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W-shaped enhanced-bandwidth patch antenna for wireless communication

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Abstract In this paper a novel form of the familiar E-shaped patch antenna is presented. In the presented approach, by using the genetic algorithm (GA) based on fuzzy decision-making, some modifications have been implemented to the incorporated slots which lead to even more enhancement in the antenna bandwidth. The MOM (Method of Moment) is employed for analysis at the frequency band of 1.8GHz–2.6GHz by the optimization parameters of supply locations and slot dimensions. In the implemented fuzzy system, inputs are parameters like population, and outputs are parameters like recombination to produce the next generation. Fuzzy inference system (FIS) is used for the control of GA parameters. The design is also optimized by successive iterations of a computer-aided analysis package and experimental modifications. Prototype antenna, resonating at wireless communication frequencies of 1.88 and 2.37 GHz, has been constructed and experimental results are in relatively good agreement with the analysis. Dimensions of the modified slots for bandwidth enhancement, while maintaining good radiation characteristics, have been determined and the obtained antenna bandwidth of 36.7% is larger than that of a corresponding unslotted rectangular microstrip antenna or a conventional E-Shaped patch antenna. Details of the antenna design approach and experimental results are presented and discussed.

Keywords W-shaped antenna · Fuzzy system · Genetic algorithm · Wideband patch antenna

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1 Introduction

Modern wireless communication systems require wide bandwidth to provide high speed data transmission. For optimum system performance, high radiation efficiency, small volume, simple and low-loss impedance matching to the receive and transmit paths are necessary prerequisites of the antennas.

Microstrip antennas are appropriate candidates to meet the mentioned requirements and therefore they are used in a broad range of applications from radars, telemetry, navigation, biomedical systems, mobile satellite communications, the direct broadcast system (DBS), global positioning system (GPS) to remote sensing, primarily due to their compactness, fabrication simplicity, conformability and low manufacturing cost. However, they have a significant drawback of narrow bandwidth.

Various designs have been proposed and implemented to reduce this effect. One of the approaches is the incorporation of two parallel slots.

The proposed design herein is thoroughly studied in the following sections. The bandwidth of the antenna is optimized using the genetic algorithm based on fuzzy decision-making. Due to the measureless number of variables and large number of output characteristics related with many antenna structures, antennas cannot be optimized by conventional techniques, which use gradient methods.

Applications of genetic algorithms for optimization problems are widely known as well as their advantages and disadvantages in comparison with classical numerical methods [1]. The genetic algorithms' performance is determined by the investigation and utilization relationship kept throughout the GA run. This balance between the utilization of the whole solution space and the detailed searching of some parts can be modified to change the GA operators setting (i.e. selection, crossover and mutation). Fuzzy logic may be used for dynamically computing appropriate GA control parameters using the experience and knowledge of the GA experts. This adaptive change of the selected GA parameters is taking place by the way of Fuzzy inference system on the basis of GA feedback [2]. GA feedback is realized by means of special designed GA characteristics. The FIS is designed on the basis of GA expert knowledge. The method of moments with the vector triangular basis function is used for analysis as well as PDE[1] Toolbox of Matlab software [3,4]. VSWR is measured and compared with the numerical data. Experimental results are presented to validate the discussed analysis. Furthermore, the current distribution on the W-shaped patch is studied to demonstrate the wide-band behavior. At the end, a wide-band W-shaped patch antenna with 36.7% bandwidth is designed to cover 1.88 and 2.37 GHz frequencies. These ranges of frequencies are the ones which are paid considerable attention in modern wireless communications.

In order to demonstrate the advantages of the proposed design studied in this paper, it's necessary to investigate what previous designs have to offer and what they lack to pave the way for better understanding of benefits of the proposed design.

One of the first schemes introduced to enhance the patch antenna's bandwidth was in [5] and [6]. Three gap-coupled microstrip antenna configurations: radiating edges gap-coupled, non-radiating edges gap-coupled, and four edges gap-coupled microstrip antennas were proposed. In those configurations, additional rectangular resonators were coupled capacitively through narrow coupling gaps either to the radiating edges, or to the non-radiating edges, or to all the four edges of the rectangular patch antennas, respectively. In [7], authors presented multiple resonator antennas wherein the coupling between the resonators is through sections of microstrip line instead of via coupling gaps used in the antennas mentioned above. The lengths of these connecting strips are taken larger than twice the substrate thickness to minimize capacitive coupling through gaps.

