measurements against a well understood reference antenna fed by carefully controlled signal sources. Additionally, data were collected by feeding the EH test antenna with a very short (insignificant) length of coaxial feedline, as well as a substantial length (approximately one wavelength long) of coaxial feedline. The purpose of this additional test was to quantify the effect of the addition of feedline to the overall antenna system based on the EH dipole antenna.

It is not the intent of this document to attempt to describe the theory of operation of the test antenna. Several explanations are described in references [1], [2], [3] and others. When predictions and explanations of both test and reference antenna performance is necessary, this document describes models based on traditional analysis methods including the Integral Method of Moments (MoM), Electromagnetic Finite Element Analysis (FEA) and well accepted analytical solutions based on traditional electromagnetic field solutions.

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)

The tuning range of the variable capacitors was not adequate to provide minimum voltage standing wave ratio (VSWR, or “SWR”) power match tuning with the PVC radome removed. For this reason, all testing was conducted with the provided PVC radome installed. In this configuration, it was found that a nominal 2:1 SWR bandwidth of approximately 200 KHz was achievable with careful tuning. Figure 2a depicts 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 2a. Installed "Backpacker" 20-Meter Test Antenna (Radome Installed)

Figure 2b shows the Backpacker 20-Meter test antenna prepared for delivery to the test site, together with small, battery-powered crystal oscillator.

Figure 2b. Pre-installed "Backpacker" 20-Meter Test Antenna (Radome Installed)

Reference Antenna

To produce meaningful, repeatable test results, a familiar reference antenna was constructed and erected. The reference is a common design employed by many amateur radio stations for fixed-installation use. The quarter-wavelength “ground-plane” antenna employs a 16-foot telescoping aluminum radiating element, supported by a 10 foot steel pipe mast supported by 6 sloping 16-foot radial elements. The steel mast and sloping radial elements form a “ground-plane” which provides an image of the radiating element, providing a well-documented far-field radiation pattern. SWR matching was provided by adjusting the length of the telescoping radiating element. An SWR match of 1.3:1 at the mean operating frequency (14.3165 MHz) was quickly obtained by this method, and a 2:1 SWR bandwidth of approximately 1 MHz, centered on the test frequency, was observed. Figure 3 shows the reference antenna as installed in its test location.

Figure 3. Installed Reference Quarter-Wavelength Reference Antenna

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, extremely flat landscape, uniform surface conductivity characteristics, and accessibility by motor vehicle. A portion of the Rogers Dry Lakebed located near the Edwards Air Force Base test complex known as the “Compass Rose” provided an ideal combination of test features for this test. Figure 4 shows an aerial view of the Compass Rose antenna test site location.

Figure 4. Compass Rose Test Site

Test Methodology

Both the test and reference antennas were placed close to the center of the Compass Rose test site. Test and reference antennas were placed 150 feet from the center of the test site, providing 300 feet of overall separation (approximately 6 wavelengths) between test and reference antenna installations.

Figure 5 depicts the overall test setup. Eight distinct test points are formed by the intersection of the perimeter of the Compass Rose with intersecting radials separated by 45 degrees of azimuth. The well-defined intersection of radials with the circle circumference provided a simple, repeatable orientation reference for the vehicle-mounted receiving equipment.

A pair of matched-amplitude RF oscillators located at each antenna provided sufficient power to register a strong measurement on the 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 eight test points around the Compass Rose perimeter. At each location, absolute received power measurements were recorded for analysis. The radius of the Compass Rose was approximately 2000 feet, providing effective low-elevation far-field radiation measurements.

