Design of Dual-Band Microstrip Antennas Using the Genetic Algorithm

H. Choo, and H. Ling
Department of Electrical and Computer Engineering
The University of Texas at Austin
Austin, TX 78712-1024 U.S.A
E-mail: hschoo@ece.utexas.edu

Abstract:

We report on the use of the genetic algorithm (GA) to design patch shapes of microstrip antennas for dual-band applications. We employ a full-wave electromagnetic solver to predict the performance of microstrip antennas with arbitrary patch shapes. Two-dimensional chromosome is used to encode each patch shape into a binary map. GA with two-point crossover and geometrical filtering is implemented to achieve efficient optimization. The GA-optimized designs are built on FR-4 substrate and measurement results show good agreement with the numerical prediction. The optimized patch design achieves good impedance match at both frequencies. The patch shape is further optimized to broaden the bandwidth at one of the frequencies. It is also shown that a frequency ratio between the two frequency bands ranging from 1.2 to 2 can be achieved using the GA design method.

Introduction:

With the growing demand of wireless applications, microstrip antennas that can operate in two or more frequency bands are in demand. Various dual-band methods for microstrip antennas have been proposed to date. For example, multi-layered structures, parasitic patches and shorting posts are some of the well-known techniques for achieving dual-band operation [1]. In this paper, we examine the use of genetic algorithms (GA) to design optimal shapes for microstrip antennas to achieve dual-band operation. The attractiveness of GA shape optimization is that dual-band performance can be achieved with little increase in overall volume or manufacturing cost.

The design of dual-band microstrip antennas using GA was first addressed by Johnson and Rahmat-Samii [2]. Air substrate was used in their study. In this work, we focus on FR-4 as the substrate material, since it is the most commonly used material in wireless devices. In our GA implementation, a two-point crossover scheme involving three chromosomes is used. Furthermore, geometrical filtering is applied to each chromosome to obtain a more realizable shape. The GA-optimized shapes for dual-band operation are presented. It is also shown that arbitrary frequency ratios between the two frequency bands ranging from 1.2 to 2 can be achieved through the GA design.

GA Optimization:

GA is implemented to optimize the microstrip patch shape in order to achieve dual-band operation. In our GA, we use a two-dimensional (2-D) 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 optimized patch shapes that are well connected from the manufacturing point of view, a 2-D median filter 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 adapted from a frequency selective surface code [4]. The formulation of the code is similar to that described in [5]. The electromagnetic analysis is carried out by using the electric-field integral equation (EFIE). The periodic Green's function for layered medium is the kernel of the integral equation. 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 greater than one wavelength to avoid coupling between the adjacent patches for single patch simulation.

The design goal is to produce good antenna radiation at two frequency bands by changing the patch shape. The low frequency is chosen at 1.9 GHz and the higher one is chosen at 2.85 GHz. To achieve dual-band design, an additive cost function is defined as

$$\text{Cost} = \frac{1}{N}\sum_{n=1}^{N} Pn \quad where \quad Pn = \begin{cases} S_{11}(dB) + 10\,dB & if\ S_{11}(dB) \geq -10\,dB \\ 0 & if\ S_{11}(dB) < -10\,dB \end{cases} \tag{1}$$

$$+ \quad \frac{1}{N}\sum_{n=1}^{\mathrm{N}} \frac{1}{\sigma}\int_{s} |J|^{2}\, ds$$

The first part of the cost function accounts for the impedance mismatch and is defined as the average of those return loss (S_{11}) values that exceeds –10dB (i.e., VSWR=2:1) within the two frequency bands of interest. The second part of the cost function accounts for the total metal loss (dB) generated by the current flowing on the patch. The conductivity of aluminum (σ = 3.82e7 S/m) is used, as the microstrip in our measurements were built using aluminum tape.

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. Intermingling the three parent chromosomes then makes 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.

