2010 5th International Conference on Industrial and Information Systems, ICIIS 2010, Jul 29 - Aug 01, 2010, India

Design of broadband patch antennas using genetic algorithm optimization

J. M. J. W. Jayasinghe and D.N. Uduwawala,
Department of Electrical and Electronics Engineering,
University of Peradeniya, Sri Lanka

Abstract—**Patch antennas are cheap, simple, robust, inexpensive and compatible with MMIC designs. But the narrow bandwidth and low efficiency are the major drawbacks. Nowadays, the patch antenna is a widely used antenna type in many applications such as cellular phones, pagers, satellite communication and missiles. In this research, Genetic Algorithm optimization (GAO) method is used to design the shape of the patch, thickness of the dielectric substrate and the permittivity of the substrate in order to optimize the bandwidth performance and gain of center feed patch antennas. It is found that thin broadband fragmented single probe feed patch antennas with fractional bandwidths up to 51% can be easily designed using GAO.**

Keywords- Patch antenna; Genetic algorithm optimization; ***Dielectric substrate; Permittivity; Bandwidth; Gain***

I. INTRODUCTION

In the most basic form, a patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. The radiating patch and the feed lines are usually photo etched on the dielectric substrate [1-3]. Patch antennas are becoming popular more and more in wireless applications due to their low-profile structure. Patch antennas are simple to fabricate using printed circuit technology and compatible with MMIC designs. They are capable of dual and triple frequency operations. The demand for patch antennas was increased due to its advantages, which are not available in any other type. For an example, with optimized patch antennas, size of mobile phones could be reduced. As a result, it was enable to introduce nice tiny mobile phones, instead of bulky models.

As the major disadvantages of the patch antennas are narrow bandwidth and low efficiency, design of wideband and efficient patch antennas is an interesting problem for the antenna research community. In the initial stage, analysis was confined to basic shapes such as rectangular, circular and elliptical. Antenna parameters were theoretically calculated and fabricated so as to suit for a specific application. Later, with the availability of advanced simulation software and development of the fabrication technology research was expanded to different configurations in order to obtain better performance and use for wideband applications [4]-[7]. The performance of patch antennas can be optimized via changing antenna parameters such as patch shape, substrate material and substrate thickness.

Genetic algorithm optimization (GAO) of patch antennas has been reported in literature. Eg:- [8-10]. It is a powerful optimization technique [10]-[13] used in patch antenna design. It is a robust, stochastic-based search method, which can handle the common characteristics of electromagnetic optimization problems that are not readily handled by other traditional optimization methods. In this paper, genetic algorithms are used to design the patch geometry, substrate thickness and permittivity in order to optimize the bandwidth and gain of the antenna. The analysis of the patch antennas was carried out by using HFSS (High Frequency Structure Simulator) which is a highly accurate commercially used electromagnetic solver.

II. ANTENNA GEOMETRY AND GAO PROCEDURE

In order to search for the optimum solution of conducting regions, the patch area is divided into small square cells as shown in fig.1 where each cell can be assigned either conducting or non-conducting properties. It is a symmetrical fragmented patch antenna which is fed by a 50 Ω coaxial line at the centre point. It is tried to optimize the antenna operation around 4GHz with bandwidth of at least 1GHz. The length (l) and width (w) were taken same as that of a rectangular patch operating in the fundamental mode [1].

As it is assumed to be symmetrical about its centre axes parallel to l and w only a quarter of the patch is coded accordingly as genes in GAO procedure. Since only two values are possible for each cell, binary coding was used. The size of a cell was taken less than 3mm for all the designs in order to achieve better results. The chromosomes describe the entire fragmented patch. When more parameters are included in the design, the corresponding genes are added into the chromosome subsequently.

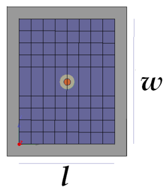


Figure 1. A gridded patch

The fitness function was defined by summing the return loss values ρ taken at 10 MHz intervals over the range of 1GHZ since the main objective was to design broadband patch antennas. Return loss values less than -10dB were considered as -10dB and the gain was also included in the fitness function. Therefore, the fitness function F which is maximized in the search for the optimum solution can be written as

$$F = (kG) - \left(\sum_{n=1}^{n=101} L(n) \right) \tag{1}$$

Where k is a weighting factor and L is defined as

$$L = \begin{cases} \rho & \rho \geq -10dB \\ -10dB & \rho < -10dB \end{cases} \tag{2}$$

and G is the gain at 4GHz.