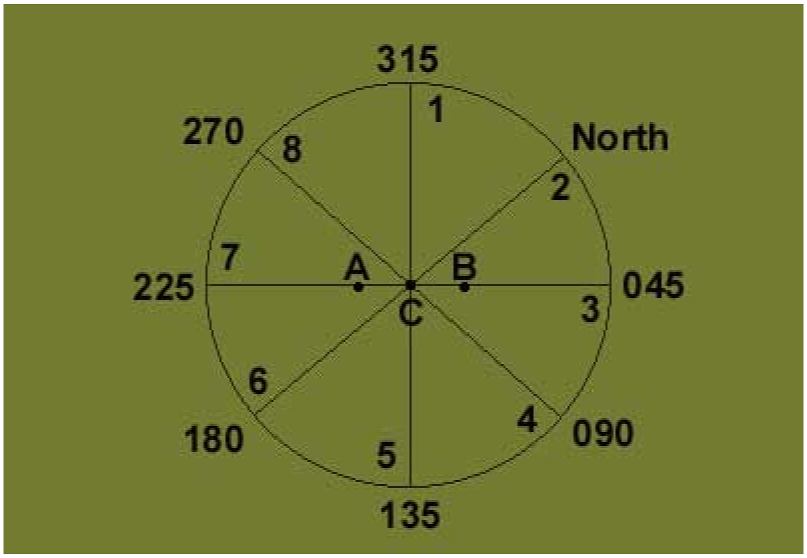


Figure 5. God’s-Eye View of Test Setup (points A & B not drawn to scale)

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 6 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. Not shown is a small 3-foot inductor-loaded vertical whip mounted on the vehicle roof to collect RF signals at the test frequencies.

Figure 6. Mobile Test Receiver (Back End)

Two matched test oscillators were constructed. Appendix A depicts the circuit schematic used to construct these signal sources. 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 6 illustrates an unshielded signal source.

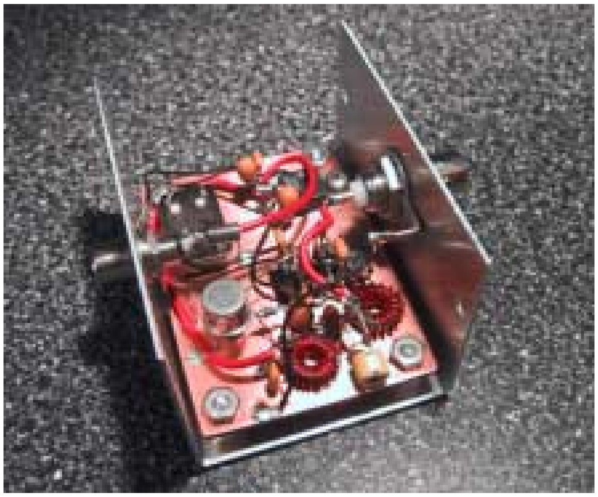


Figure 6. Custom Designed Low-Distortion Crystal Oscillator/RF Source

Figure 7a depicts both signal sources, while Figure 7b illustrates these sources matched to within 0.06 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 7a. Matched Pair of Signal Sources

Figure 7b. Matched Sources Within 0.06 dB Prior to Testing

Due to concerns expressed 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 much greater than 100 MHz. Additionally, this device provided a measurement of SWR during the test operation. This combined SWR/Broadband Transformer is shown in Figure 8. Accuracy of this SWR measuring device was confirmed by initial test antenna matching using an MFJ-269 portable SWR/Impedance analyzer. Figure 9 shows a very favorable match of the test antenna, resulting in a near perfect 50-Ohm resistive match just prior to final vertical installation.

Figure 8. Small VSWR Meter Combined with Broadband Matching Transformer

Figure 9. MFJ-269 Showing Excellent Source Match of Test Antenna During Test Antenna Setup

Test Points

Two distinct sets of data were collected. The first set consisted of a baseline comparison of the "bare" test antenna performance without the inclusion of any significant length of coaxial feedline. In fact, the test antenna was delivered with a small length (approximately 4 inches) of coaxial feedline. The first set of data was collected by energizing the test antenna with the small RF oscillator located at the end of this small feedline. Figure 10 shows the installed test antenna in this "zero-coax" feedline configuration.

Figure 10. Installed Test Antenna In "Zero-Coax" Feedline Configuration

The second set of data was collected from a test antenna connected to the matched RF oscillator by way of 70 feet (approximately one wavelength physical length) of coaxial feedline. This feedline was arranged as a sloping wire with one end attached to the end of the supplied 4 inch coaxial feedline, and the other end attached to a small wooden ladder (2.5 foot tall) a the opposite end. The test antenna required retuning to achieve a good power match. After several tuning attempts, a final SWR of 1.4:1 was achieved. The particular length of coaxial feedline chosen for this configuration may have prevented a 1.1:1 match (as achieved for the "zero-coax" configuration). Due to test time limitations, it was determined that the slightly poor SWR match was adequate for the purposes of this test configuration. Figure 11 shows the installed test antenna using the "one-lambda" coaxial feedline configuration.

