Current Vector Alignment and Lowered Resonance in Small Planar HF Wire Antenna Designs

W. Perry Wheless, Jr.
Department of Electrical and Computer Engineering
The University of Alabama
Tuscaloosa, AL 35487
Email: wwheless@coe.eng.ua.edu

***Abstract*— Current vector alignment is a significant guide to whether a proposed small HF antenna design will be effective in lowering resonant frequency as a function of total wire length. The effect is illustrated here through three case studies of planar designs for the 160-meter amateur radio band (1.8 - 2.0 MHz).**

I. Introduction

There is considerable interest in electrically small antennas. The discussion here is generally applicable, but is presented in the context of three small antenna candidates for the 160-meter amateur radio band so that quantitative illustrations are possible. A major conclusion of this study is that the minimum size of a resonant wire antenna remains an open consideration, despite pronouncements to the contrary. For example, the Hilbert curve fractal dipole (configuration sketched in Figure 1 [1]) is said by some to exhibit the lowest resonant frequency of any antenna of the same size.

For a resonant frequency at 1.9 MHz, the Hilbert curve fractal dipole would require a wire length of approximately 168.6 m and dimensions approximately 9.84 m $\times$ 9.84 m (based on a resonant frequency of 267 MHz for a wire length of 1.2 m and area 7 cm $\times$ 7 cm). However, a look at current vector alignment for this wire antenna geometry, shown in Figure 2, is immediately suggestive. The close proximity of many oppositely directed current vector segments indicates that this antenna actually should be expected to be relatively ineffective in lowering resonant frequency as a function of total wire length. It is easy to produce numerous examples that substantiate that conclusion, and lead to the premise of this paper that the wire antenna configuration that truly has the lowest resonant frequency for a given size (occupied planar area) remains open for discovery.

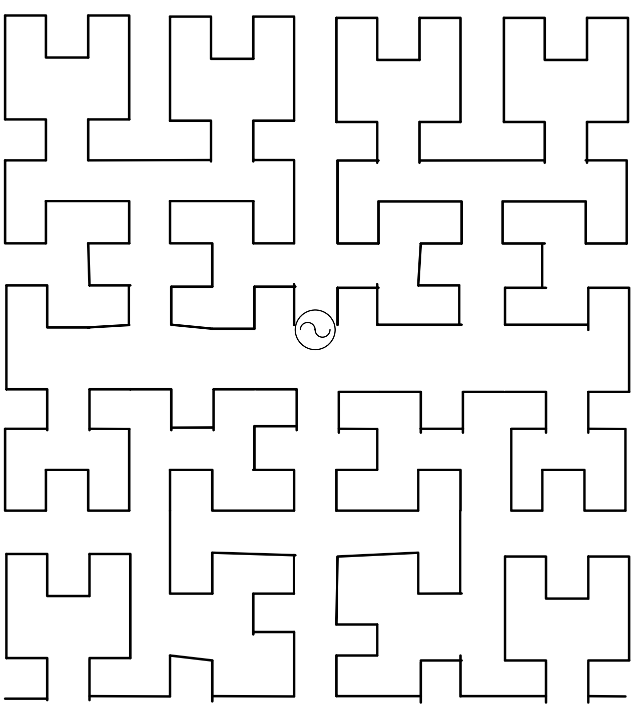

Fig. 1. Hilbert Curve Fractal Dipole.

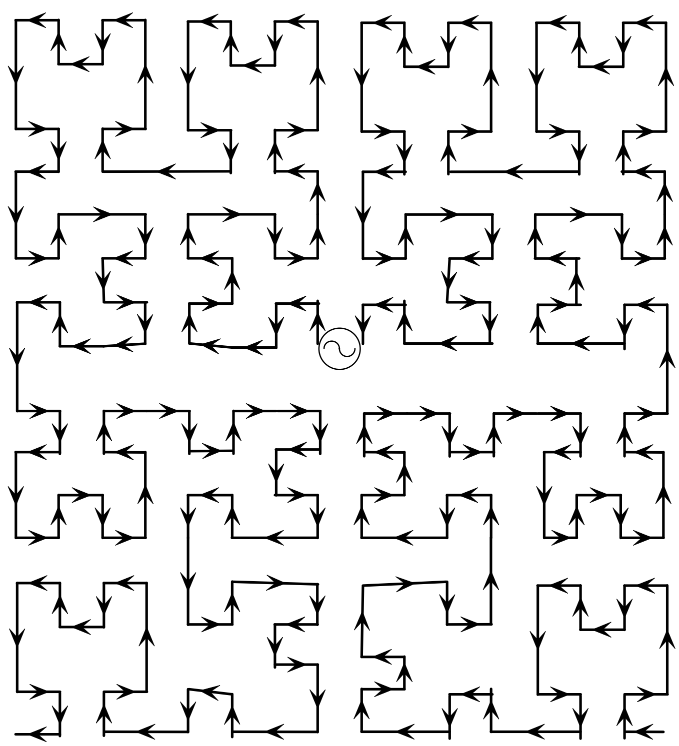

Fig. 2. Current vector alignment on Hilbert fractal dipole.

