A THREE-BAND PATCH ANTENNA USING A DEFECTED GROUND STRUCTURE OPTIMIZED BY A GENETIC ALGORITHM FOR THE MODERN WIRELESS MOBILE APPLICATIONS

Khadija Abouhssous[1], Layla Wakrim[2], Asmaa Zugari[3] and Alia Zakriti[1]

(Received: 30-Oct.-2022, Revised: 1-Jan.-2023 and 8-Jan.-2023, Accepted: 9-Jan.-2023)

ABSTRACT

This paper presents a design and optimization approach for a tri-band miniature planar rectangular patch antenna structure for wireless mobile applications. The tri-band operation while maintaining a compact size has been achieved by introducing a defected ground structure (DGS) to control the surface current distribution on the patch antenna and consequently achieve multi-band operation. The geometry of the patch and the position of the DGS were optimized by a genetic algorithm to achieve the desired performance using a simple and miniature design with a size of 16 mm × 20 mm × 1.6 mm, an 82% reduction in the size occupied by a conventional single-band structure used in the optimization process. The proposed GA-optimised antenna provided tri-band operation with bandwidths for $|S11| > 6$ dB from 3.2 - 3.5 GHz, 5.5 - 5.9 GHz and 6.3 - 7.1 GHz. At the centre frequencies of 3.4, 5.7 and 6.7 GHz, the peak gains were 0.7, 1.76 and 2.93 dB, respectively. The optimally designed antenna is etched on an FR-4 substrate. Simulation and measurement results show good agreement, making the proposed structure a suitable candidate for mobile applications requiring small and multifunctional telecommunication devices.

KEYWORDS

Defected ground structure, Genetic algorithm, Tri-band, Miniaturization, Wireless mobile applications.

1. INTRODUCTION

Due to the accelerated development of wireless communication systems, new systems are needed that can operate in multiple frequency bands and accommodate multiple standards. Multiband RF components, which consist of single circuits and operate at several specific frequencies, provide compact solutions for modern wireless communication systems. Due to their advantages, such as lower manufacturing cost, simpler geometry, easier fabrication and integration, microstrip antennas are competitive candidates for many wireless applications. However, these are generally restricted to mono-band operation and their bandwidth is relatively narrow in comparison to other antenna types. Various approaches to multiband antenna design have been developed and studied. For example, a typical technique is to make slots on the radiation patch of the microstrip antenna. As reported in [1], etching two MIM (metal-insulator-metal) rings on a square patch have been shown to change the surface current distributions, effectively improving the radiation and forming a multiband antenna. Other commonly used methods to realize multiband antennas include the addition of parasitic coupling units [2], the insertion of stub-resonant elements [3], introduction of a DGS structure in the form of a squared ring slot incorporating multiple asymmetrical vertical slots [4], the use of two F-shaped resonators with a patch truncated from its central point [5], the use of etched metamaterial with a spiral structure to behave as a complementary split ring resonator (CSSR) antenna [6], as well as the adoption of fractal iteration technology [7]. Among the major disadvantages of all these types of antennas is the size, which is an area of competition for antenna designers, in addition to the narrow bandwidth and the complexity of implementation. Furthermore, to achieve an optimal design and to improve the patch antenna performance, many different optimization algorithm methods are used, such as particle swarm optimization (PSO) [8] and genetic algorithms (GAs) [9]-[10].

1. K. Abouhssous and A. Zakriti are with Lab. of Sci. and Advanced Tech., Department of Civil and Industrial Sci. and Tech., National School of Applied Sci., Abdelmalek Essadi Uni., Morocco. Emails: abouhssoukhadija@gmail.com and azakriti@uae.ac.ma
2. L. Wakrim is with Lab. of Innovation in Management and Engineering for Business (LIMIE), Higher Institute of Engineering and Business (ISGA), Marrakech, Morocco. Email: Layla.wakrim@isga.ma
3. A. Zugari is with Inf. and Telecomm. System Lab., Abdelmalek Essadi Uni., Tetouan, Morocco. Email : azugari@uae.ac.ma

The GA is an evolutionary learning approach similar to the learning of beings. The GA concept is based on the Darwinian evolution theory, according to which organism populations develop by natural selection by transmitting to their descendants variations which allow for survival and replication. However, the potential solutions in GA-based optimization are registered as individuals in the population that need to progress to better solutions. Indeed, an individual's parameters defining a proposed solution are coded like genes on the chromosome. During the optimization process, the GA repeatedly explores the search space and achieves a number of optimized solutions using bio-inspired operations, such as selection, crossover and mutation. At each step, the less adapted individuals of the previous population are substituted by the more adapted ones and the more suitable individuals are selected as the next-generation population. This process is iterated until the final requirement is achieved and therefore the optimal structural parameters are obtained.

