Impedance bandwidth optimization of double slots circular patch antenna using genetic algorithm and the Interface Fuzzy Logic

F. Hojjat Kashani, A. A. Lotfi Neyestanak, K. Barkeshli

Abstract: A modified circular patch antenna design has been proposed in this paper, the bandwidth of this antenna is optimized using the genetic algorithm (GA) based on fuzzy decision-making. This design is simulated with HP HFSS Program that based on finite element method. This method is employed for analysis at the frequency band of 1.4 GHz- 2.6 GHz. It gives good impedance bandwidth of the order of 15.5% at the frequency band of 1.67GHz-1.95GHz and 10.6% at 2.23GHz- 2.48GHz. It means that impedance bandwidth increases above 4.9% than the impedance bandwidth of ordinary circular patch antennas and band width rise from 1.78GHz- 1.98GHz (10.6%) to 1.67GHz- 1.95GHz (15.5%) and 2.23GHz- 2.48GHz (10.6%). The antenna fabricated with two slots on circular patch antenna. The measured results of the optimized antenna validate a high compatibility between the simulation and the measurements.

Key words: E-Shaped Circular Patch Antenna, Genetic Algorithm, Fuzzy System, Wide Band Antenna.

1 Introduction

Wireless communications systems are in use in multitude of sizes ranging from small hand-held devices to devices mounted on vehicles. 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 themes in these designs is employing additional capacitance which is realized by integrating parasitic metallic strips in the microstrip antenna structure. This is usually implemented by addition of parasitic patches either laterally or vertically or by increasing the overall substrate thickness. Another approach is the incorporation of two parallel slots.

Due to the immeasurable quantity of variables and outsized number of output characteristics connected to the antenna structure, antennas cannot be optimized by conventional techniques, which use gradient methods.

Applications of genetic algorithms for optimization problems are generally well-known. Their advantages and disadvantages in comparison with classical numerical methods are also acknowledged [1].

In short Genetic Algorithms (GA) is stochastic-based search methods modeled on the principles and concepts of natural selection and evolution [1].

In the GA each variable is represented as a binary code called a gene. These genes are then arranged and combined to form a chromosome. Each chromosome has an associated fitness value, assigning a value of merit to the chromosome. A high fitness value being the characteristic of a good quality chromosome.

The algorithm begins by generating a number of random chromosomes. A selection strategy is then implemented which decides which chromosomes will take part in the evolution process. The unacceptable chromosomes are simply discarded. The chromosomes that survive become parents, by swapping some of their genetic material to produce two new offspring. The mating process is repeated between the remaining chromosomes until enough new chromosomes have been produced, leaving a constant number of chromosomes after each iteration. This algorithm is repeated until a satisfactory fitness is reached or a predefined number of iterations/generations have been run. The algorithm also makes use of mutations, which cause small random changes in chromosomes to explore other solutions which may not have been in the optimizer's search space [1].

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Fuzzy logic may be used for dynamically computing appropriate genetic algorithm control parameters using the experience and knowledge of the operators. This adaptive change of the selected parameters is made by way of Fuzzy Inference System on the base of genetic algorithm feedback [2].

HP_HFSS software has been utilized for simulating the antenna structure and deriving its characteristics. Due to the limited bandwidth of the microstrip patch antenna, several designs of single-layer broadband patch antennas have been reported [3]. These related broadband designs are achieved by embedding a U-shaped slot in the microstrip patches of various shapes [3]–[5] or a wider arc-shaped slot in a circular microstrip patch.

In [6], the paper was concerned with the bandwidth improvement of electromagnetically coupled microstrip dipoles by adapting one or two parasitic metallic strips either in a stacked fashion between the embedded microstrip transmission line open end and the radiating microstrip dipole antenna or co-planar to and near the open end of the embedded microstrip transmission line.

In [7], a resistive load was strategically coupled to the patch antenna in a two-port configuration. Variation of coupling to the resonant patch yielded enhanced bandwidth.

In [8], authors presented a technique to increase the bandwidth of a microstrip antenna using a leaky-wave concept.

In [9], a stacked square ring microstrip patch antenna with slot coupling was presented which had a 10-dB return loss bandwidth of 15.8%, good front-to-back ratio and cross-polarization over the band 4.65–5.45 GHz.

