

An Automated Optimization Technique of a MSPA for Broadband Communication

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ABSTRACT

In this research paper, an automated design technique is used to optimize the variables of a microstrip patch antenna (MSPA), for reliable broadband communication systems. The method is based on a computerized procedure to produce a special defect in the ground plane, alongside with dimensions optimizing using genetic algorithm. Conventionally, either cut and try, or dimension optimization is used separately for this purpose. The novelty of the method presented here resides in the fact that the cut and the optimization techniques are automated to produce an wideband antenna. The resulting antenna gave a return loss of less than -10dB between 3GHz and 8GHz i.e. a bandwidth of 5GHz. Compared to other literature techniques, the achieved bandwidth is considered to be the best. The dimensions and the bandwidth of the designed antenna are attractive for next generation communication systems.

أسلوب تصميم آلي محسن لهوائي المايكروسترب خاص لاتصالات المايكروويف ذات النطاق العريض

الخلاصة

في هذا البحث، تم استخدام أسلوب تصميم آلي لتحسين متغيرات هوائي المايكروسترب (MSPA)، خاص لنظم الاتصالات ذات النطاق العريض في حزمة المايكروويف. الأسلوب يستند إلى إجراءات محوسبة لإنتاج قطع خاص في اللوحة الارضية للهوائي، جنباً إلى جنب مع ايجاد الأبعاد المثلى باستخدام الخوارزمية الجينية. تقليدياً، يتم استخدام القص والمحاولة، أو الأبعاد المثلى بشكل منفصل لهذا الغرض. حداثة الطريقة المعروضة في هذا البحث تكمن في أن تقنية القص، وتقنية التحسين الآلي استخدمت معاً بشكل محوسب لإنتاج هوائي ذو حزمة عريضة. أعطى الهوائي الناجم عن ذلك حزمة عريضة قدرها 5 كيكاهيرتز بين 3 و 8 كيكاهيرتز. مقارنة بغيرها من التقنيات الحديثة، يعتبر عرض الحزمة المحقق هو الأفضل حتى الآن. الأبعاد وعرض النطاق الترددي للهوائي المصمم في هذا البحث مفيدة لنظم اتصالات الجيل القادم.

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INTRODUCTION

The widespread applications of microwave and millimeter-waves have resulted in the emergence of new technology that is used in large capacity networks as well as small mobile devices which provide better mobility. For high data rate transmission and small mobile terminals, compact size and wideband antennas, covering a wide range of frequencies are required. Microstrip antennas are suitable for such applications owing to their light weight, easy fabrication and low cost. Despite these advantageous attributes, the microstrip antenna is known to have a very narrow bandwidth, typically about 5% of the central frequency [1]. Therefore, the challenge is to design a compact size microstrip antenna that meets the requirement of broadband applications [2]. These requirements complicate the geometry of the microstrip antenna. Unfortunately, as the antenna geometry is complicated, there is no precise formulation to analyze it, and the use of numerical methods becomes imperative [3]. Therefore, the design of modern antennas relies on the use of developed full-wave models or commercial electromagnetic simulators, such as Computer Simulation Technology (CST) microwave studio, Empire or HFSS software among others, to evaluate antenna performance before a physical prototype is fabricated. With these simulators, time for antenna design can be greatly reduced. However, even with the support of these electromagnetic simulators the design depends upon the experience of the designer and in most cases the optimal design is achieved by 'cut and try'. The approach of 'cut and try' is relatively time consuming, and therefore a robust optimization method is desired. Sophisticated optimization methods such as Genetic Algorithm (GA), have been developed to aid the antenna designer in optimization of various microstrip antenna geometries [4].

Microstrip antenna has been a good candidate for the modern communication technologies, owing to its light weight, low cost, easy fabrication [5]. However, the traditional microstrip antenna has a very narrow bandwidth which is not suitable for the modern wideband communications. A simple and straight forward method to widen the bandwidth is to use thicker substrate [6], which in turn, increases the antenna weight and size. Large antenna sizes are not suitable for the ever-decreasing sizes of the new generations of wireless communication devices. Also, as the substrate thickness increases, an increasing fractional power delivered by the source is lost into a surface wave. Another method to widen the bandwidth is to increase the size of the radiating element, which also increases the size of the antenna. It has been realized that decreasing the antenna size degrades its performance and the bandwidth decreases [7]. Therefore, achieving a small sized antenna with wide bandwidth is not easy in practice. In this research paper, an approach of mixing a special cut in the ground plane structure, with dimension optimization is sought to achieve a compact size and relatively wideband microstrip patch antenna targeted for broadband wireless communication in the microwave region. The aim here is to optimize a microstrip antenna with a defected ground plane structure (DGS), for modern wireless communication devices.