This paper presents a conventional patch antenna adapted by using notches, operating at 3.5 GHz.The proposed-structure parameters are calculated by mathematical equations based on the theoretical studies of the patch antennas [11]. The design results show that the overall size of the proposed structure is $40mm \times 45mm \times 1.6mm$, which is a bulky size, with a limited operation in a single frequency band and narrow bandwidth. To overcome these problems and improve the conventional antenna performance in terms of miniaturization, multi-frequency and broadband operation, a defective ground structure (DGS) in the form of a rectangular slot with T-shaped heads on the edges is introduced. The main interest of this work is the application of the genetic algorithm to determine the location of the slot on the ground plane, as well as to optimize the antenna parameters. The results of the optimization by the genetic algorithm show a miniaturization rate of 82% compared to the conventional structure with a tri-band operation and improved bandwidths. A prototype of the optimized tri-band patch antenna has been fabricated and tested in order to validate the procedure. The simulated and measured results show good agreement.

2. METHODOLOGY DESIGN

This section presents an overview of the patch-antenna theory, the Defected Ground Plane-based Structure (DGS) design method and the Genetic Algorithm (GA) based optimization of the antenna parameters and its optimal shape.

2.1 Patch Antenna Theory

The conventional design consists of a rectangular patch printed on a dielectric substrate with a completely metalized bottom side. The substrate has a relative permittivity $\varepsilon_r = 4.4$ and a thickness $h = 1.6\ mm$. The antenna is intended to operate at a frequency of 3.5 GHz.
The transmission-line model implies that for the fundamental mode, along the width of the patch, there is a maximum voltage and a minimum current [11]. This means that the edges along the width of the patch are considered radiating slits. The effect of edges and slot radiation is modeled by an equivalent capacitance and radiation resistance. This extends the dimensions around the periphery of the patch.
The effective patch length and width can be written as [11]:

$$L_e = L + 2\Delta L \quad (1)$$

$$W_e = W + 2\Delta W \quad (2)$$

$\Delta L\ and\ \ \Delta W$ are the extensions along L and W.

The patch length extension is calculated by the equation:

$$\Delta L = \frac{h}{\sqrt{\varepsilon_e}} \quad (3)$$

The propagation in two media having clearly different permittivities requires the determination of an approximate value of ε_e.

for a band such as $\frac{W}{h} \geq 1$: $$\varepsilon_e = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\left(1 + 12\frac{h}{w}\right)^{\frac{-1}{2}} \quad (4)$$

In a rectangular patch antenna, so that an antenna radiates as efficiently as possible, W must be equal to $\frac{\lambda}{2}$ and is calculated by the equation: $$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (5)$$

where C is the velocity of light in a vacuum.

The effective length is given by the equation: $L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}}$ (6)

where f_0 is the resonance frequency calculated by the equation:

$$f_0 = \frac{c}{2L_e\sqrt{\varepsilon_e}} \quad (7)$$

In this work, the antenna is excited with a notched feed line due to the fact that it is easy to manufacture and simple to adapt to the antenna.

The patch impedance is given by the equation: $Z_a = 90\frac{\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2$ (8)

A simple formulation is developed for the calculation of the length of the notch [12]. This value is now constant, since it does not influence the resonance frequency of the antenna.

$$l = 10^{-4} \times \frac{L}{2} \times [0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697] \quad (9)$$

This formula is valid for $2 \leq \varepsilon_r \leq 10$.

2.2 Defected Ground Structure (DGS)

The DGS structures are an evolution of the EBG (Electro-Magnetic Bandgap) structures. They are mainly intended for the design of compact and efficient microwave devices. The DGS consists of a defect (etch) in the ground plane of a microstrip transmission line, a coplanar waveguide or any structure where a ground plane exists. Microstrip antennas can be miniaturized by introducing defects in the ground plane [13]. A DGS equivalent circuit is a parallel series tuned circuit with a transmission line that it is coupled to. There are different forms of DGSs that have similar functions and features of the slow wave effect and high-impedance and size miniaturization with the same equivalent circuit [14]. However, to enhance the antenna circuit performance, the DGS structure can be modified or changed.