Results:

Fig. 1(a) shows the GA-optimized microstrip shape for dual-band operation. A 72mm × 72mm square 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 4.3) is 1.6 mm. In the GA-optimized shape, the dark pixels are metal and the white pixels have no metal. The white dot shows the position of the probe feed. Fig. 1(b) shows the predicted return loss (S_{11} in dB) of the resulting microstrip antenna. Good matches are exhibited by the return loss curve at the design frequencies of 1.9 GHz and 2.85 GHz. The bandwidths at the two design frequencies are about 4% and 1.4%, respectively.

Previously, we have used GA to achieve broadband operation for a single-band microstrip [6]. The resulting bandwidth on 1.6 mm FR-4 substrate is about 8%. Here, we try to increase the bandwidth of the dual-band microstrip antenna from the above design. The low frequency (1.9 GHz) is chosen to be our target for broadbanding, while the bandwidth of high frequency is kept the same. During the GA iterations, we gradually increase the frequency range centered at 1.9 GHz in our cost function definition until the broadband design is achieved. Fig. 2(a) shows a bandwidth-enhanced dual-band result. To experimentally verify the GA design, we have built and measured such a microstrip patch. Fig. 2(b) shows the measurement and simulation return loss for the shape in Fig. 2(a). Good agreement is observed between the measurement and simulation results (the square dots show the predicted values). Figs. 2(c) and (d) show the measured boresight radiations (S21 dB) for the two diagonally oriented polarizations. Also plotted in the insets are the predicted current distributions at three frequencies of interest. We note that near 1.9 GHz, there are two modes with orthogonal current directions at two closely spaced frequencies, leading to the broadening of the impedance bandwidth in Fig. 2(b). At 2.9 GHz, only a single mode exists.

In the above examples, the ratio between the two frequency bands is chosen to be 1:1.5. We next carry out the dual-band design steps using GA to achieve different frequency ratios between the low and the high frequency band. During the design, we keep the low frequency band fixed around 1.9 GHz, while varying the design frequency for the high band. Frequency ratios from 1:1.2 to 1:2 are attempted using GA. Figs. 3(a), (b) and (c) show the optimized shapes and the corresponding return loss versus frequency curves for the frequency ratios 1:1.2, 1:1.4 and 1:1.74, respectively. We find that it is possible to use the GA approach to cover the entire dual-band frequency ratio from 1:1.2 to 1:2.

Conclusions:

Optimized patch shapes for dual-band microstrip antennas on thin FR-4 substrate have been investigated using the genetic algorithm. The resulting microstrip designs show good operation characteristics for dual frequencies. The bandwidth of the microstrip can be further broadened by optimization. This result has been verified by laboratory measurement. Finally, it has been shown that the frequency ratio between the two bands ranging from 1:1.2 to 1:2 can be achieved using the same GA methodology.

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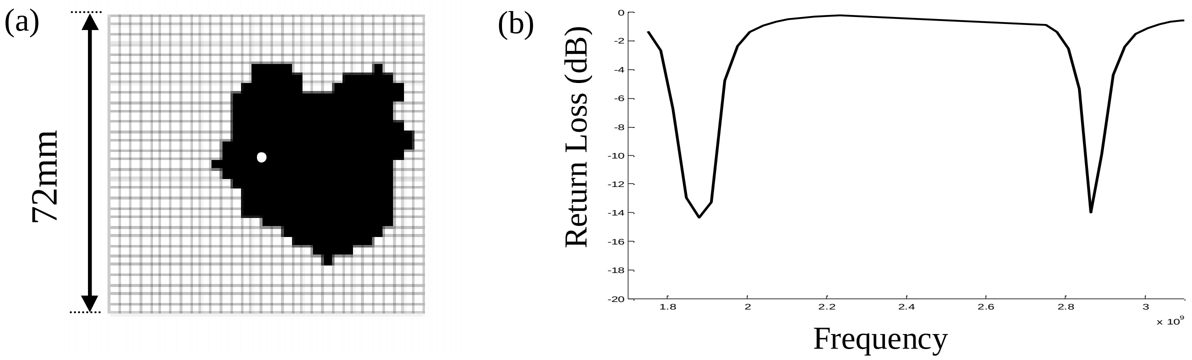

Fig. 1. GA optimized dual-band microstrip antenna (frequency ratio 1:1.5).

