Single-feed dual-band circularly polarised microstrip antenna

Gui-Bin Hsieh, Ming-Huang Chen and Kin-Lu Wong

A novel technique for obtaining dual-band circular polarisation (CP) radiation of a single-feed circular microstrip antenna is proposed and demonstrated. By embedding two pairs of arc-shaped slots of proper lengths close to the boundary of a circular patch, and protruding one of the arc-shaped slots with a narrow slot, the circular microstrip antenna can perform dual-band CP radiation using a single probe feed. Details of the antenna design and experimental results are presented.

Introduction: Dual-frequency operations of microstrip antennas have received much attention, and many related designs have also been reported [1]. However, the dual-frequency designs available in the literature are mainly for linear polarisation (LP) operation. Little attention has been given to the dual-band circular polarisation (CP) design, especially for the case using a single probe feed. This is probably because single-feed dual-band CP design is more complicated than that required for dual-band LP design. The typical dual-band CP microstrip antennas that have been reported include design using an aperture-coupled stacked microstrip antenna [2] or a combination of the spur-line filter technique and a nearly square patch antenna [3]. In this Letter, we propose a novel and simple design method using a single-layer circular microstrip antenna to achieve single-feed dual-band CP operation. The proposed antenna can easily be implemented by embedding two pairs of arc-shaped slots, with one of the arc-shaped slots having a narrow radial protruding slot, close to the boundary of the circular patch. Details of the proposed antenna design are described, and experimental results for CP performance are presented and discussed.

Antenna design: Fig. 1 shows the proposed dual-band CP design of a circular microstrip antenna with two pairs of arc-shaped slots. The circular patch has diameter D and is printed on a substrate of thickness h and relative permittivity ε_r. The two pairs of arc-shaped slots, having a narrow width w, are placed close to the boundary of the circular patch with a distance of S. These two pairs of slots are also centred with respect to the centrelines (x and y axes) of the circular patch. The pair of arc-shaped slots centred on the x axis is subtended by an angle θ_1 and its left-hand slot has a radial protruding slot of length ℓ. The other pair of arc-shaped slots, centred on the y axis, is subtended by an angle θ_2 ($\theta_2 \neq \theta_1$). It should first be noted that, for each pair of arc-shaped slots, dual-frequency operation with same polarisation planes and broadside radiation patterns can be obtained by feeding the patch using a single probe feed along the centreline between the two slots. This dual-frequency characteristic is similar to that reported for a dual-frequency rectangular microstrip antenna with a pair of narrow slots [4] in which the perturbed TM_{10} and TM_{30} modes are excited for dual-frequency operation. For the proposed structure, the two operating modes are associated with the TM_{11} and TM_{12} modes of

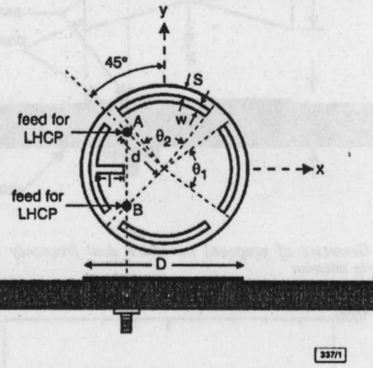

Fig. 1 *Geometry of single-feed, slotted circular microstrip antenna for dual-band CP operation*

the unslotted or simple circular microstrip antenna. With the presence of the two pairs of arc-shaped slots of slightly different subtending angles in the proposed design, it is expected that the first two operating modes can both consist of two near-degenerate orthogonal resonant modes, if a single probe feed is placed along the direction 45° to the centrelines of the circular patch. This feeding arrangement uses the design method described in [5]. However, from experiments, it is found that the resonance of the first (lower) operating mode (the perturbed TM_{11} mode) is very slightly affected by the variation in the subtending angle. Conversely, the resonant frequency of the second (higher) operating mode (the perturbed TM_{12} mode) is significantly decreased with increasing subtending angle. Therefore, by adjusting the subtending angles, two near-degenerate orthogonal modes with equal amplitudes and 90° phase difference for CP operation can be excited for the second operating mode. To fine-adjust the two near-degenerate orthogonal modes of the first operating mode to have equal amplitudes and 90° phase difference for CP operation, a radial narrow slot protrudes from one of the arc-shaped slots (see Fig. 1). It is found that, with perturbation of the protruding slot, the desired CP operation for the first operating mode can be achieved, while the CP performance of the second operating mode is very slightly affected by the protruding slot. That is, by carefully selecting the subtending angles of the arc-shaped slots and the length of the protruding slot, dual-band CP operation of microstrip antennas can be obtained. For the single probe feed placed at point A,

