

Optimization of Reduced Size Microstrip Patch with slots using a Genetic Algorithm

Andrea Wyant¹, Jayanti Venkataraman¹

¹ Department of Electrical Engineering, Rochester Institute of Technology,
79 Lomb Memorial Drive, Rochester, New York, 14623, U.S.A.
amw4607@rit.edu ; jnveee@rit.edu

Abstract

Genetic algorithm optimization has been used in the past for size reduction of microstrip antennas by removing pixels from the entire metal area of the patch. This results in an unwieldy antenna that is not very practical. In the present work, a new methodology is developed for reducing the size of microstrip patch antennas by removing predefined slot shapes from the metal. A genetic algorithm is used to optimize the size and location of the slots on the patch in order to make it resonate at a much lower frequency. This technique is demonstrated for a 10 GHz patch antenna that is optimized to resonate at 6 GHz resulting in a 75% size reduction. The algorithm has been further improved to include a desired input impedance of 100 ohms into the fitness function in order to improve the overall gain. The work has been performed by interfacing the genetic algorithm to Ansoft High Frequency System Simulator (HFSS). Validation of the results is shown through design, construction, and measurement.

1. Introduction

Antenna design has grown more stringent and difficult over the years with inherent tradeoffs that exist between gain, radiation pattern, bandwidth, and physical size making antenna design a lengthy process. Many techniques have been used to attempt to achieve this reduction in size with varying success. Recently, evolutionary algorithms, such as a genetic algorithm (GA) and particle swarm optimization (PSO) have been used to optimize patch antennas [1, 2]. A genetic algorithm was used to determine the patch length and width and feeding point in the design of a coaxially fed circularly polarized rectangular patch antenna [3]. A dual-band microstrip patch antenna was designed using genetic algorithms to control the position of multiple slots or shorting pins between the patch and ground. Multiport analysis was used to determine the effects of the slots or pins on the input impedance, and thus assign fitness values to each of the antennas [4]. Genetic algorithms can also be used to change the shape of the patch itself and thus optimize the antenna. By dividing a regular square microstrip patch antenna into a grid of symmetrical squares, and using genetic algorithms to selectively remove the smaller metallic grid squares from the patch, novel non-intuitive shapes can be produced. This method has been employed to create dual-band antennas, and wide-band antennas [5, 6], and used to optimize antenna size [7].

In the present work, a new methodology is developed for reducing the size of microstrip patch antennas by removing predefined slot shapes from the metal. The genetic algorithm is used to optimize the size and location of the slots on the patch. Conditions for resonant frequency and input impedance of 100 ohms have been included in the fitness function. The work has been performed by interfacing the genetic algorithm to Ansoft High Frequency System Simulator (HFSS). Validation of the results is shown through design, construction, and measurement.

2. Optimization Procedure

A genetic algorithm is used to control the removal of slots from the metal of a patch antenna. The increase of path length as the surface current meanders, leads to an increase in electrical length of the patch antenna, which in turn causes a downward shift in the resonant frequency. A standard rectangular microstrip patch antenna that resonates at 10 GHz is used as the base antenna from which slots are cut. The dimensions of this patch, 15mm by 9.063 mm, the dielectric permittivity of 2.33, and the dielectric height of 1/32" are all constants in the optimization problem. The feed point location is fixed along the edge of the patch at the center. A particular slot shape is specified in addition to the number of such slots that need to be removed from the patch surface to the genetic algorithm. The variables in the optimization problem are the size and location of the slot. Fig. 1 shows a single rectangular slot of width 'w' and length

' l '. The coordinates corresponding to the center of the slot are (c_x, c_y) with θ as the angle that allows the slot to be rotated.

The variables that pertain to the different slot configurations are encoded into a binary string of length that is dependent on the number and precision of the variables. Several different slot configurations are used in conjunction with the genetic algorithm. The encoding/decoding involves determining the range and precision of each variable. Each antenna must then be ranked in terms of desired performance, which is done via the fitness function. The fitness function is calculated as the weighted sum of both the fitness functions for the resonant frequency, $fitness_1$, and for the input impedance, $fitness_2$, as shown below.

$$fitness = \alpha \cdot fitness_1 + (1 - \alpha)fitness_2 \quad (1)$$

The constant α ranges between 0 and 1 and controls the emphasis placed on the resonant frequency of the antenna within the overall fitness. The return loss and S_{11} of each antenna is determined by Ansoft's High Frequency System Simulator (HFSS). The resonant frequency of the antenna is defined as the frequency where the reactance goes to zero. The input impedance is also found from the S_{11} and is used to calculate the fitness of each antenna as shown in (1). $fitness_1$ and $fitness_2$, have values ranging between zero and one and are determined through piecewise functions.