When the DGS is introduced into a microwave antenna, the ground plane etch defect geometry disturbs the current distribution. This disturbance leads to an increase in the effective capacitance and inductance which influence the input impedance and current flow of the antenna [15], thereby reducing its size relative to a resonance frequency and/or causing other resonance frequencies to appear.

2.3 Genetic Algorithm Methodology

The genetic algorithm is a stochastic search technique that is based on Darwin's evolution theory. It is an extremely important approach to solving large search space problems for which conventional approaches are not available and for which the possible solutions lie in a large search space. Gas' most significant benefit over other approaches is their high precision [16]. With the exception of its high computational cost due to GA (which takes time), this technique has the following advantages [17] .

- Possibility to optimize continuous or discrete variables.
- Possibility of operating with a great number of variables.
- Being suitable to be used with numerically generated data, experimental data or analytical functions.

The concepts of biological evolution are used in GAs to solve optimization problems. Gene combination principles in biological reproduction are used to repeatedly modify a population of individual points.

Due to its random nature, it increases the chances of identifying a global solution. Consequently, it is extremely efficient and stable in finding globally optimal solutions. A GA's objective is to compute the extrema of an identified function in a data space. An evolutionary process is used to solve a problem using GA, where possible solutions (chromosomes) will be utilized to expand new solutions. Such group of possible solutions will be called a population. For the objective of creating the next generation of the population, only one (particular) population will succeed and be used. The solutions used for creating a new solution (offspring) will be selected based on their fitness function. Which chromosome is most suitable to be reproduced is the best fit.

2.4 Optimization Procedure

The optimization procedure for the proposed design is summarized in the flowchart in Figure 1. We use MATLAB software to implement the genetic algorithm. The advantage of MATLAB is the ability to invoke external programs; it represents a powerful calculator for complex matrix operations. The VBA script for the antenna design and analysis is available in CST. The genetic algorithm is written in MATLAB by invoking a VBA script in CST that controls the analytical operations on CST Studio. However, the key procedure of the genetic algorithm used to optimize the main parameters of the proposed antenna can be summarized by the steps presented in the flowchart in Figure 2:

Step 1: The identification of the different variables to be optimized and the definition of the maximum and minimum bounds for each variable to be optimized.

Step 2: The optimization process is started by generating a random population, where each individual (in the form of linear vectors) is presented by a chromosome and modeled in the Antenna Toolbox for the calculation of the S_{11} return losses on the ranges of each frequency band. The fitness value of each individual was calculated as shown in (10). Then, these individuals have been sorted by their fitness value.

$$\text{fitness:}\ \ Q(x) = \frac{1}{N}\sum_{fmax}^{fmin} Q(f) \tag{10}$$

where $\boldsymbol{S_{11}}$ is the reflection coefficient,

$$Q(f) = \begin{cases} S_{11} for\ S_{11} \geq -6 \\ -10\ for\ S_{11} < -6 \end{cases}$$

$$S_{11} = 20log\left|\frac{Z_{in}-Z_C}{Z_{in}+Z_C}\right|$$

$\boldsymbol{Z_{in}}$ is the antenna input impedance and $\boldsymbol{Z_C}$ is the microstrip line characteristic impedance.

Step 3: The choice of the selection procedure and applying it to each variable (each individual of the chromosome), so that the fittest individuals were selected for crossing to reproduce offspring. In addition, additional offspring were obtained by mutations of some random individuals to ensure the exploration of globally optimal solutions. The fitness values of the offspring are calculated. **Step 4:** The descendants and previous-generation individuals are selected based on their fitness values. The most suitable individuals are passed onto the next generation. Steps 3 and 4 are repeated until the endpoint is met.

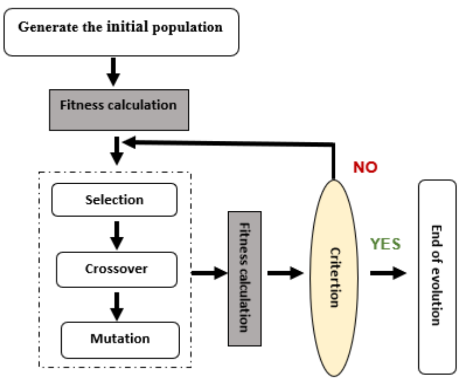


Figure 1. Genetic algorithm organigramme.