By stacking two shorted patch antennas, it was reported that a wider operating bandwidth, compared to that of a single shorted patch antenna, could be obtained. The bandwidth enhancement for this kind of antenna was obtained by adjusting the lengths of the two stacked shorted patches to be slightly different, which made it possible for the excitation of two resonant modes at close frequencies. A wider impedance bandwidth formed by the two closely excited resonant modes was thus obtained. In [10], two designs of stacked shorted patch antennas with a low profile and a wide bandwidth (larger that 10%) were presented. In design process, the upper and lower shorted patches had a common shorting wall, and were both printed on dielectric substrate. Wide impedance bandwidth was obtained by adjusting the lengths of the upper and lower patches to be slightly different, leading to the excitation of two closely excited resonant modes. In [11], a stacked E-shaped patch antenna was proposed. As compared to the E-shaped microstrip patch antenna in [12], the proposed antenna had a higher input impedance bandwidth about 38.41%. The radiation patterns of the proposed antenna were found to be relatively constant throughout the entire band of operation. However, the broadband operation is very sensitive to small variations in the dimensions of the inserted microstrip structure for providing the reactive loading, especially when applying the inserted-loading technique to a circular patch antenna. This makes the presented broadband circular microstrip antennas have strict manufacturing tolerances. In this paper, we place a pair of arc-shaped slots close to the side edges of the circular patch, which is connected with a narrow rectangular slot oriented along the keyed up surface current direction of the fundamental resonant mode of the circular patch. Owing to the embedded arc-shaped slots around the boundary of the circular patch antenna, the surface current path of the TM_{21} mode is disconcerted and expanded to create the working frequency lowered. And, by inserting the rectangular slots the null voltage point of the TM_{21} mode is moving from the center toward the boundary of the circular patch. Therefore, the surface current distribution becomes uniform in the central portion of the circular patch, which is similar to that of the fundamental resonant mode of the unslotted circular patch antenna. However, the operating frequency of the fundamental mode TM_{11} can be slightly affected. It is found that by adjusting the narrow rectangular slot's length to be 1.2–1.38 times the radius of the circular patch, the obtained two operating frequencies are close to each other to achieve a wide operating bandwidth, which is 2.3 times that of the conventional unslotted circular patch antenna. And, the proposed broadband design is easier to be implemented and less sensitive than the design with the embedded reactive loading. In this paper, we present a single-patch wide-band microstrip antenna: the circular patch antenna with two slots. When two parallel slots are incorporated into the antenna patch, the bandwidth increases above 4.9%.

However, these methods have their own drawbacks as well, such as enlarging the antenna size, either in the antenna plane or in the antenna height, leading to higher dielectric loss and the emergence of surface waves by thick substrates, which degrades the antenna radiation pattern and reduces radiation efficiency. Single-patch wide-band antennas have attracted many researchers' attention because of the mentioned reasons. In comparison to the previously outlined designs, the optimized E-shaped circular patch antenna is relatively simple in construction and provides even more enhanced bandwidth.

2 E-shaped Circular Patch Antenna Analysis

The results of the improvement of a compact wideband radiator for use in wireless communications applications are offered in this section. Bandwidth is specified as the frequency bandwidth in which the voltage standing-wave ratio (VSWR) is less than 2:1 and that is equivalent to about -10dB return loss.

The schematic diagram of the proposed microstrip antenna is given in Fig.1. and two parallel slots are cut on the circular patch with a uniform inter sectoral angle of 90° and uniform distance of about 1cm from the centre of the patch. The location of the feed point is t at a distance of about 3.2cm from the centre of the patch.

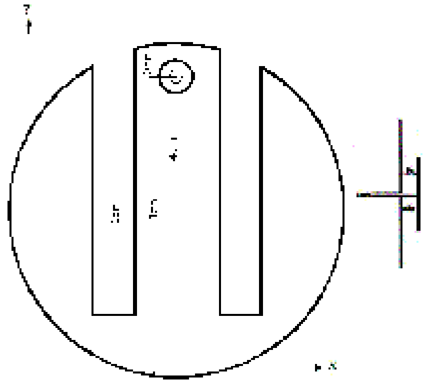


Fig.1 Top view of circular patch antenna

An experimental model can be useful in an initial design and usually plays an appreciable role in antenna scaling. Typically, these experimental models include the cavity model and the transmission line model for modeling of microstrip patch antenna. The transmission line analysis for a microstrip patch antenna is a well-known approach among the antenna engineers. In [13], based on the examination of the current distribution, a simplified transmission-line equivalent circuit for the modeling of E-shaped patch antenna was recommended. The proposed model can be used for antenna's resonant frequency prediction. It can be concluded that around the E-shaped arms, there are three coupled transmission lines based on the current distribution on the patch.