Proposed MSPA Design and Automation Procedure

Microstrip antenna impedance bandwidth depends directly on the volume of the antenna. This dependence of the bandwidth on volume possesses leads to great deal of

difficulty in the design of microstrip antennas for small sized communication devices. The electrical characteristics of the antenna are also very sensitive to the physical dimensions and material parameters of the antenna. The difficulty in designing a compact antenna with wide bandwidth makes the cost of manufacturing very high. Special techniques have to be used to either to enhance the resistivity or to remove the substrate below the antenna selectively [8]. For instance, expensive Rogers RT laminates and extremely narrow slot line with strict fabrication tolerance are used in manufacturing a wideband antenna in [9]. However, the contemporary market requires that the cost of the antenna be kept as low as possible. To satisfy this requirement, it is then necessary to go for optimized design which requires the application of accurate electromagnetic models, such as the full-wave models, coupled with efficient optimization algorithm. In this research paper, the design of a compact size, wideband microstrip antenna with I-shaped DGS is performed using the transmission line model, while Genetic Algorithm coupled with the use of full-wave FDTD-based Computer Simulation Technology (CST) microwave studio is used to give optimum antenna design. Figure (1) shows the geometry of the proposed antenna before optimization i.e. with optimum dimensions W , L and L_g not determined yet, where W and L are the width and the length of the patch respectively and L_g is the length of the defected ground plane.

The dielectric substrate chosen is FR4 with thickness, $h=1.6\text{ mm}$, a dielectric constant $\epsilon_r = 4.3$, and loss tangent, $\tan \delta = 0.025$. FR-4 or “glass reinforced epoxy laminated sheet” is a popular and widely used owing to its high dielectric constant, high mechanical strength, light weight, and resistance to moisture. The length, L_s and the width, W_s , of the substrate are chosen to be 30mm and 20mm respectively. Partial ground plane of width, $W_g = 20\text{ mm}$ and length, L_g (which is to be optimized), is used.

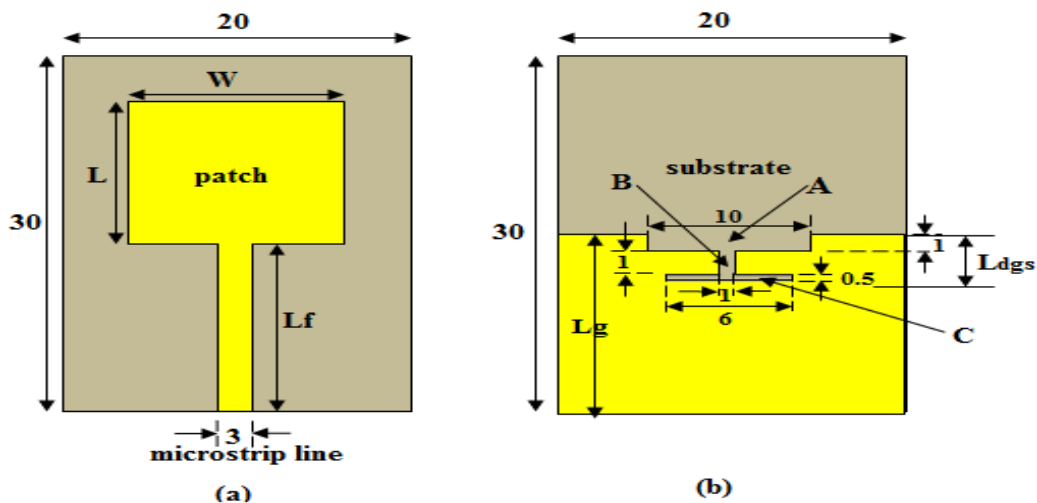


Figure. (1): Geometry of the proposed antenna, (a) top view, (b) bottom view. (All dimensions in millimeter)

The idea of a partial ground plane (for impedance matching) is implemented by introducing an I-shaped defect in the ground structure. The patch is optimized by varying its dimensions as well as varying the position of the I-shaped DGS with its length L_g , other dimensions are kept fixed as shown in Fig. 1. The problem here is to optimize the ground plane length, L_g as well as the I-shaped DGS position, the patch width, W and length of the patch, L , to produce a compact size, broadband MSPA. To perform this multivariable optimization, Matlab based Genetic Algorithm coupled with Full-wave FDTD-based CST microwave studio are used to automate the design problem. CST microwave studio is equipped with visual basic for application (VBA) development environment, where VBA-scripts are written specially for this purpose. A VBA-script is written to control the CST microwave studio. Genetic algorithm is implemented in Matlab interfaced with CST microwave studio to obtain the optimum antenna design.