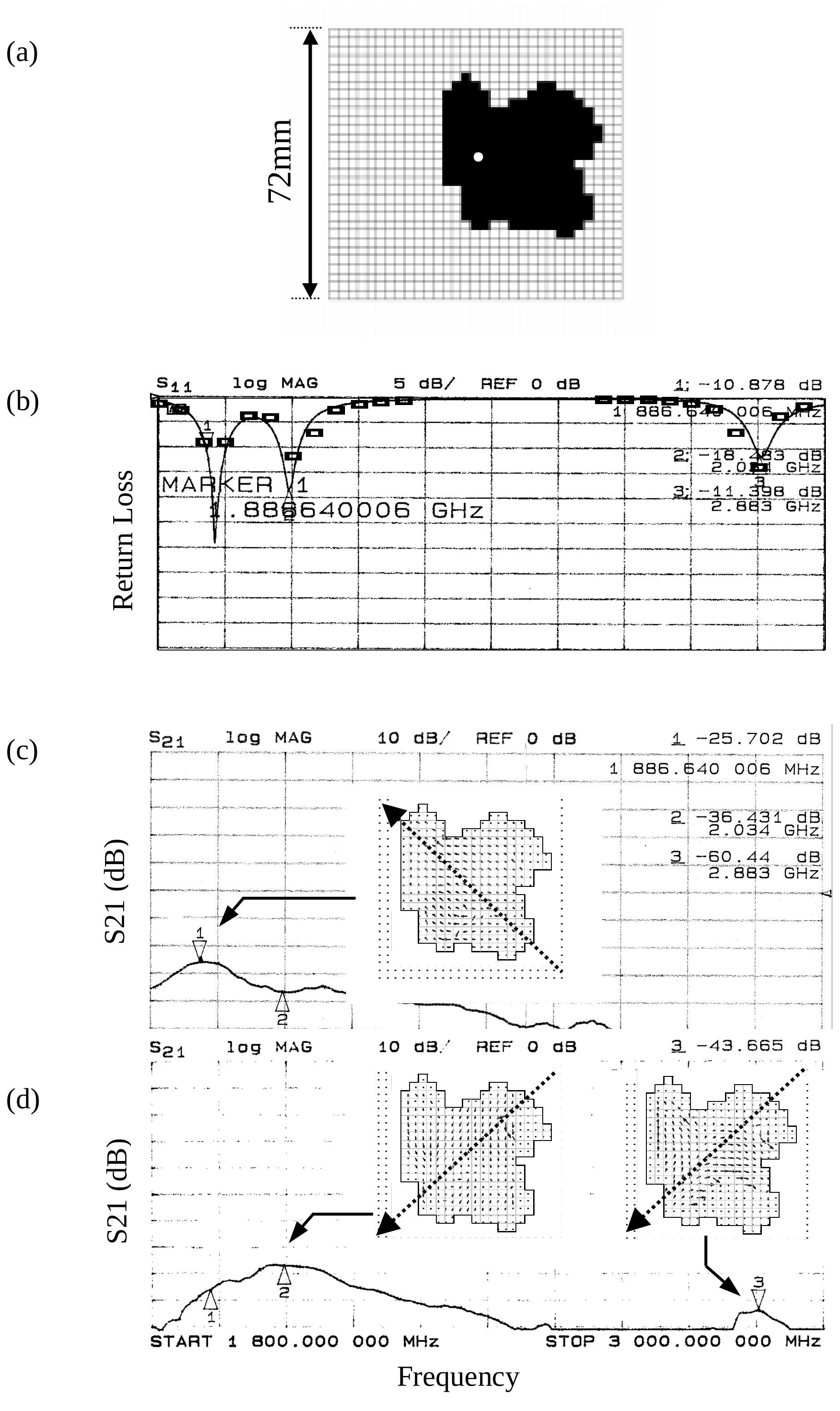

Fig. 2. Dual-band microstrip antenna design with enhanced bandwidth at the low band.