II. Current Vector Alignment

Generally speaking, when current vectors in close proximity oppose, the result is reduced radiation moment (i.e., more transmission line effect) which decreases the effective length of the antenna wire. On the other hand, when current vectors align both the radiation moment and the effective length of the antenna wire are increased. The condition to be emulated is clearly shown by the journeyman half-wave dipole:

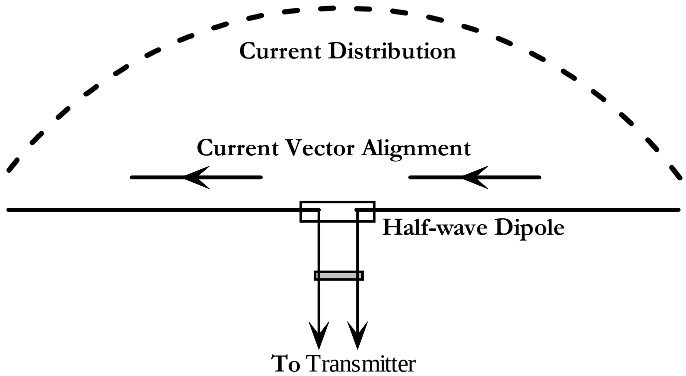

Fig. 3. Half-wave dipole current alignment.

III. Antenna 1

The first example of a configuration that will produce a lower resonant frequency within the constraint of a 7 cm × 7 cm size is offered in Figure 4.

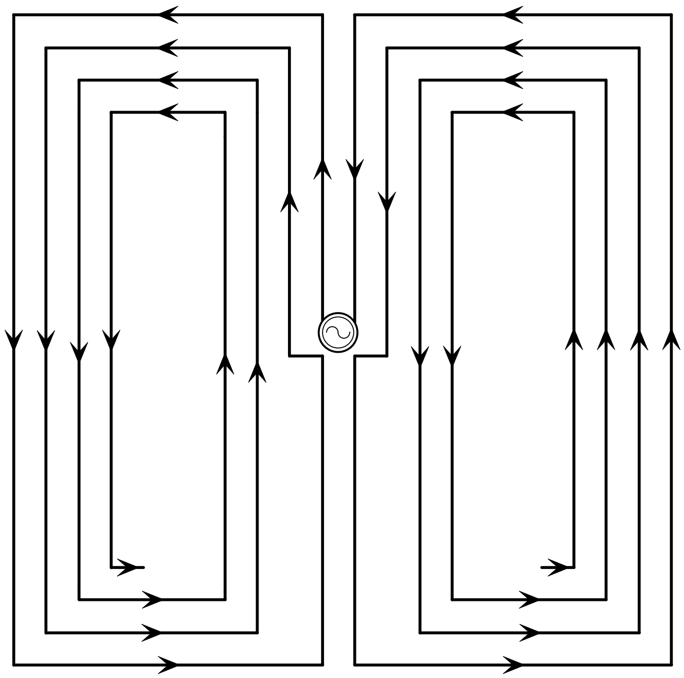

Fig. 4. Example 1 wire antenna configuration.

Here, current vector alignment indicates this antenna configuration whould be more effective in lowering resonant frequency as a function of total wire length. For a total wire length of 1.2 m and size 7 cm × 7 cm, the resonant frequency for this antenna is approximately 155 MHz, significantly lower than the 267 MHz resonance of the Hilbert fractal dipole. Directly scaling to 1.9 MHz, the total wire length becomes 98.7 m and the overall size is approximately 19.1 feet × 19.1 feet.

To analyze the attractiveness of this design as a 160-meter small antenna candidate, numerical modeling with EZNEC version 4.0 [2] was applied. For all EZNEC results reported here, real/high accuracy ground was selected with $\sigma = 3$ mS/m and $\epsilon_r = 12$, typical of west central Alabama soil conditions. Also, "copper" wire loss was selected, so the results here include conductor loss. In all cases, these planar antennas are vertically oriented (in the $y - z$ plane at $x = 0$), with +y corresponding to the compass direction North, and +x corresponding to the compass direction East. Therefore, in contemplating these example antennas in actual 160 m operation in the real world, azimuth angle $\varphi = 0°$ is toward the East, $\varphi = 90°$ is toward the North, and so forth.