The use of a Defected Ground Structure (DGS)

The traditional patch antenna characteristics can be changed by introducing a Defected Ground Structures (DGS) in the ground plane [10]. Normally, DGS is introduced by etching off a shape (rectangular, square, L-shape, V-shape, etc.) in the ground plane. Depending on the DGS shape, position and dimensions, the shield current distribution in the ground plane is disturbed, resulting a controlled excitation and propagation of the electromagnetic waves through the substrate layer [10]. The DGS is used to increase the surface current path and to decrease the resonant frequency of the traditional microstrip antenna for a given patch dimensions [11]. When the patch dimensions (W and L) are to be optimized, the resonance frequency is not fixed. However, the patch to be optimized can be designed based on the work by Jayasinghe and Uduwawala [12], where the optimized patch maintains its original dimensions, while some square-shaped fragments of the patch are removed.

The idea of partial ground plane used in this research is based on the work by Nabil, *et. al.* [13]. In reference [13] a rectangular slot is introduced in the patch whose original dimensions (width and length) are maintained. In this research, an I-shaped DGS is created as shown in Fig. 1(b). The dimensions of the I-shaped DGS are fixed, and its position is varied as the length of the ground plane, L_g , is varied. The ground plane length, L_g , (the I-shaped DGS position), the patch width, W and length, L , are to be optimized using Genetic Algorithm coupled with Full-wave FDTD-based CST microwave studio. As far as feeding method is concerned, the transmission line model is used to determine the width, W_f , of the microstrip line feeding the antenna. The width, W_f , is normally taken to be about half a wavelength [14].

Interfacing Design Tools

The genetic algorithm optimization of the design is controlled from Matlab in connection with CST microwave studio. The computational process is automated such that Matlab and CST cooperate via Visual Basic for Application (VBA) interface. The commands that call various CST microwave studio functions are written in “•bas” file

using the VBA editor. For more details on VBA commands refer to [15]. The flow of information from Matlab through VBA to Microwave Studio and vice versa is shown in Fig. 2. Matlab generates and writes the design variables (W, L, L_g) to a text file. Having read the data, the VBA program opens the CST microwave studio model file. This file contains the antenna model being optimized. The VBA program opens the file and instructs CST microwave studio to change the dimension values of the model (using the data read from the input data file called (Optimizing Antenna.txt) and rebuild the antenna model. The antenna model being optimized appears on the screen as it is being rebuilt with the new variables values. The changes happening to the model can be observed by the user. Next, the VBA program commands CST microwave studio to start solver and save results after simulation is finished. When the simulation finishes and results are saved, control returns to Matlab and CST microwave studio window closes.