The unslotted microstrip patch antenna can be modeled as a simple LC resonant circuit and discussed in [13] and its L and C values are determined by the length of currents path which extends from the feeding point toward the edges. Incorporation of two slots into the patch affects the resonance characteristic of the patch in such a way that the current has to flow around the slots at the edge part of the patch. In the middle part of the patch, there is almost no change and it represents the initial LC circuit and resonates at the initial frequency but the increased path length of the current at the edge part introduces additional series inductance ΔL_s as studied in [14, 15]. Therefore, it is apparent that the equivalent circuit of the edge part resonates at a lower frequency. So it can be concluded that the antenna changes from a single LC resonant circuit into a dual resonant circuit in which coupling between the circuits occurs and a wide bandwidth can be achieved.

In this paper, the mention equivalent circuit is validated for circular patch antenna with two slots. Fig. 2 shows that the current distribution of the circular E-shape patch antenna.

3 Optimization Method (GA-FIS)

Fuzzy Inference System is used for the control of GA parameters. The following must be determined for applications of FIS to control the GA parameters:

Input Values:

The input values are crisp numbers. This inputs are obtain from special GA characteristics.

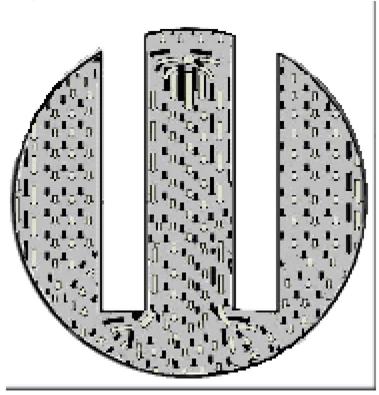


Fig. 2 The current distribution on the circular E-shaped

Model of FIS with crisp output:

The FIS is a popular computing structure based on the concept of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. The output represents parameters of the GA operators. Outputs are obtained by means of defuzzification. With crisp inputs and outputs, a fuzzy inference system implements a nonlinear mapping from its input space to output space.[2]

To simulate, HPHFSS, Genetic algorithm and Fuzzy toolbox of Matlab are employed.

A short description of the FIS is given in [2]. In this paper Sugeno fuzzy model is used and compared by Mamdani fuzzy inference system using min and max.

In sugeno reasoning the consequence, the output size is deterministic [16]:

$$\textit{if } x = X_i \textit{ then } y = y_i \tag{1}$$

The Mamdani reasoning the determinism is produced with singletons.

Sugeno type of reasoning with weighted average leads to:

$$y(x) = \frac{\sum_{i=1}^{m} \mu_{X_i}(x) y_i}{\sum_{i=1}^{m} \mu_{X_i}(x)} \tag{2}$$

where y_i a discretization point of membership functions and m is is number of rules. Weighted average requires that the rule base is complete and input fuzzy membership functions cover the input space. Otherwise there is a danger to divide with zero. Sugeno reasoning allows us to use also functions of input x, not only constants, on the right hand side. The rules would look like:

$$\textit{if } x = X_i \textit{ then } y = f_i(x) \tag{3}$$

Function f_i can be a different nonlinear mapping for each rule. *x* may be a vector and more complicated rule structures can also appear.

Sugeno systems using constants or linear functions in the consequence are clearly parameterized maps. Therefore it is possible to use optimization techniques to find best parameters to fit data instead of trying to do it heuristically.

Mendel-Wang's Mamdani type, fuzzy logic system is given by [16]:

$$y(x)=\frac{\sum_{j=1}^{n} w^{j}\left(\prod_{i=1}^{m} \mu_{X_i^j}\left(x_i\right)\right)}{\sum_{j=1}^{n}\left(\prod_{i=1}^{m} \mu_{X_i^j}\left(x_i\right)\right)} \tag{4}$$

where w^j is the place of the output singleton. The membership function $\mu_{X_i^j}(x_i)$ corresponds to the input x_i of the rule j. The and-connective in the premise is realized with product and defuzzification with center of gravity method. The rules of the mamdani type comparing the equation with the sugeno expression, it is easy to see choosing y^j to be constant and $w_j = y^j$, the result is same.