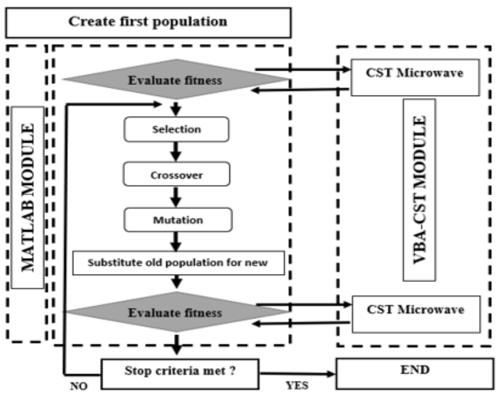


Figure 2. GA's implementation with the CST-MATLAB interface.

2.5 Optimized Tri-band Patch Antenna

The GA parameters, such as population type, population size and the total number of generations, used for the optimization of the geometry parameters of the proposed patch antenna are presented in Table 1 and the optimum parameters resulting from this optimization are presented in Table 2.

A satisfactory solution has been achieved in the 11^{th}-generation optimization, so that the overall size is $16mm \times 20mm \times 1.6mm$, which has a size saving of 82% compared to the conventional structure presented before. The frequency responses of the proposed antenna show a tri-band frequency operation and a bandwidth enhancement with $|S11| > \ 6\ dB$.

Table 1. Genetic algorithm optimization parameters.

GA Parameter	Value
Number of variables	50
Population type	Double vector
Population size	100
Selection	Roulette
Scaling	Rank
Reproduction elite count	2
Crossover fraction	0.8
Crossover	Single-point crossover
Mutation	Uniform (0.03)
Migration fraction	0.2
Total number of generations	100

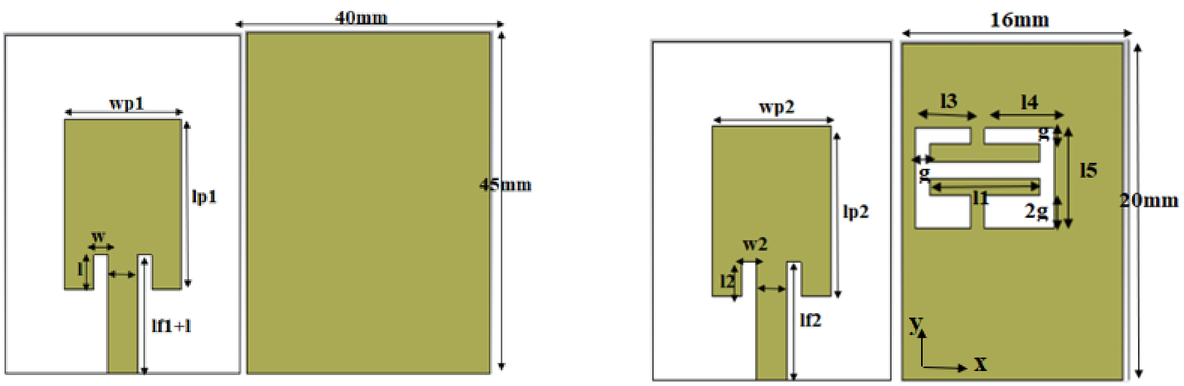
Table 2. Optimized tri-band patch antenna parameters.

Parameter	Value (mm)
w_{p1}	7.179
l_{p1}	10.789
w_{f1}	1.137
l_{f1}	6
w_1	1
l_1	1.8
l_2	8
l_3	6
l_4	5
l_5	4
g	1

3. Results And Discussion

3.1 Antenna Evolution

To describe in detail the design procedure of the proposed patch antenna, two design steps are used, as shown in Figure 3.



Antenna 1 Antenna 2

Figure 3. Antenna evolution steps to achieve the proposed tri-band patch antenna.

Firstly, a rectangular patch antenna is designed [Antenna1]. All design parameters are calculated from the equations in sub-section 2.1. The total size of this antenna is $40mm \times 45mm \times 1.6mm$. The frequency response of this antenna has a single frequency band centred at 3.5 GHz. The return loss $|S11|$ is 27.8 dB, with a bandwidth of 3.46 GHz to 3.53 GHz. The simulation result of the radiation pattern at the resonance frequency shows a maximum gain of 5.37 dB. The performance of this antenna is similar to that of the conventional antenna, with a narrow bandwidth and a bulky size. This antenna serves as a reference design, which has been improved to find the optimal final design.