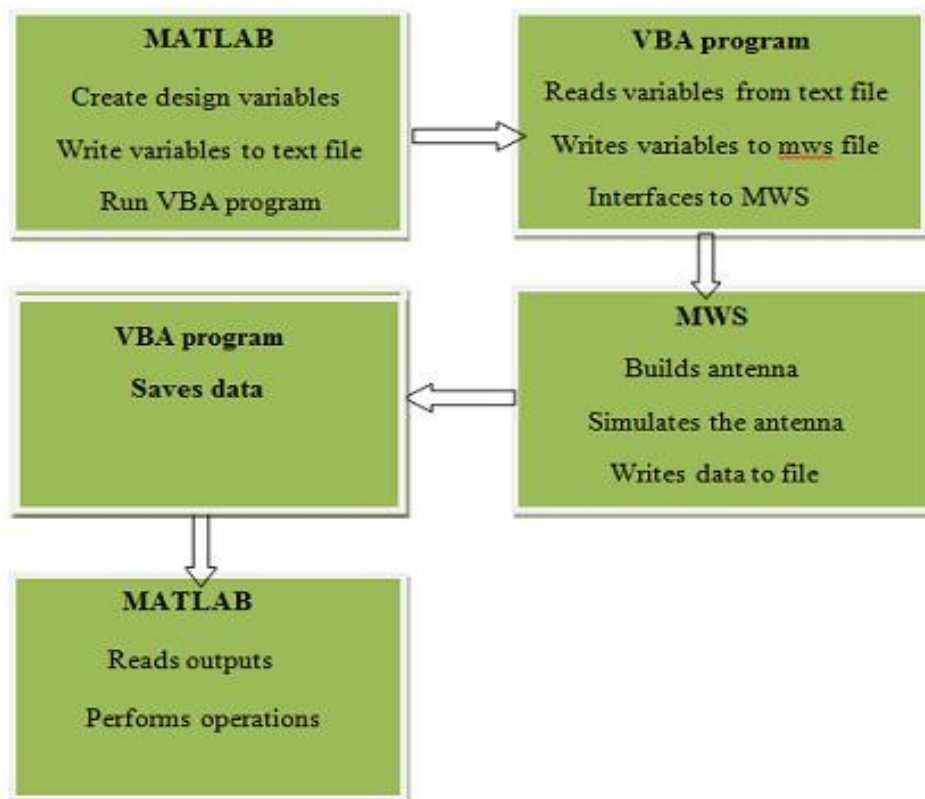


Figure.(2): Matlab-CST microwave studio flowchart

The CST microwave studio window opens every time the VBA program is called from Matlab. This is the interfacing between Matlab and CST microwave studio via VBA program. The complete flowchart of the optimization algorithm is shown in Fig. 3.

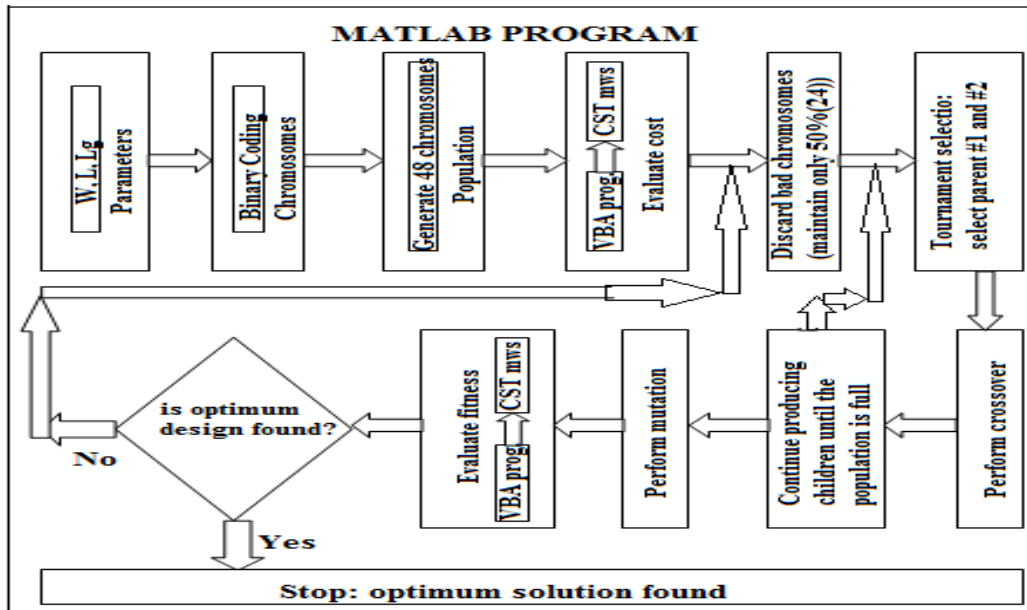


Figure. (3): optimization algorithm flowchart.