When it was necessary to obtain a higher bandwidth, limit of ρ was changed for calculating L. Return loss values less than -15dB were considered as -15dB and return loss values less than -20dB were considered as -20dB in two designs. Another method followed for obtaining a higher bandwidth is to increase the substrate thickness. The population size was 20 chromosomes per generation in all designs. The probability of crossover was 100% and single point crossover method was used. One bit was mutated in 60% of the individuals within a generation [11]. The program was run over iterations until the fitness value converges.

III. SIMULATION RESULTS

The simulation along with GAO was programmed using HFSS scripts. The simulations were carried out under different categories based on the techniques used to obtain broadband performance and the number of parameters inserted in the GAO. The techniques are selecting different return loss limits for fitness function and changing the range of substrate thickness. The parameters are the geometric shape, substrate thickness and the substrate permittivity.

A. The simulation results of return loss and radiation patterns of a conventional rectangular patch antenna is shown in Fig. 2. The permittivity ε_r is 3.2 and substrate thickness is 6 mm. Using the equations for designing rectangular shape patch antenna l and w were taken as 17.5mm and 26mm respectively.[1] Bandwidth which is resonated at 4 GHz validate the theorotical calculations and simulation results. The antenna is narrowband with a 10dB fractional bandwidth of 9% which is 1.1:1. The radiation patterns are obtained on two vertical planes phi=0 and phi=90 as shown in the fig. 2. The maximum radiation is along 20 deg from the axis perpendicular to the patch. In the phi=0 plane the gain is 6.48 dB and phi=90 plane the gain is 5.64 dB. The aim of this study is to improve the bandwidth while maintaining a sufficient gain as evident in the following sections.

