Controlled-Current-Distribution Antenna Performance: By Analysis

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I became interested in controlled-current-distribution (CCD) antennas after reading about them in *The ARRL Antenna Compendium, Volume 2*.[1,2] I later had a QSO with Jim Gray, W1XU, who was using a CCD antenna and putting out a good signal. Jim provided me with several references[3-6] which increased my curiosity. I found myself asking a lot of questions but getting inadequate answers concerning the theory of CCD antenna operation. The purpose of this article is to present the results of an extensive analysis performed using the MININEC antenna analysis program.[7]

Background

A CCD antenna consists of a length of wire broken into short sections separated by capacitors. As explained in the preceding article by the CCD inventors, the capacitor values are chosen to resonate or nearly resonate the inductance of the wire lengths at the design frequency, as shown in Fig 1 here. The capacitively loaded wire antenna may be configured as a dipole, vertical, loop or any other shape.

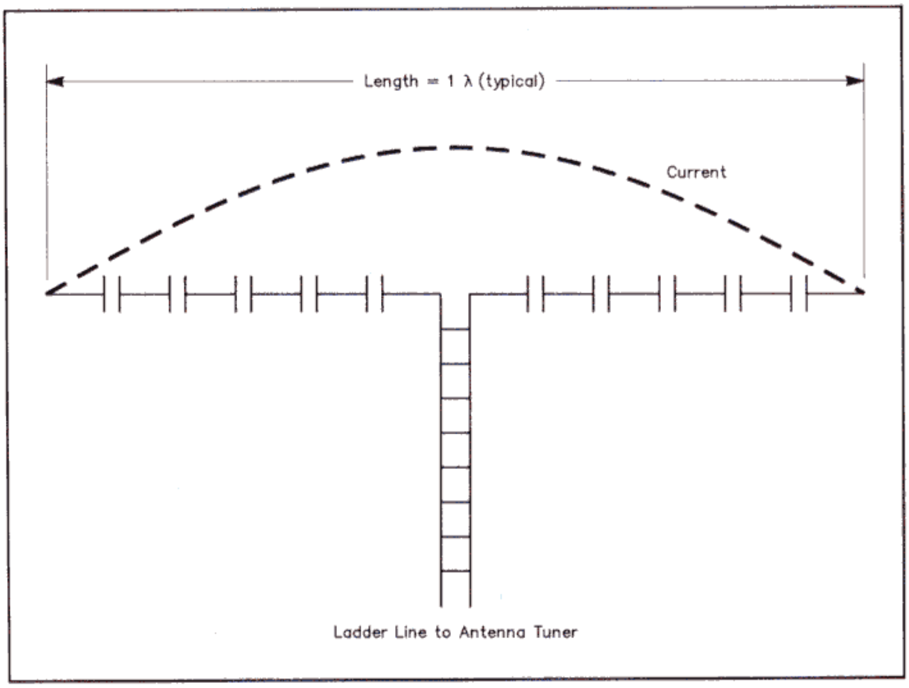

Fig 1—CCD dipole antenna configuration and current distribution. CCD dipoles are typically constructed with about 20 capacitors per half wavelength.

The main feature of a properly designed CCD antenna is the current distribution. For a CCD dipole of any length the current is at maximum at the feed point and decreases to zero at the open ends without the current reversals present in long-wire antennas. Since the phase reversals in a long-wire antenna are responsible for multiple lobes in the radiation pattern, the CCD antenna only contains the main lobes. One additional feature of a full-wave CCD is its low input impedance. A full-wave center-fed wire (two half waves in phase) has a center feed-point impedance of several thousand ohms due to the current minimum at its center, while a CCD dipole of the same length has a moderately low impedance.

The CCD dipole is simply a cascade of series-resonant circuits, each of which has no net phase shift through it. The phase shift through the inductive wire section is canceled by the opposite phase shift of the capacitor. It looks like a length of wire with current flowing through it but with no traveling-wave phase shift as observed in a plain length of wire. The open-circuit boundary condition at the dipole ends forces the current to zero at these points. The current distribution is *not* uniform in a CCD dipole, as some authors have suggested.

