Design of Multiband Microstrip Antennas Using a Genetic Algorithm

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***Abstract*—A genetic algorithm (GA) is used to design patch shapes of microstrip antennas for multiband operations. For dual-band operation, the optimized patches show that arbitrary frequency spacing ranging from 1:1.1 to 1:2 can be achieved. Tri-band and quad-band microstrip shapes are also generated and the resulting designs show good operations at the designated frequencies. All results were verified by laboratory measurements on FR-4 substrate.**

***Index Terms*—Genetic algorithms, microstrip antennas, multifrequency antennas.**

I. INTRODUCTION

MICROSTRIP antennas that operate in multiple frequency bands are required in many wireless communication devices. Various multiband designs employing parasitic patches or shorting pins have been proposed to date [1]. However, these techniques usually lead to an increase in antenna size or manufacturing cost. Johnson and Rahmat-Samii first applied genetic algorithms (GA) to the design of dual-band microstrip antennas on air substrate [2]. The attractiveness of the GA design over the aforementioned methods is its ability to achieve the desired performance by using a single, unique patch shape. In [3], we reported on a GA-designed dual-band microstrip on high-permittivity substrate based on slots cut into the patch. However, metal loss was found to be significant due to the introduction of the slots. In this paper, we report on the design of optimal patch shapes without slots for two, three and four frequency bands of operation using GA. In our approach, we employ a full-wave patch code to evaluate the performance of each microstrip shape. In the GA implementation, we use two-dimensional (2-D) chromosomes to encode each shape. A two-point crossover scheme involving three chromosomes is employed. A geometrical filter is applied to achieve well-connected shapes. Selected results of dual-band antennas with frequency spacing ratios ranging from 1:1.1 to 1:2 between the two bands are presented. Next, we show designs for tri-band and quad-band microstrips. All designs were verified by measurements on FR-4 substrate. These shapes can be scaled in size to different operating frequencies of interest or to other substrate materials with only minor modifications.

II. APPROACH

GA is implemented to optimize microstrip patch shapes in order to achieve multiband operation. The methodology is similar to what we have reported earlier for a broadband microstrip design [4]. In our GA implementation, we use a (2-D) chromosome to encode each patch shape into a binary map [5]. The metallic subpatches are represented by ones and the nonmetallic areas are represented by zeros. Since it is more desirable to obtain optimized patch shapes that are well connected from the antenna efficiency and manufacturing point of view, a 2-D median filter [6] is applied to the chromosomes to create a more realizable population at each generation of the GA.

To evaluate the performance of each patch shape, we use a full-wave periodic patch code [7]. The electromagnetic analysis is carried out by using the electric-field integral equation (EFIE) with the periodic Green's function for layered medium as the kernel. Rooftop basis functions are used to expand the unknown current on the metal patch and fast Fourier transform (FFT) is used to accelerate the computation of the matrix elements. To reduce the matrix fill-time, matrix element calculation is done only once and stored before the GA process. Because of the assumed periodicity in this patch code, we use a period that is about one dielectric wavelength to simulate the single patch design.

The design goal is to maximize antenna bandwidth at multiple frequency bands by changing the patch shape. To achieve the design goal, the cost function in (1) is defined as the average of those S_{11} values that exceed -10 dB (i.e., VSWR $= 2:1$) within the frequency bands of interest.

$$\mathrm{Cost} = \frac{1}{N}\sum_{n=1}^{N}(P_n) \tag{1}$$

where

$$P_n = \begin{cases} S_{11}\ (\mathrm{dB}) + 10\ \mathrm{dB}, & \text{if } S_{11}\ (\mathrm{dB}) \geq -10\ \mathrm{dB} \\ 0, & \text{if } S_{11}\ (\mathrm{dB}) < -10\ \mathrm{dB}. \end{cases}$$

Based on the cost function, the next generation is created by a reproduction process that involves crossover, mutation, and 2-D median filtering. A two-point crossover scheme involving three chromosomes is used. The process selects three chromosomes as parents and divides each chromosome into three parts. The three parent chromosomes are then intermingled to create three child chromosomes. It is found that the two-point scheme exhibits a faster convergence behavior than the one-point scheme. The GA process is iterated until the cost function converges to a minimum value.