The antenna is optimized using fuzzy Guassian set for Pc (Cross Over) and Pm (Mutation) parameters. A binary coding was used for the genetic algorithm. Fig. 3 shows flowchart of the optimization algorithm. The population size was 100 individuals and 100 generations were evaluated [2].

The purpose is to minimize the maximum S_{11} magnitude at three frequencies, 1.9 GHz, 2.1and 2.4 GHz. The fitness function in this case was given by:

$$\text{fitness} = \min(S_{11_n}) \qquad , \qquad \forall n \tag{5}$$

where the subscript *n* refers to sample points in the S_{11} versus frequency function

In the genetic algorithm, if requirements dictate that the antenna structure be simulated for more than one frequency, there are two options for calculating the fitness namely: by calculating the fitness for each frequency and averaging them. A second approach is to simply use the worst ratio over the frequency range.

4. Measurements and Miscellaneous issues

In first steps the variation of VSWR with frequency for a 50 ohm coaxial feed line of ordinary circular patch antenna is simulated. The patch radius was to resonate at the dominate TM_{11} mode and is considered by [17]:

$$f_r = \frac{1.8411c}{2\pi a_e\sqrt{\varepsilon_r}} \tag{6}$$

$$\frac{a_e}{a} = \sqrt{1+\frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{a}{2h}\right)+(1.41\varepsilon_r+1.77)+\frac{h}{a}\left(0.268\varepsilon_r+1.65\right)\right]} \tag{7}$$

where c is the velocity of light and a_e is the effective radius, h is the substrate height, a is the patch radius, and ε_r is the dielectric constant of the patch.

Fig. 4 shows that resonance frequency of an ordinary circular patch vs. height variation for some radius and can be used in the design procedure.

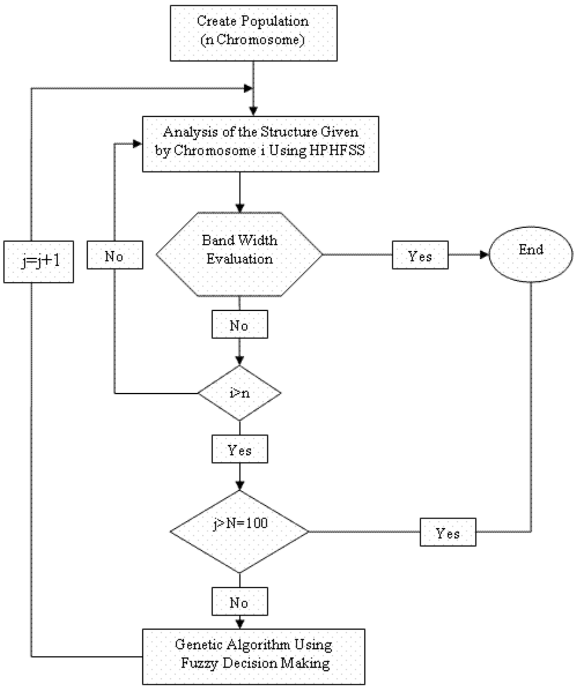


Fig. 3 Flow chart of the optimization algorithm

The impedance bandwidth of ordinary circular patch antennas is from 1.78 GHz-1.98 GHz (10.6%). In next step the optimized circular patch antenna with two slots is fabricated on a 1.5 cm thick dielectric substrate having a dielectric constant of $\varepsilon_r = 1$. The radius of the patch is 4 cm and the strips are placed at a distance of about 0.8 cm from the centre of the patch. Fig. 5 shows that VSWR vs. frequency for the unoptimized circular patch antenna with two slots.