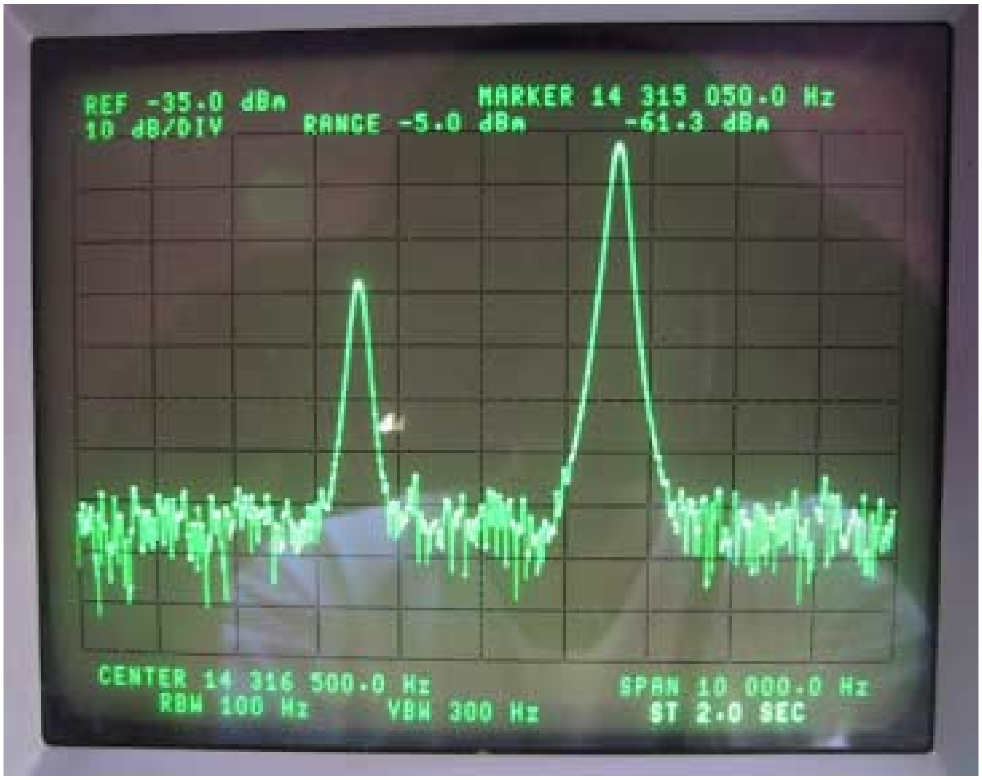
Figure 11. Installed Test Antenna In “One-Lambda” Feedline Configuration

In both tests, the test and reference antennas were placed along the line which is normal to the 315/135 compass lines (i.e. zero azimuth of the antenna is rotated by 45 degrees with reference to the North direction of the compass rose).

Test Results

Zero-Coax Feedline Test Results:

Figure 12 Shows an example screen-shot of the spectrum analyzer used as a sensitive measuring receiver. These data were collected during the “peaking” process of the test antenna. The receiver vehicle was located at the center of the test site (point C), equidistant between the pair of antennas.



REF -35.0 dBm MARKER 14 315 050.0 Hz
10 dB/DIV RANGE -5.0 dBm -61.3 dBm
CENTER 14 316 500.0 Hz SPAN 10 000.0 Hz
RBW 100 Hz VBW 300 Hz ST 2.0 SEC

Figure 12. Example Screen Shot of Measurement Receiver Used to Collect Far-Field Power Data

Figure 13 shows a polar plot of measured received power at the mobile receiver. The small squares (pink) illustrate the absolute amplitude of the power measured from the test antenna. The larger squares (blue) illustrate the absolute amplitude of the power measured from the reference antenna. Plots are constructed by simply connecting the data points using linear functions (no attempt to fit spline curves to data).

Additionally, it is realized that the small difference in antenna position from the center of the Compass Rose (150 feet) tended to bias the omni-directional field pattern slightly to the side on which the particular antenna was located. It was found that the measured amplitude difference was notable, but relatively insignificant given the magnitudes of differential power measurements. No further attempt was made to correct for this difference.

