~98.59% (1.765–4.921GHz) for a S_{11} of less than –10dB. The fabricated antenna dimensions are as follows: Feed: ε_r = 4.3; h = 1.0mm; W_f = 1.94mm; l_d = 21mm; l_u = 10mm; offset = 11mm; Slot: l_s = 50mm; W_s = 32mm.

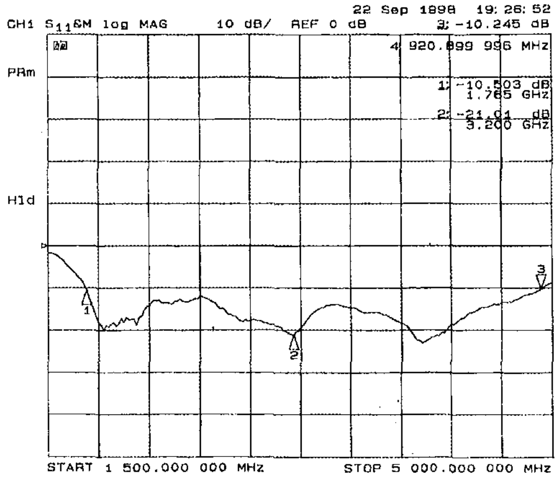

Fig. 3 *Measured return loss*

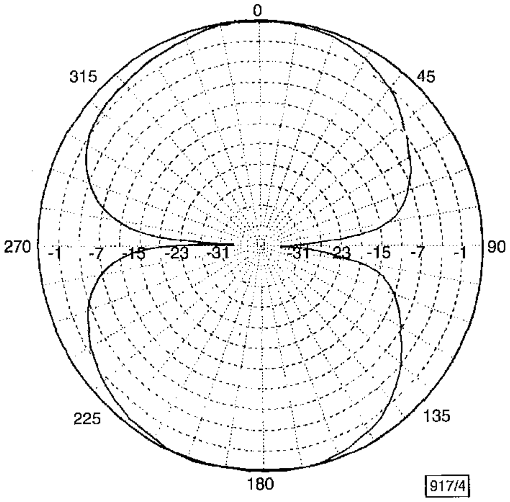

Fig. 4 *Measured radiation pattern in x-z plane at f = 3.2GHz*

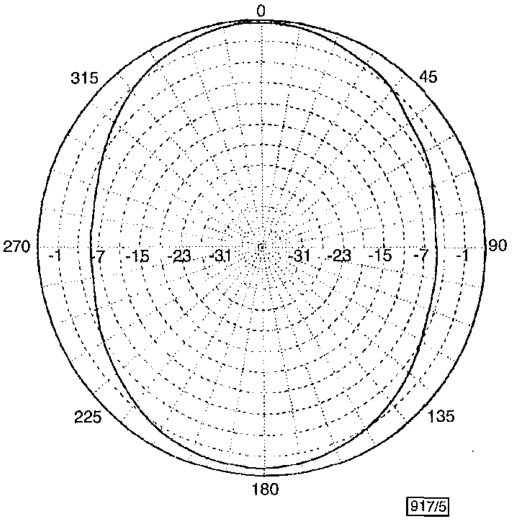

Fig. 5 *Measured radiation pattern in y-z plane at f = 3.2GHz*

Fig. 4 presents the experiment for an x-z plane radiation pattern at f = 3.2GHz. After calibration using a horn antenna, we measured the radiation pattern at the far field. Fig. 5 shows the experiment for a y-z plane radiation pattern at the centre frequency.

Conclusion: The results of a cross-shaped microstripline-fed printed slot antenna having large bandwidth have been described. The measured bandwidth of the antenna is 98.59% for $S_{11} \leq$ –10dB. The measured radiation patterns have also been presented. This antenna could be used to realise a powerful broadband array antenna.

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Shape optimisation of broadband microstrip antennas using genetic algorithm

H. Choo, A. Hutani, L.C. Trintinalia and H. Ling

The genetic algorithm (GA) is used to design patch shapes for microstrip antennas on FR-4 substrate for broadband applications. Measurement results of the GA-optimised designs show good agreement with numerical prediction. The optimised patch design achieves a fourfold improvement in bandwidth when contrasted with a standard square microstrip antenna.

Introduction: It is well known that standard microstrip patch antennas exhibit very narrow bandwidth. Various broadbanding methods have been proposed to date. For instance, adding parasitic patches, using thick air substrate, stacking patches and using shorting post for reactive loading are well known techniques for extending microstrip bandwidth [1]. Recently, Johnson and Rahmat-Samii reported on the use of the genetic algorithm (GA) to search for novel patch shapes for broadband operations [2]. The attractiveness of GA shape optimisation is that improved bandwidth performance can be achieved without increasing overall volume or manufacturing cost. They used thick air substrate, and explored metallic patch sizes up to half a wavelength.

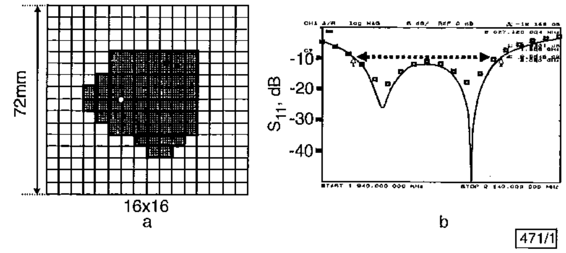
In this Letter, we also examine the use of GA for broadband applications. In contrast to the work of Johnson and Rahmat-Samii, we employ FR-4 as the substrate material, since it is the most commonly used material in wireless devices. In addition, fewer geometrical constraints are used in the GA in hope of obtaining better global optimum. We report a fourfold bandwidth improvement from our GA-optimised microstrip shape compared to that of a standard square microstrip antenna.