In [8], an antenna structure was proposed which had some advantages over other candidate elements because the bandwidth was increased while maintaining a low-profile geometry and without additional internal matching networks. This antenna was the radiation-coupled Dual L antenna.

In [9], the authors presented a coaxially-fed single-layer single-patch microstrip antenna in the form of a rectangular patch with a U-shaped slot which exhibited relatively wideband characteristic. In [10], experimental results on the U-slot patch, including cross polarization measurements and the effects of patch size, slot size and feed position on performance were discussed.

In [11] (and also in [12]), the author presented a new structure: it was a microstrip patch etched-out of sheet metal and supported in the center by a post (metallic or nonmetallic). It could be fed by another microstrip line, which was either at the same level and parallel to the patch itself, or oblique or even perpendicular to the ground plane.

In [13], authors presented a C band aperture fed microstrip antenna element with stacked configuration of two patches with thick substrates and an air gap which showed good wide-band behavior.

In [14] with the loading of a pair of right-angle slots and a modified U-shaped slot in a rectangular microstrip patch, bandwidth enhancement of microstrip antennas was demonstrated.

In [15], authors presented a single-layer rectangular patch antenna using a coupled line feed. The coupled line matching technique increases the bandwidth of the patch antenna by a factor of more than 2.5 as compared to the normal edge-fed patch with the same geometrical dimension.

[1] Partial differential equation.

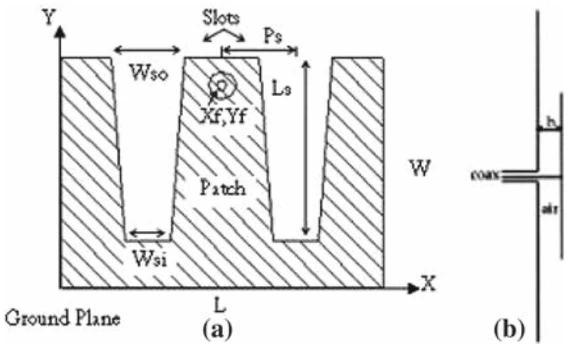


Fig. 1 Geometry of a wide-band W-shaped patch antenna which has two V-shaped slots. (**a**) Top view, (**b**) Side view

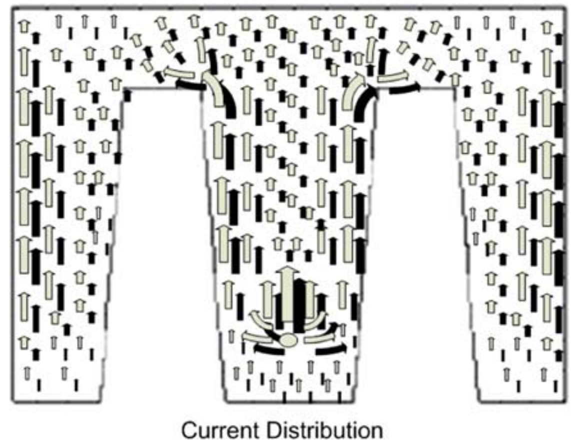


Fig. 2 The geometry of the current distribution

In [16] (and also in [17] and some other earlier papers), the E-shaped patch antenna was introduced. Two parallel slots were incorporated into the patch of a microstrip antenna to expand its bandwidth. The slot length, width, and position were optimized to achieve a wide bandwidth. A 32.3% E-shaped patch antenna was also designed.

In [18], a broadband low-profile E-shaped patch antenna with a novel microstrip-compatible feed is presented. The new feed structure makes E-shaped patch antennas more suitable for integration with microstrip circuits.

In [19], a novel coaxial-fed E-shaped microstrip patch antenna is proposed. The proposed antenna is found to have a much broader impedance bandwidth as compared to the U-slot antenna. An impedance bandwidth of about 33.8% is achieved for this antenna.

