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Design of circularly polarised printed spiral antenna using dual objective genetic algorithm

R.M. Edwards, G.G. Cook, S.K. Khamas, R.J. Aidley and B. Chambers

A single arm spiral printed on a grounded dielectric substrate is designed using a genetic algorithm with Pareto ranking of a 2D search plane, with dual objectives of a unity axial ratio and a boresight main lobe. The antenna is shown to be efficient with good circular polarisation over a useful bandwidth.

Introduction: The printed spiral antenna offers the advantages of a circularly polarised main beam and a wide operating bandwidth, but these attributes are dependent on several physical parameters which have nonlinear relationships, and a procedure is needed for finding the optimum combination of these. In this Letter, a printed spiral electromagnetics code is run under a genetic algorithm (GA) which selects these parameters, to find an optimal design for the spiral which best meets the performance criteria. Previously, GAs have been used in microstrip structures to optimise phase tapers [1], dual-polarised printed patch antennas [2] and slot-coupled loaded patch antennas [3].

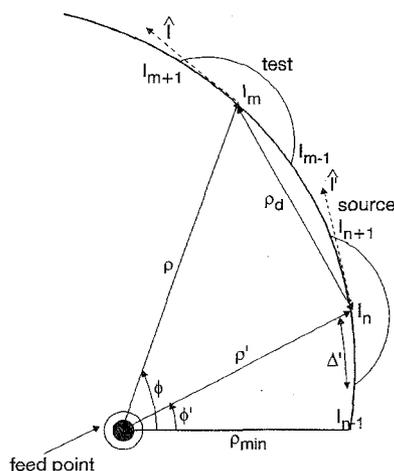


Fig. 1 Spiral model and side view of spiral antenna

Electromagnetic analysis: The analysis technique used to determine the performance of printed spirals is one developed by the authors [4, 5], using a Galerkin type moment method solution to Pocklington's equation for printed wires, where the Green's functions are

expressed as summations of eigenmodes in Sommerfeld type integrals [6]. Piecewise sinusoidal basis and testing functions are expressed over curved segments which follow exactly the spiral contour, thereby providing significant computational efficiency improvements over linear segmentation due to fewer curved basis functions being required for an accurate representation of the spiral contour and current distribution. Such a reduction in CPU time becomes increasingly important when the code may need to be run many times in an optimisation routine such as a GA. A typical printed spiral is illustrated in Fig. 1, being a generic curl antenna [7] where a single spiral arm is printed onto a grounded dielectric substrate, and fed through the groundplane and dielectric from an unbalanced coaxial feed. The subdomain sinusoidal basis and testing functions each span two curved segments over the spiral arm. Typical moment method impedance terms are then of the form

$$Z_{mn} = -\frac{1}{\sin(k\Delta l)} \left[\int_{m-1}^m \sin(k(1-l_{m-1})) + \int_m^{m+1} \sin(k(l_{m+1}-1)) \right] \frac{E}{I_n} dl \quad (1)$$

where E denotes the electric field tangential to a curved segment m of the printed spiral arm due to a piecewise sinusoidal current flowing over segment n . The reader is referred to [5] for a complete description of the electromagnetic analysis technique. For an Archimedean spiral:

$$\rho = a\phi \quad (2)$$

where a is the spiral constant. The spiral contour therefore exists between two limits in winding angle, ϕ_{min} and ϕ_{max} .

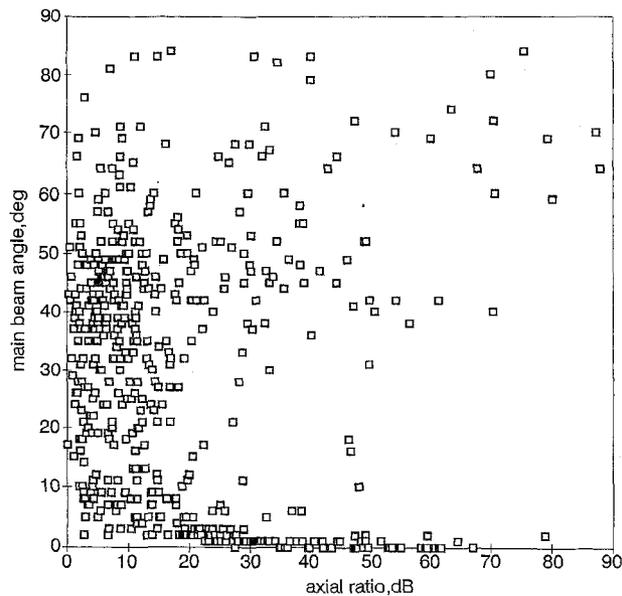


Fig. 2 Pareto surface after 520 runs of electromagnetic spiral model

Genetic algorithm: The criteria targeted for the printed spiral design are a good circularly polarised main lobe which is on the spiral axis (on boresight). This involves using a dual objective Pareto ranked GA [8], one objective sought being the minimum angle of the main beam off boresight and the other being the best axial ratio on boresight. It is not sufficient to have only a single objective of good circular polarisation on boresight, since this may correspond to a low boresight radiation field due to the main lobe shifting as the spiral parameters are varied. Pareto ranking allows the generation of a single scalar fitness function produced from two nonlinearly related optimisation criteria. The genes chosen to form the chromosome are those attributes which are significant in affecting the spiral's targeted performance. Here, six genes are chosen and they are listed in Table 1. For this analysis, a population of 20 chromosomes is used, with initially random genes. All genes are kept within the specified ranges which are derived from published data on curl antennas [7]. The previously mentioned electromagnetics analysis code is therefore run 20 times for the first set of chromosomes, and the two chromosomes producing radiation patterns having the best fit with the target pattern are

copied. The two worst chromosomes are discarded. The 18 best chromosomes are now randomly paired for cross-breeding, with an additional mutation probability of 0.2 applied to each chromosome. Failure requires that one gene of that chromosome is randomly recreated. The high mutation probability avoids stagnation in the relatively small populations and therefore allows the GA to search a large intractable multi-attribute space with the least CPU overhead. Eighteen new chromosomes and the two previously saved best examples now form the new population. The GA uses real as opposed to integer genes and ranked population selection. Fig. 2 shows the Pareto surface as a dense area (bottom left of the Figure) for 26 generations (520 runs) of the electromagnetic model.