Resonance with a very thin wire of 0.1 mm diameter has a (numerically) predicted feed-point impedance of $136 + j2\ \Omega$, which is quite encouraging. Unfortunately, achieving resonance and a favorable feed-point impedance does not necessarily mean the antenna is an effective radiator. Figures 5a and 5b show the elevation patterns for azimuth $\varphi = 0°$ (East-West, broadside to the antenna plane) and $\varphi = 90°$ (North-South, in the plane of the antenna) with the bottom of the antenna only 1m above real ground, and gain of only about -21 dBi is clearly disappointing. A natural immediate question is whether the close proximity to ground is the cuprit, but raising the antenna bottom to 80m above ground only improves the gain by about 1 dB as shown in Figure 5c. Figure 5c does show, however, that the radiation pattern is significantly modified by raising the antenna up high in the air.

Most radio amateurs aspiring to operate on the 160-meter band from a space-restricted residential lot have at least enough room to accommodate a half-wave 75-m dipole. A full $\frac{\lambda}{2}$ dipole in free space has a gain of 2.15 dBi, and gain performance is generally expected to be a comparable value for an proposed alternative antenna system to be considered as a viable candidate. Since operating a 75m dipole as a half-sized dipole at 160m would give a gain penalty only in the -20 dBi range, the majority would probably opt for having good performance at 75m and -20 dBi gain at 160m from a single antenna, versus erecting both the planar 160m small Antenna 1 and a 75m dipole to cover the two bands.

However, several positive results have come from studying this design: (1) it shows one definitely can do better than the Hilbert fractal dipole with a given size limitation, (2) the resonant feed-point impedance is quite robust, (3) the size of this small 160m planar wire antenna is less than 20 feet on a side, and (4) adding current vector alignment as a consideration to our design toolkit boosts optimism for better future designs.

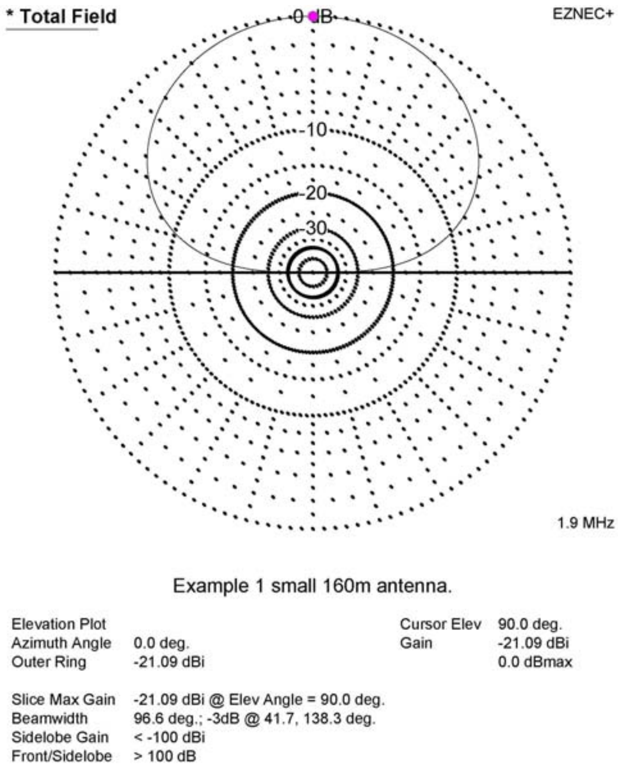

Fig. 5a. Example 1 $\varphi = 0°$ elevation plot.