In [20], the authors presented a design of a broadband probe-fed planar patch antenna. The proposed antenna had a thick air-layer substrate, and bandwidth enhancement was achieved by cutting a small portion of the ground plane and adding an inverted U-shaped ground plane to be close to the radiating patch, and then feeding the antenna at the inverted U-shaped ground-plane portion using a 50 Ω coax feed with a short probe pin. Experimental results showed that an impedance bandwidth greater that 20% could be achieved for the proposed antenna.

However, these methods typically enlarge the antenna size, either in the antenna plane or in the antenna height. Thick substrates lead to higher dielectric loss and the emergence of surface waves which degrades the antenna radiation pattern and reduces radiation efficiency. Other proposed designs usually suffer from complex fabrication processes. Due to these reasons, single-patch low-profile wide-band antennas have attracted many researchers' attention. Compared to previous mentioned microstrip patch antenna designs, the W-shaped patch antenna is simpler in construction and offers even more enhanced bandwidth.

2 Geometry

The antenna geometry is shown in Fig. 1. The antenna has one patch and (L,W,h) parameters are used to characterize the size of the patch. The patch is fed by a coaxial probe at position (X_f, Y_f). For enhancing the antenna bandwidth, two V-shaped slots are incorporated into the patch and positioned as illustrated in the Fig. 1. The shape of the patch resembles the letter "W", therefore the name "W-shaped patch antenna" is chosen for referring to the structure. The slot length (L_s), position (P_s), outer width (W_{so}), and inner width (W_{si}) are the parameters which have been optimized to obtain the desirable bandwidth.

An empirical model can be useful in an initial design and usually plays an appreciable role in antenna scaling. Typically, these empirical models include the cavity model and the transmission line model for modeling of the initial microstrip patch antenna. The transmission line analysis for a microstrip patch antenna is a well-established approach among the antenna engineers [21].

In [22] and [23], based on the observation of the current distribution, a simplified transmission-line equivalent circuit for the modeling of E-shaped patch antenna was proposed. The proposed model can be used for antenna's resonant frequency prediction. It can be concluded that around the W-shaped arms, there are three coupled transmission lines based on the current distribution on the patch (Fig. 2).

Surface current plots can take the role of facilitating the understanding of electromagnetic behavior of intricate antenna structure which radiates in a complicated wireless package environment. They provide insight into the radiation characteristic of the antenna and give a snapshot of the interactions between the antenna and wireless package.

3 Fuzzy Inference System

The fuzzy inference system is a popular computing structure based on the concept of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. Therefore it is used for the control of GA parameters [2].

Fuzzy inference systems are the most essential modeling tool based on fuzzy set theory. Our FIS is built by domain experts [2] and is used for automatic adaptation (control) of strategic GA parameters. The Matlab Fuzzy Logic Toolbox was used for FIS development [2].

A short description of FIS:

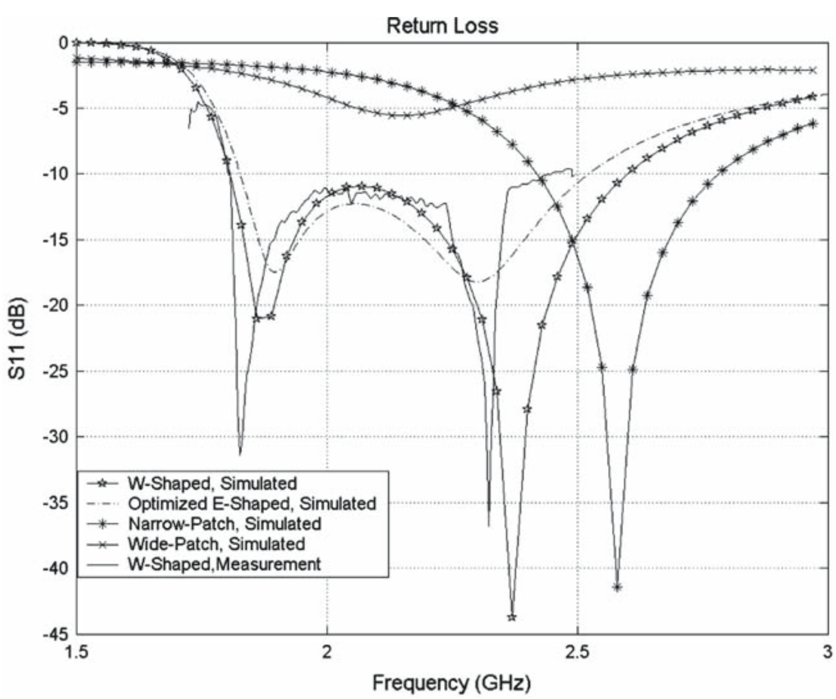
1. Input: GA characteristics (population P).
2. Fuzzy models: The Sugeno fuzzy model [3].
3. Fuzzy rules and membership Function: Made by field expert knowledge.
4. Output: Crisp values of selected GA parameters (we have to use a defuzzifier to convert a fuzzy set to a crisp value).
5. Values of selected GA parameters:
   P_c: Probability of Crossover
   P_m: Probability of Mutation (percentage of bit mutation)