The next step is to introduce a rectangular slot DGS with T-shaped heads on the edges in the ground plane to provide multi-band functionality and a compact size. All parameters of the patch antenna [Antenna 1] and the position of the DGS on the ground plane are optimized by the genetic algorithm following the process detailed in sub-section 2.4. The results of this optimization give a tri-band and miniature structure [Antenna 2] with a size of $16mm \times 20mm \times 1.6mm$.The return loss | S11| of this optimal antenna is 21 dB, 24 dB and 17.2 dB at 3.4 GHz, 5.7 GHz and 6.7 GHz, with bandwidths of 300 MHz, 400 MHz and 800 MHz, respectively.

A comparison between the simulated characteristics and the performance of the two antennas is presented in Table 3.

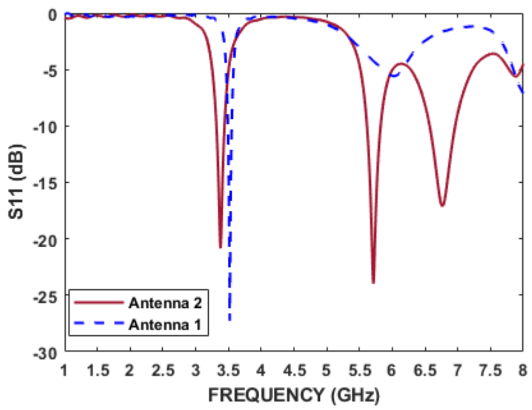


Figure 4. Antenna reflection coefficients.

Table 3. Comparison of antenna characteristics.

	Antenna 1	Antenna 2		
Frequency (GHz)	3.5	3.4	5.7	6.7
S11 (dB)	-27.8	-21	-24	-17.2
BW(MHz)	70	300	400	800
Gain (dB)	5.37	0.7	1.76	2.93
Size (mm^3)	40×45×1.6	16×20×1.6		

3.2 Parametric Study

To confirm the results of the genetic algorithm optimization and the proposed optimal structure of the tri-band patch antenna, a parametric study of the position of the DGS and the depth of the notch is proposed. Each parameter is optimized individually in the optimal solution neighborhoods given by the genetic algorithm; therefore, the same dimensions and the same optimal structure proposed previously are kept and DGS is varied horizontally and vertically on the one hand and the notch depth on the other hand, in such a way that each time two parameters are fixed at the optimal value given by the GA and the third is varied independently. The parameters and optimization conditions of this study are given in Table 4 and some simulated results are presented in Figures 5,6 and 7.

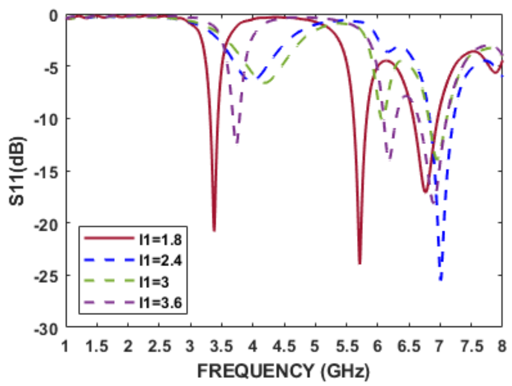


Figure 5. Result of the notch optimization.

Table 4. Optimization parameters.

Parameter		Notch depth	Horizontal position	Vertical position
		L1	x	y
Bounds	Min.	0	-2	-6
	Max.	3.6	2	6
Pat value		0.6	0.5	0.5
Best value		1.8	2	2

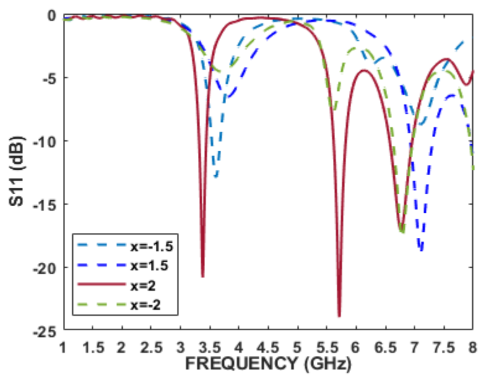


Figure 6. Result of the DGS horizontal position optimization.