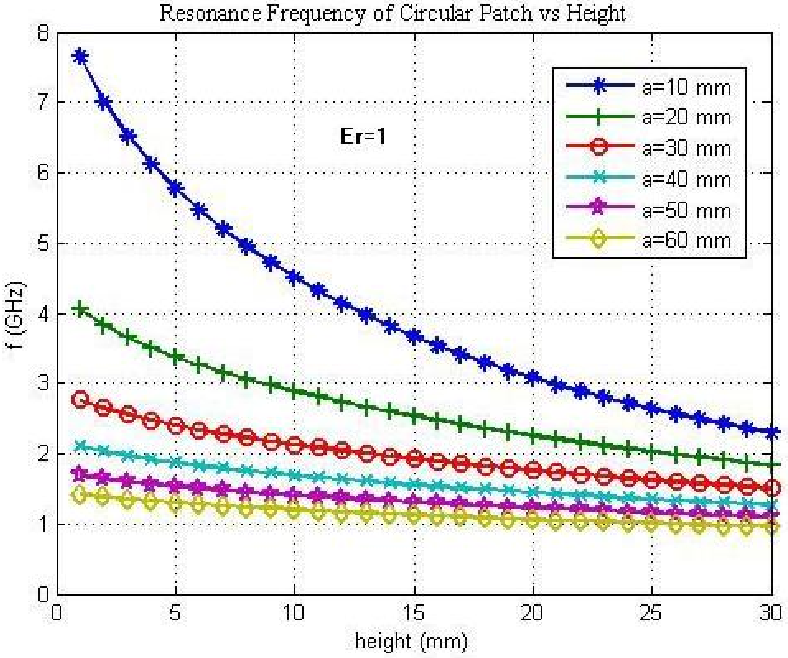


Fig. 4 Resonance frequency of an ordinary circular patch vs. height

The variation of VSWR with frequency for the optimized antenna with genetic algorithm based fuzzy decision making is shown in Fig.6. The 2:1 VSWR bandwidth of the antenna is 15.5% at the frequency band of 1.67GHz-1.95 GHz and 10.6% at 2.3 GHz-2.48 GHz. It means that impedance bandwidth increases above 4.9% than the impedance bandwidth of ordinary circular patch antennas. This is much larger than the impedance bandwidth of 10.6% (Fig. 6) of ordinary circular patch antennas.

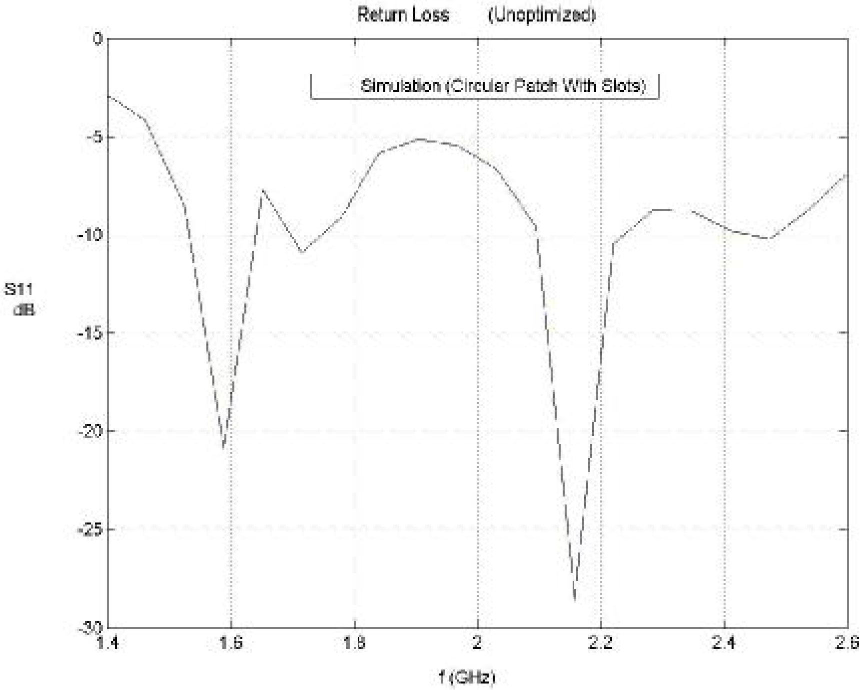


Fig. 5 S_{11} vs. frequency (unoptimized antenna), Dimension: a=4 cm, h=1.5 cm, feed point (center)=24 mm, slot width=0.25 cm