The antenna is optimized using fuzzy Gaussian set for P_c and P_m parameters, and also genetic algorithm by binary coding. The population size was 70 individuals and 50 generations were evaluated. The goal is to minimize the maximum S_{11} magnitude at three frequencies, 1.9 GHz, 2.1 GHz, and 2.4 GHz. The cost function in this case was given by:

$$\text{Cost\_Function} = \min(S_{11n}) \quad , \quad \forall n \tag{1}$$

where the subscript n refers to the number of frequencies in analysis and n = 3 in this paper.

Fig. 3 S_{11} of the W-shaped patch antenna (measured and calculated) in comparison to unslotted patch antenna



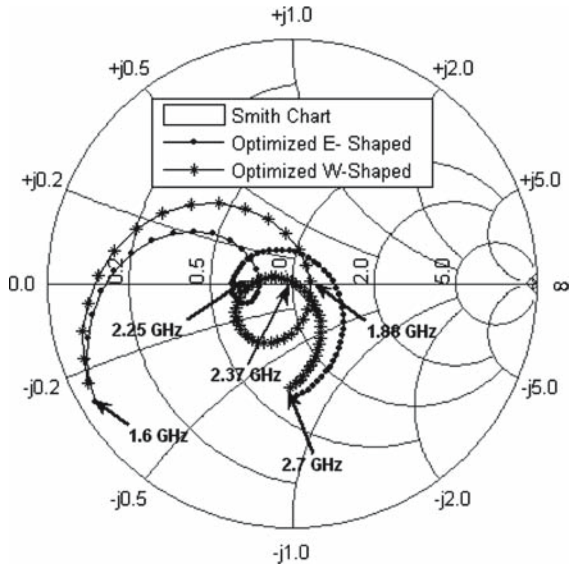


Fig. 4 Input impedance response

4 Measurement and Miscellaneous Issues

In this section, a wide-band W-shaped patch antenna, which is an optimized E-shaped antenna using genetic algorithm based on fuzzy decision making, is studied in detail. The antenna dimensions and feed position follow: (in millimeters):

$$(L,W,h) = (70, 50, 15)$$
$$L_s = 40\,, W_{si} = 10, W_{so} = 16, P_s = 16$$
$$(X_f, Y_f) = (35, 44)$$

Fig 3 shows the S_{11} results of the W-shaped patch antenna that are calculated by PDE Tool Box of MATLAB and measured on an HP- 8410C network analyzer.

It can be seen that the W-shaped patch antenna resonates at 1.88 and 2.37 GHz frequencies and has a wide bandwidth of 36.7%. Two simple patch antennas without slots and an E-shaped patch antenna, which is optimized and has closest possible dimensions to the W-Shaped patch, are also simulated for comparison. The E-Shaped patch antenna has a bandwidth of about 31.8%.

Simple patch antennas have the same height and width as the W-shaped patch antenna. The narrow patch antenna, which has a 19-mm length, has a bandwidth of 13.8% while the wide patch antenna with the same length as the W-shaped patch antenna doesn't match to50 Ω.

Time required for simulation by using a Pentium IV (CPU: 2.4 GHz) PC and 1 GHz RAM has been about 13:30 h and this time is about 1:30 h less than ordinary genetic algorithm optimization.

Figure 4 shows the impedance curve for W-shaped and E-shaped antenna on the smith chart.