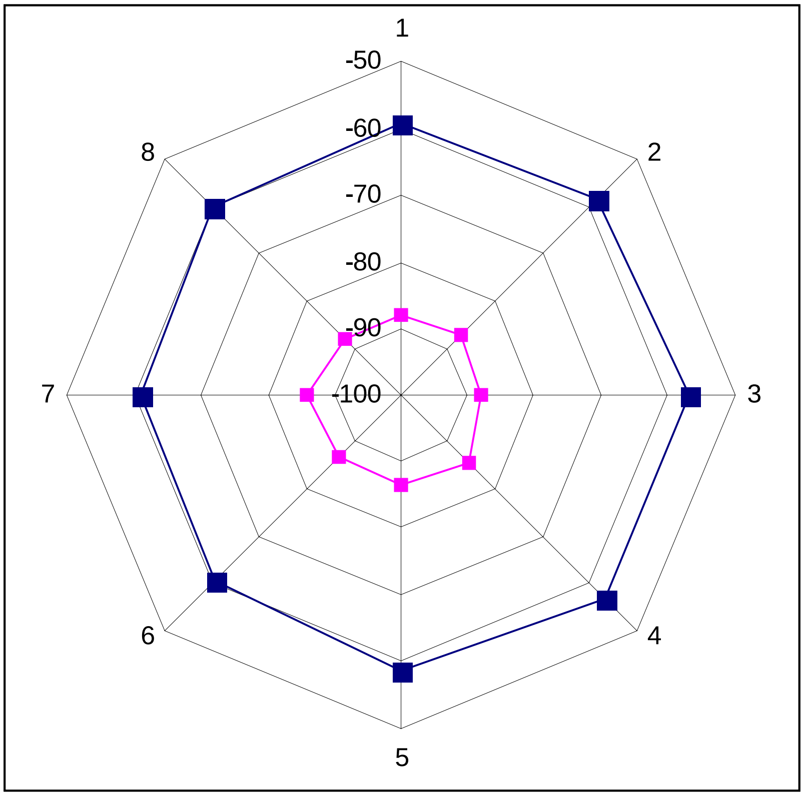


Figure 13. Absolute Polar Amplitude Plots of Both Test and Reference Antenna for Zero-Coax Test

Table 1 records the raw data taken during the zero-coax test

Test Point	Ref Pwr (dBm)	Test Pwr (dBm)	Difference (dB)	Compass	Ant Azimuth
1	-59.3	-88.1	-28.8	315	0
2	-58.3	-87.2	-28.9	North	45
3	-56.8	-88	-31.2	045	90
4	-56.8	-85.7	-28.9	090	135
5	-58.6	-86.4	-27.8	135	180
6	-60.5	-86.8	-26.3	180	225
7	-61	-86	-25	225	270
8	-60.1	-88.1	-28	270	315
Mean	-58.925	-87.0375	-28.1125		
Deviation	1.596200847	0.966492185	1.864278872		
Mean (mW)	1.28E-06	1.98E-09	1.54E-03		

Table 1. Recorded Received Power Data From “Zero-Coax” Test

Figure 14 shows similar data as that in Figure 13, however, test antenna received power data is normalized to the absolute measured power of the reference antenna.