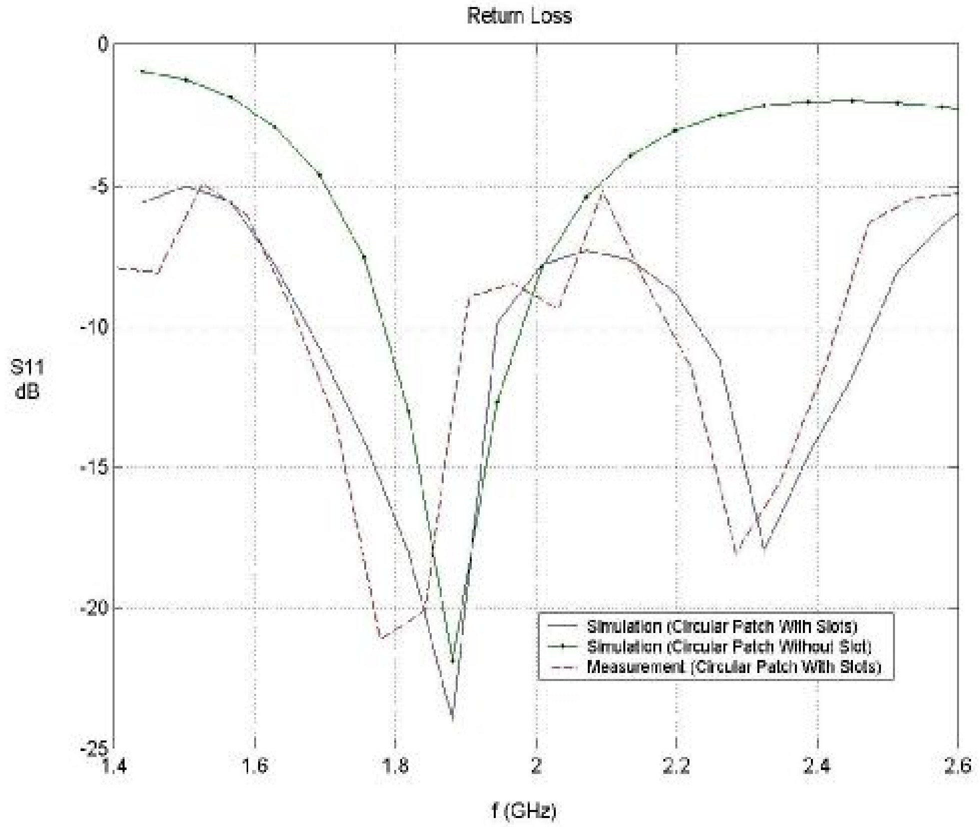


Fig. 6 S_{11} vs. frequency (optimized antenna)

5 Patterns Measurements

The radiation pattern of the circular E-shaped patch antenna is measured in the far-field chamber. The measured results of Radiation patterns of antenna are given in Fig. 7 at 1.9 GHz and 2.4 GHz. Maximum gain of this design is 7.5 dB and of the ordinary is 7 dB.

For the circular patch antenna with two slots in the E plane, the 3-dB beam width is 60 degrees at 1.9 GHz and 50 degrees at 2.4 GHz and in the H-plane, the 3 dB beam width is about 48 degrees at the both frequencies. Although it is a small piece high, it's not an important factor in some communication applications. Table 1 and 2 and 3 show the specifications of the no optimized and optimized circular E-Shape antenna and compare with ordinary circular patch antenna.

The fractional bandwidth of the unoptimized E-Shaped antenna and the proposed antenna are also given in Table 1 and 2. As noted, the proposed antenna has the highest bandwidth. Table 3 compare ordinary circular patch antenna with optimized circular patch antenna with two slots at the low frequency.

Table 1 Specifications of unoptimized antenna (Circular E-Shape)

Freq. (GHz)	1.59	2.16
S_{11}(dB) Simulated **Fractional Band Width**	-21 7%	-28 10.3%