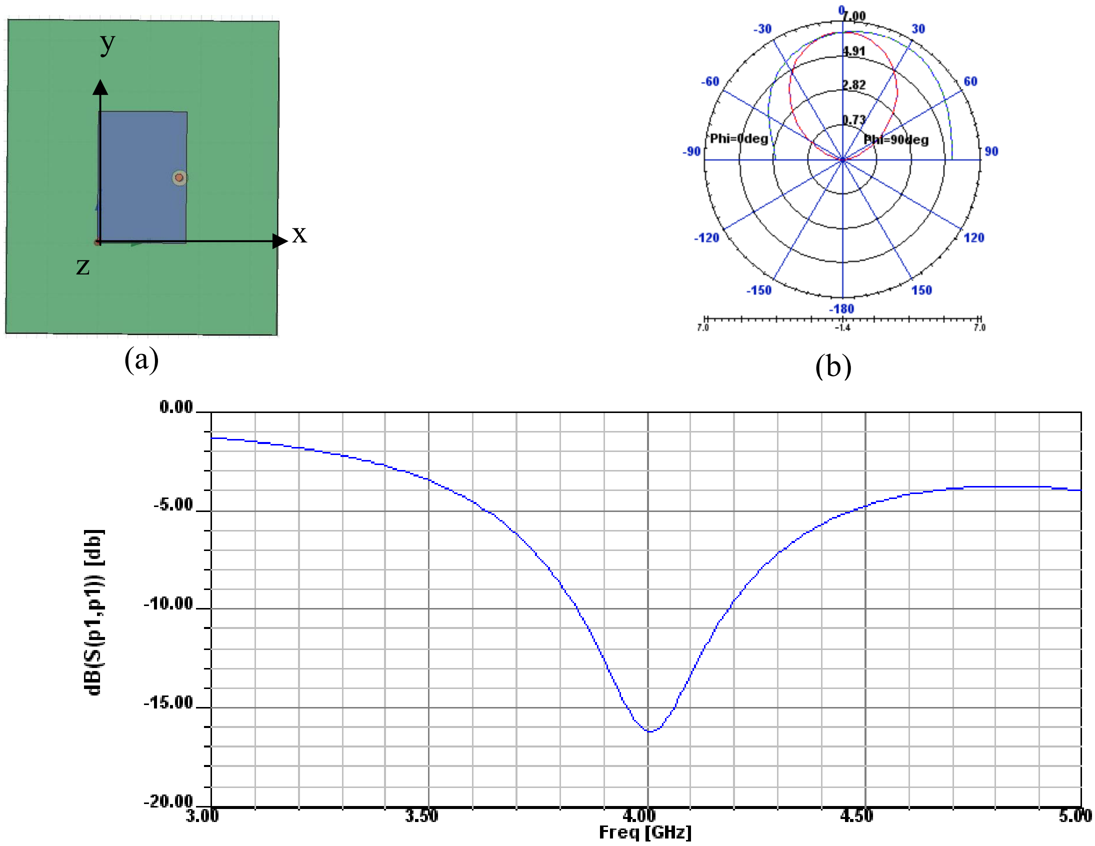


Figure 2. Simulation results of a rectangular shape patch with 6mm substrate thickness (a) patch antenna (b) radiation pattern (c) return loss plot

B The patch shape, substrate material and substrate thickness were included to be optimized. In the chromosome, first 12 genes describe the patch shape. Next 3 genes describe the substrate material by taking eight discrete permittivity values between 2.08-10.2. The substrate thickness was changed from 1-8mm. For calculating the fitness values, return loss values less than -10dB were considered as -10dB and k was taken as 10. The script was written to stop when there are no changes in the fitness values for 20 generations consecutively. The thickness of the optimized design was 7mm and the permittivity was 9.2 and the results are shown in fig3. The bandwidth is 1.4:1. The antenna is broadband with a 10dB fractional bandwidth of 16.8%. The maximum radiation is along the antenna plain with 4.19 dB in phi=90 deg plane and 2.43 dB in phi=0 deg plane.

C The substrate thickness was changed from 9-16mm. Dimensions of the patch, permittivity values, content of the chromosome and GAO procedure were kept same as part B. The thickness of the optimized design was 1.2cm and the permittivity was 4.5 and the results are shown in fig4. The bandwidth of the antenna is improved upto a 10dB fractional bandwidth of 43.6% which is 1.6:1. The maximum radiation is along the antenna plain with 4.19 dB in phi=90 deg plane and 2.43 dB in phi=0 deg plane.