Above the design frequency the capacitive reactance decreases and the antenna behaves more like a plain wire. Below the design frequency the capacitive reactance gets larger. For the designs I have analyzed,

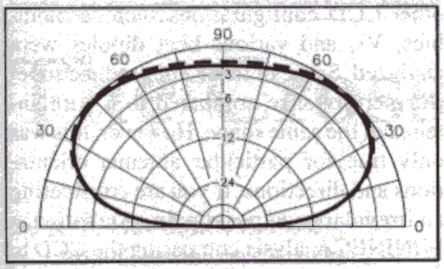

Fig 2—Vertical-plane radiation patterns of 40-meter center-fed antennas of 1 λ. Solid line: CCD dipole; broken line, center-fed wire (two half waves in phase). Note that the CCD dipole shows no performance advantage over the full-wave wire. CCD design: 48 equal-length wires, total length 140 feet, with 46 390-pF capacitors. Center-fed wire length = 130 feet. Maximum gain for both antennas is at a 51° elevation angle.

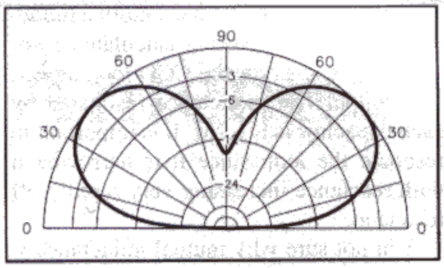

Fig 3—Vertical-plane pattern of an 80-meter horizontal full-wave CCD loop 40 feet above ground. The azimuth pattern is within 0.4 dB of being circular. This loop has its gain peak at 44° elevation. This is much better than the straight-up radiation characteristics of a wire loop at the same height. Design: 40 7-ft wires with 38 470-pF capacitors and a 235-pF capacitor opposite the feed point (to resonate two inductors). Calculated radiation resistance: 32 Ω.

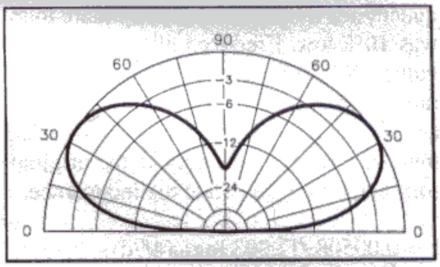

Fig 4—Vertical-plane pattern of a 40-meter horizontal full-wave CCD loop 40 feet above ground. Its azimuth pattern is within 0.8 dB of being circular. The gain peak of this loop is a very respectable 36°. Design: 40 3.5-ft wires with 38 270-pF capacitors and a 135-pF capacitor opposite the feed point. Calculated radiation resistance: 71 Ω.

Table 1
Dipole Performance Comparison

Antenna Type	*Frequency (MHz)*	*Gain (dBi)*	*Impedance (ohms)*
Full-wave CCD	7	6.4	306
Full-wave wire	7	6.8	>4k
Half-wave CCD	7	5.6	62*
Half-wave wire	7	5.5	84
Full-wave CCD at half frequency	3.5	7.8	11.5*

*Real part only (resistive component)

however, radiation at half the design frequency does take place with performance comparable to a half-wave wire dipole.

Analysis

My interest in this unique antenna is a product of my desire for a better 40-meter signal. I use a beam for the higher frequency bands with good results, but it's hard to compete for DX on 40 meters with an inverted V up only 40 feet at its apex. Since I can't put my antennas any higher, I performed my analysis at 40 feet. This should be of interest to amateurs with limited space for antennas. I didn't compute free-space patterns since I was only interested in the performance over real ground. I used a ground conductivity of 4 mS/m and a dielectric constant of 13 for all of my calculations. There may be errors in the impedances calculated by MININEC since real-earth ground effects are not taken into account by this analysis program. The gains and antenna patterns *do* take real-ground reflections into account. [But the gain calculations in turn use the results of the impedance calculations, so cannot be taken as absolutely accurate.—*Ed.*]

CCD Dipole Performance

A summary of the computed performance for CCD full- and half-wavelength dipoles and their wire counterparts is shown in Table 1. Calculated antenna radiation patterns for the full-wave versions are shown in Fig 2. There is no significant performance difference between the CCD dipole and a wire antenna of the same length. The only advantage of the CCD full-wave antenna is its low input impedance.

Table 1 does not show the large input reactance of a CCD dipole when operated at half frequency. The 3.5-MHz example shown has a 1500-Ω capacitive input reactance which may make matching difficult at high power levels since the input resistance is very low. The half-wave CCD dipole is also not resonant. The original authors pointed out this fact,[4] and the analysis provided verification.

CCD Horizontal Loop Performance

A CCD loop differs from a dipole in a very significant way: it has no open-circuit ends to cause the current to be zero. A virtually uniform current distribution exists around the entire loop at resonance. The performance of a loop of any size with a constant current is described in Section 6-6 of *Antennas* by John Kraus.[8] The familiar donut-shaped pattern of a small loop is maintained for diameters up to ¾ λ.

