Size Reduction of a Folded Conical Helix Antenna

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Introduction

Recently a wire antenna that utilizes spiraling and folding has been reported [1]. This antenna, called the folded conical helix antenna (FLEX), shows performance that is comparable to other successful small antenna designs [2,3]. Because of the long wavelengths at HF and VHF, even electrically small antennas can be physically large. The original FLEX antenna reported in [1] was approximately 0.1λ in radial extent (FLEX No. 1). For many applications, this may still be too large. This effort focuses on the development of reduced size versions of this antenna, FLEX No. 2, 0.03λ in radial extent, and FLEX No. 3, 0.016λ in radial extent.

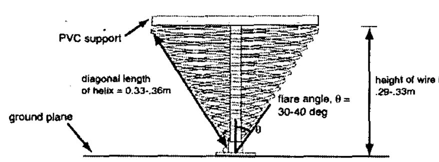

Figure 1. Folded conical helix (FLEX) antenna shown with four monopoles

As reported in [1], the folded conical helix antenna is a composition of multiple folded monopole antennas spiraled in the form of a cone. The cone angle was about 35 degrees chosen to provide 50 ohms impedance for a large conical structure. The resonance frequency of the antenna is determined by the length of the individual folded monopoles. The spiral is an Archimedes spiral. The overall electrical size is determined by the number of monopoles used and the number of turns of the antenna. Impedance transformation of the folded monopole spiraled in the antenna appears to be similar to the impedance transformation expected in a simple monopole. However, double tuning becomes more difficult as the size is decreased. A very curious result is that at very small sizes, kr of 0.1, this antenna appears to have a wider bandwidth that would be expected from a second order antenna even when the reduced efficiency is accounted for.

Analysis

We measured efficiency with the Wheeler cap method. We compared these measurements to relative gain measurements made comparing the FLEX antenna to a reference monopole. One problem with Wheeler cap measurements is that placing a cap over the antenna causes a shift in the resonance frequency of the antenna. McKenzie [4] has proposed a phase rotation method to try to correct for the resonance shift. However, we found that we got better agreement between the cap measurements and the relative gain measurements if we translated the cap data in frequency to align the reactance zero crossing points, then computed the efficiency assuming a series RLC circuit model.

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After frequency translation, we noted that the reactance curves from the capped and uncapped measurements agreed very closely in the vicinity of the zero crossing. Since the reactance of the antenna is very sensitive to the current distribution on the antenna, the similarity of reactance curves may indicate that, except for a small shift in frequency, the overall distribution of the currents are not altered significantly by the cap near the frequency of interest. Simulations with NEC of a simple quarter-wave monopole also show that frequency translation of the cap data to compare with the free-field data will give results close to actual efficiencies.

Because of the relative difficulty of comparing antennas of different sizes, we introduce a figure of merit for small antennas, ψ,

$$\psi = \frac{ebQ_{rad}}{2} \qquad (1)$$

where e is the fractional efficiency, b is the fractional bandwidth, and Q_{rad} is the nominal radiation Q of the antenna defined by the kr of the enclosing sphere at the center frequency. We use the exact expression for radiation Q given in [5]. The resulting figure of merit is equal to unity for an antenna with a bandwidth of $2/Q_{rad}$ (loaded second order antenna) and an efficiency of unity. Including the efficiency term allows correction for the fact that losses decrease the Q of the antenna. The advantage of equation 1 is that it normalizes out the effects of changes in bandwidth with antenna size, and allows antennas of different sizes and efficiencies to be compared.

Results

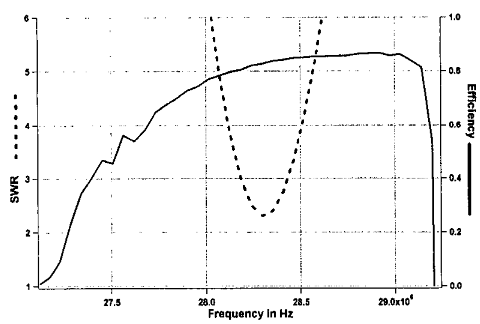

Figure 2. Wheeler cap efficiency and SWR for the kr=0.2 FLEX No. 2 antenna

The SWR and efficiency measurements for the FLEX No. 2 antenna composed of four monopoles are shown in Figure 2. The center frequency is 28.3MHz, the minimum SWR is 2.3, and the half power bandwidth (SWR = 5.8) is about 570KHz. The linear extent of this antenna is about 13 inches making it a kr of 0.2, and the diameter ratio of parasitic to driven wire was 2.3, and the driven wire was 16 gauge solid copper magnet wire. At resonance the efficiency as measured by the Wheeler cap is 0.83. The measured gain was 1.5dB less than a reference quarter wave monopole.

