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Understanding the CWTHA

This technical reprint about resonant contrawound toroidal helixes is good food for thought.

Here, the resonant CWTHA is examined via a moment-method simulation. The results show a very high impedance at first resonance, with a narrow bandwidth and low efficiency. At second resonance, the resistance is less than an ohm, the reactance is zero, and again, the bandwidth is narrow. The azimuth patterns are not omnidirectional, but may have a dip of 10 dB or more. The simulation shows a loop-mode cancellation of at least 140 dB.

The contrawound toroidal helix antenna has aroused considerable interest in recent years. The concept is simple: The two windings fed out of phase cancel the loop mode and augment the dipole mode, thereby providing a low-profile antenna that radiates an electric field normal to the plane of the toroid. As originally conceived by the inventor, Dr. Corum, the CWTHA was a resonant antenna — that is, it operated at a frequency where the antenna was resonant.[1]

A recent study[2] showed that, when the winding length is less than quarter wavelength, the current is approximately constant, and the pattern in the plane of the toroid is omnidirectional. However, it was shown that the radiation resistances for these small antennas were extremely low. The objective of this work is to examine the larger self-resonant CWTHA.

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Moment-method simulation

Although the exact vector potential solution has been written for the CWTHA, numerical integration is required to obtain numerical values. Here, the antenna is simulated via the moment method. The code used is the Tilston-Balmain bridge current modification of the Richmond piecewise sinusoidal Galerkin code.[3] Studies on single-turn loop antennas have shown that 12 segments per turn gives an excellent representation of a circular turn. Thus, the results discussed here are based on 12 segments per turn. The coordinates of the two windings can be written exactly in spherical coordinates.[4] The two windings have one common feedpoint. The number of segments for each winding is then 12 times the number of turns of wire around the helix. To obtain a preliminary idea of the performance of the resonant CWTHA, the two cases examined both have a ratio of toroid diameter to turn diameter of 10, and a ratio of turn diameter to wire radius of 20. This allows a reasonably fat wire, but assures convergence. A wire conductivity of 90% of that of pure copper was used. Because the matrix is poorly conditioned due to the counteracting windings, all calculations have been done in double-precision complex.

Results

Case 1 involved 20 turns. To avoid a multiple-parameter presentation, 100 MHz was selected as a realistic value, representing, in general, both HF and UHF effects. Of course, these antennas