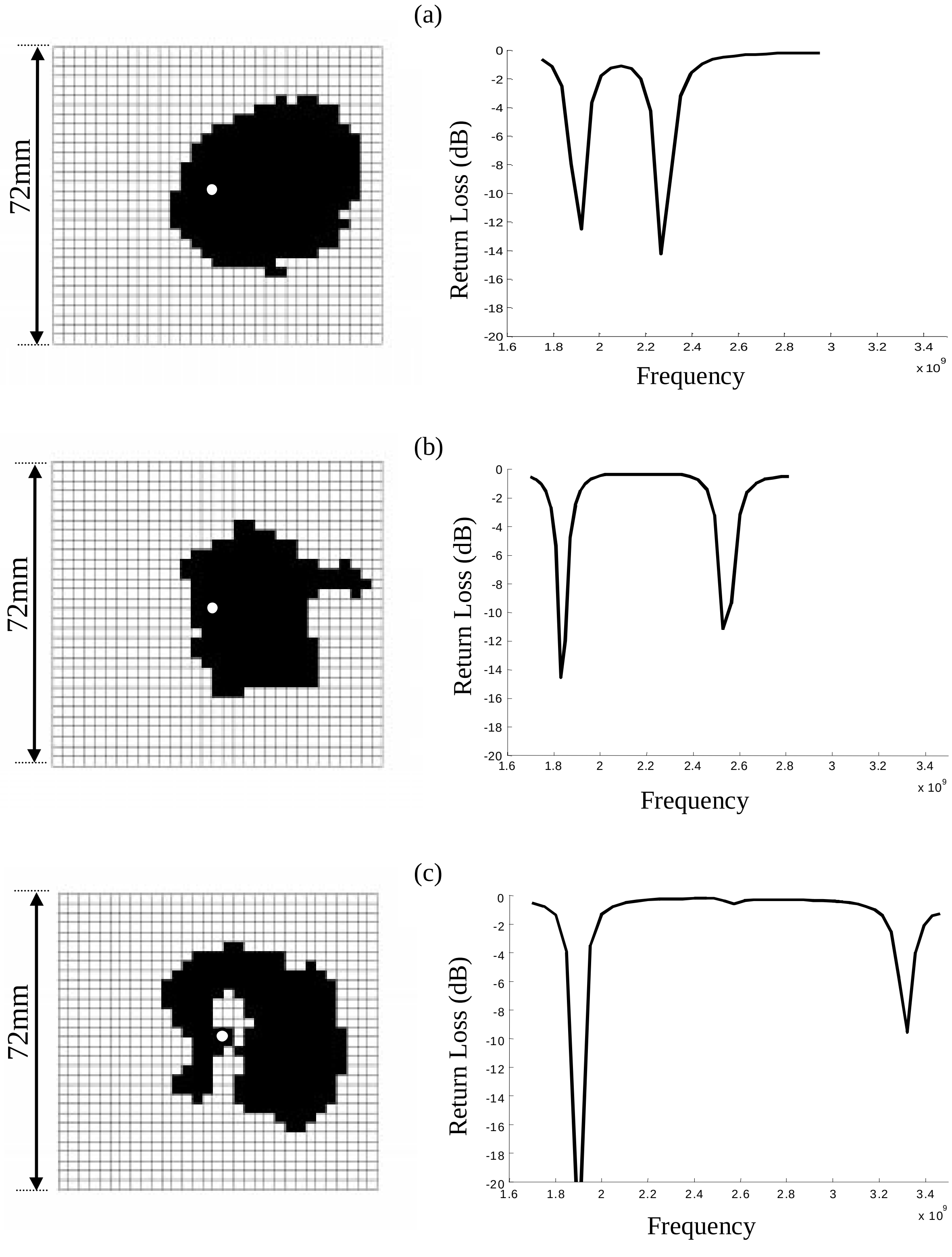

Fig. 3. GA-designs for dual-band frequency ratios of (a) 1:1.2 (b) 1:1.4 and (c) 1:1.74.