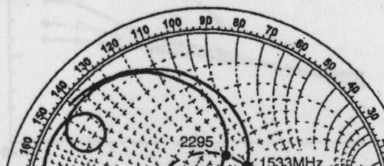

Fig. 2 *Measured input impedance for proposed antenna with dual-band left-hand CP operation*

Feed at point A; h = 1.6mm, ε_r = 4.4, D = 50mm, ℓ = 10mm, S = 1mm, w = 1mm, d = 16mm, θ_1 = 88°, θ_2 = 89°

$$a_5 = d_5 = \frac{1}{s_5} \tag{25}$$

$$e_5 = \left(\frac{1}{s_1} + \frac{1}{s_2}\cos\theta_2 + a_3 + \frac{1}{s_4}\cos\theta_4\right)L \tag{26}$$

L is the projected length of the fractal dipole as indicated in Fig. 3. Here the geometry of the FAE is uniquely determined by the parameters s_1, s_2, s_4, s_5, θ_2, θ_4 and L. These parameters may be encoded into a genetic algorithm (GA) [4 – 6] for the purpose of determining the optimal FAE configuration that will best satisfy a particular set of design requirements.

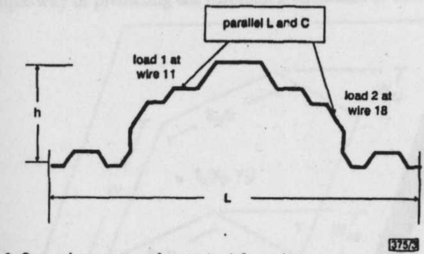

Fig. 3 *General structure of optimised fractal antenna*

GA-FAE design: In this Section we employ a GA approach to evolve an optimal design for a dualband FAE. The target frequencies of the antenna are 1.225 and 1.575 GHz. The VSWR requirements for both frequencies are to be less than 2. In addition to the VSWR requirement, we aim to reduce the size of the antenna by over 50% compared to a conventional half-wave dipole at 1.225 GHz (the lower frequency). Two LC loads were applied to the antenna so that the VSWR requirement can be satisfied at the higher frequency of 1.575 GHz. The genetic algorithm technique was used in conjunction with an IFS fractal generating subroutine and a method of moments (MoM) code to systematically optimise the antenna characteristics, e.g. VSWR and gain. The fractal geometry of the antenna, the load component values (Ls and Cs) and the load locations are the parameters simultaneously optimised by the GA. The GA provides selected parameters, s_1, s_2, s_4, s_5, θ_2, θ_4 and length L, to the fractal generating subroutine that employs the IFS technique to create the FAE geometry. Subsequently, along with the FAE geometry, the LC load component values and the load locations, which are also assigned by the GA, are made available to the MoM code in order to compute the radiation characteristics of the candidate antenna (i.e. VSWR, gain, etc.). Our goal here is to achieve low VSWRs for both of the target frequencies and, therefore, the objective function for the design is chosen to be

$$F = \sum_{i=1}^{N_f} |VSWR(f_i) - 1|^2 \tag{27}$$

where N_f is the number of frequencies of interest (in this case, they are 1.225 and 1.575 GHz).

