Planar Elliptical Element Ultra-Wideband Dipole Antennas

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Abstract:

This note introduces a new class of planar ultra-wideband (UWB) dipoles that use elliptical elements. These antennas offer good dipole performance over nearly two octaves in frequency. Unlike more traditional broadband dipole elements that must be around a quarter-wavelength to radiate efficiently, planar elliptical UWB dipoles still exhibit a –10 dB return loss for a 0.20λ element size, and remain 50% efficient (–3 dB return loss) for a 0.14λ element size. A wide variety of techniques including exponential and Klopfenstein tapers, and an energy flow analysis all converge to an element axial ratio of about 1.5:1 being optimal.

Introduction:

A variety of planar dipoles antennas exhibit ultra-wideband performance. These include bow tie antennas[1] and diamond dipoles.[2] Recently, work has been done on elliptical and disk monopoles that are well matched to 50 Ω and exhibit superior broadband performance.[3] One might expect that if a monopole element were well matched to 50 Ω, the corresponding element in a dipole configuration would have a characteristic impedance of around 100 Ω.

This note introduces a new class of planar ultra-wideband (UWB) dipoles that use elliptical elements. Counter to expectation, these antennas are well-matched to 50 Ω, and offer good dipole performance over nearly two octaves in frequency. This note discusses the performance of a variety of elliptical planar dipoles with differing eccentricity.

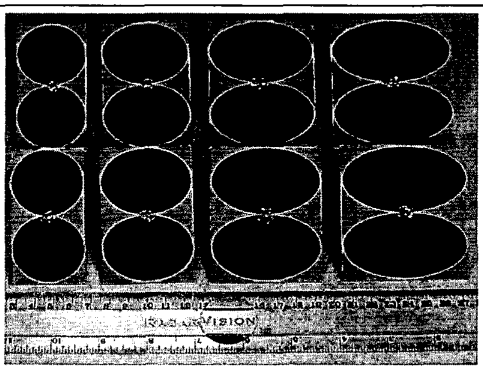

Figure 1: Matched pairs of planar elliptical dipoles. From left to right, the ratio of major to minor axes are: 1.00:1, 1.25:1, 1.50:1, and 1.75:1

Elliptical Dipoles:

Four different elliptical dipoles are discussed in this note. The ratio of major to minor axes of the test antennas were 1.00:1, 1.25:1, 1.50:1, and 1.75:1. A photo of these antennas is provided in Figure 1. The antennas were implemented on 60 mil Rogers RO4003 substrate.

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Matching:

Figure 2 shows return loss or S_{11} for four planar elliptical dipoles with various eccentricities. All four antennas have a return loss –10 dB or better for minor axis $l_\lambda \geq 0.20\lambda$. This is somewhat smaller than the 0.25λ usually thought to be necessary for efficient radiation. In fact, these antennas have a radiation efficiency of greater than 50% for $l_\lambda \geq 0.14\lambda$.

Match improves with increasing eccentricity. The 1.00:1 elliptical (circular) elements yield an S_{11} of around –12 dB; for the 1.25:1 elliptical elements, the S_{11} is about –15 dB; the 1.50:1 elliptical elements' reflection is about -20 dB; and the 1.75:1 elements exhibit an S_{11} around –30 dB.

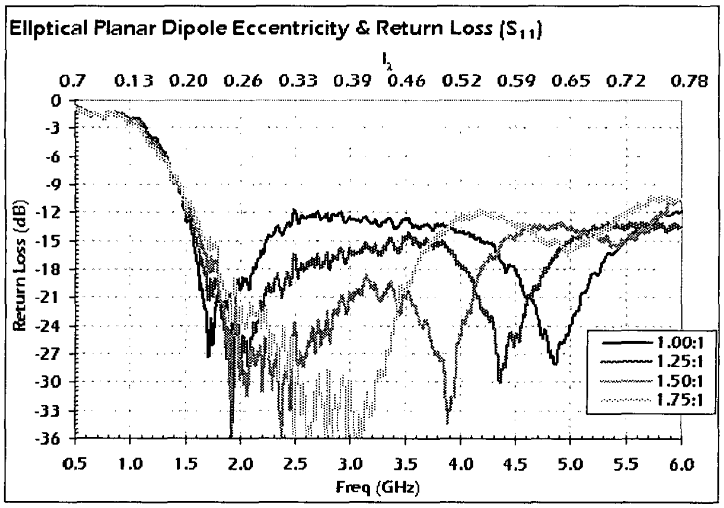

Figure 2: *Return loss (S_{11}) for various eccentricity planar elliptical dipoles.*

Gain and Pattern:

In their lowest order mode, these antennas behave like dipoles. This dipole behavior dominates for roughly a 1:3.5 span in frequency. Boresight gain is nominally around 2.0 dBi, as one would expect for a dipole. Boresight gain is shown in Figure 3. A time domain impulse pattern range was used to acquire azimuthal (H-plane) patterns of these planar dipoles. A broadband 1-6 GHz impulse source was used to excite the antenna, and the peak radiated power was determined as a function of angle. The resulting patterns are shown in Figure 4. As can be seen, increasing eccentricity yields an increasingly asymmetric pattern.