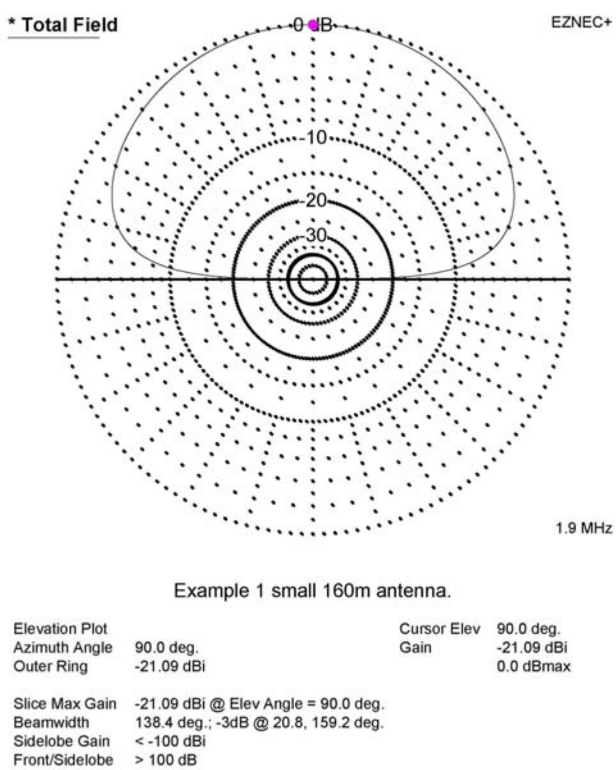

Fig. 5b. Example 1 $\varphi = 90°$ elevation plot.

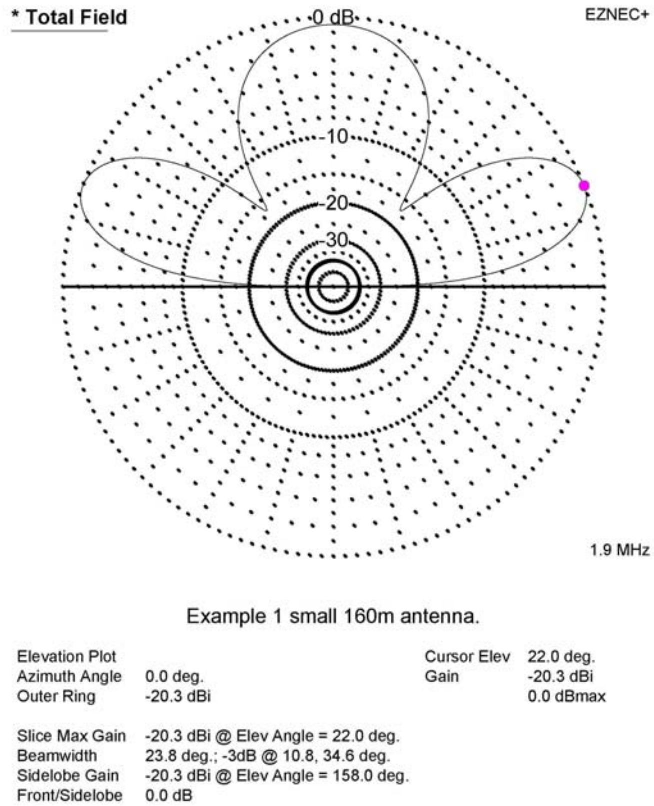

Fig. 5c. Example 1 $\varphi = 0°$ elevation plot, 80m height

IV. ANTENNA 2

The next candidate small 160m antenna to be presented has the geometry shown in Figure 6. A VHF implementation of this geometry with 0.54m of wire length exhibitied a resonant frequency about 245 MHz, implying that a version with 1.2m of wire would resonate at approximately 122 MHz, even lower than that of the Antenna 1 antenna above.

The total wire to make a 160m version of this antenna is approximately 73.2 meters, with overall size 30.2 feet $\times$ 30.2 feet. Using 2 mm antenna wire in the EZNEC modeling, now the feed-point impedance at resonance is about $7 + j24\ \Omega$. While this is an impedance that remains reasonably amenable to getting rf power into the antenna, it is obviously less than would be desired and much lower than that obtained from the Antenna 1 geometry.

Examining the currect vector alignment in Figure 6, some areas of field cancellation are apparent. On the other hand, there is less "folding" of wires in comparison to the Antenna 1 antenna and therefore the prospect for better radiation performance.

The three radiation patterms corresponding to those of Figure 5a-c for the Antenna 1 antenna are given below for the Antenna 2 configuration in Figure 7a-c. The patterns confirm that Antenna 2 is a superior radiator in comparison to Antenna 1, at the expense of a somewhat more challenging feed-point impedance.