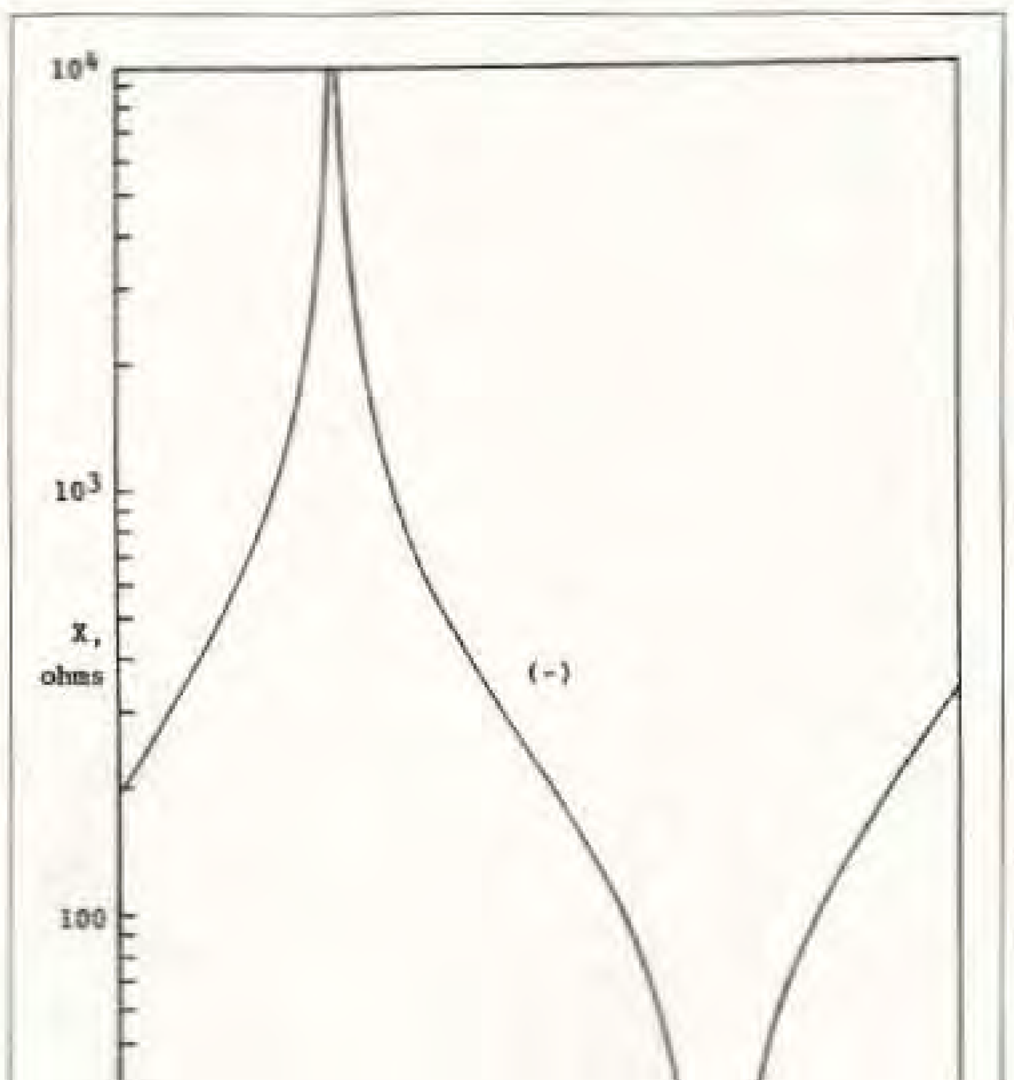

Fig. 1. Reactance for 20-turn CWTHA.