Table 1: Genes used with allowed variations and final optimal values

Genes	Range	Good example
ϕ_{max} [rad]	$\pi/2 \rightarrow 6\pi$	3.795π
ϕ_{min} [rad]	$0 \rightarrow \phi_{max} - \pi/2$	0.356π
a [m/rad]	$0.0025 \rightarrow 0.001$	0.0025
Substrate ϵ_r	$1.001 \rightarrow 10$	2.1
Substrate h [m]	$0.001 \rightarrow 0.041$	0.021
Wire radius [m]	$0.001 \rightarrow 0.0015$	0.0021

Results: The result with the smallest radial distance from the origin in Fig. 2 therefore corresponds to a design whose performance closely meets the targeted criteria, and is produced by the chromosome in the right hand column of Table 1. The design frequency used here is 1.8GHz, and the axial ratio of this antenna is < 3 dB over a 7.5% bandwidth, as shown in Fig. 3, over which frequency range the gain remains close to 6.6dBi and the efficiency is 78%. Such a bandwidth and gain are typical for curl antennas [7]. Although the antenna has not been optimised for size, the spiral diameter is only 5.2cm.

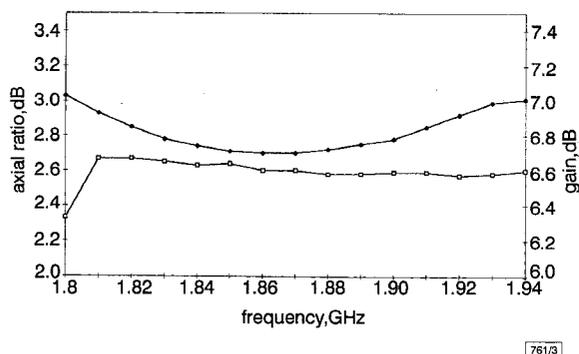


Fig. 3 Performance of good example spiral antenna

◆ axial ratio (dB)
□ gain (dBi)

Conclusion: A single arm spiral printed on a grounded dielectric substrate has been designed using a genetic algorithm with Pareto ranking of the 2D search plane, to produce an efficient antenna having a boresight main lobe with good circular polarisation and gain. Owing to the many parameters affecting performance, it would be difficult to achieve these properties from intuitive runs of the electromagnetics code alone. Clearly, one could optimise for other parameters such as bandwidth, input impedance, etc., and also specify a squinted main lobe angle, perhaps using a multi-dimensional search space at the expense of increased computation.

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Dual-frequency electronically tunable CPW-fed CPS dipole antenna

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A CPW-fed CPS dipole antenna is presented which operates at dual frequencies. A wideband CPW-to-CPS balun was designed and used. Dual-frequency operation of the CPS dipole antenna was realised by introducing a small gap in the length of the dipole. Varactors were integrated with CPS dipoles to form integrated antennas. The CPS dipole antenna was electronically tuned by varying the varactor bias voltages. Measurements showed good results of dual operating frequencies, frequency range, and antenna pattern.

Introduction: In recent years, coplanar waveguide (CPW) and coplanar strip (CPS) transmission lines have undergone intensive investigations due to their advantages of easy fabrication, no requirement for via holes, and compatibility with solid-state devices. These coplanar transmission lines have been analysed and calculated [1, 2]. Tilley *et al.* [3] presented a coplanar waveguide-fed coplanar strip dipole antenna. A broadband coaxial-coplanar waveguide-coplanar strip-fed spiral antenna was also investigated in [4]. The design of a coplanar waveguide-fed uniplanar bow-tie antenna at 2.4GHz was recently described [5]. In [6], a dual-frequency coplanar strip dipole antenna was studied experimentally. Very little work has been found on electronic frequency tuning of coplanar waveguide-fed dipole antennas, especially on dual operating frequency tuning. In this Letter, frequency tunable CPW-fed CPS dipole antennas using varactors have been designed, fabricated, and measured. Dual-frequency operation has been realised and tuned electronically. Varactors were integrated with coplanar strip (CPS) dipoles to form integrated antennas. The varactors provide various capacitive loadings to the CPS dipole antenna. The varactor junction capacitance varies against bias voltage and can be calculated from the bias voltage [7]. These different capacitive loadings correspond to various electrical lengths of the dipole antenna, and thus different resonant frequencies. The CPS dipole antenna is electronically tuned at these two operating frequencies over wideband by varying the varactor bias voltages. The dual-frequency tuning provides fast tuning and switching over a wide frequency range, as is required for many applications.

Circuit and antenna configuration: Fig. 1 shows the configuration of a dual-frequency CPW-fed CPS dipole antenna. A wideband coplanar waveguide-to-coplanar strip balun was designed and used to transform the unbalanced CPW feed line to a balanced CPS feed line for the dipole antenna. The entire circuit was fabricated on an RT-Duroid substrate with thickness of 1.5748mm and