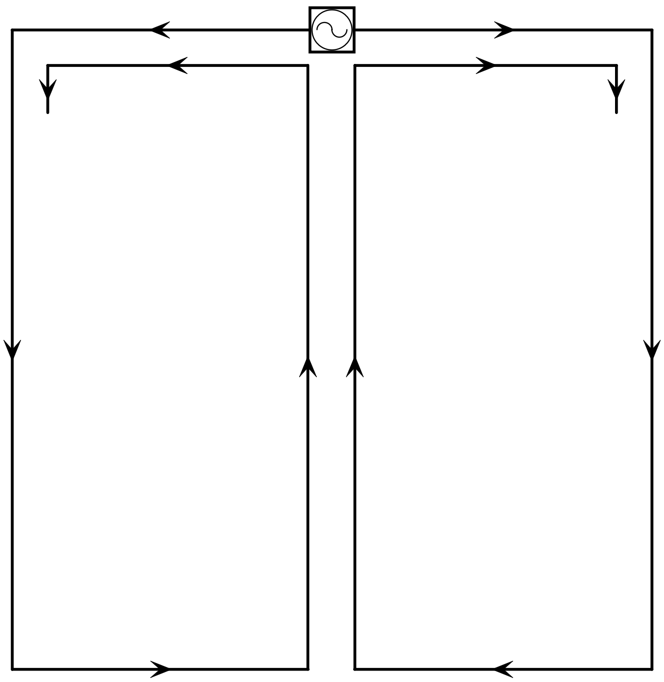

Fig. 6. Example 2 configuration.

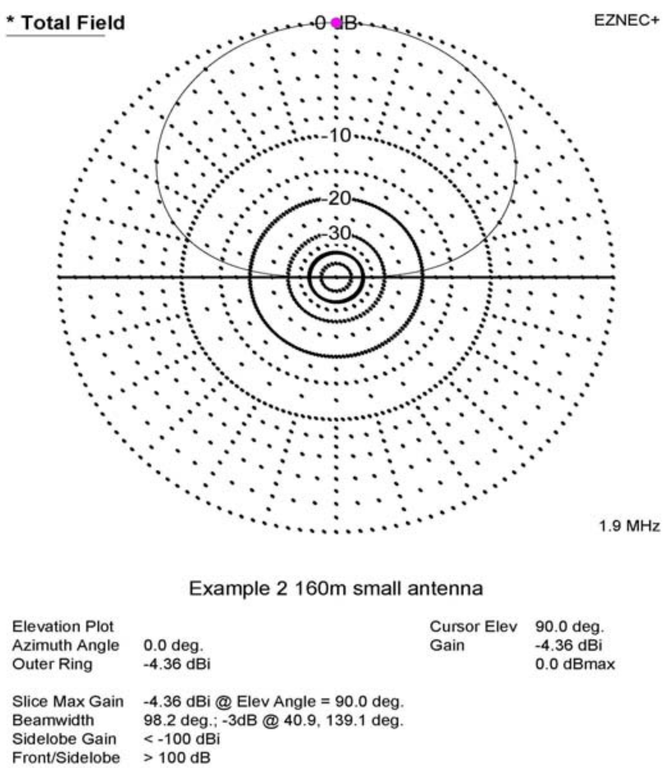

Fig. 7a. Example 2 $\varphi = 0^\circ$ elevation plot.

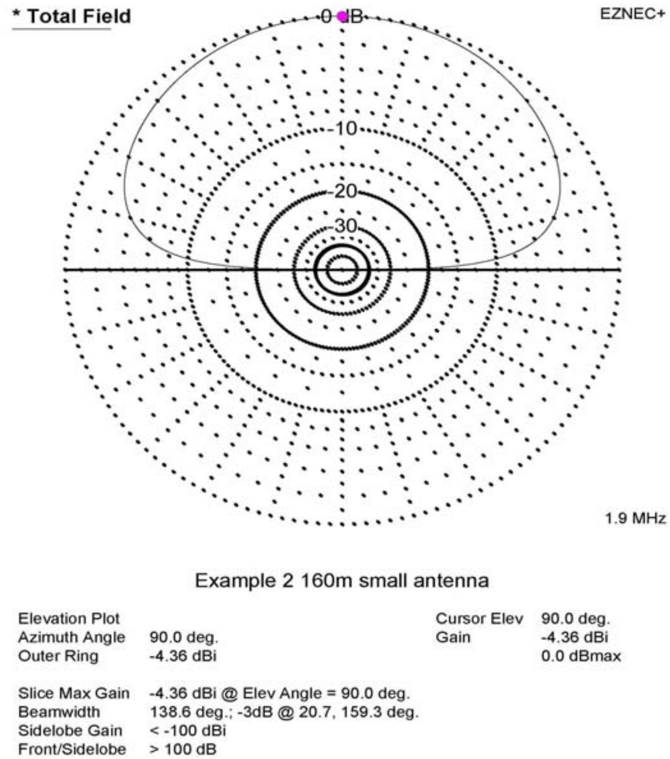

Fig. 7b. Example 2 $\varphi = 90^\circ$ elevation plot.