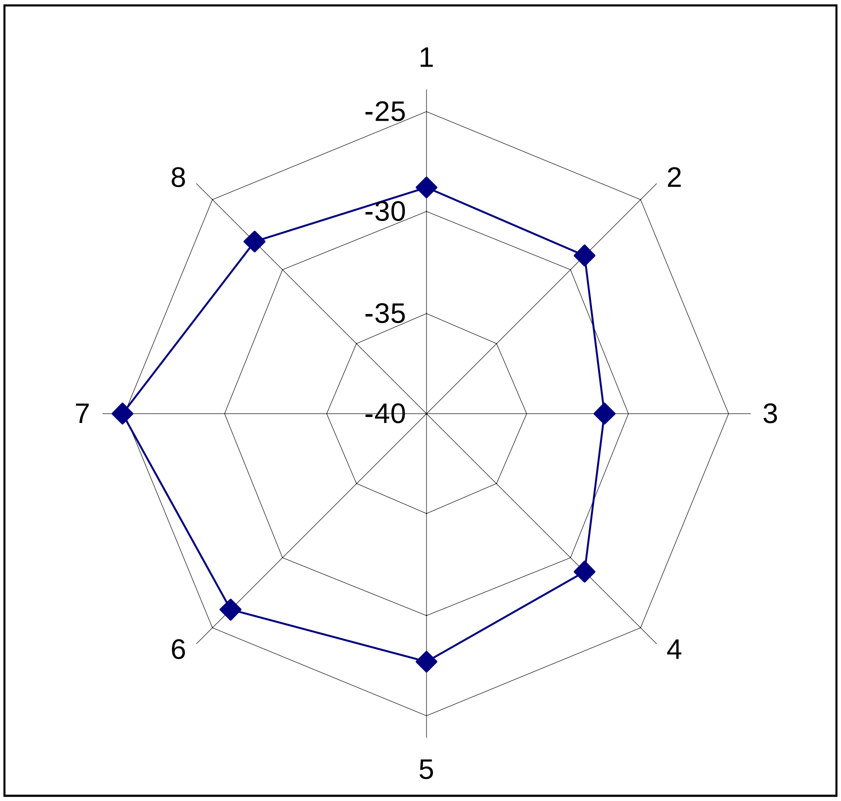


Figure 14. Polar Amplitude Relative to Reference Antenna Amplitude for Zero-Coax Test

One-Lambda Coax Feedline Test Results:

Figure 15 shows a polar plot of measured received power at the mobile receiver. The small squares (pink) illustrate the absolute amplitude of the power measured from the test antenna. The larger squares (blue) illustrate the absolute amplitude of the power measured from the reference antenna. Plots are constructed by simply connecting the data points using linear functions (no attempt to fit splines to data).

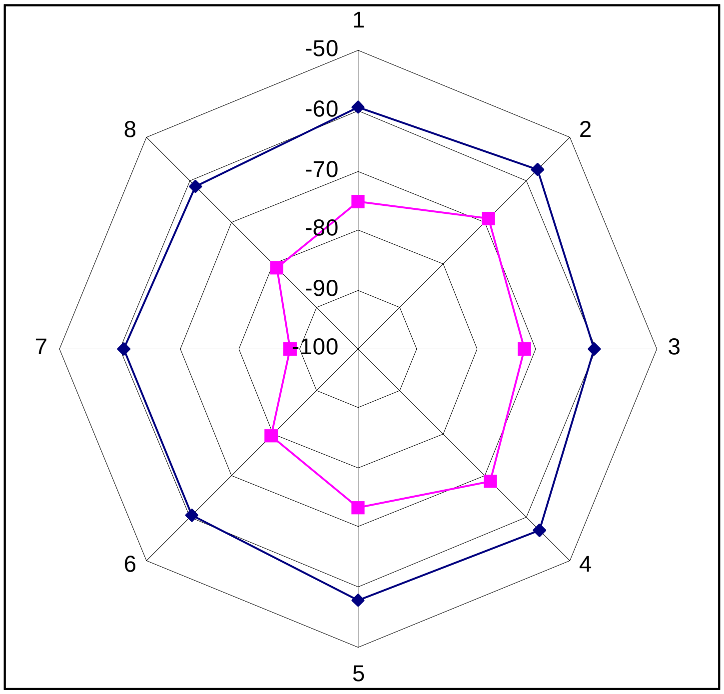


Figure 15. Absolute Polar Amplitude Plots of Both Test and Reference Antenna for 1-Lambda Coax Test

Table 2 records the raw data taken during the one-lambda coax test

Test Point	Ref Ant Pwr (dBm)	Test Ant Pwr (dBm)	Difference	Compass	Ant Azimuth
1	-59.4	-75.3	-15.9	315	0
2	-57.4	-69.4	-12	North	45
3	-60.4	-72.2	-11.8	045	90
4	-57.1	-68.8	-11.7	090	135
5	-58	-73.4	-15.4	135	180
6	-60.5	-79.4	-18.9	180	225
7	-60.8	-88.5	-27.7	225	270
8	-61.5	-80.6	-19.1	270	315
Mean	-59.3875	-75.95	-16.5625		
Deviation	1.683056319	6.612110102	5.4100271		
Mean (mW)	1.15E-06	2.54E-08	2.21E-02		

Table 2. Recorded Received Power Data From “One-Lambda Coax” Test

Figure 16 shows similar data as that in Figure 15, however data is normalized to the absolute power amplitude of the reference antenna