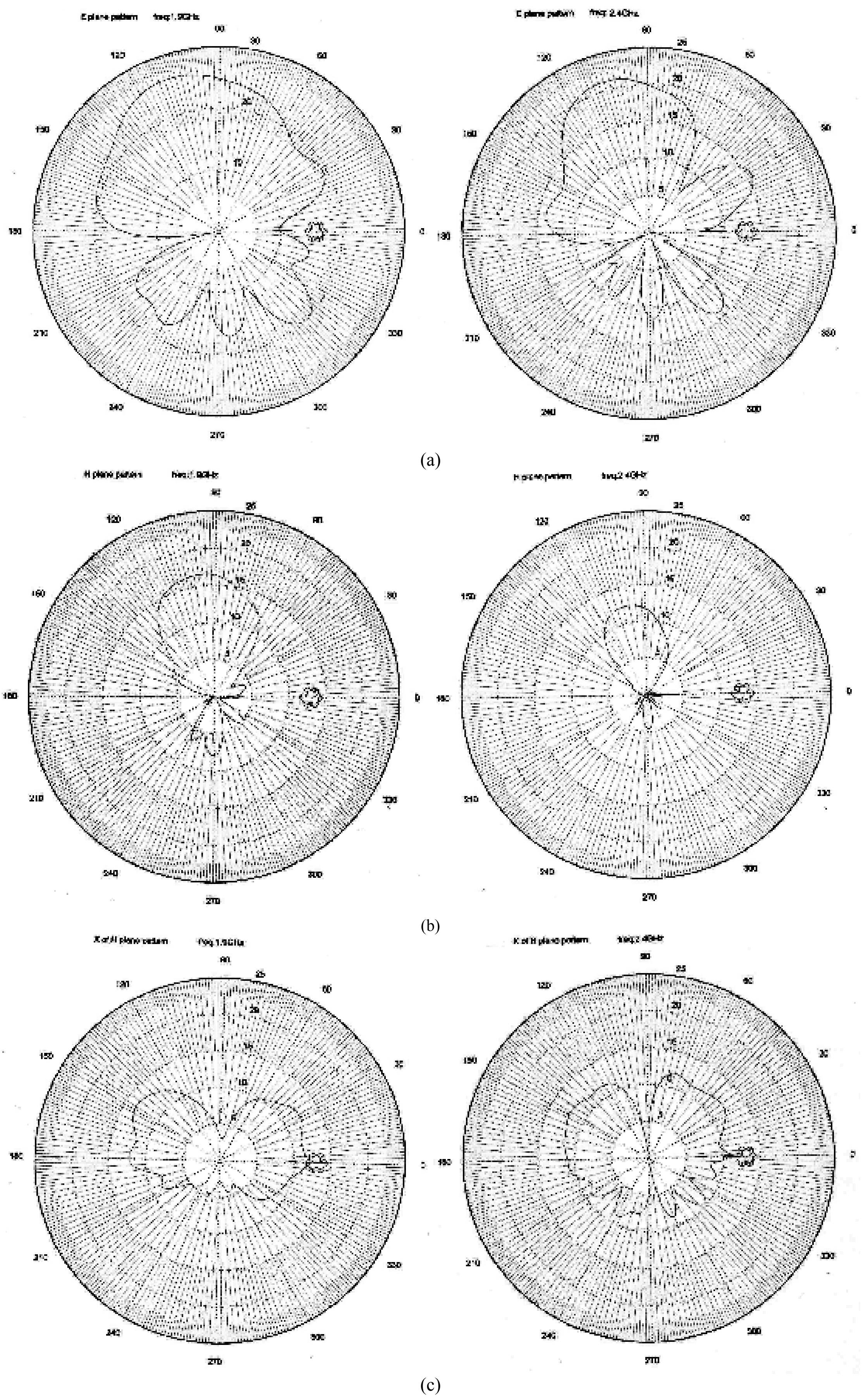
Table 2 Specifications of optimized antenna antenna (Circular E-Shape)

Freq. (GHz) Simulated **Measurement**	1.88 1.8	2.32 2.28
S_{11}(dB) Simulated **Measurement**	-24 -21	-18 -18
Fractional Band Width	15.5%	10.6%
Gain (dB)	7	7.3

Table3 Comparison of optimized circular patch antenna with two slots and circular patch antenna

	Circular patch	**Circular patch with two slots**
Freq. (GHz)	1.88	1.88
S_{11}(dB)	-22	-24
Gain (dB)	6.7	7

The image of constructed double slot circular patch antenna is shown in Fig. 8.



(a)

(b)

(c)

Fig. 7 Measured co-pol and cross-pol radiation patterns at frequency of 1.9 GHz and 2.4 GHz (a). E plane pattern (b) H plane pattern. (c) cross-pol H plane

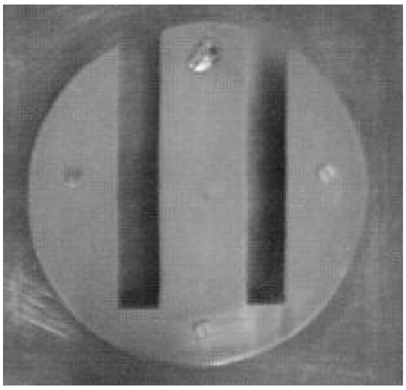


Fig. 8 Photo of Constructed Double Slot Circular Patch Antenna

6 Concluding Remarks

In this paper the broad band and compact E-shaped circular patch microstrip antenna with 50 ohm coaxial feed has been developed. The E-shaped circular patch antenna with wide bandwidth was optimized using genetic algorithm based on fuzzy decision-making.