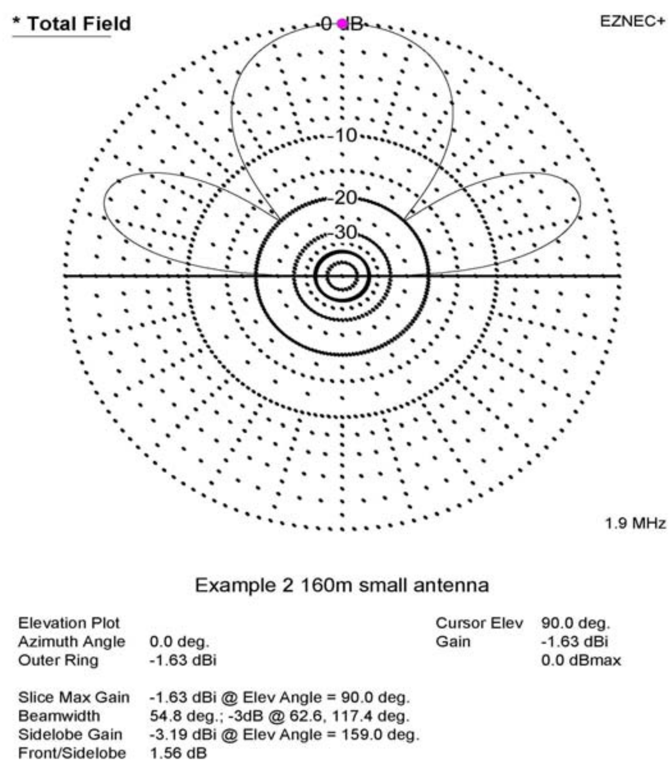

Fig. 7c. Example 2 $\varphi = 0^\circ$, 80m height.

V. Antenna 3

The third example geometry is shown in Figure 8, and is an exercise in re-configuring Antenna 2 to give greater current vector alignment. In this case, the right "half-panel" of the Antenna 2 antenna is rotated up, so that the overall bounding geometry is no longer square.

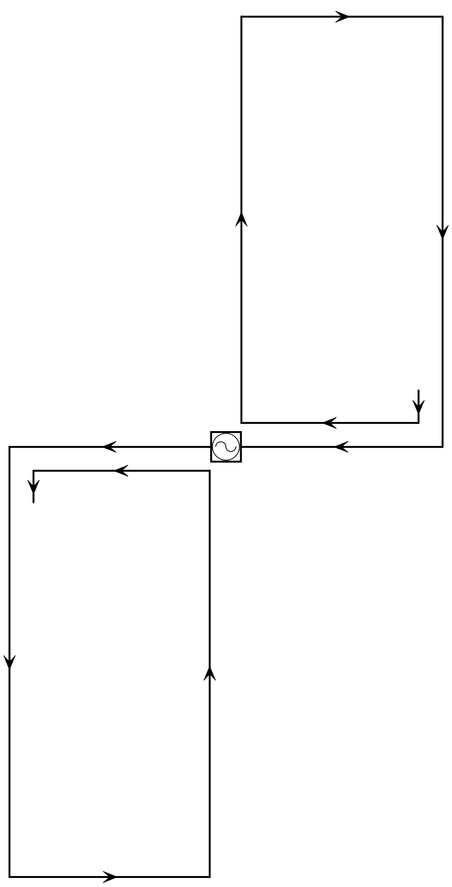

Fig. 8. Example 3 configuration.

This antenna geometry, with a wire diameter of 2 mm and height (of the antenna's bottom) above ground of 1 meter gives a resonant frequency close to 1.9 MHz with a feed-point impedance of $13 - j24\ \Omega$. Total wire length is again about 73 meters. This configuration is more awkward to implement, as each of the two antenna "panels" are 15 feet wide by 30 feet tall, so there is the mechanical complication that the overall height is some 60 feet, and the two panels do not sit one on top of the other vertically. Nonetheless, it is a logical re-arrangement of the Antenna 2 antenna to further increase current vector alignment. The improved feed-point impedance is encouraging, and the three elevation plots corresponding to the earlier cases are presented below in Figure 9a-c. As before, the antenna bottom is 1 meter above real ground with $\sigma = 3$ mS/m and $\epsilon_r = 12$ in Figure 9a-b, with the diffence in Figure 9c being that the antenna has been elevated to 80 meters above ground.