After defining variables and bounds, it is necessary to define the fitness function. The antenna is modeled in such a way that changes in the variables are effected in the model. For any combination of patch width (W), patch length (L) and ground length (L_g), the antenna is simulated from frequency range of 3GHz to 8GHz. Samples are taken at every 0.01GHz from 3GHz to 8GHz and the simulation result is used to evaluate the fitness of the antenna. The fitness function is defined as follows [16]:

$$fitness = \frac{1}{N} \sum_{f=3GHz}^{f=8GHz} P(f) \quad \dots (1)$$

$$P(f) = \begin{cases} |S_{11}(f)| & S_{11} \geq -10 \\ 10 & S_{11} < -10 \end{cases}$$

Where

N is the number of samples taken from 3GHz to 8GHz at every 0.01 GHz. $N=(8-3)/0.01=500$, S_{11} is the return loss in dB. After defining fitness function, variables and their bounds, the next step is to translate the variables into chromosomes. In biology, chromosomes consist of genes. In this research, the genes are the variables (W, L and L_g). Each variable (gene) is translated into 8 binary bits. Then, these genes are arranged to form a chromosome of $3 \times 8 = 24$ bits. The first 8 bits represent the patch width (W), the next 8 bits represent the patch length (L) and the last 8 bits represent the

ground plane length (L_g). A randomly generated chromosome of 24 bits may then be written as follows:

$$\text{Chromosome} = \underbrace{10011100}_{W} \underbrace{11100111}_{L} \underbrace{00100110}_{L_g}$$

The binary chromosomes used in this design can be converted into decimal chromosomes by using a decoding method. The equation used in this design is given below:

$$v = \left(\frac{v_{\max} - v_{\min}}{2^{n_{\text{bit}}} - 1} \right) \sum_{n=0}^{n_{\text{bit}}-1} 2^{-n} b_n + v_{\min} \quad \dots (2)$$

Where v is the variable (for example W). v_{\min} and v_{\max} are the lower and upper limit of the variable, respectively. The bounds on the variables are given in Table 1. Using these bounds and the equation above, the above chromosome can be written in a decimal format as follows:

$$\text{Chromosome} = \underbrace{102588}_{W} \underbrace{136941}_{L} \underbrace{112745}_{L_g}$$

Results and Discussion

The variables used in the optimization are the patch width (W), the patch length (L) and the ground length (L_g). The upper and lower bounds of these variables are defined in Table 1.

Table (1): Lower and upper bounds of the variables

Variables	Bounds	
	min(mm)	max(mm)
W	4	18
L	4	16
L_g	5	13

The lower limit of the patch width (W) is chosen to be 4mm because choosing values less than 4mm may result in insignificant patch width. For example, a patch width of 3mm results in a microstrip line. The upper limit of the patch is chosen to be 18mm. This allows the patch to have wide range of variation from 4mm to only 1mm away from the left and right edges of the substrate. The lower limit of the patch length is also made 4mm and the upper limit is chosen to be 16mm. With the length of the microstrip line (L_f) fixed at 13mm and the lower limit fixed at 4mm, the patch length (L) from figure 4 can vary between 17mm and 29mm. Because of the configuration of the I-shaped DGS and the ground plane L_g , the lower limit of ground plane is chosen to be 5mm and the upper limit is chosen to be 13mm. This allows the position of the I-shaped DGS to have variations from 5mm to 13mm.

Ten best designs (one from each generation) obtained by the genetic algorithm have been selected for return loss plots analysis. The analysis on the ten designs shows how

the genetic algorithm evolves better individuals as they pass through generations. The return loss plots of the ten designs are obtained from CST Microwave Studio. The optimum design is compared with the designs reported in recent literature [13], [16]. Evaluation is presented in terms of Return loss performance. The return loss plots of the ten designs are shown in Fig. 4. The figure shows how the impedance bandwidth changes from one design to another. The best design in the first iteration has minimum return loss of -13.5 dB at 3.42GHz resonant frequency. The impedance bandwidth is 0.74GHz (3.08GHz-3.82GHz).