For all of the FLEX antennas discussed in this paper including the antenna in [1], the ground plane was a 2m x 2m brass screen over plywood with the antenna mounted in the center. For the lowest frequencies, additional ground radials of one quarter wavelength or greater were attached to the ground screen, but no effect was observed on the impedance measurements.

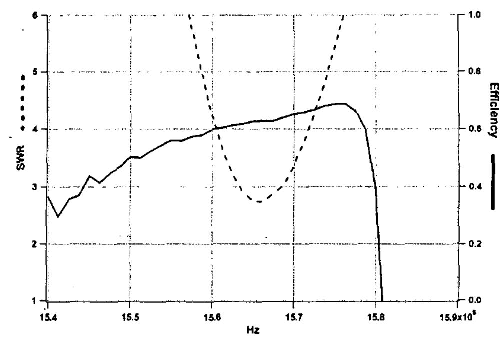

Figure 3. Wheeler cap efficiency and SWR for the kr=0.2, FLEX No. 3 antenna

Figure 3 shows the combined SWR and Wheeler cap efficiency for the FLEX No. 3 antenna. The SWR shows that this antenna is well matched with a minimum SWR of 2.7 and a resonance frequency of 15.6MHz. The physical size of this antenna is the same as the FLEX No. 2 antenna, and is about 1ft tall, and 8" in radius at the top of the cone. The bandwidth is about 180KHz or about 0.012. The efficiency curve for this antenna appears to drop off at the upper end of the band. However, we note that the Wheeler cap measurement is only rigorous at the resonance frequency. We made relative gain measurements for two versions of this antenna and found that the gain was 2dB to 2.5dB less than a commercially available center-loaded whip that was approximately 7 ft tall. Furthermore relative gain measurements were made across a frequency band of 160KHz showing that the gain bandwidth was comparable to the impedance bandwidth of the antenna.

Comparison and Figure of Merit

Table 1 shows the sizes and figures of merit for some of the well known types of small monpole antennas. We find for FLEX 3 (kr = 0.108, Q_{rad} = 797), the measured 3dB bandwidth is 0.012, and the efficiency is about 0.60. Thus the value of ψ is 2.9. For FLEX 2 kr = 0.196, e=0.83, b = 0.02, and Q_{rad}=138, then ψ is 1.14. (might want to 2 and 3 in order). We see that the FLEX antennas compare very favorably to other types of small monopoles.

Although the figure of merit proposed here is intended to be independent of antenna size as well as compensate for variations in antenna efficiency, it is very important to realize that this figure of merit depends on the definitions of bandwidth and efficiency used. Although the half power bandwidth is useful for a variety of applications, there are other definitions of bandwidth, such as the matching area used by Wheeler [6], which are integral types of definitions and include the effects of the quality of the match over the band.

Table 1. Comparison of Figures of Merit of Various Antennas

Antenna	Size (kr)	ψ
Folded Monopole [3]	1.00	0.8 (no efficiency data)
Parallel Strip Monopole [2]	0.73	0.75
FLEX No. 1 [1]	0.68	0.66 (100 ohm reference)
FLEX No. 2	0.18	1.14
FLEX No. 3	0.1	2.9

Conclusions

We have shown that the folded conical helix or FLEX antenna performs very well as an electrically small monopole antenna. Using the figure of merit proposed in this work we can quantitatively compare this antenna to other types of electrically small antennas in different size ranges and efficiencies. This highest figure of merit is achieved by the electrically smallest antenna, which has a size of kr=0.1, and it appears to be considerably higher than might be expected. Two different efficiency measurements show reasonably consistent results, and the measured gain bandwidth is consistent with the impedance bandwidth. Therefore, the FLEX antenna should be a practical and broadband compact antenna for the MF, HF, and VHF frequency ranges.

Acknowledgements

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