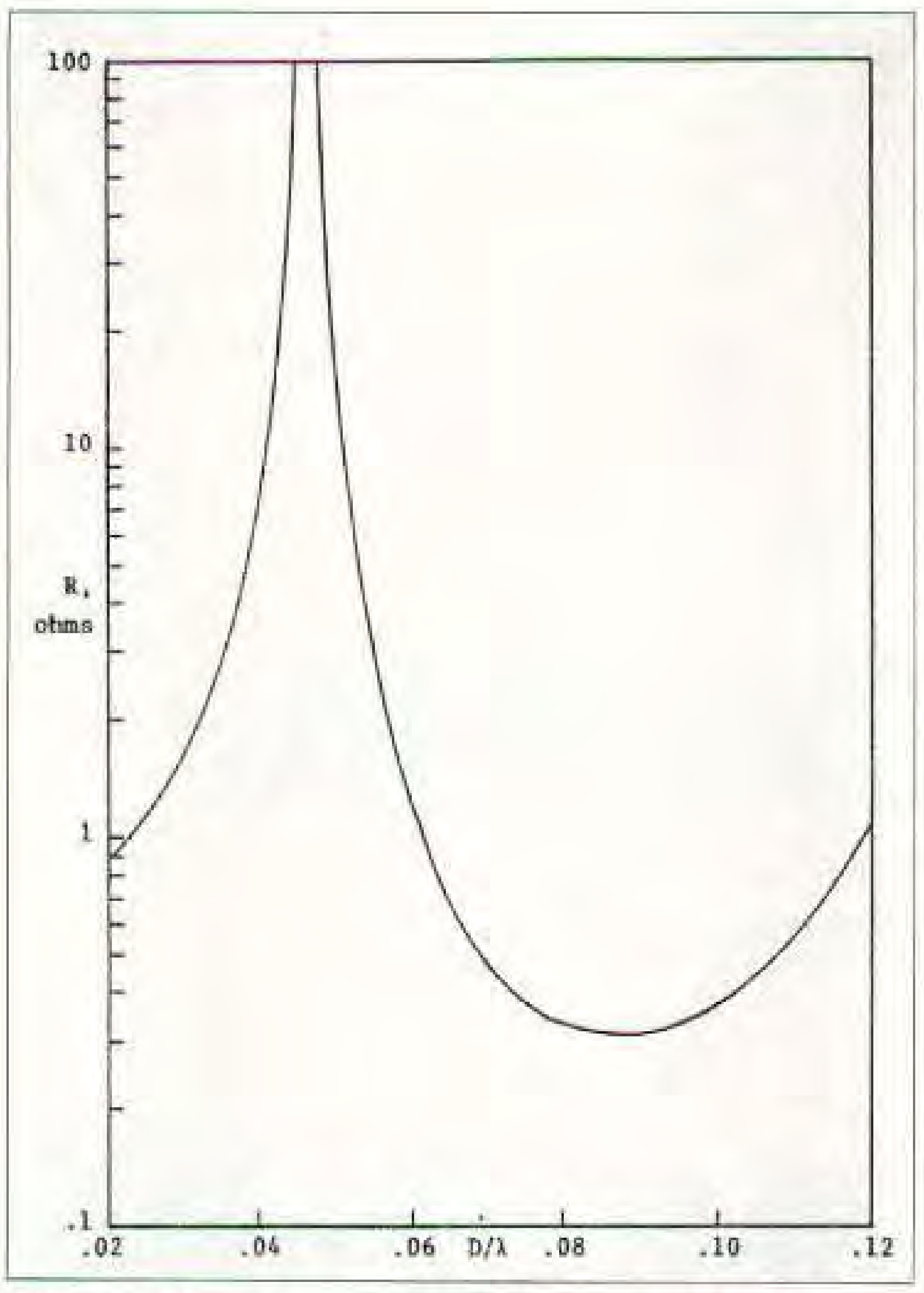

Fig. 2. Resistance for 20-turn CWTHA.

are of no use in the microwave region, where electrically small antennas are not needed. This case used 481 equations. One unknown couples the two windings. The loop-mode cancellation was 143 dB. **Fig. 1** shows the reactance of this antenna for a diameter range from 0.02 to 0.12 wavelengths. It can be seen that the first resonance is extremely sharp and the Q is high. It occurs for a toroid diameter of 0.046 wavelengths. At the second resonance, toroid diameter of 0.091591, the reactance is zero. **Fig. 2** shows the corresponding input resistance, and again, the Q has increased the intrinsic radiation plus loss resistance at first resonance. At the second resonance, the resistance is varying slowly, and is roughly 0.3Ω. A calculation of Q, assuming constant resistance, gives a value of 1,635 there. It is interesting to note that the currents opposite the feedpoints are almost the same as those at the feed, with maxima at ±90° points. This is probably because the structures, although resonant due to the winding, are still small in wavelengths. **Fig. 3** shows a quarter of the azimuth pattern normalized to 0 dB at f = 0; the other quadrants are images. Note that there is almost a 10 dB dip at ±90°, so the antenna is not at all omnidirectional. The elevation pattern is closely that of sin q. Note that, in the patterns, the z-component of the electric field is used, rather than the spherical coordinate component. The efficiency was less than 0.2% due to the small intrinsic radiation resistance. At second resonance, the efficiency was 7.4%, but matching losses, to match 0.3 to 50Ω, would decrease this significantly.[5] For a toroid diameter of 0.43821, the input resistance was 50Ω. However, the inductive reactance was 3,000Ω, which would provide a very small bandwidth if matched with a capacitor.