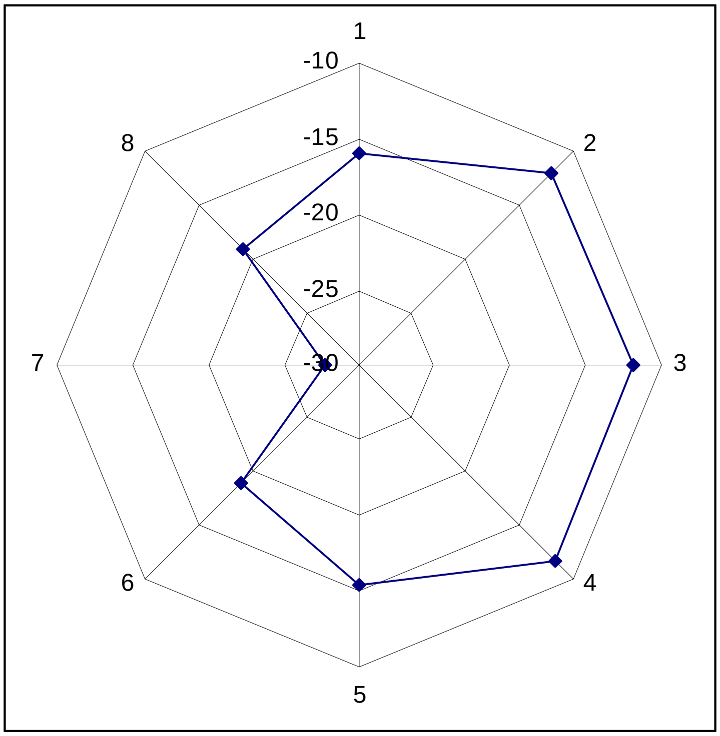


Figure 16. Polar Amplitude Relative to Reference Antenna Amplitude for 2-Lambda Coax Test

Appendix B documents the GPS derived locations of each of the eight test point locations, as well as the GPS derived locations of each of the two antennas and Compass Rose center-point.

Additional Test Considerations/Limitations

Tuning of the test antenna required great care, mainly due to the relatively narrow SWR bandwidth. Local human body interaction required several fine-tuning re-adjustments to ensure good SWR match. Merely climbing down from the 6 foot painter's ladder often required a small re-adjustment to return the SWR to below 1.2:1 ratio. It was noted that these small SWR adjustments had almost no effect on displayed signal strength. However, signal strength fluctuated dramatically when human body parts were moved in proximity of the test antenna. This was noted for both the baseline and added coaxial feedline configurations.

To prevent RF from traveling from the matched oscillators to the battery power source, a large ferrite torroid was employed to choke RF currents that might have escaped from the shielded oscillator enclosure.

No attempt was made to collect data at other than the zero degree elevation plane (horizontal to the Earth's surface).

The inventor [1] indicates in his literature and in notes included with the test antenna [5], that lengths of coaxial feedlines in multiples of half-wavelengths are advisable to assist the operator in tuning the antenna. For this reason, a 70-foot length of coax was selected for this test.

These tests were conducted on 22 Mar 2003 by amateur radio operators N1GX and WA1ZEB. Neither amateur operator owns or operates any public or private interests in the manufacture, distribution or resale of this patented antenna construct.

Analysis of Results

The reduced baseline signal amplitude of the test antenna compared to that of the reference ground-plane antenna is very significant. An average loss of 28 dB was measured across the eight data points taken in the zero-elevation plane. A loss of 28 dB indicates degradation in signal strength by a factor of approximately 630.

It is clear from the data that the addition of this particular length (70 feet) and orientation of feedline caused non-uniform azimuthal gain over that of the baseline antenna configuration. In particular, the azimuth radiation pattern increased by as much as 15.8 dB at one measured azimuth (location 3). At all but one azimuth (location 7), the gain pattern was measured to be significantly higher than that for the baseline (zero-coax) configuration. Average measured gain increased by an average of 11.5 dB from that of the baseline configuration. The only variable changed for this test compared to the baseline test was the addition of 70 feet of coaxial feedline.

Despite a somewhat poor match of the test antenna (1.4:1 SWR, relative to 1.1:1 or less for the "zero-coax" configuration), the radiated field pattern of the antenna/coaxial feedline combination was significantly better than that of the test antenna alone. This clearly indicates that the feedline contributes a significant portion of the radiated field pattern. In fact, for the cases where only 12 dB of attenuation was measured relative to the reference gain pattern (locations 2, 3 and 4), the vast majority of the radiated field was contributed by the feedline alone. At those same three locations, an average of 29.7 dB of attenuation relative to the reference antenna was noted for the baseline configuration.

The efficiency of this antenna may be estimated to a rough degree. Assuming a 95% efficiency of the aluminum/steel construction reference ground-plane antenna, the test antenna efficiency was calculated to be much less than one percent. The addition of one physical wavelength of coaxial feedline dramatically increased the antenna/feedline combination efficiency to between 2 and 10 percent, depending on the measurement azimuth. These figures assume that both the test and reference antennas have similar gain patterns in the elevation plane; however, this test did not explore the radiation of energy at other than the zero-degree elevation plane.