Table 1: GA selected parameters and corresponding VSWRs for the three designs

Case	Antenna structure parameters						Load component values				Load location (wire)		Projected length		VSWR	
	S_1	S_2	S_4	S_5	θ_2 deg	θ_4 deg	L_1 nH	L_2 nH	C_1 pF	C_2 pF	Load 1	Load 2	L cm	h cm	1.225 GHz	1.57 GHz
1	5.43	4.83	4.99	5.46	44.29	46.23	15.44	12.05	0.66	0.33	5	25	9	1.75	1.04	1.14
2	5.26	4.74	4.55	5.45	47.36	44.96	19.5	17.95	0.10	0.81	19	23	7	1.49	1.33	1.10
3	5.90	4.70	4.40	5.30	50.44	46.20	12.51	15.87	0.54	0.93	16	22	5.5	1.22	1.94	1.79

Results: Three design examples using the GA-FAE optimisation technique are considered. The general fractal antenna structure for all three cases is illustrated in Fig. 3, which is the second iteration of a generating antenna similar to that shown in Fig. 2. The antenna structure in all three cases consists of 25 wires as illustrated in Fig. 3. The antenna structure parameters, load component values and load locations, which are all selected by the GA, are listed in Table 1 for each of the three designs considered. The first design has a projected length of L = 9 cm and a VSWR of 1.04 and 1.14 for 1.225 and 1.575 GHz, respectively. The second design has a projected length of $L = 7$ cm and a VSWR of 1.33 and 1.10 for 1.225 and 1.575 GHz, respectively. Finally, the third design has a projected length of only $L = 5.5$ cm with a corresponding VSWR of 1.94 and 1.79 at 1.225 and 1.575 GHz, respectively. This last case represents an overall size reduction of 55%. Fig. 4*a* shows a conventional half-wave dipole at 1.225 GHz; while Fig. 4*b* shows the geometry of the optimised FAE for the last case. This comparison clearly demonstrates the degree of miniaturisation that can be achieved through the use of the GA-FAE design optimisation technique introduced in the preceding Section.

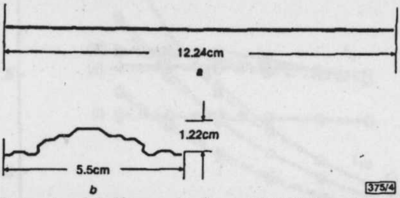

Fig. 4 *Conventional half-wave dipole at 1.225 GHz and geometry of miniaturised fractal dipole for case 3*

a Conventional half-wave dipole
b Geometry of dipole

Conclusion: A genetic algorithm technique has been successfully developed for use in conjunction with an IFS approach for generating fractal geometries and a computational electromagnetics analysis code based on the method of moments to systematically optimise the performance characteristics of FAEs. For the three examples considered, the VSWRs of the optimised FAEs were less than 2 at each of the specified target frequencies. It was also shown that the projected length of a fractal dipole may be reduced by as much as 55% compared to a conventional dipole by the optimal choice of antenna shape as well as load locations and associated component values.

21 June 2001
Electronics Letters Online No: 20010802
DOI: 10.1049/el:20010802

D.H. Werner and P.L. Werner (*Department of Electrical Engineering, The Pennsylvania State University, University Park, PA 16802, USA*)

K.H. Church (*Sciperio, Inc., 5202-2 N. Richmond Hill, Stillwater, OK 74075, USA*)

References

1 PEITGEN, H.-O., JURGENS, H., and SAUPE, D.: 'Chaos and fractals: new frontiers of science' (Springer-Verlag, 1992)
2 BARNSLEY, M.: 'Fractals everywhere' (Academic Press, Inc., 1988)
3 WERNER, D.H., and MITTRA, R.: 'Frontiers in electromagnetics' (IEEE Press, Piscataway, NJ, 2000)
4 HAUPT, R.L., and HAUPT, S.E.: 'Practical genetic algorithms' (John Wiley & Sons, Inc., New York, 1997)
5 RAHMAT-SAMII, Y., and MICHIELSSEN, E.: 'Electromagnetic optimization by genetic algorithms' (John Wiley & Sons, Inc., 1999)
6 COHEN, N.: 'Fractal coding in genetic algorithm (GA) antenna optimisation'. Proc. IEEE Antennas and Propagation Society Int. Symp., Montreal, Canada, July 1997, Vol. 3, pp. 1692–1695