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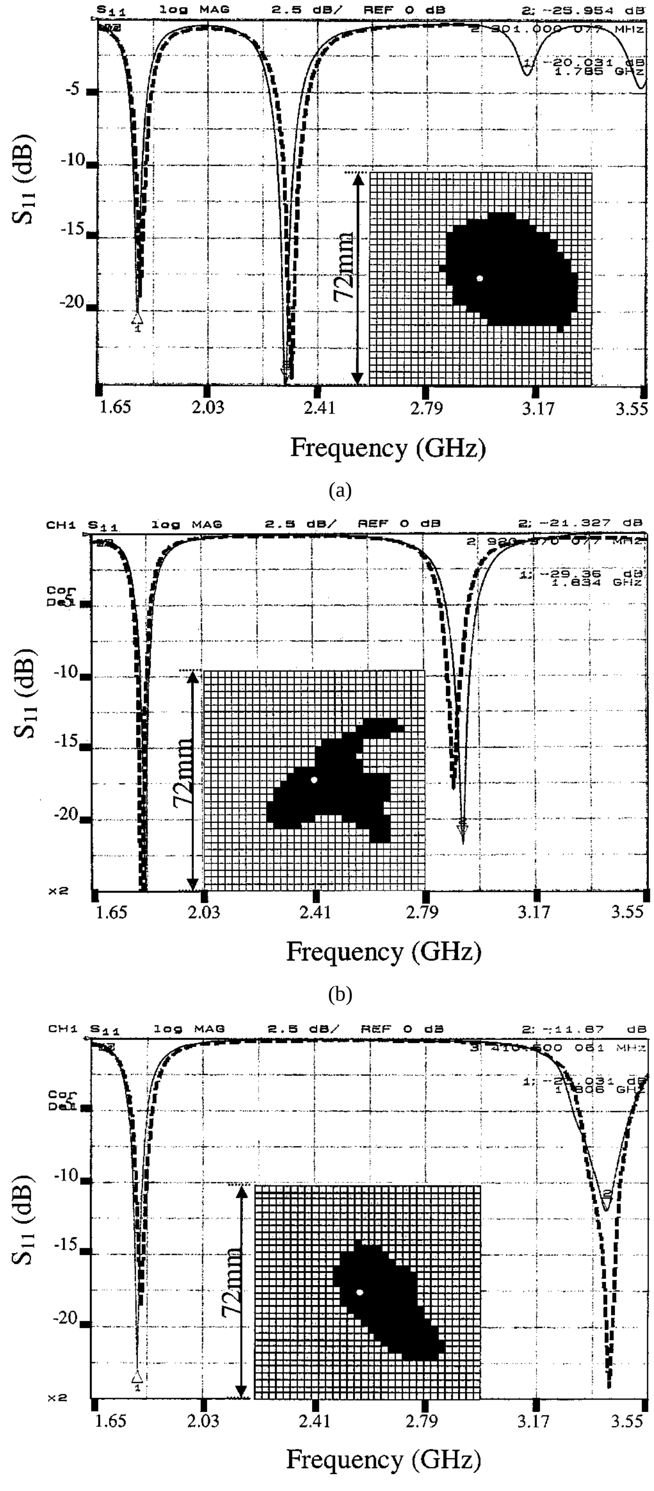
III. RESULTS

First, we carry out the dual-band design to achieve different frequency ratios between the low and the high bands. For each microstrip, we fix the low frequency band at 1.8 GHz while varying the high frequency band. The insets in Figs. 1(a), (b), and (c) are the GA-optimized designs for the frequency ratios of 1:1.3, 1:1.6, and 1:1.9, respectively. A 72×72 mm^2 design area in which the metallic patch can reside is discretized into a 32×32 grid for the chromosome definition. The thickness of the FR-4 substrate (dielectric constant of about 4.3) is 1.6 mm. The white dot shows the position of the probe feed. In the same figure, the calculated return loss (S_{11} in dB) of the resulting microstrip is plotted as a dashed line. It shows good dual-band operation at the designed frequencies. To experimentally verify the GA design, we built and measured the microstrip patches described above. Copper tape was used to construct the metallic patches and the dimension of the ground plane was 15.3×15.3 cm. The measurements were taken on an HP8753C network analyzer. The solid lines in Fig. 1 are the measured return losses versus frequency. Good agreement can be observed between the measurements and simulations.

We also measured the radiation patterns for these microstrips. All three microstrips show broadside radiation patterns at both operating frequencies, with linear polarizations that are nearly orthogonal to each other. The measured realized gains for these three antennas range from -1.3 to 2 dB in the broadside direction. Due to the high loss tangent of FR-4, the dissipation in the antenna (and thus the radiation efficiency) is mainly dominated by dielectric loss. We verified this by running the simulation with and without dielectric loss, and found that dielectric loss causes a 4 to 8 dB loss in gain. In addition to the three frequency spacings presented in Fig. 1, designs for other frequency ratios ranging from 1:1.1 to 1:2 were also realized using GA. All designed shapes showed good dual-band operation at the two design frequencies. We also numerically verified that these shapes could be scaled in size to different operating frequencies of interest or to other substrate materials with only minor modifications.