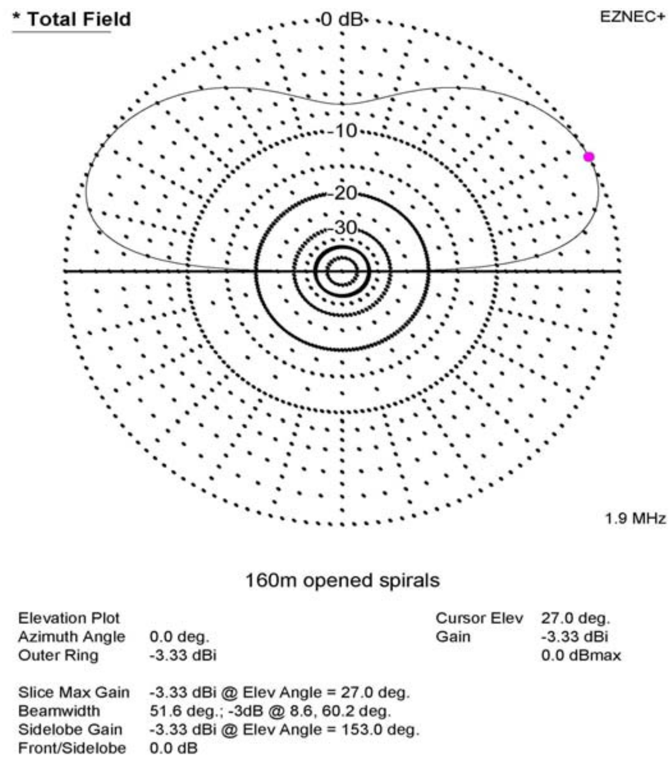

Fig. 9a. Example 3 $\varphi = 0^\circ$ elevation plot.

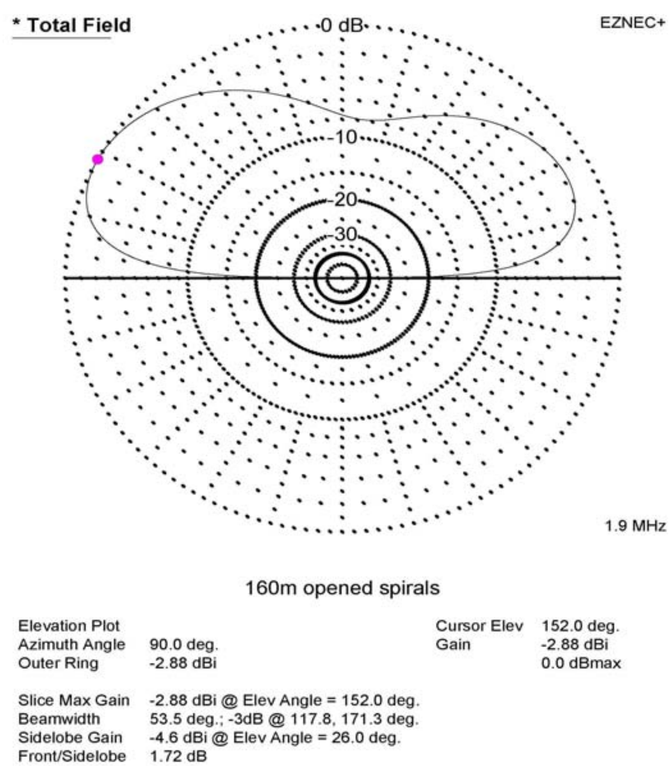

Fig. 9b. Example 3 $\varphi = 90^\circ$ elevation plot.

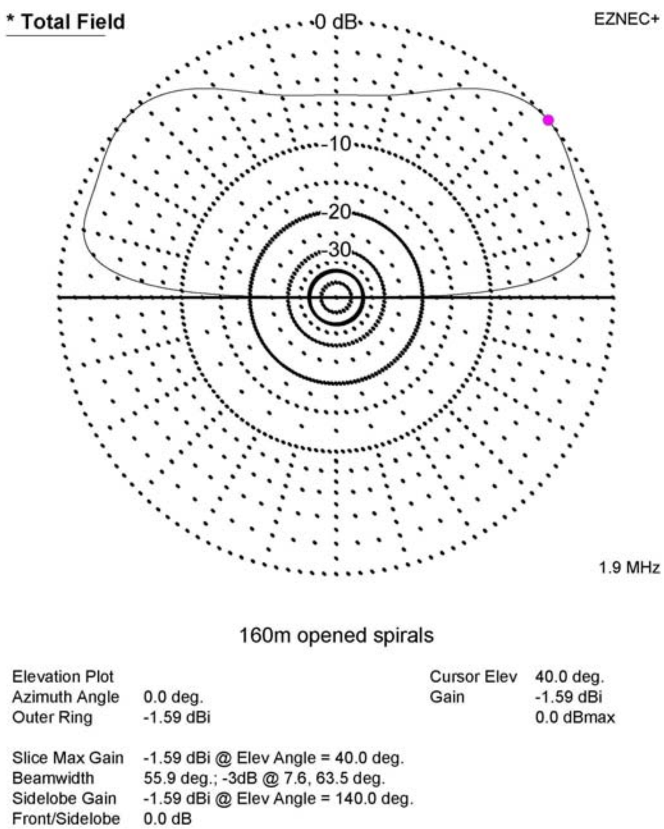

Fig. 9c. Example 3 $\varphi = 0°$, 80m height.