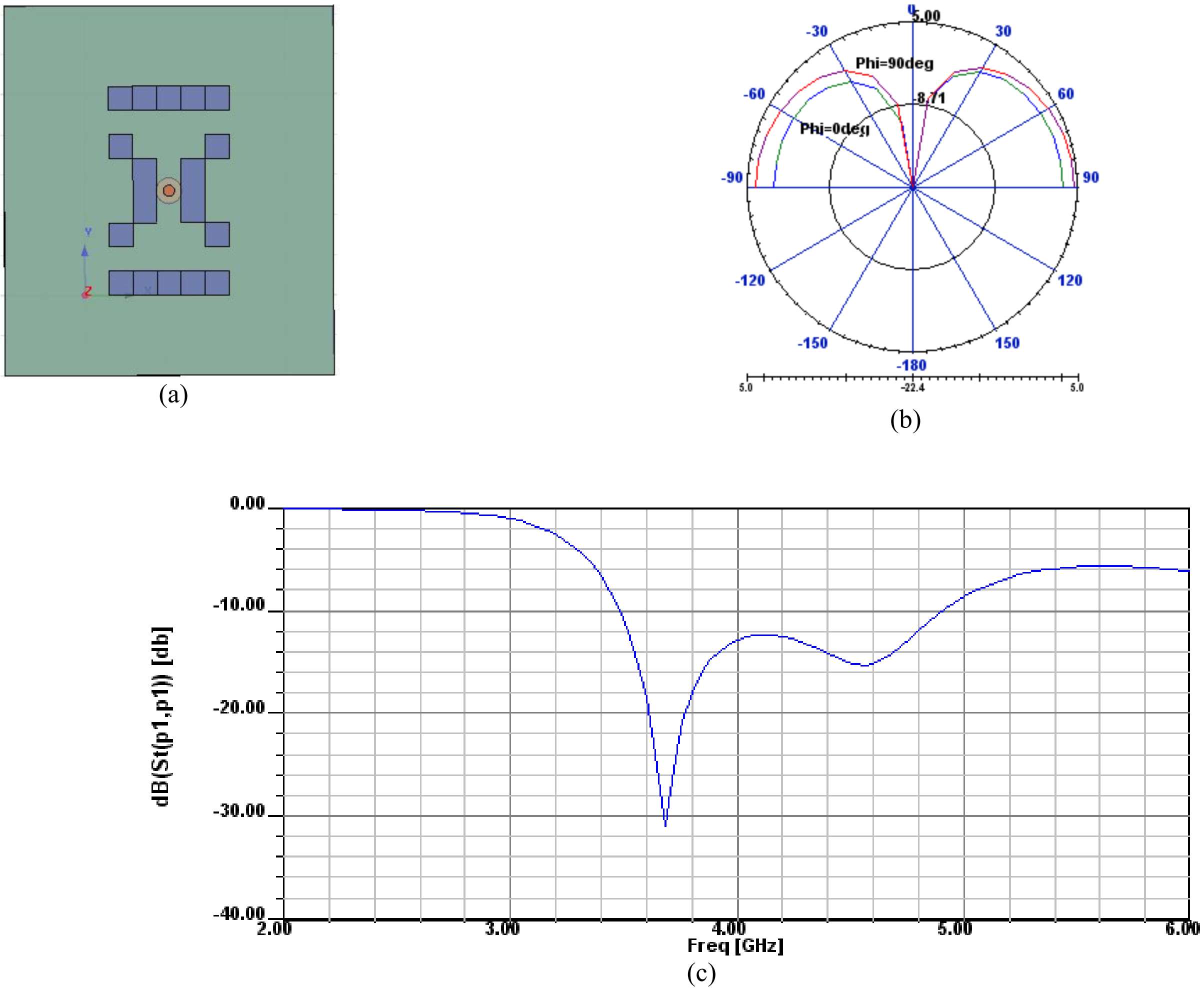
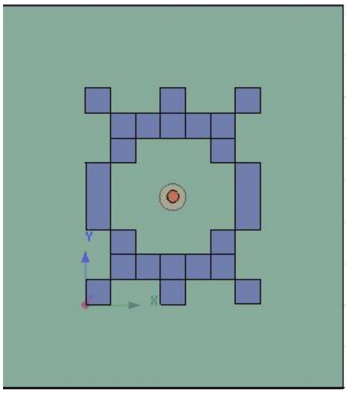
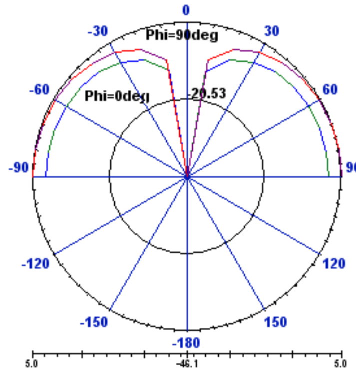


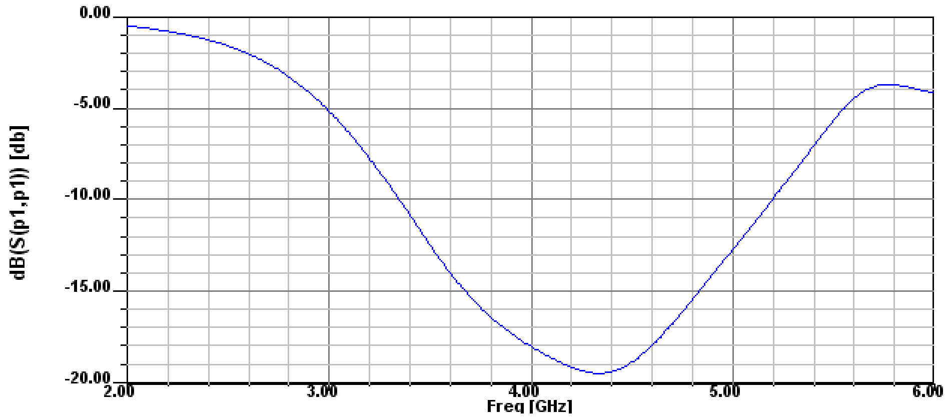
Figure 3. Design results when optimize patch shape, substrate thickness and substrate material (a) patch antenna (b) gain plot (c) return loss plot