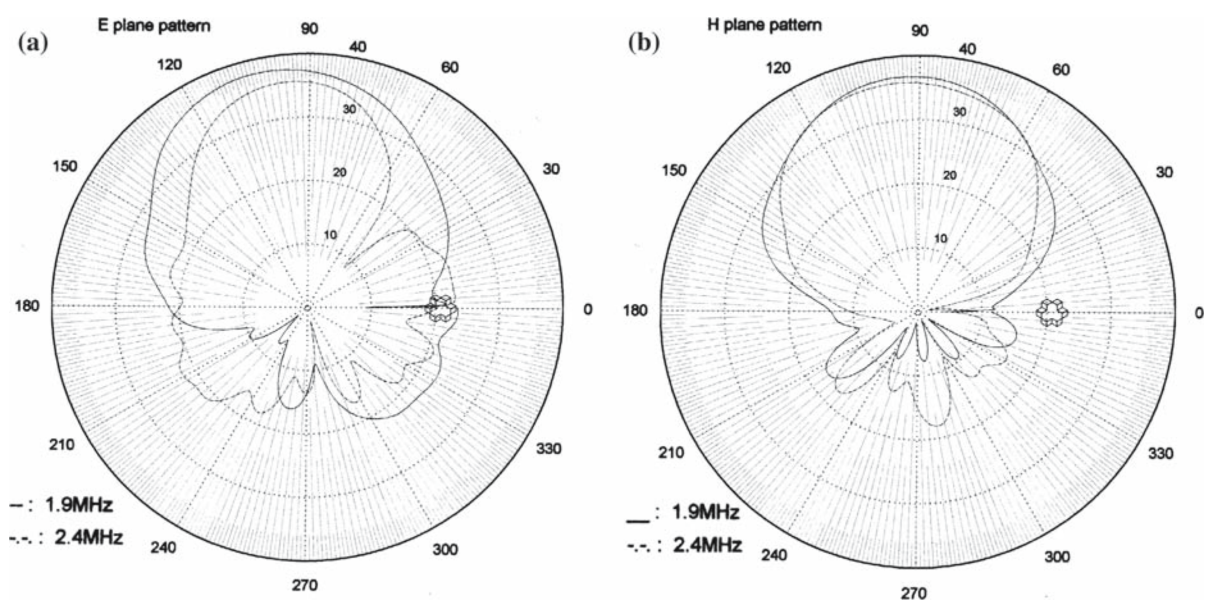


Fig. 5 Measured co-pol. patterns at two frequencies of 1.9 GHz and 2.4 GHz. (**a**) E-plane pattern, (**b**) H-plane pattern