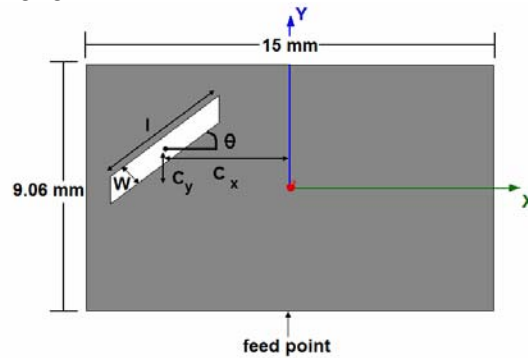


Figure 1: Algorithm variables

The implemented GA uses a population size of ten and stochastic universal sampling to determine the mating pool. Uniform crossover is implemented with a probability of crossover of 80%. Mutation is allowed to occur with a probability of 3%. The genetic algorithm runs until a fitness higher than 0.95 is achieved or 20 generations are reached. On average, each generation of the algorithm takes approximately 12 minutes on a 3.2 GHz processor.

3. Antenna Design

The genetic algorithm is implemented with five different slot configurations. The input impedance is not initially considered and α is set to one. Three configurations, the single slot, the two and four slots, are given target resonant frequencies of 6 GHz. The two arcs configuration uses a target of 6.5 GHz and the two crosses uses 7 GHz. The resulting optimized antennas for the different configurations are shown in Figure 2.

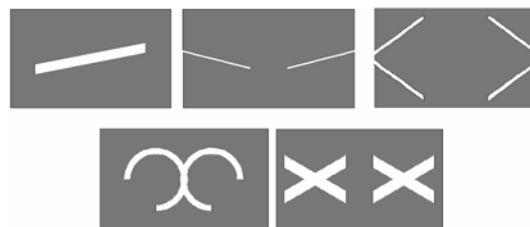


Figure 2: Optimized antennas

The HFSS simulation results displayed in Table 1 show that there is quite a difference in gain between the five configurations. The single, centered slot display the highest gain due to the lower input impedance. This demonstrated

the need to add a target input impedance to the fitness function. The algorithm was run five times for both the single slot and two slot configurations with different seeds for the random number generator to validate the success of the algorithm. An α of 0.6 was used with a target resonant frequency of 6 GHz and a target input impedance of 100 ohms. The results for the five runs are summarized in Table 2 and Table 3.

Table 1: HFSS Results for GA Optimized Antennas

Slot Geometry	Resonant Frequency (GHz)	Input Impedance (Ω)	Max Gain (dB)	-10 dB S_{11} BW (MHz)
Single Slot	6.01	110	5.27	80
Two Slots	6.03	295	2.93	60
Four Slots	5.99	210	2.83	60
Two Arcs	6.48	465	3.74	70
Two Crosses	6.99	390	5.44	100

Table 2: HFSS Results for Centered Slot ($\alpha = 0.6$)

Seed	Fitness	Resonant Frequency (GHz)	Input Impedance (Ω)	Gain (dB)	Slot Dimensions (mm)	Slot Angle (degrees)
10	0.978	5.93	100.0	4.98	4.6 x 13	-5.50
23	0.797	5.40	102.4	5.35	2.8 x 8.6	22.01
50	0.959	6.02	100.0	5.17	1.4 x 10.6	-8.25
67	0.962	6.04	101.6	5.19	1.6 x 10.4	8.25
4532	0.994	6.00	100.0	5.35	3.0 x 11.4	2.75

Table 3: HFSS Results for Two Slot Configuration ($\alpha = 0.6$)

Seed	Fitness	Resonant Frequency (GHz)	Input Impedance (Ω)	Gain (dB)	Slot Dimensions (mm)	Center of Slot (mm)	Slot Angle (degrees)
10	0.769	7.22	109	4.8	2 x 4	7	27.52
23	0.809	6.86	109	4.76	2.2 x 4.5	6	34.67
50	0.785	7.16	95	4.3	0.2 x 7.5	7	11.01
67	0.793	7.29	93	5.14	3 x 2	7	-19.26
4532	0.865	6.58	97	4.95	2.2 x 6.5	7	30.27

4. Experimental Results

The antennas in Figure 2, optimized using $\alpha = 1$, have been fabricated and tested to validate the simulation results. Measurements were made using the Agilent PNA E8363B (10MHz-40GHz)