VI. Wire Diameter

It should be noted that the diameter chosen for the antenna wire has a significant effect on the antenna feed-point impedance, resonant frequency, and efficiency. To illustrate the effect, the table below contains the results for various diameters in the case of Antenna 2 at height 1 m above real ground. The tabulated feed-point impedances are at resonance, which decreases about 400 kHz through the 160m band as the wire diameter increases from 0.05 mm to 25 mm. Recall that copper conductor loss has been included in all the numerical modeling runs.

Wire Diam.	Feed-point Z	Max. Gain ($\varphi = 0°$)
0.05 mm	$392 + j10\ \Omega$	-21.6 dBi
0.25 mm	$29 + j48\ \Omega$	-10.4 dBi
1 mm	$9 - j21\ \Omega$	-5.76 dBi
5 mm	$5 - j2\ \Omega$	-3.37 dBi
25 mm	$4 + j23\ \Omega$	-3.5 dBi

The trend is clearly illustrated. Namely, increased wire diameter gives a more efficient antenna, but the improved maximum gain assumes that full power can still be transferred into the antenna while the feed-point impedance is simultaneously moving in a direction that makes full power transfer more and more difficult to achieve.

A general conclusion from multiple case studies is that a minimum wire diameter of 1 mm is necessary for acceptable antenna efficiency. Since a wire diameter of 0.08" (a readily available electrical wire size, #12) corresponds to 2 mm, it is not hard to comply with minimum efficiency expectations.

VII. Concluding Remarks

The three example antennas discussed here all demonstrate that the best wire geometry for a given rectangular size limit that will produce a natural resonance at the 160m amateur band (or other frequency of interest, for that matter) with the least overall wire length remains to be discovered. Antennas 1 -3 are all superior to the touted Hilbert fractal dipole in this regard.

Comparing "apples to apples" by looking at feed-point impedances and maximum gain for a wire diameter of 2 mm for all three example antennas allows some useful practical comparisons. First, it is noteworthy that a characteristic they share is that maximum gain broadside to the plane of the antenna barely depends on height above ground. The elevation pattern plot changes qualitatively as each is elevated to 80 m above ground, but the maximum gain is essentially unchanged from that with the antenna bottom only 1 m above ground. The example antennas all are more "cloud burners" with high-angle radiation when mounted close to ground, but high angle radiation is widely desired among a large segment of the amateur radio community for 160m and 75m operation so, to many, this is actually an attribute.

Antenna 1 is the most compact, measuring slightly less than 20 feet on a side. However, its maximum gain is approximately -10 dBi, which is almost two full S-units (1 S unit = 6 dB) down from the 2.15 dBi gain of a half-wave dipole in free space. Probably this is more sacrifice in radiation efficiency than most users would be willing to accept. Antenna 2 is larger, at approximately 30 feet on a side, but is only one S-unit down from the full sized dipole. Given that the antenna can be mounted at ground level, this makes it an attractive possibility. The radiation resistance of Antenna 3 is twice that of Antenna 2 and it has a maximum gain about 1.5 dB greater. The disadvantages of Antenna 3 are an awkward geometry for construction and deployment, and its overall height of 60 feet.

It would not be unreasonable to conclude that Antenna 2 is the best overall compromise antenna of the lot.

Readers are invited and encouraged to devise and analyze their own alternative designs, taking current vector alignment into consideration as new geometries are conceptualized. The author would welcome any reports of progress and noteworthy successes.

Finally, the reader will note that references [3]-[7] are not associated with specific points or statements in the text of this article, which is somewhat unusual. They are included, however, as deserving mention and credit because their content is relevant to, and influenced, this paper. The author gratefully acknowledges inspiration for this engineering application study gained from the short course on advances in electrically small antennas conducted by Steven Best at the 2004 IEEE International Symposium on Antennas and Propagation.

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[2] EZNEC is a software product of Roy Lewallen, as described at http://www.eznec.com/.

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