GA optimisation: GA is implemented to optimise the microstrip patch shape to achieve broad bandwidth. In our GA, we use a two-dimensional (2D) chromosome to encode each patch shape into a binary map [3]. The metallic sub-patches are represented by ones and the no-metal areas are represented by zeros. Since it is more desirable to obtain optimised patch shapes that are well-connected from the manufacturing point of view, a 2D median filter is applied to the chromosomes to create a more realisable population at each generation of the GA.

To evaluate the performance of each patch shape, a full-wave electromagnetic patch code is used to predict its bandwidth performance [4]. The formulation of the code is similar to that described in [5] and is based on the solution to the electric field integral equation with the periodic, layered medium Green's function as its kernel. Roof-top basis functions are used to expand the unknown current on the metal patch and fast Fourier transform is used to accelerate the computation of the matrix elements. Because of the assumed periodicity of the patches in this code, we use a large enough period to simulate a single patch.

The design goal is to broaden the bandwidth of a microstrip antenna with a centre frequency of 2GHz by changing the patch shape. To achieve the design goal, the cost function is defined as the average of those S_{11} values that exceed –10dB (i.e. VSWR = 2:1) within the frequency band of interest. The target frequency range is between 1.9 and 2.1GHz.

Based on the cost function, the next generation is created by a reproduction process that involves crossover, mutation and 2D median filtering. A two-point crossover scheme using three chromosomes is devised. The process selects three chromosomes as parents, and divides each chromosome into three parts. Intermingling the three parent chromosomes then makes three child chromosomes. This crossover scheme exhibits a more disruptive characteristic for regeneration than the conventional one-point or two-point crossover. It serves to counteract the median filtering effect and is found to result in better convergence rate. The reproduction process is iterated until the cost function converges to a minimum value.



a

b

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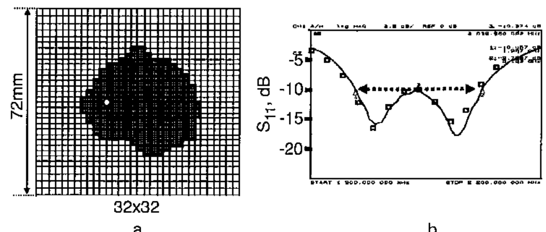
Fig. 1 *Schematic diagram and return loss of GA-optimised microstrip antenna*

a GA-optimised microstrip antenna using 16 × 16 resolution within 72 × 72mm area
Grey pixels are metal and white dot shows position of probe feed
b Return loss of antenna
— simulation
☐ measurement

Results: Fig. 1*a* shows the shape of the GA-optimised microstrip. A 72 × 72mm square design area in which the metallic patch can reside is discretised into a 16 × 16 grid for the chromosome definition. The thickness of the FR-4 substrate (dielectric constant of 4.3) is 1.6mm. In the GA-optimised shape, the grey pixels are metal and the white pixels have no metal. The white dot shows the position of the probe feed. To experimentally verify the GA design, we have built and measured such a microstrip patch. Fig. 1*b* shows the return loss comparison between the measurement and simulation results. The solid line is the measurement result taken from an HP8753C network analyser. The square dots represent the simulation result. Good agreement can be observed between the measurement and simulation. The graph shows a bandwidth of 6.16% by simulation and 6.18% by measurement. This is about three times that of a square microstrip antenna (36 × 36mm), which has a bandwidth of 1.98%. Further improvements in the bandwidth can be obtained from the GA by increasing the grid resolution from 16 × 16 to 32 × 32. Figs. 2*a* and *b* show, respectively, the GA-optimised patch shape and the bandwidth performance in the higher resolution design. The bandwidth is found to be 8.04% by simulation and 8.10% by measurement. This is about four times that of a square microstrip antenna.

Finally, the operating principle of the GA-optimised shape is interpreted. It is clear from the two frequency dips in Fig. 2*b* that the antenna contains two operating modes that are very closely spaced in frequency. We have verified the two modes by examining the current distributions on the patch at 1.99 and 2.07GHz. In addition to the dualmode principle, another important bandwidth enhancement effect is achieved through the ragged edge shape. We have found that when the patch is restricted to singlemode operation (by imposing symmetry constraints), the introduction of ragged edges in the GA-optimised shape can enhance the bandwidth by ~30%. Therefore, the GA-optimised design combines both the dualmode operation and ragged edge shape to achieve the broadest bandwidth.



a

b

471/2

Fig. 2 *Schematic diagram and return loss of GA-optimised microstrip antenna*

a GA-optimised microstrip antenna using 32 × 32 resolution within 72 × 72mm area
Grey pixels are metal and white dot shows position of probe feed
b Return loss of antenna
— simulation
☐ measurement

Conclusions: Optimised patch shapes for microstrip antennas on thin FR-4 substrate have been investigated using the genetic algorithm. The optimised shape shows a fourfold improvement in bandwidth when contrasted with a standard square microstrip antenna. This result has been verified by laboratory measurement. The basic operating principle of the optimised shape can be explained in terms of a combination of dualmode operation and ragged edge shape.

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