Next, we try tri-band designs having three operating frequencies at 1.6 GHz (GPS/L1), 1.8 GHz (DCS), and 2.45 GHz (ISM/Bluetooth). Fig. 2 shows the optimized shape using our GA technique and the corresponding return loss. It shows excellent tri-band operation at the design frequencies. The measured result again shows close agreement with the simulation result. The bandwidths obtained at these frequency bands are, respectively, 2.36%, 2.54%, and 1.22% from simulation and 1.81%, 2.16%, and 1.42% from measurement. Finally, we try quad-band designs having operating frequencies at 0.9 GHz (GSM900), 1.6 GHz, 1.8 GHz, and 2.45 GHz. Reasonably good quad-band operation is demonstrated in Fig. 3. Simulation shows a return loss of less than -10 dB (the design goal) at all four bands. The measured result shows a return loss of less than -10 dB at the first, third and fourth band, while the second band has a slightly higher (-9.4 dB) return loss. The results demonstrate that it is possible to use this GA approach in designing a multiband microstrip that requires very specific frequency bands of operation.



(a)

(b)

(c)

Fig. 1. Shapes of three GA-optimized dual-band microstrip antennas, and the resulting return loss from simulation (------) and measurement (———). (a) Frequency ratio of 1:1.3 (1.8 GHz and 2.34 GHz). (b) Frequency ratio 1:1.6 (1.8 GHz and 2.9 GHz). (c) Frequency ratio of 1:1.9 (1.8 GHz and 3.42 GHz).

IV. CONCLUSION

Optimized patch shapes for multiband microstrip antennas have been investigated using a genetic algorithm. For dual-band operation, it has been shown that the frequency ratio between the two bands ranging from 1:1.1 to 1:2 can be achieved using the

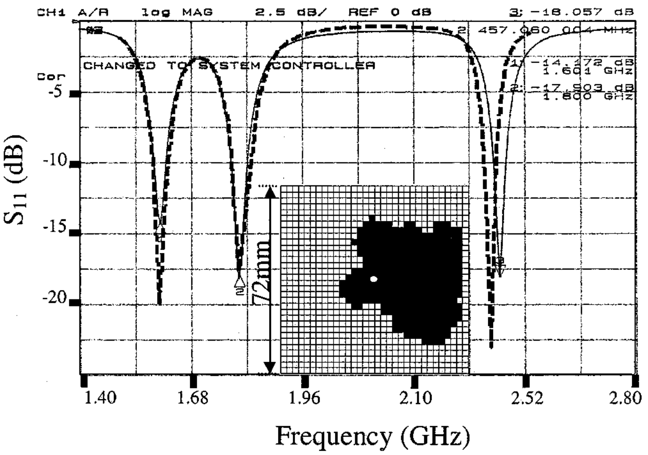


Fig. 2. Shape of the GA-optimized tri-band microstrip antenna that operates at 1.6 GHz, 1.8 GHz, and 2.45 GHz, and the resulting return loss of the antenna from simulation (- - - - - -) and measurement (———).

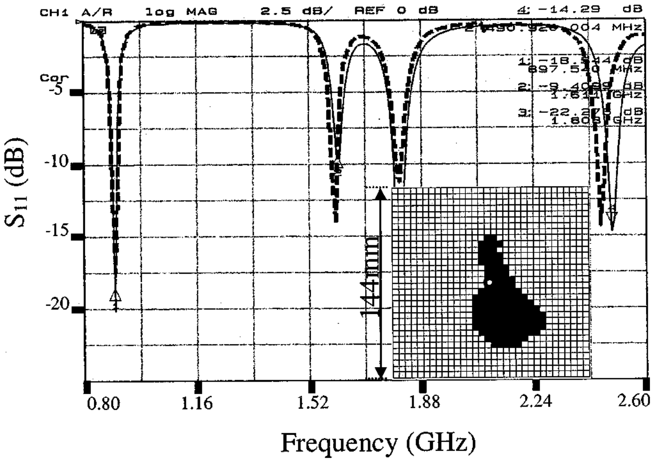


Fig. 3. Shape of the GA-optimized quad-band microstrip antenna that operates at 0.9 GHz, 1.6 GHz, 1.8 GHz, and 2.45 GHz, and the resulting return loss of the antenna from simulation (- - - - - -) and measurement (———).

GA methodology. Tri-band and quad-band microstrip shapes have also been generated and the resulting antennas showed good operation at the design frequencies. All results have been verified by laboratory measurements on FR-4 substrate.

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