(a)



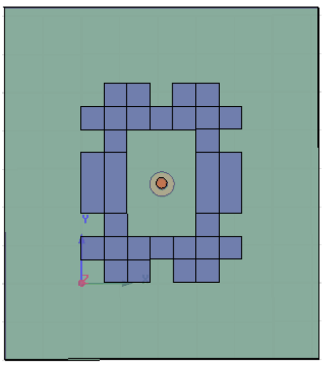
(b)



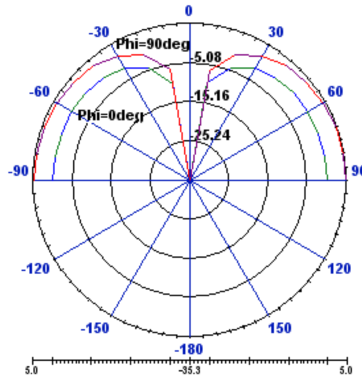
(c)

Figure 4. Design results when increasing substrate thickness (a) patch antenna (b) gain plot (c) return loss plot

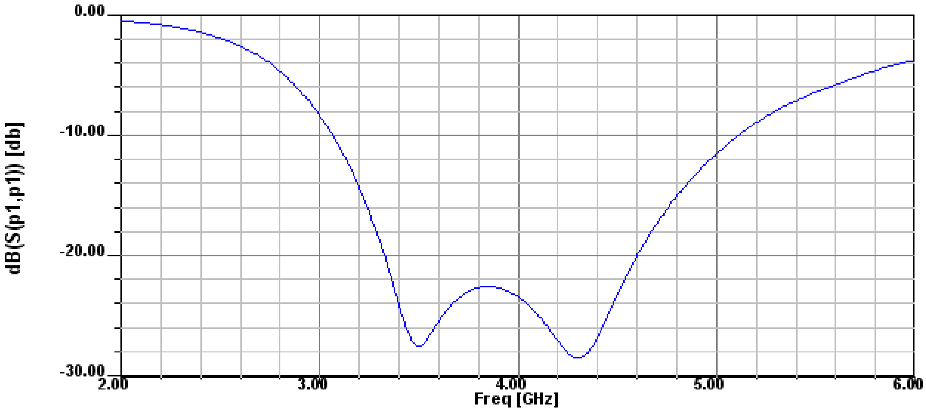
D Another design was done by considering return loss values less than -20dB were as -20dB for calculating the fitness values using the properties in part C. The thickness of the optimized design was 1.1cm and the permittivity was 6 and the results are shown in fig6. The bandwidth is 1.7:1. The antenna is broadwband with a 10dB fractional bandwidth of 50.7%. The maximum radiation is along the antenna plain with 4.64 dB in phi=90 deg plane and 2.28 dB in phi=0 deg plane.



(a)



(b)



(c)

Figure 5. Design results when Changing return loss limits to -20 (a) patch antenna (b) gain plot (c) return loss plot

IV. DISCUSSION

When using conventional rectangular shape patch antennas the results show narrowband properties. It is the main drawback in patch antennas. Therefore, several methods were successfully implemented in center feed small thin patch antennas to achieve broadband performance using GAO. The gain was also kept at sufficient levels by including it in the fitness function. Radiation patterns for all center feed antennas show omni directional performance. All the designs were obtained by running scripts until convergence. The fitness convergence rate for the design in partB is shown in Fig6.

Performance of patch antennas were optimized by including patch shape, substrate material and substrate thickness in GAO. While including these parameters in the chromosomes without keeping them fixed, patch antennas show broadband performance. Comparison of return loss plots in Fig2 and Fig3 shows the success of this method.

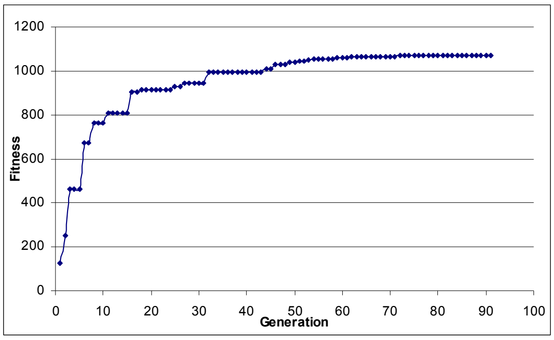


Figure 6. Fitness convergence rate

Another successful method to improve bandwidth performance and gain is to use higher thickness values in substrates. The thickness range for design in Fig3 was 1-8mm and for design in Fig4 was 9-16mm. The fractional bandwidth has improved from 16.8% to 43.6%. For the higher thickness range the convergence occurred within lesser generations.