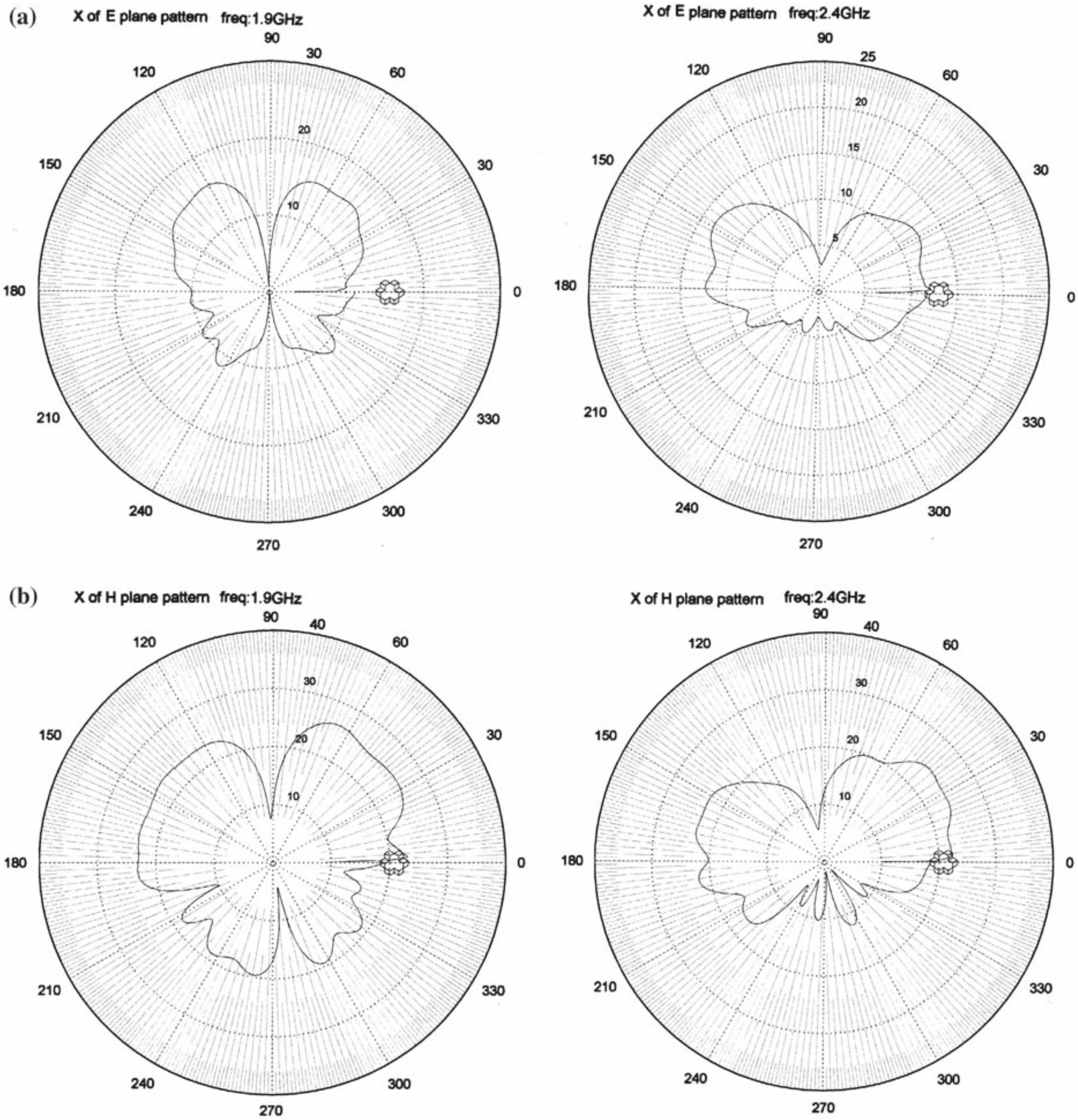


Fig. 6 Measured cross-pol radiation patterns at two frequencies of 1.9 GHz and 2.4 GHz. (**a**) x-E plane patterns (**b**) x-H plane pattern

5 Pattern Measurements

The radiation pattern of the W-shaped patch antenna is measured in the far-field chamber located at the Khajenasir university antenna lab. The patterns are measured at two resonant frequencies: 1.9 and 2.4 GHz and shown in Figs. 5 & 6. In the E plane, the 3-dB beam width is 45° at 2.4 GHz and 60° at 1.9 GHz.

In the H-plane, the radiation pattern is similar at 1.9 GHz and 2.4 GHz. The 3 dB beamwidth is 60° at both frequencies. This high cross-pol is a result of the leaky radiation of the slots. Although it is a bit high, it's not an important factor in some communication applications.

Fig. 7 shows that the simulated directivity of the antenna. It is 9.1 dB at 2.4 GHz and 8.2 dB at 1.9 GHz.

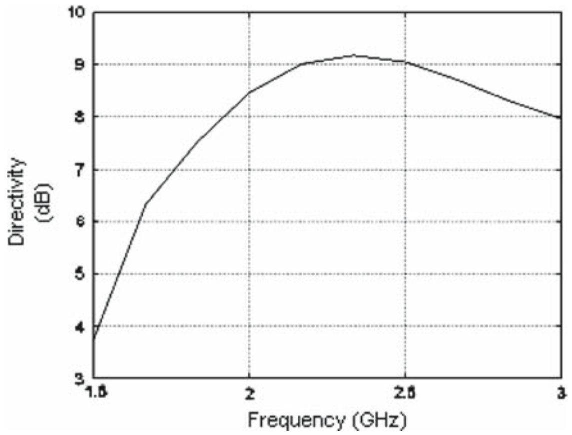


Fig. 7 Calculated directivity of the E-shaped patch antenna versus frequency

Since the antenna matches well in this frequency range, it should have the similar level of gain. The efficiency is noticeably higher, since there are no dielectric losses and no surface wave losses.