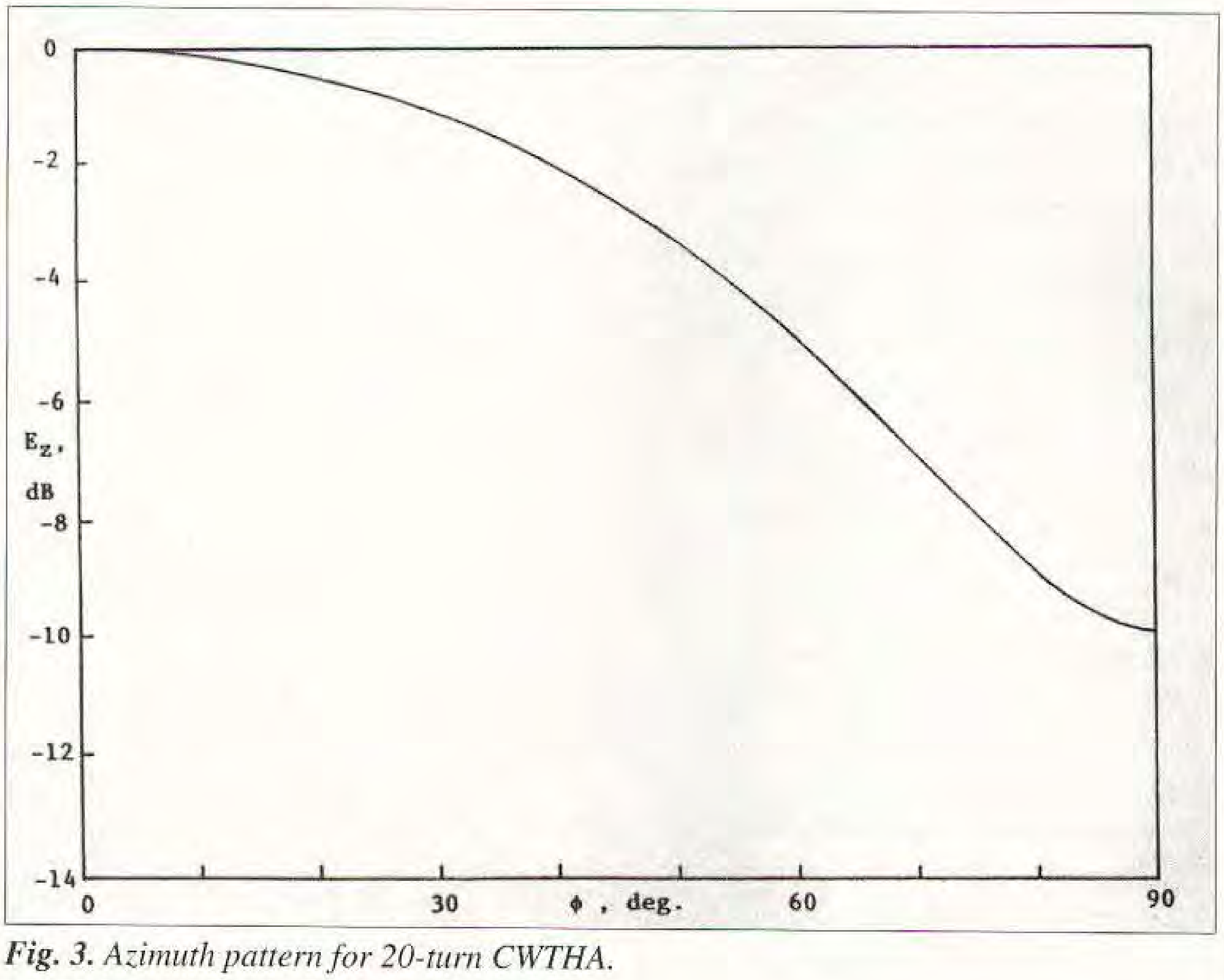

Fig. 3. Azimuth pattern for 20-turn CWTHA.

Case 2 was similar, except that it employed ten turns. All other parameters were the same. For this antenna, 341 equations were used. The principal change is that first resonance now occurs for a toroid diameter of 0.09121, and second resonance occurs for a toroid diameter of 0.18081 due to the smaller number of turns. Again, both the real and imaginary parts of impedance are very sharply peaked at first resonance, indicating a high Q. The efficiency is roughly 1%. The reactance is also rapidly varying at second resonance; Q was calculated to be 2,300. The efficiency there was higher, 30%, but the small resistance of 0.3Ω makes matching very lossy. The azimuth pattern is flatter, showing a dip of somewhat more than 4 dB. Again, the elevation pattern is essentially sin q. The loop-mode cancellation is 181 dB. The 50Ω input resistance occurred for a toroid diameter of 0.087573 wavelengths; again, the inductive reactance was 4,000Ω, very large. It is to be expected that the impedance will again be very high at the third resonance. However, at the higher resonances, the toroid diameter is no longer electrically very small.

The winding length is given approximately by

$$l \cong \pi D\sqrt{1 + [NT \cdot NS\sin(\pi / NS) / \pi(D / d)]^2}$$

where the toroid and turn diameters are D and d, NT is the number of turns, and NS is the number of segments per turn. For case 1 with $NT = 20$, the wire lengths at the two resonances are 0.321 and 0.641; for case 2 with $NT = 10$, they are 0.641 and 1.261.

Conclusions

The resonant CWTHA exhibits a very high Q at the first two resonances, and as expected, a very narrow bandwidth at both. Azimuthal dips occur with depths depending on the ratio of toroid to turn diameter and the number of turns. For the two cases calculated, the dips at first resonance range from

Continued on page 59

Understanding the CWTHA

continued from page 32

4 to 10 dB. At the second resonance, the azimuth pattern is a figure eight. Efficiencies at first resonance are very low; they range from less than 1% for 20 turns to 1% for 10 turns.

Footnotes

1. J.F. Corum, Toroid antenna, U.S. patent 4,622,558, Nov. 11, 1986.
2. R.C. Hansen and R. Ridgley, Modes of contrawound toroidal helix antenna, *Microwave Opt Technol Letter 23* (1999), 365–368.
3. M.A. Tilston and K.G. Balmain, On the suppression of asymmetric artifacts arising in an implementation of the thin-wire method of moments, *IEEE Trans Antennas Propagat 38* (1990), 281–285.
4. T.S. McLean and F. Rahman, Small toroidal antennas, *Electron Lett 14* (1978), 339–340.
5. R.C. Hansen, Superconducting antennas, *IEE Trans Aerosp Electron Syst 26* (1990), 345–355.

Additional reference

R.C. Hansen, Fields of the contrawound helix antenna, *Trans. IEEE,* Vol. AP-49, August 2001, 1138–1141.