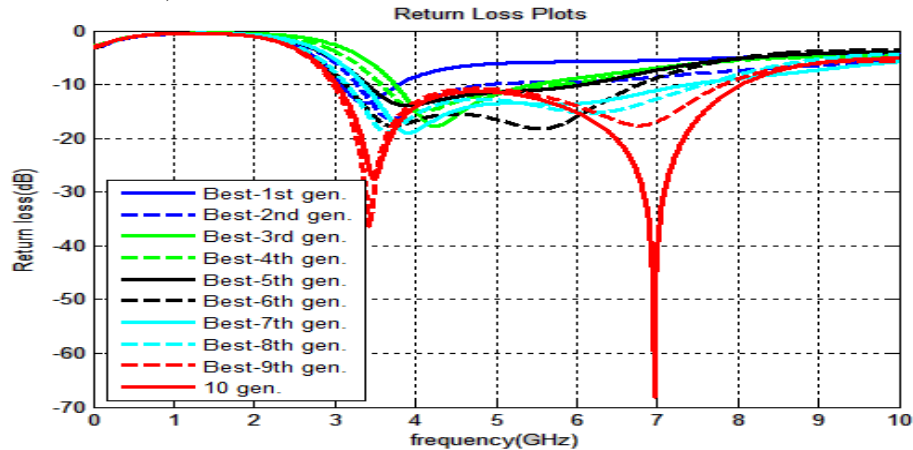
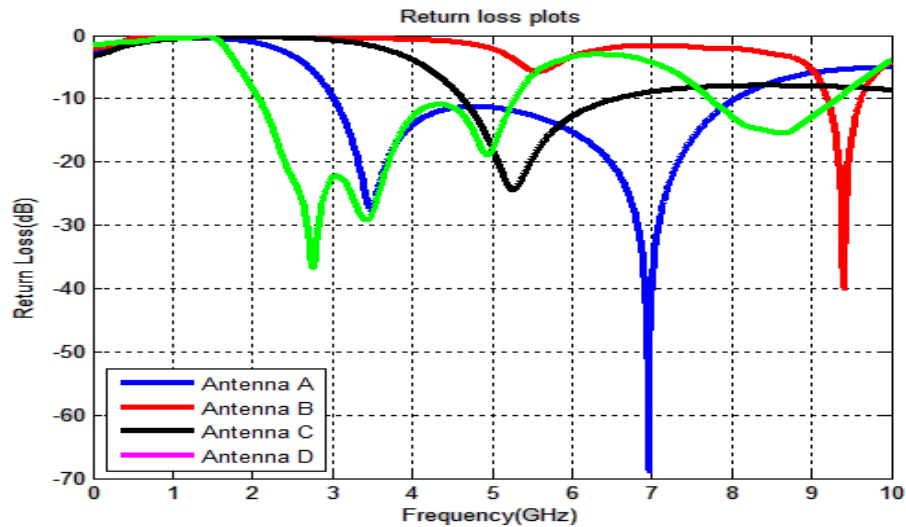


Figure. (4): Return loss plots of ten best designs

The best design obtained in the 10th generation achieves a bandwidth of 5GHz (3GHz-8GHz). The antenna exhibits resonance at 3.5GHz and 7.0GHz. The return loss at 3.5GHz is -28dB and that at 7GHz is about -70dB. The analysis of the ten designs is summarized in Table 2 below.

Table (2): Summary of the ten best designs

Iteration	Best design					
	W (mm)	L (mm)	Lg (mm)	Range(GHz)	B.W. (GHz)	Min. RL(dB)
1 st	12.9882	8.0314	7.1176	3.08-3.82	0.74	-13.5
2 nd	11.6789	8.5634	8.9981	3.30-4.88	1.58	-16.0
3 rd	9.4588	4.8941	8.2302	3.74-5.46	1.72	-18.0
4 th	12.4645	6.2331	9.2341	3.56-5.78	2.22	-15.0
5 th	14.8764	7.8765	9.6892	3.40-6.15	2.75	-14.0
6 th	15.2801	11.6082	10.3998	3.14-6.70	3.64	-18.2
7 th	11.7609	9.0865	9.9906	3.36-7.40	4.04	-19.0
8 th	12.6543	11.0032	9.9964	3.15-7.59	4.44	-19.0
9 th	10.0168	14.5697	10.8769	3.00-7.83	4.83	-29.0
10 th	10.4400	13.2040	10.3994	3.00-8.00	5.00	-70.0



Figure(5): Return loss plots: Proposed with DGS (antenna A), Proposed with full ground plane (antenna B), presented in reference [13] (antenna C), presented in reference [16](antenna D),

The genetic algorithm optimization was set to search in such a way that the optimum design would have less than -10dB return losses from 3GHz to 8GHz. The range from 3GHz to 8GHz covers the 3.5GHz WLAN and 3.5GHz Wimax standards. The antenna also covers WLAN (5.15-5.35 GHz / 5.725-5.85 GHz), and Wimax (3.3-3.8 GHz / 5.25-5.85 GHz). The optimized microstrip patch antenna is compared with the microstrip antennas reported in [13] and [16]. Fig.5 shows the return loss plots of the proposed antenna and the antennas reported in [13], [16] and the proposed antenna when the ground plane is replaced with full ground plane.