Table 1 shows the specifications of the optimized E-shaped antenna

Table 2 illustrates the provision of the optimized W-shaped antenna.

And Table 3 compare narrow patch antenna with W-shaped antenna.

A photo of the antenna is shown in Fig. 8.

6 Conclusion

The low-profile W-shaped patch antenna with wide bandwidth was presented in this paper. Optimization was carried out using genetic algorithm based on fuzzy decision-making. GA–FIS is improving GA with self-control mechanism based on fuzzy inference system (FIS). Parameters were set by GA–FIS. Measured results on fabricated antenna were used to confirm the simulation results. The visualization of the surface currents on the W-Shaped antenna was used to explain the antenna radiation characteristics. The results and design details on the antenna presented here can be chosen as beginning design for professionals interested in utilizing low-profile integrated antennas. At the end, a 36.7% bandwidth W-shaped patch antenna is designed, measured, and characterized in detail which can be applied to modern wireless communication frequencies of 1.88 GHz to 2.37 GHz.

Table 1 Specifications of optimized E-shaped antenna BW = 31.8%

Freq. (GHz)	1.9	2.3
S_{11} (dB) Simulated	−15.5	−16

Table 2 Specifications of optimized W-shaped antenna (new method) BW = 36.7%

Freq. (GHz) Simulated	1.88	2.37
Measurement	1.83	2.32
Simulated	−21	−44
S_{11} (dB) Measurement	−31	−37
Gain (dB)	7.6	8
Efficiency	87%	77.6%

Table 3 Comparison of optimized W-shaped antenna with ordinary patch antenna (Narrow Patch)

	Narrow patch	W-shaped antenna
Freq. (GHz)	2.58	2.37
S_{11} (dB)	−41.5	−44
Fractional bandwidth	13.8%	36.7%

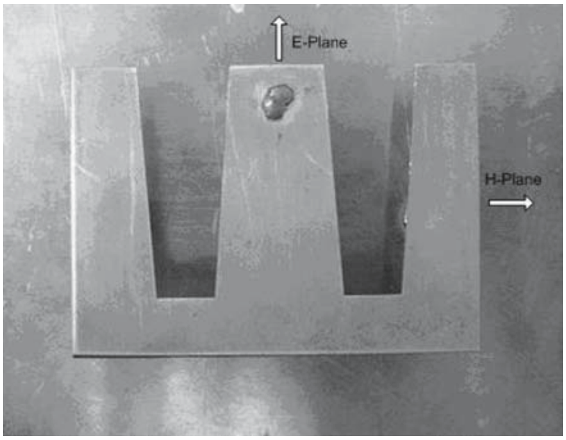


Fig. 8 A photo of a W-shaped patch antenna resonating at frequencies of 1.88 and 2.37 GHz