Conclusions

The Backpacker 20-Meter EH antenna, as tested, was found to be an extremely poor far-field radiator. When combined with a significant length of coaxial feedline, the coax/antenna combination was found to provide fairly good far-field radiation in at least one direction. Although a detailed study of various coaxial feedline/antenna combinations was not conducted, these data support that the EH antenna alone is not a significant source of radiation. Without a significant length of coaxial feedline, the Backpacker EH antenna produces a far-field radiation pattern approximately 630 times weaker than that produced by a resonant quarter-wavelength ground-plane antenna.

Although no data were measured at other than the zero degree above horizon elevation plane, it is assumed (modeling the test antenna as a short dipole) that far-field radiated power at elevated elevations would be similarly reduced in a zero-coax feedline configuration.

Although no formal study of feedline length or orientation was conducted during this test, the addition of the coaxial feedline created peaks and valleys in the nominal (baseline) gain pattern. It is assumed that this gain may cause the appearance of a fairly strong antenna gain pattern in a particular direction, leading to increased confidence in this small antenna's radiation capabilities along those particular directions. This observation might explain the plethora of anecdotal field-strength reports by amateur radio operators using this antenna construct. This is especially important to understand when these reports are submitted by radio stations that have no other antenna to directly compare performance.

No data were collected that indicate the test antenna performed according to physical laws other than those well established in the general body of conventional electromagnetic theory.

It appears that the test antenna acted as an effective matching network which allowed the connected coaxial feedline to efficiently radiate from its outer shield, in much the same way that a random wire antenna is matched by a variable matching network located between the random wire and the RF source. In this case, however, the matching network is located at the far-end of the RF source/random-wire combination.

The poor performance of this small antenna construct is entirely consistent with conventional electromagnetic predictions relating to very small dipole antennas. Analysis of Infinitesimal Dipoles found in [4] provides a detailed analysis of antennas similar in size to the test antenna. It should be noted that such analysis predicts a far-field gain pattern, which is very similar to that of a resonant ½-wave dipole over fairly conductive Earth ground. However, difficulties encountered during the power matching process of an RF source to an antenna with such low radiation resistance typically create significant inefficiencies and undue radiated power loss.