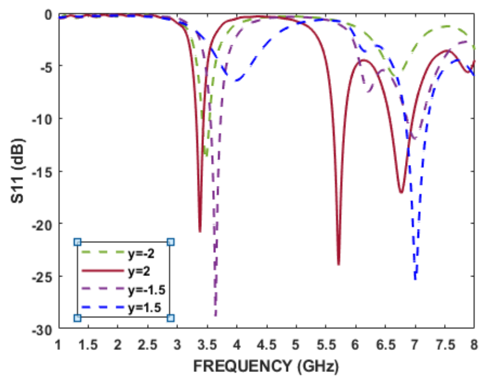


Figure 7. Result of the DGS vertical position optimization.

The first observation on the results of these optimizations is that each variation of these three parameters leads directly to a significant change in the resonance frequencies and multi-band operation, on the adaptation and on the bandwidth. Therefore, for a multidimensional search space composed of several parameters, it is necessary to have a large number of individuals to allow convergence to the optimal or near-optimal solution, which becomes difficult and restricted for traditional optimization. In contrast, the genetic algorithm parameters and results have proved their possibilities and efficiency to converge to the optimal solution and the design of the antenna in an optimal and original or non-intuitive way.

3.3 VSWR: Voltage Standing Wave Ratio

To evaluate the degree of matching or mismatching of the antenna, its Voltage Standing Wave Ratio (VSWR) must be simulated for the required frequency ranges. Figure 8 shows the simulated VSWR for the three resonance frequencies of the optimized antenna. The VSWR has values of 1.2 at 3.4 GHz, 1.25 at 5.7 GHz and 1.8 at 6.7 GHz. These VSWR values are less than 2, which is an acceptable performance according to the simulation results.

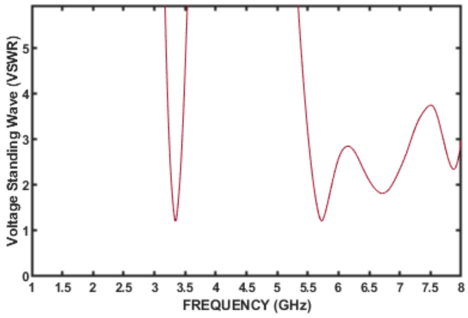


Figure 8. The VSWR of the proposed antenna.

3.4 Radiation Pattern

Figure 9 shows the two-dimensional radiation patterns at the three resonance frequencies. We can see that the proposed patch antenna provides an omnidirectional radiation pattern at 3.4 GHz (Figure 9 (a)) with a peak gain of 0.7 dB and a nearly directional radiation pattern with peak gains of 1.76 dB and 2.93 at 5.7 GHz and 6.7 GHz, respectively (Figure 9 (b) and Figure 9 (c)).

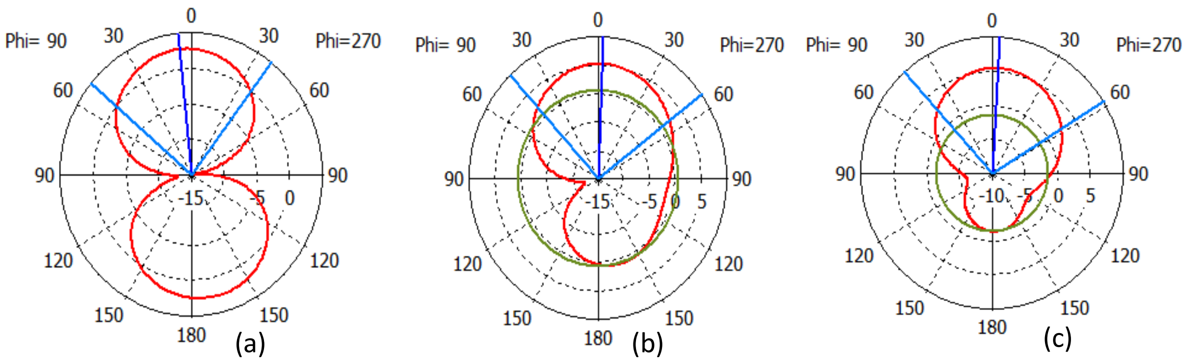


Figure 9. 2D radiation pattern: (a) at 3.4 GHz ;(b) at 5.7 GHz; (c) at 6.7 GHz.