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References

1. Rahmat-Samii, Y., & Michielssen, E. (1999). Electromagnetic optimization by genetic algorithms. New York, NY: Wiley.
2. Lotfi Neyestanak, A. A., Hojjat Kashani, F., & Barkeshli, K. (2005). E-shaped patch antenna design based on genetic algorithm using decision fuzzy rules. *IJECE, 4*(1), 18–24.
3. PDF Documents of fuzzy and PDE toolbox of Matlab 7, http://www.mathworks.com/, 2005.
4. Makarov, S. N. (2002). *Antenna and EM modeling with Matlab*. New York, NY: John Wiley and Sons Inc.
5. Kumar, G., & Gupta, K. C. (1984). Broad-band microstrip antennas using additional resonators gap-coupled to the radiating edges. *IEEE Transaction Antennas and Propagation, AP-32,* 1375–1379.
6. Kumar, G., & Gupta, K. C. (1985). Nonradiating edges and four edges gapcoupled multiple resonator broad-band microstip antennas. *IEEE Transactions Antennas and Propagation, AP-33,* 173–178.
7. Kumar, G., & Gupta, K. C. (1985). Directly coupled multiple resonator wide-band microstrip antenna. *IEEE Transactions on Antennas and Propagation, AP-33*, 588–593.
8. Virga, K., & Rahmat-Samii, Y. (1995). An enhanced bandwidth integrated dual L antenna for mobile communications systems-design and measurement. *IEEE Antennas and Propagation Symposium Diges*, Newport Beach,CA, pp. 1120–1123, June 1995.
9. Huynh, T., & Lee, K. F. (1995). Single-layer single-patch wideband microstrip antenna. *Electronic Letters, 31*(16), 1310–1312.
10. Lee, K. F., Luk, K. M., Tong, K. F., Yung, Y. L., & Huynh, T. (1996). Experimental study of the rectangular patch with a U-shaped slot. *Antennas and Propagation Society International Symposium, AP-S. Digest, 1*, 10–13.
11. Herscovici, N. (1998). New considerations in the design of microstrip antennas. *IEEE Transactions on Antennas and Propagation, 46*, 807–812.
12. Herscovici, N. (1998). A wide-band single-layer patch antenna. *IEEE Antennas and Propagation Society International Symposium, 2*, 1108–1111.
13. Barilese, B., & Peixeiro, C. (1998). Wide-band microstrip patch antenna element. *IEEE Antennas and Propagation Society International Symposium, 2*, 1104–1107.
14. Sze, J.-Y., & Wong, K.-L. (2000). slotted rectangular microstrip antenna for bandwidth enhancement. *IEEE Transactions on Antennas and Propagation, 48*(8), 1149–1152.
15. Van Wyk, M. D., & Palmer, K. D. (2001). Bandwidth enhancement of microstrip patch antennas using coupled lines. *Electronics Letters, 37*(13), 806–807.
16. Yang, F. Zhang, X.-X., Xiaoning, Y., & Rahmat-Samii, Y. (2001). Wide-band E-shaped patch antennas for wireless communications. *IEEE Transactions Antennas and Propagation, 49* (7), 1094–1100.
17. Yang, F., & Rahmat-Samii, Y. (2000). Wideband dual parallel slot patch antenna (DPSPA) for wireless communications. *IEEE Antennas and Propagation Society International Symposium, 2000, 3*, 1650–1653.
18. Ge, Y., Esselle, K. P., & Bird, T. S. (2004). A broadband E-shaped patch antenna with a microstrip compatible feed. *Microwave and Optical Technology Letter, 42*(2), 111–112.
19. Ooi, B. L., & Shen, Q. (2000). A novel E-shaped broadband microstrip patch antenna. *Microwave and Optical Technology Letter, 27*(5), 348–352.
20. Teng, P.-L., Tang, C.-L., & Wong, K.-L. (2001). A broadband planar patch antenna fed by a short probe feed. *Microwave Conference*, 2001. APMC 2001. 2001 Asia-Pacific, vol.3, pp.1243 -1246, 3-6 Dec. 2001.
21. Bahl, I. J., & Bhartia, P. (1980). *Microstrip antennas*. Dedham, MA:Artech House.
22. Ooi, B. L., Leong, M. S., & Shen, Q. (2001). A novel equivalent circuit for E-shaped slot patch antenna. *IEEE Antennas and Propagation Society International Symposium, 2001, 4*, 482–485.
23. Zhang, X.-X., & Yang, F. (1998). The study of slit cut on the microstrip antenna and its applications. *Microwave Optical Technology Letter, 18*(4), 297–300.

Biographics

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Kasra Barkeshli (Deceased, June 2004) was born in Tehran on August 12, 1961. He received his Ph.D. degree in Electrical Engineering Department from University of Michigan, Ann Arbor, US. He is currently an Associate Professor. in Electrical Engineering Department of Sharif University of Technology, he chaired the department from 1995 to 1999. Dr. Barkeshli is a Senior Member of IEEE and has published numerous papers in international journals and conferences.He died on June 29, 2004. It is with deep regret that I learned of the demise of Prof. Kasra Barkeshli, a respected academic member of the Electrical Engineering Department, Sharif University of Technology, Tehran, Iran. Peoples who had known Prof. Barkeshli including his alumni, colleagues, and friends were very much impressed with his sincere dedication to his academic life as well as a respected human being with good wills and wishes.