Bi-layer, mode 2, four-arm spiral antennas

M. Buck and D. Filipović

A bi-layer, four-arm, printed spiral antenna having a well-formed conical pattern with a simple, vertically oriented feed is proposed. Mode 2 performance is verified computationally and experimentally. A novel helical arm termination is also introduced and enhanced performance is demonstrated.

Introduction: Spiral antennas [1] are commonly used for applications that require broadband, circularly polarised operation. These antennas typically have the characteristics of very low axial ratio, azimuthally symmetric far-field radiation patterns [2, 3], and frequency consistent input impedances over several octaves. Regarding feeding, usually a complex modeformer network, that is also broadband, is needed to generate the proper phase progression between successive spiral arms. The design and fabrication of this type of modeformer is challenging, expensive, and complex depending on the total number of arms of the spiral antenna and the required mode of operation.

A vertical coaxial feed is presented in this Letter without the need for an additional modeformer and/or balun. The required phase progression for mode 2 operation [4] is accomplished through the utilisation of a bi-layer metallisation where equally phased arms are on the same metallised layer. A similar though more complex feed was presented in [5] for a log-periodic structure, however this design still contains an integrated balun and modeformer. The antenna is designed using a method-of-moments (MoM) code, FEKO. Numerical results compare favourably with measurements from the fabricated structure. A simple helical arm extension is also proposed and improved performance is demonstrated computationally.

Antenna geometry and coaxial feed: The four-arm spiral antenna is 10 cm in diameter with a theoretical lowest frequency of operation of $f_0 = 2$ GHz for mode 2. Top and bottom metallised layers of the fabricated prototype are shown in Fig. 1. The antenna was built on 0.51 mm-thick Roger's Duroid® 5880 substrate. The structure is self-complementary when considering both layers and has four rotations per arm with an Archimedean spiral growth rate of 0.2 cm/rad.

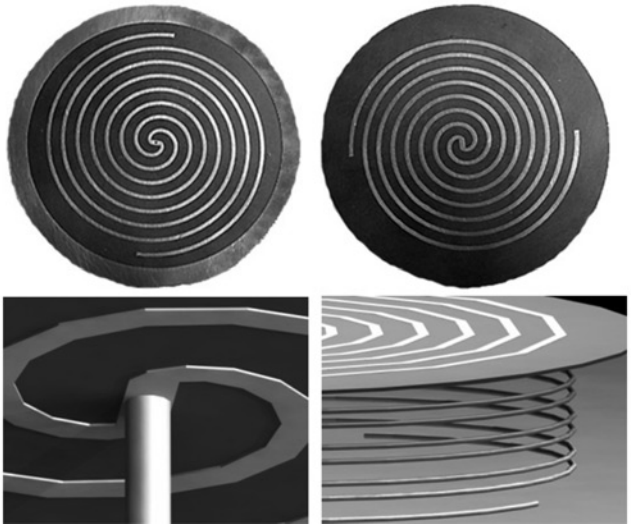

Fig. 1 *Photographs of bottom (top-left) and top (top-right) substrate metallisations for four-arm, mode 2 spiral antenna. Also shown is enlargement of bottom metallisation showing connection to outer coaxial conductor (bottom-left) and suggested helical termination (bottom-right).*

The coaxial feed is perpendicular to the metallised planes of the spiral. The outer conductor is connected to the bottom spiral arms. A small void is left in the centre of the bottom metallisation for passing the centre conductor through to the top metallised spiral layer. This feed generates a phase difference of 180° between the two arm pairs. Thus, a {0°, 180°, 0°, 180°} progression between the four arms is obtained to enable the mode 2 excitation.

The antenna is modelled as a free-standing structure; however, fabrication requires the addition of an absorber filled cavity on one side of the aperture to ensure unidirectional operation. The assembled cavity is 5 cm deep with an ARC-ML-1 0051 (ML-75) multilayer absorber material in the lower 3 cm of the cavity. A 2 cm air space is present between the spiral and absorber to ensure there is no near-field interaction between the spiral and the absorber.

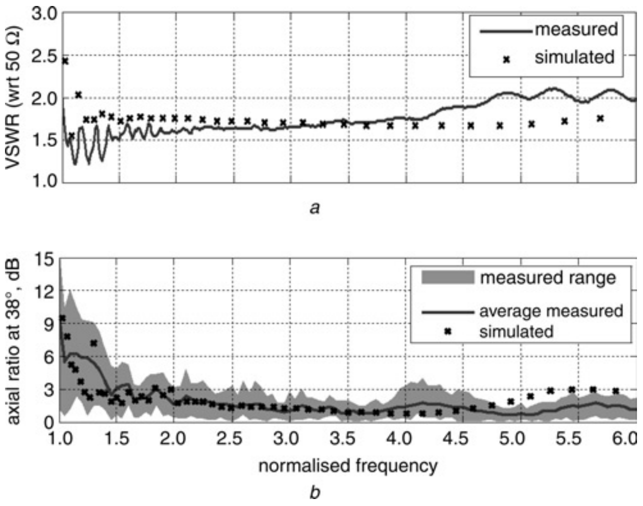

Fig. 2 *Measured and simulated VSWR with respect to 50Ω (Fig. 2a) and axial ratio at θ = 38° (Fig. 2b) for bi-layer, four-arm spiral. Also shown is measured range of axial ratio over azimuthal cuts*

