Wide-Elevation Circular-Polarized Quadrifilar Helical Antenna Handset Design for Satellite Communication Using Genetic Algorithms

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Abstract

A circularly-polarised quadrifilar helical antenna, operated at 2.4 GHz band and intended for the applications of satellite mobile communications, was designed and optimised using genetic algorithm. The antenna design was firstly attempted on an infinite ground plane and then optimised further on small size mobile handset. The performance of the GA-optimised antenna design was validated through a hardware realization in terms of VSWR, axial ratio and power gain. The attained results indicate that the optimal antennas met design objectives under several certain constraints. Moreover, the capabilities of GA are shown as an efficient optimisation tool for selecting globally optimal parameters to be used in simulations with an electromagnetic antenna design code, seeking convergence to designated specifications.

1. INTRODUCTION

Genetic algorithms (GA) are random search methods based on the principle of natural selection and evolution [1]. An approach of using GA in cooperation with an electromagnetic simulator has been introduced for antenna designs and has become increasingly popular recently [2]. For example, GA have been employed to design wire antennas [3, 4] and microstrip antennas [5]. The benefit of applying GA is that they provide fast, accurate and reliable solutions for antenna structures.

The quadrifilar helical antenna (QHA) is very attractive candidate antennas for satellite mobile handsets due to the symmetry of their geometry, properties of balanced feeding and their ability to provide circular polarization over a broad angular region [6].

Presented in this paper are results of study in which GA are applied to design and optimise QHA with the inclusion of a small size satellite mobile handset for circular polarisation. The optimal solution of the antenna structure derived using GA was constructed and examined in detail against the simulation results.

2. GENETIC ALGORITHMS

Genetic algorithm driver [7], written in Fortran, was adopted in this work in conjunction with the industry-standard NEC-2 Fortran source code [8], which was used to evaluate the randomly generated antenna samples. A QHA was proposed for optimisation with GA. For this optimisation, real-valued GA chromosomes were used. Antenna parameters of VSWR and axial ratio (AR) are optimized and only at a single frequency of 2.44 GHz. Each antenna sample was computed using NEC-2 source code and its results were compared with desired fitness using the following cost function ‘F’:

$$F = W_1 \times (1/VSWR) + W_2 \times A.R. \tag{1}$$

Where $VSWR = (1+\Gamma)/(1-\Gamma)$

$\Gamma = \left|(Z_{in} - 50)/(Z_{in} + 50)\right|$

VSWR is the voltage standing wave ratio, A.R. is the axial ratio, Z_{in} is the input impedance, Γ is the reflection coefficient and W_1 and W_2 are the weighting coefficients. The objective was to maximise F.

The GA was applied using the following procedure: The GA erratically chooses the initial population and then converts each antenna configuration to a file which can be read by NEC-2. The NEC-2 program is executed and the results will feed back to GA for evaluation process. This will continue till GA converges to an optimum solution.