The computed antenna patterns for 80- and 40-meter full-wave CCD loops are shown in Figs 3 and 4. The very respectable low-angle radiation performance of these loops makes them an attractive alternative for low-band enthusiasts. A full-wave wire loop at this height radiates straight up and exhibits a free-space impedance of about 100 Ω. (The MININEC computed impedances are shown in the captions for the figures.) The accuracy of the radiation resistance is questionable at 80 meters, however, since the antenna is less than ¼ λ high and since MININEC does not accurately account for the influence of real ground when calculating radiation resistance.

CCD Horizontal Loop Analysis

I have analyzed a number of antennas with open-circuit ends, including a horizontal loop with a gap opposite the feed point. Their resonant frequencies all coincide with the resonance of the wire sections with the capacitors. You can imagine my surprise when the computed resonant frequency for a full-wave closed square loop was 10% low. I reduced all the capacitor values by 10% and the loop resonance moved up about 5%. Since the capacitors are ideal loads, this meant the inductance must be wrong. I went back to the original formula used to calculate the inductance.

$$L = 0.00508\,\ell[2.303\log_{10}(4\ell/d) - 0.75]\ \mu\text{H}$$

where

ℓ = wire length, inches

d = wire diameter, inches

I checked my calculations and found they were correct. Then it dawned on me that two inductors brought close together have mutual inductance. Terman's *Radio Engineers Handbook*[9] contains formulas for the mutual inductance of straight wire sections connected end to end and with a gap between them (designated as "D"). For equal-length wire sections connected end to end the formula reduces to

$$M = 0.00352\,\ell\ \mu\text{H}$$

For wire sections with a gap D,

$$M = 0.00585\,(2\ell + D)\log_{10}(2\ell + D) + D\log_{10}D - 2\,(\ell + D)\log_{10}(\ell + D)\ \mu\text{H}$$

The computer performs its analysis with no gaps in the wires, but practical CCD antenna construction techniques use insulating spacers to support the series capacitors. When the effects of mutual inductance were included, the calculated resonant frequencies for the CCD loop agreed within 1%. The inductance resonated by each capacitor is L + 2M. It is important to resonate the loop since it is narrowband with reactance increasing very rapidly off resonance.

I'm not sure why mutual inductance is not a factor in determining CCD dipole resonance, but it is important to note that the radiation mechanisms for the two antenna types are significantly different.[10] The CCD loop antenna radiates because the moving electric charge is accelerated as it moves in a curve. On the other hand, the dipole radiates due to the acceleration of the reflected charges at the open ends and the feed point. The charges oscillate back and forth and undergo periodic acceleration. Currents traveling in opposite directions may cancel whatever mutual inductance is present.

Conclusions

CCD full-wave horizontal loops are an exciting option for the low-band enthusiast with limited space. Additional work needs to be done to measure or compute the impedance of loops close to ground. A CCD dipole, on the other hand, exhibits no real advantage over a wire dipole. Although not presented in this article, CCD verticals were analyzed and found to offer no advantage over conventional verticals, in my opinion.

During the course of this investigation, other CCD configurations such as rhombics, Vs, and various bent dipoles were analyzed. Some of these *did* produce superior performance compared to a wire antenna of the same shape. However, this was only true for particular antenna orientations and directions. If you are considering an irregularly shaped dipole installation, a MININEC analysis comparing the CCD to a wire antenna would be worthwhile.

References

[1] S. Kaplan and E. Bauer, "The Controlled Current Distribution (CCD) Antenna," *The ARRL Antenna Compendium, Volume 2*, 1989, pp 132-136.

[2] S. Keen, "The End-Coupled Resonator (ECR) Loop," *The ARRL Antenna Compendium, Volume 2*, 1989, pp 137-139.

[3] H. A. Mills and G. Brizendine, "Antenna Design: Something New," *73*, Jul 1981, pp 282-289.

[4] H. A. Mills and G. Brizendine, "The CCD Antenna—Another Look," *73*, Jul 1981, pp 50-57.

[5] D. Atkins, "The High-Performance, Capacitively Loaded Dipole," *Ham Radio*, May 1984.

[6] G. Rennie, "Again, The CCD," *73*, Sep 1985, pp 12-14.

[7] ELNEC by Roy Lewallen, W7EL, was used for the dipole calculations. MNC by Brian Beezley, K6STI, was used to analyze the CCD loops.

[8] J. Kraus, *Antennas* (New York: McGraw Hill, 1988), Chapter 6.

[9] F. Terman, *Radio Engineers Handbook* (New York: McGraw Hill, 1943), pp 48 and 66.

[10] See pp 50-52 of Ref 8.