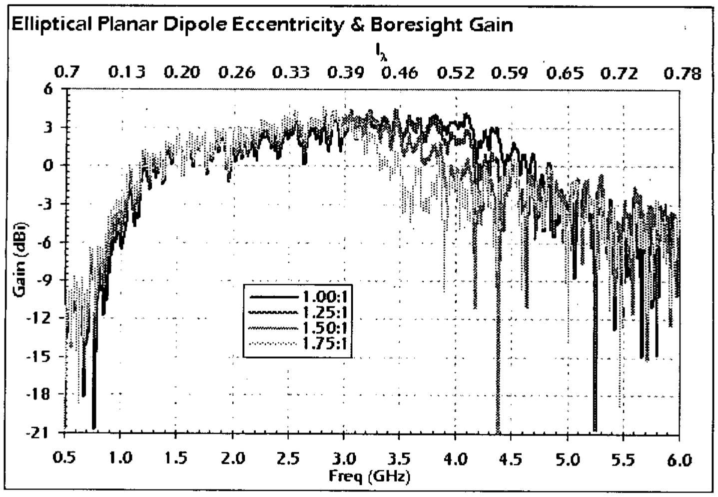

Figure 3: Boresight gain of various eccentricity planar elliptical dipoles.

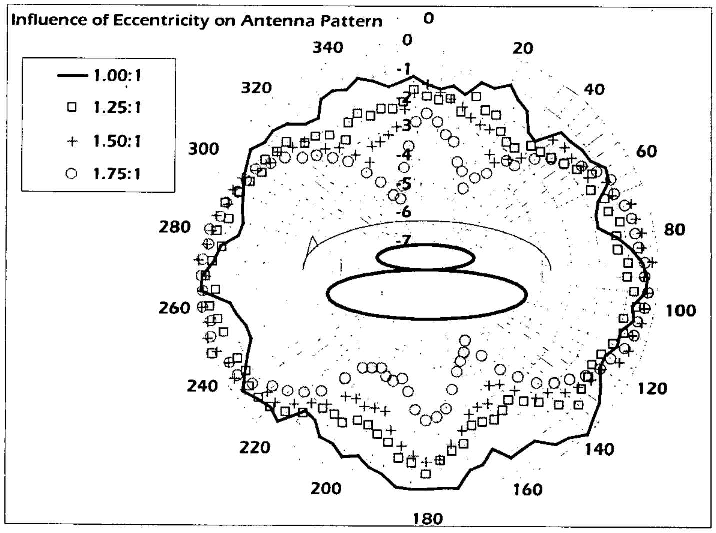

Figure 4: Azimuthal (H-plane) peak power patterns of various eccentricity planar elliptical dipoles.

Planar Elliptical Dipoles As Parallel Horns:

One way to think of a planar elliptical dipole is as a pair of opposing slotline horns. Expressions are available to calculate the impedance of a slotline.[4] Treating the slotline as a 100Ω-377Ω transformer between the feed and a circular boundary, slot widths were calculated assuming an exponential and a Klopfenstein taper.[5] Additionally, an analysis of energy flow around an ideal dipole was used to determine yet another taper.[6] All three of these methods yielded results virtually indistinguishable from an elliptical dipole with an element axial ratio of 1.50:1 (see Figure 5). These concepts were used in the Time Domain Corporation's patent pending "BroadSpec™" family of ultra-wideband planar dipole antennas.[7]

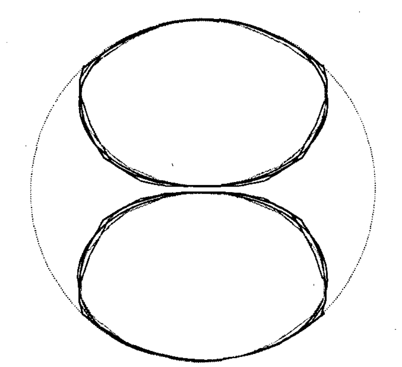

Figure 5: *Antenna shapes found using an exponential taper (black), a Klopfenstein taper (red), an energy flow analysis (green) and a 1.50:1 element axial ratio ellipse (blue). All four results are virtually identical.*

Summary:

The planar elliptical dipole is a well-matched, high efficiency radiator and receiver of ultra-wideband RF energy. Increasing eccentricity yields improved matching but a less uniform azimuthal (H-plane) pattern. A wide variety of techniques including exponential and Klopfenstein tapers, and an energy flow analysis all converge to an element axial ratio of about 1.5:1 being about optimal.

References:

[1] J. Kraus, ***Antennas*** 2nd ed. (New York: McGraw Hill, 1988) pp. 354-5.

[2] H. Schantz & L. Fullerton, "The Diamond Dipole: A Gaussian Impulse Antenna," 2001 IEEE Antennas & Propagation Society International Symposium, Vol. 4, July 8-13, 2001, pp. 100-103.

[3] N.P. Agrawall, G. Kumar, and K.P. Ray, "Wide-Band Planar Monopole Antennas," IEEE Transactions on Antennas and Propagation, **46** 2 February 1998 pp. 294-295.

[4] K.C. Gupta et al, ***Microstrip Lines and Slotlines***, 2nd ed. (Boston: Artech House, 1996), pp. 282-286.

[5] D. Pozar, ***Microwave Engineering***, 2nd ed. (New York: John Wiley & Sons, 1998), pp. 290-295.

[6] H. Schantz, "Electromagnetic Energy Around Hertzian Dipoles," IEEE Antenna and Propagation Magazine, Vol. 43 No. 2, April 2001, pp. 51-62.

[7] H. Schantz, "Ultra Wideband Technology Gains a Boost from New Antennas," Antenna Systems & Technology, Vol. 4 No. 1 January/February 2001, p. 25. See also http://www.timedomain.com/Files/PDF/news/AntennaSchantz.pdf