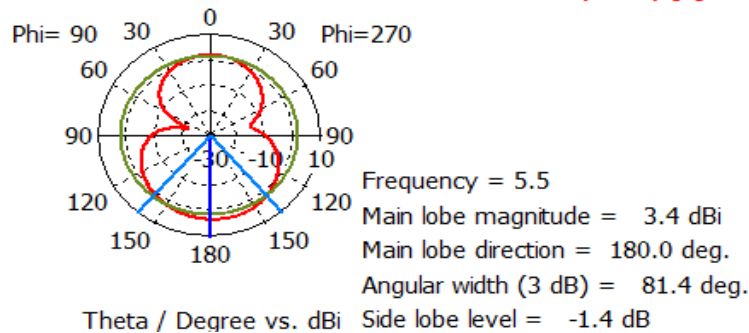
It can be observed from Fig.5 that the antennas reported in [13] (Antenna C) and [16] (Antenna D) do not achieve bandwidth as wide as the proposed antenna (Antenna A). The use of a partial ground plane provides impedance matching and bandwidth broadening. Also, the use of a defected ground structure (DGS) increases bandwidth by introduction of resonances at lower frequencies. When the resonances overlap, a wider bandwidth is obtained. The use of partial ground plane and the DGS provides a much wider bandwidth. It can be seen that with the combined effects of the partial ground plane and DGS (I-slot in this work), the proposed antenna achieves a wide bandwidth of 5GHz. The figure also shows that if ground plane of the proposed antenna is replaced with full ground plane (Antenna B), the bandwidth will shrink to a very narrow bandwidth of only about 420MHz and the resonance frequency shifts to a higher frequency. Table 3 compares the proposed antenna with the five reviewed antennas. It is obvious that proposed antenna has smaller size and wider bandwidth compared to the antennas found in recent literature, and it is very interesting for next generation communication networks. The simulated 2D radiation patterns of the optimized antenna at 5.5GHz are shown in Fig. 6, in which the directivity and the main lobe gain are as indicated in the figure.

Table (3): Comparison of antennas in recent literature with the presented antenna

Reference	Patch size(mm)	Frequency range (GHz)	Bandwidth	Substrate dimensions (mm)	Min. Return loss(dB)	Bandwidth/Area
[16]	30×30	2.25-2.27	430MHz	Thickness=5	-18.5	0.47
[17]	-	2.0-5.3	3.3GHz	50.8×50.8×0.762	-47	-
[18]	2.5×4.8	14.83-19.17	4.34GHz	97.18×99.48×15.78	-47.5	361.6 (very thick substrate)
[12]	17.5×26	3.2-5.2	2GHz	Thickness=16	-19	4.4
[13]	7×12	4.8-6.5	1.7 GHz	0.7×15×20	-24	20
This research	13.204×10.44	3.0-8.0	5GHz	20×30×1.6	-70.0	36.27

Farfield Directivity Abs (Phi=90)

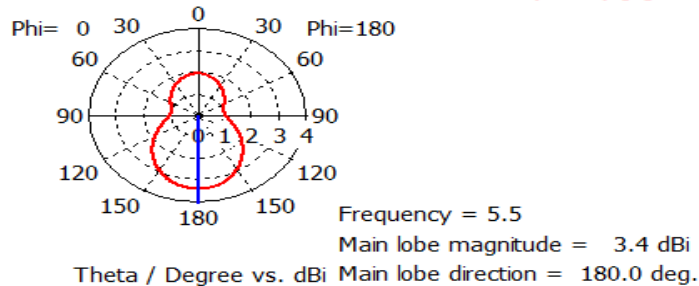
farfield (f=5.5) [1]



(a)

Farfield Directivity Abs (Phi=0)

farfield (f=5.5) [1]



(b)

Figure(6). Radiation patterns at 5.5GHz. (a) y-z plane, (b) x-z plane

CONCLUSIONS

An automated design environment in which genetic algorithm optimization is steered from Matlab, with the fast and highly accurate FDTD based CST microwave studio, has been used to produce a compact, broadband microstrip patch antenna with I-shaped defected ground structure. The resulted microstrip patch antenna possesses a smaller size and a wider bandwidth than those found in recent literature. The bandwidth is 5GHz lies over a frequency span from 3GHz to 8GHz. Therefore, the proposed antenna can be very useful for next generation communications since it has a substantially wideband suitable for large number of users, and can accommodate complex internet applications in smart phones.

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