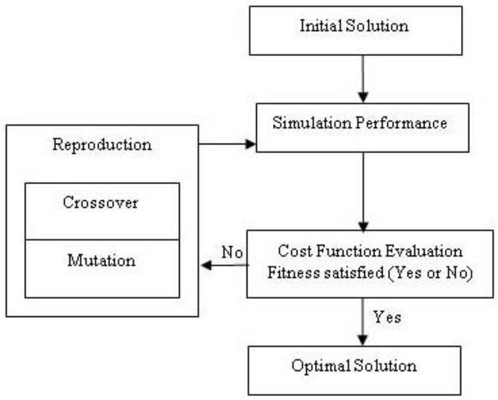


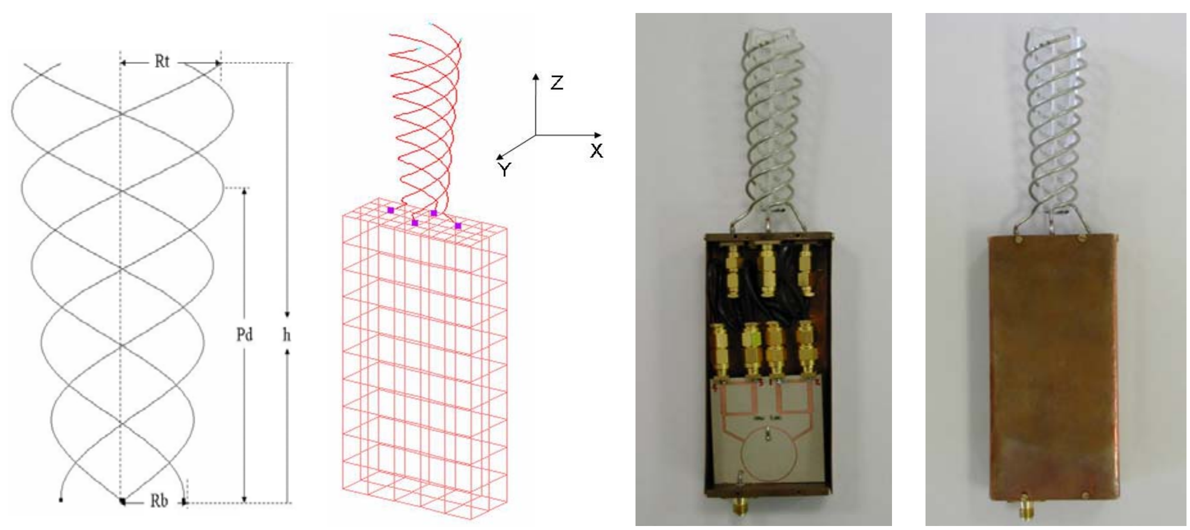
Figure 1 Flow chart of the genetic algorithm adopted in this study.

Table 1 Summary of GA input parameters, antenna variables and optimum values with the handset included.

GA parameters	QHA Design with the handset	
	Parameters (m)	Optimum (m)
Number of population size = 4	Pitch distance (P_d) (0.01-0.048)	0.03026
Number of parameters = 4	Axial length (h) (0.05-0.12)	0.06294
Probability of mutation =0.02	Radius at the bottom (R_b) (0.005-0.015)	0.00721
Maximum generation =200	Radius at the top (R_t) (0.01-0.02)	0.01194
Number of possibilities=32768	Radius of wires Distance above handset	0.00075 0.005

3. ANTENNA DESIGN USING GA

In general, the proposed antenna is firstly considered as a test on an infinite ground plane and then optimise further on small size handsets [9]. The design frequency of the proposed QHA was considered at 2.44 GHz. The attained optimal antenna geometry is presented in Fig. 2. As can be seen, the proposed antenna models are mounted on the infinite ground as Fig. 2a and handset body as in Fig. 2b. Table 1 presents the GA input parameters, their constraints and the optimal values for each specified parameter of the design geometry. It has to be noted that the weighted coefficients W_1 and W_2 were found to be 0.5 and 0.75 respectively after a few attempts. Within the maximum generation, the value of maximum fitness function for QHA design achieved was about 1.06.



(a) (b) (c) (d)

Figure 2 Geometry of the proposed QHA antenna (a) QHA antenna configuration used by GA optimization, (b) the NEC-2 model, (c) internal view of the completed assembly, (d) overall completed assembly.

Initially, taking into considerations the achieved antenna design structure on infinite ground, the design of QHA with a small size handset was then carried out. The handset dimensions for this study were selected to be 20 x 50 x 100 mm. The GA input parameters were kept unchanged, but their constraints and the number of maximum generation were adaptively altered for maximizing the VSWR and AR, as demonstrated in Table 1.

It is notable that in order to ensure that the antennas is properly connected with the top plane of the handset, a wire with 5 mm length from each of the selected feeding points on the handset was added and then the antenna was considered to be designed and optimized on these extended wires. Under this arrangement, maximum value of the cost function was found to be 1.12, using the same weight coefficients as for the foregoing designs.

4. RESULTS AND DISCUSSION

Configurations of optimal proposed QHA antenna, with excellent VSWR and AR, were found within the maximum generation; antenna parameters of the best designs are shown in Table 1.

For validation, a prototype of the GA-optimised QHA antenna was built up and tested. Photographs of prototype antenna, including configuration of the proposed antenna in NEC-2 model and an overall view of the complete assembly, are presented in Fig. 2. It is notable that the hybrid feeding network for the QHA was arranged to accommodate inside the handset box. The QHA arms were made of copper wires with radius of 0.75 mm. The relative bandwidth (for VSWR ≤ 2) at the input ports of the proposed circularly-polarised antenna was calculated and measured over the targeted frequency bands, i.e. 2.4 GHz band from 2400 MHz to 2485 MHz, as illustrated in Fig. 3. The narrow bandwidth of the designed antenna bandwidth was not considered in the GA cost function, the optimal antenna appears to have excellent impedance matching that covers the bandwidth requirements at 2.4 GHz band for satellite mobile communications. Both the simulated and measured VSWR are in good agreement.