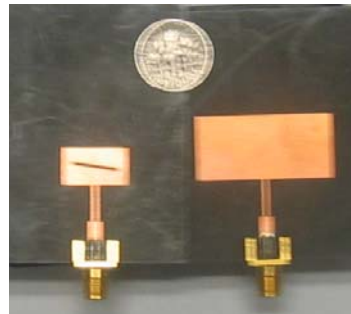
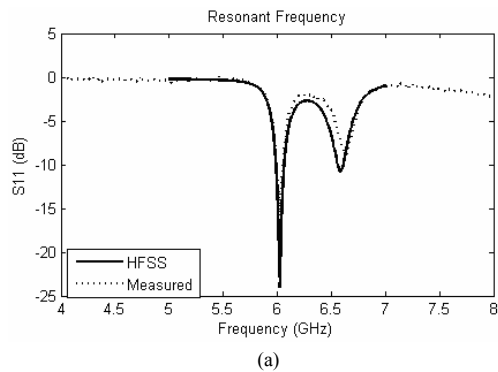


Figure 4: (a) Experimental and simulated S_{11} for optimized single slot configuration (b) 6 GHz antenna with a single slot and 10 GHz antenna without slot

Fig. 4 shows very good agreement between measured and simulated return loss with less than 2% error. In fig 4b, the single slot antenna is shown next to a solid patch antenna that resonates at the same frequency illustrating a dramatic size reduction of 73%. The measured results for all of the slot configurations are summarized in Table 4.

Table 4 : Summary of Hardware Results

Slot Geometry	Simulation Resonant Frequency (GHz)	Measured Resonant Frequency (GHz)	Simulated S_{11} (dB) with Feed Network	Measured S_{11} (dB)	Size Reduction (%)
Single Slot	6.02	6.02	-23.65	-15.82	73
Two Slots	6.00	6.14	-13.4	-17.04	73
Four Slots	5.99	6.06	-18.73	-14.17	73
Two Arcs	6.51	6.50	-30.4	-26.47	47
Two Crosses	7.03	7.06	-22.3	-22.76	38

5. Conclusion

A significant size reduction has been achieved for microstrip patch antennas by selectively removing slots from the patch metal. Given the number and shape of the slot, the genetic algorithm is used to optimize the size and location of the slot on the patch. Patch size reduction up to 75% has been achieved with a radiation pattern typical of microstrip patch antennas. Various slot shapes and numbers have been tried in order to optimize for gain as well as size reduction. Input impedance was added to the fitness function in order to increase the gain exhibited by the antennas. While there is still a slight lowering of gain between solid patch antennas and the optimized antennas with slots, this could be easily compensated through the use of an antenna array.

Future work involves creating dual frequency antennas by applying the concept of removal of slots that have a predefined shape and number. The genetic algorithm optimization will determine the size and location of the slots. In addition it will include input impedance in the fitness function so that the same impedance matching network can be used at both frequencies.

6. References

1. J. Robinson and Y. Rahmat-Samii, "Particle swarm optimization in electromagnetics," *IEEE Trans. Antennas Propagat.*, vol. 52, no. 2, pp. 397-407, Feb. 2004.
2. N. Jin and Y. Rahmat-Samii, "Parallel particle swarm optimization and finite-difference time-domain (PSO/FDTD) algorithm for multiband and wide-band patch antenna designs," *IEEE Trans. Antennas Propagat.*, vol. 53, no. 11, pp. 3459-3468, Nov. 2005.
3. D. Lee and S. Lee, "Design of a coaxially fed circularly polarized rectangular microstrip antenna using a genetic algorithm," *Microw. Opt. Technol. Lett.* 26(5):288-291 (Sept. 2000).
4. O. Ozgun, S. Mutlu, M.I. Aksun, and L. Alatan, "Design of dual-frequency probe-fed microstrip antenna with genetic algorithm," *IEEE Trans. Antennas Propagat.*, vol. 51, pp 1947-1954, Aug. 2003.
5. F. J. Villegas, T. Cwik, Y. Rahmat-Samii, and M. Manteghi, "A parallel electromagnetic genetic-algorithm optimization (EGO) application for patch antenna design," *IEEE Trans. Antennas Propagation*, vol. 52, no. 9, pp. 2424-2435, Sept. 2004.
6. J. M. Johnson and Y. Rahmat-Samii, "Genetic algorithms and method of moments (GA/MOM) for the design of integrated antennas," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1606-1614, Oct. 1999.
7. N. Herscovici, M. F. Osorio, and C. Peixeiro, "Miniaturization of rectangular microstrip patches using genetic algorithms," *IEEE Antennas and Wireless Propagation Letters*, vol. 1, pp 94-97, Jan. 2002.