Reducing the return loss value limits to -15dB or -20dB instead of using -10dB is another method to improve bandwidth. Comparison of Fig4 and Fig5 shows an improvement in fractional bandwidth from 43.6% to 50.7% change the limit from -10dB to -20dB.

V. CONCLUSION

In this paper, GAO is used to design the patch geometry, substrate thickness and permittivity in order to optimize the bandwidth and gain of the antenna. The design parameters and content of fitness function were changed and tested for achieving higher bandwidth properties.

The results show that including antenna parameters such as patch geometry, substrate thickness and permittivity in GAO improves the antenna performance than conventional rectangular shape antenna. Performance can be improved furthermore, by using higher thickness values for substrates and by taking lower return loss value limits.

Using higher thickness values in substrates give comparatively higher bandwidth improvements than reducing return loss value limits. Using the latter method ensures a very low return loss values over the operating bandwidth.

REFERENCES

[1] C. Balanis, *Antenna theory and design:* 2nd edition, Willey & sons, Inc., 1997.
[2] J.W. Howell, “Microstrip antennas,” *IEEE trans. Antennas propagate.* , Vol 23., pp 90-93, January, 1975.

[3] K.R. Karver and J.W. Mink, " Microstrip antenna technology," *IEEE trans. Antennas propagate. ,* Vol 29., pp 2-24, January, 1981.

[4] C.K Aanandan, K.G.Nair, "Compact broadband microstrip antenna", Electronic letters, IET, Vol 22, pp 1064-1065, 1986

[5] H.F. Pues and A. R. Van de capelle, "An impedance matching technique for increasing the bandwidth of microstrip antennas," *IEEE trans. Antennas propagate. ,* Vol 37., pp 1345-1354, November, 1989.

[6] Y. Guo, K. Khoo, L. C. Ong, "Wideband Dual-Polarized Patch Antenna With Broadband Baluns," *IEEE trans. Antennas propagate. ,* Vol 55., pp 78-83, January, 2007.

[7] M. Ali, R. Dougal, G. Yang, and H.-S. Hwang, "Wideband Circularly Polarized Microstrip Patch Antenna for Wireless LAN Applications", Department of Electrical Engineering, University of South Carolina, Swearingen Building, Columbia, SC, 29208.

[8] F. J. Villegas, T. Cwik, Y. Rahmat-Samii and M. Manteghi, "A parallel Electromagnetic genetic-Algorithm optimization application for patch antenna design," *IEEE trans. Antennas propagate. ,* Vol 52., pp 2424-2435, 2004.

[9] B. Thors, H. Steyskal, H. Holter, "Broadband fragmented aperture phased array element design using genetic algorithms," *IEEE trans. Antennas propagate. ,* Vol 53., pp 3280-3287, 2005.

[10] J. M. Johnson and Y. Rahmat-Samii, "Genetic algorithms in engineering electromagnetics," *IEEE Trans. Antennas Propagat. Magazine,* Vol.39, pp. 7-21, August 1997.

[11] Milan Polivka, Milan Drahovzal, Jan Rohan, Pavel Hazdra, "Multiband patch antenna with perturbation elements generated by genetic algorithm", Proc. 'EuCAP 2006', pp 6-10, 2006

[12] D. S. Weile and E. Michielssen, "Genetic algorithm optimization applied to electromagnetics: A Review," IEEE Trans. Antennas Propagat. , Vol.45, pp. 343-353, March 1997.

[13] D. S. Weile and E. Michielssen, "Genetic algorithm optimization applied to electromagnetics: A Review," *IEEE Trans. Antennas Propagat. ,* Vol.45, pp. 343-353, March 1997.C. Balanis, *Antenna theory and design:* 2nd edition, Willey & sons, Inc., 1997.