Fig. 4 illustrates the AR of the GA-optimized antenna against the elevation angle θ at 2350, 2400, 2420 and 2450 MHz for two vertical planes (i.e. z-x and z-y planes). As can be observed, the proposed antenna shows ±70° elevation angle variations for a working axial ratio less than 4 dB. The observations confirm the superior circular polarized characteristic of the proposed optimal design. Fig. 5 presents the radiation pattern of the optimal antenna at 2450 MHz for the same vertical cuts of the measured axial ratio. Radiation patterns at other frequencies across the intended band (not shown in this paper) were also measured and it was found, the symmetrical and identical variations were obtained for all the radiation patterns. In addition, the maximum gain of the antenna is found to be around 6 dBi over the 2.4 GHz band.

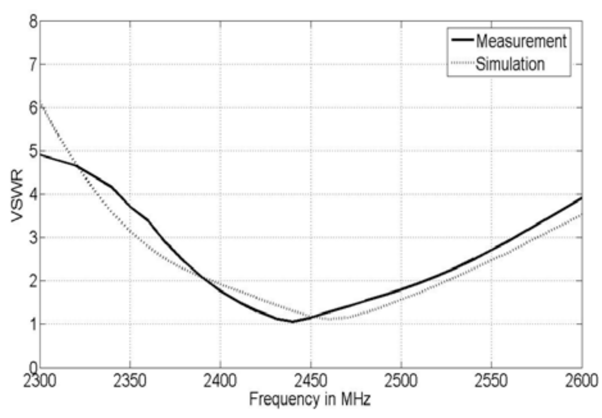


Figure 3 Comparison of the computed and measured return loss.

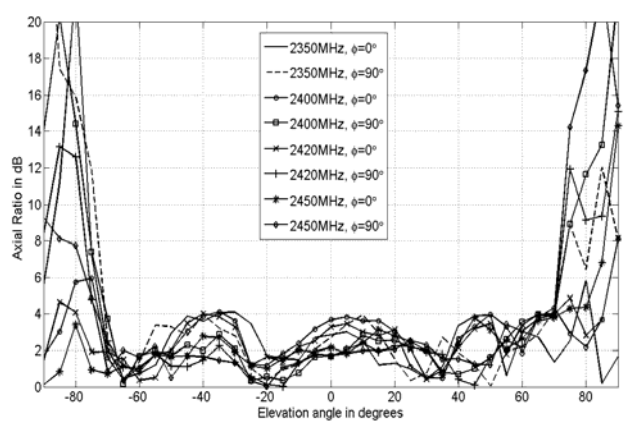


Figure 4 Measured AR in dB against the elevation angles for two vertical plane cuts and four operating frequencies.

5. CONCLUSION

An efficient GA optimisation technique, to design circularly-polarised quadrifilar helical antenna built on a small size mobile handset, has been presented. The performance of the best selected antenna structure was validated and compared using commercial EM simulator and measurement. The results confirm that an axial ratio of less than 4 dB over ±70° elevation angle can be achieved with acceptable 6 dBi power gain. The GA has proven its advantage for quickly finding solutions for antenna designs.

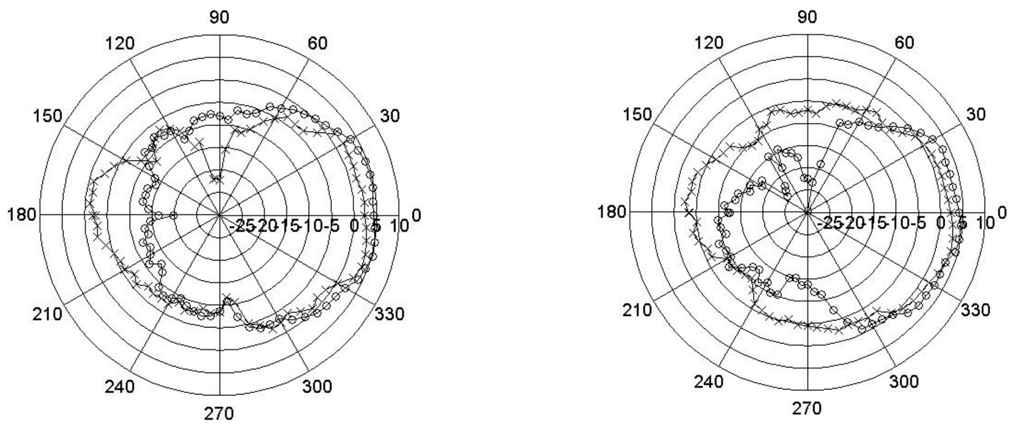


Figure 5 Measured radiation pattern of the proposed antenna at 2450 MHz for two vertical planes z-x (left) and z-y (right); 'o-o-o': co-polar field component, 'x-x-x': cross-polar field component.

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