The additional use of a termination (such as the helical structure shown in Fig. 1) can further improve the axial ratio at lower and mid frequencies. By using this type of in-cavity termination, the overall volume occupied by the complete antenna remains unchanged. Thus, far-field performance can be improved without adding additional bulk or significant weight to the structure. The lower turn is modelled as a distributively loaded 3 kΩ resistance. For this termination, the helix is 3 cm deep and consists of two full turns per arm.

Results and discussion: The presented data is shown in terms of normalised frequency, $f_n = f/f_0$. Voltage standing wave ratio (VSWR) fluctuates little with frequency. It is demonstrated here that the VSWR is less than approximately 2:1 over the bandwidth. The theoretical arm-to-ground impedance of a four-arm, mode 2 spiral is 94Ω. Because of this type of feed, the total input impedance seen at the feed is a series combination of both sets of two arms in parallel or 94Ω. Owing to the substrate effects, the nominal input resistance is somewhat lower. The mean axial ratio over 36 azimuthal cuts, taken at $\theta = 38°$, is below 2 dB for approximately $f_n = 1.5$ to 6. This data is shown in Fig. 2. Additional far-field parameters are shown in Table 1 including WoW (difference in maximum and minimum gain over azimuthal angles), broadside null data, and cumulative far-field phase. The mean values of these parameters from $f_n = 1$ to 6 are shown. It should be noted that the total cumulative phase of a mode 2 pattern is 720°, and very similar to the values measured. Measured co-polarised far-field patterns are shown in Fig. 3. The antenna was placed in a 1 m diameter circular ground plane. Note that the pattern undulations and somewhat increased WoW are due to the diffraction from the untreated ground plane edges.

Table 1: Mean measured far-field parameters

	Null gain (dB)	Null squint (°)	θ_{max} (°)	WoW at θ_{max} (dB)	Cumulative far-field phase at θ_{max} (°)
Mean	−38	2.4	41.4	3.7	721
Standard deviation	7.4	1.7	2.9	1.0	1.5

By using the previously described helical termination, the axial ratio can be significantly improved for lower frequencies. When compared to the free-standing, non-terminated structure, the axial ratio is on average around 1 dB less from $f_n = 1$ to 6 (Fig. 4). With additional consideration to the resistive taper of the helix, optimisation would result in further improvements.

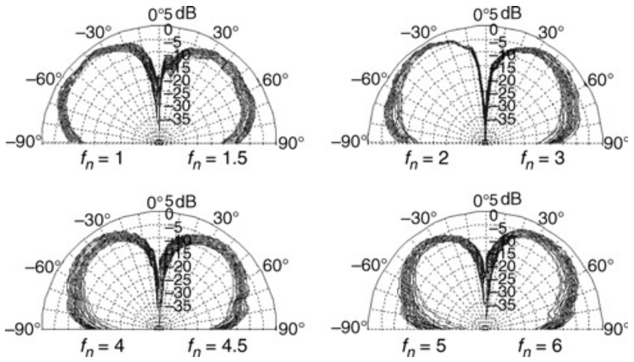

Fig. 3 *Measured co-polarised far-field patterns taken at various normalised frequencies (overlaid are 36 consecutive azimuthal patterns from $\phi = 0°$ to $350°$)*

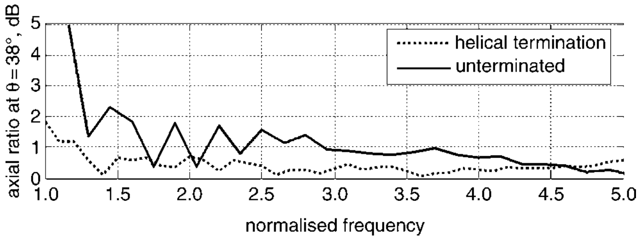

Fig. 4 *Use of a termination on spiral arm ends can improve axial ratio at lower frequencies (modelling performed on free-standing antennas without substrate)*

Conclusion: A 50Ω coaxial transmission line is used to vertically feed a two-layer, four-arm spiral antenna in mode 2. No other integrated baluns or modeformers are used which keeps the complexity and physical size to a minimum and reduces fabrication costs. Impedance matching is below approximately 2:1 over large bandwidths and far-field patterns are correct and well formed. An in-cavity helical termination was also suggested. This termination improves lower frequency operation while maintaining the same aperture size.

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M. Buck and D. Filipović (*Department of Electrical and Computer Engineering, University of Colorado, 425 UCB, Boulder, CO 80309-0425, USA*)

E-mail: michael.buck@colorado.edu

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