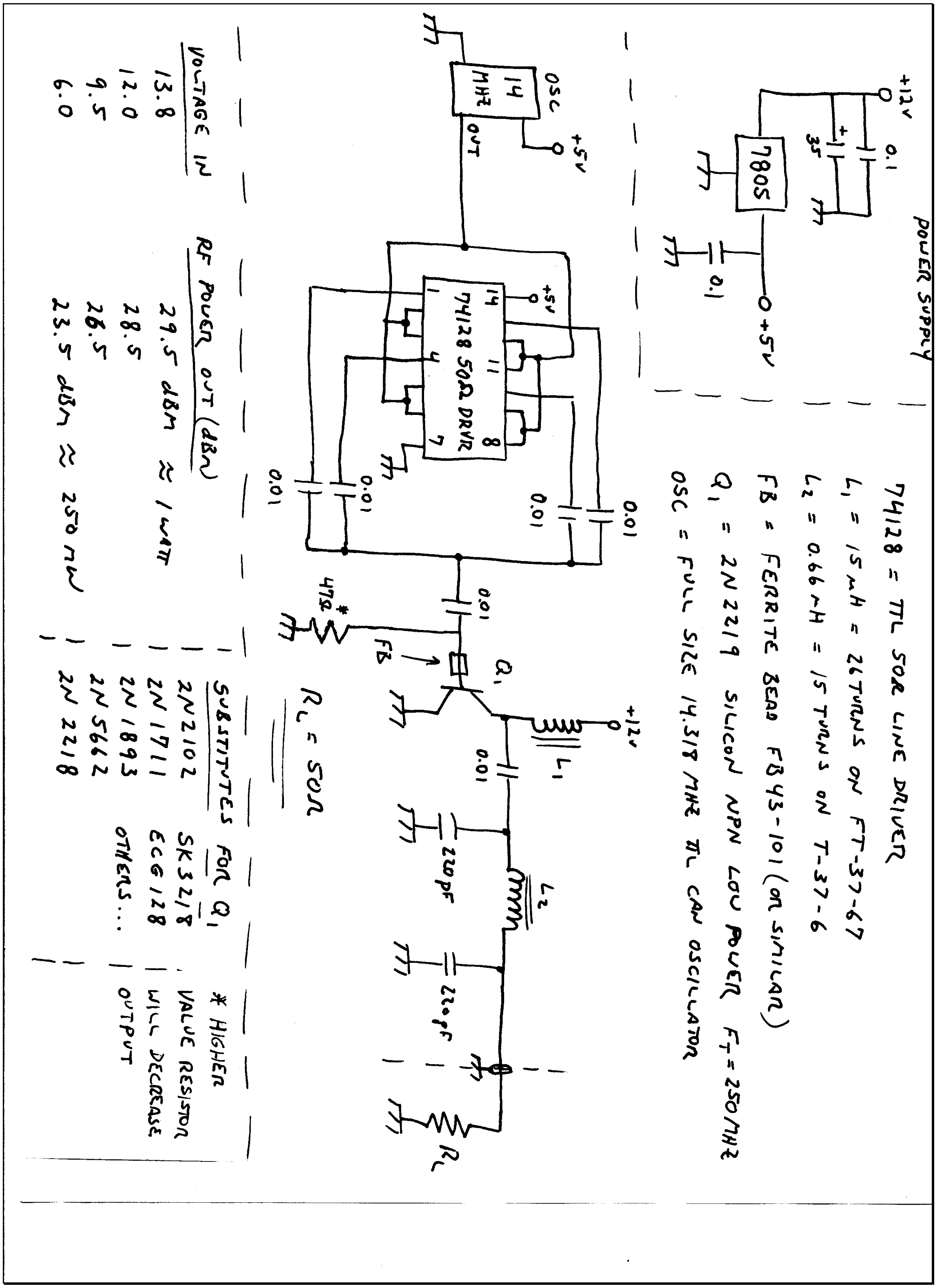
Recommendation

Due to the poor measured performance of the EH Backpacker antenna as tested, further field testing is not warranted. Several tests were initially planned, including elevated elevation far-field power measurements, other-than-vertically oriented test antenna orientation tests, varied coaxial feedline length/orientation tests, etc. It is recommended that these data requirements be fulfilled by employing well established antenna modeling computer software (MoM, FEA, etc) using conventional physically based electromagnetic analysis. Given the vast number of coaxial feedline configurations found in a typical amateur radio station, as well as parasitic interfering objects, open-air testing would provide only limited prediction of performance for these installation configurations.

Summary

The far-field radiation of a novel small antenna was compared to a full size quarter-wavelength ground-plane vertical antenna for two distinct test configurations. 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 were collected for both the reference and test antennas over eight azimuth positions at a single elevation angle parallel to the Earth. No effort was made to investigate the far-field gain pattern as a function of elevation. Baseline test data was collected by feeding the test antenna with a very short length of coaxial feedline. Additional data were collected by feeding the test antenna with approximately one physical wavelength (70 feet) of coaxial feedline. Far-field radiation of the small test antenna fed by a very short length of coaxial cable was measured at an average 28 dB loss referred to the azimuth radiation pattern of the quarter-wave reference antenna. Far-field radiation of the small test antenna fed by 70 feet of coaxial feedline was measured at between approximately 12 and 28 dB of loss relative to the reference antenna, dependent on the azimuth of the measuring receiver. The inclusion of coaxial feedline to the test antenna configuration caused significant increase in measured far-field pattern received power at all but one point along the perimeter of a circular measurement range. No data were collected that suggest that the test antenna obeyed physical laws other than those properties well described in the common body of experimental and theoretical electromagnetic literature.

Appendix A – Crystal Oscillator RF Source Used to Generate Reference Signals



Appendix B – Measured Data Location Data (GPS Derived)

Test Point Number	GPS Latitude	GPS Longitude
A (Test Antenna Location)	34,57.231	117,52.436
B (Ref Antenna Location)	34,57.264	117,52.362
C (Center Point of Test Site)	34,57.247	117,52.399
1 (315)	34,57.336	117,52.786
2 (North)	34,57.566	117,52.292
3 (045)	34,57.413	117,52.047
4 (090)	34,57.159	117,52.010
5 (135)	34,56.961	117,52.198
6 (180)	34,56.922	117,52.503
7 (225)	34,57.083	117,52.746
8 (270)	34,57.535	117,52.600

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.