GA-FIS improves GA with self-control mechanism based on fuzzy inference system (FIS). Parameters were set by GA-FIS.

The impedance band width of the antenna is 15.5% at lower frequency band and 10.6% at higher band.

At the end, a circular E-shaped patch antenna is designed, measured, and characterized in detail, which can be applied to modern wireless communication frequencies of 1.8 to 2.4 GHz.

The measured results of the optimized antenna confirm a high compatibility between the simulation and the actual experience.

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8 References

[1] Y. Rahmat-Samii and E. Michielssen, Electromagnetic Optimization by Genetic Algorithms, New York, NY: Wiley, 1999.

[2] A. A. Lotfi Neyestanak, F. Hojjat Kashani, and K. Barkeshli, "E-Shaped Patch Antenna Design Based on Genetic Algorithm Using Decision Fuzzy Rules", IJECE, vol. 4, no. 1, pp. 18-24, 2005.

[3] Jui-Han Lu, "Bandwidth Enhancement Design of Single-Layer Slotted Circular Microstrip Antennas", IEEE Tran. Antennas and Propagation, vol. 51, no. 5, May 2003.

[4] K. F. Lee, K. M. Luk, K. F. Tong, S. M. Shum, T. Huynh, and R. Q. Lee, "Experimental and simulation studies of the coaxially fed U slot rectangular patch antenna", Proc. IEE Microwave Antennas Propagation, vol.144, pp. 354–358, 1997.

[5] K. L. Wong and W. S. Hsu, "Broadband triangular microstrip antenna with U-shaped slot", Electron. Lett., vol. 33, pp. 2085–2087, 1997.

[6] K. F. Lee, K. M. Luk, K. F. Tong, Y. L. Yung, and T. Huynh, "Experimental study of the rectangular patch with a U-shaped slot", Antennas and Propagation Society International Symposium, AP-S. Digest, vol. 1, pp.10-13, 21-26 July 1996.

[7] E. E. Okon and C. W. Turner, "Investigation of loaded microstrip patch antennas for wide-band mm-wave applications", IEE National Conference on Antennas and Propagation, 1999, pp. 140-143, 31 March-1 April 1999.

[8] V. Nalbandian and C. S. Lee, "Bandwidth enhancement of microstrip antenna with leaky-wave excitation", IEEE Antennas and Propagation Society International Symposium, vol.2, pp.1224 -1227, 11-16 July 1999.

[9] Y. M. M. Antar,; Dajun Cheng, and Guozhong Jiang, "Wide-band microstrip patch antenna for personal communication", The 6th IEEE International Conference on Electronics, Circuits and Systems, 1999. Proceedings of ICECS '99, vol.3, pp.1305 -1308, 5-8 Sept. 1999.

[10] Gwo-Yun Lee; Tzung-Wern Chiou, and Kin-Lu Wong, "Broadband stacked shorted patch antenna for mobile communication handsets" ,Microwave Conference. APMC, vol.1, pp.232 -235, 3-6 Dec. 2001.

[11] B. L. Ooi, and Q. Shen, ,"A novel stacked E-shaped patch antenna", IEEE Antennas and Propagation Society International Sym., 2001, vol.4, pp. 478 -481, 8-13 July 2001.

[12] F. Yang,; Zhang Xue-Xia; Ye Xiaoning, and Y. Rahmat-Samii, , "Wide-band E-shaped patch antennas for wireless communications", IEEE Trans. Antennas and Propagat., vol. 49, Issue: 7, pp. 1094 -1100, July 2001.

[13] B. L. Ooi,; M. S. Leong,, and Q. Shen, ,"A novel equivalent circuit for E-shaped slot patch antenna", IEEE Antennas and Propagation Society International Sym., 2001, vol. 4, pp. 482 -485, 8-13 July 2001.

[14] K. C. Gupta and A. B. Norwood, "Microstrip Antenna Design". Norwood, MA: Artech House, 1988.

[15] X. -X. Zhang and F. Yang, "The study of slit cut on the microstrip antenna and its applications", Microwave Opt. Technol. Lett., vol. 18, no. 4, pp. 297-300, July 1998.

[16] "PDF Documents of Genetic Algorithm and Fuzzy Toolbox of Matlab 7" http://www.mathworks.com/.

[17] I. J. Bahl, P. Bhartia, Microstrip antennas, Norwood, MA: Artech House, 1980.