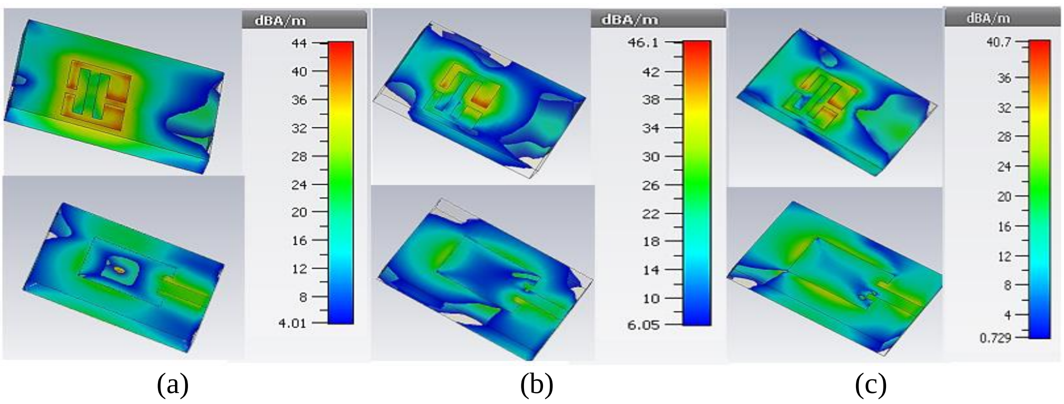


Figure 10. Simulated surface current distribution of the proposed antenna: (a) at 3.4 GHz; (b) at 5.7 GHz; (c) at 6.7GHz.

3.5 Current Distribution

Figure 10 shows the current distribution for the optimized patch antenna. It is apparent that the current is more concentrated along the DGS ground plane, the thing that explains that defects in the metal ground plane structure disrupt the current distribution, resulting in controlled excitation and propagation of the electromagnetic wave through the substrate layer and a change in the resonance peak.

3.6 Fabrication and Measurement

The structure of the designed antenna is etched on an FR-4 substrate, as shown in Figure 11.

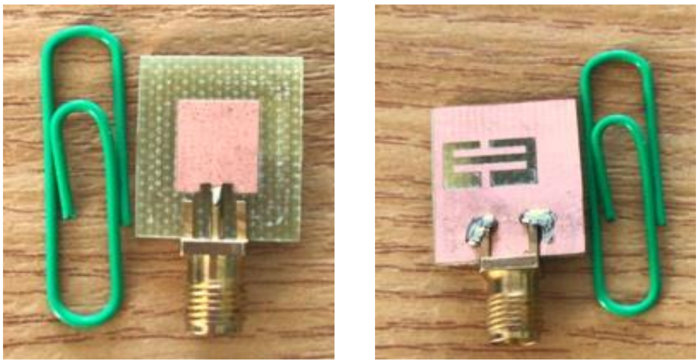


Figure 11. Prototype of optimized tri-band microstrip patch antenna.

The physical design of the fabricated microstrip antenna has a compact size with a high miniaturization rate compared to the conventional antenna. The measurements and frequency responses are shown in Figure 12. It can be seen that the practical results correspond well to the simulated results. Nevertheless, some deviations have been noted, caused by the inaccuracy of the manufacturing and measurement conditions.

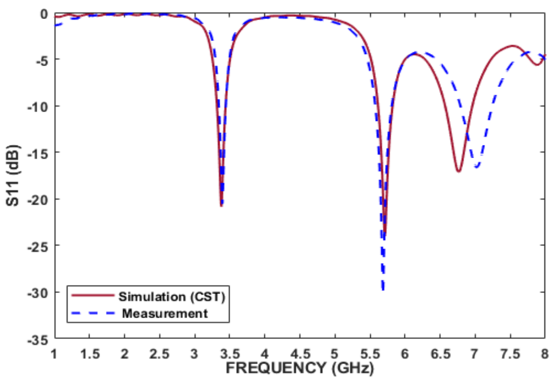


Figure 12. The simulated and measured reflection coefficient of the proposed tri-band patch antenna.

3.7 Comparative Study

To properly evaluate the results of our work, a quantitative comparison between the proposed tri-band antenna and the antennas reported in previously published works in terms of different parameters (resonance frequency, bandwidth, return loss, gain and size) is made. The results of this comparison are given in Table 5. All these designs have been presented in many different forms and techniques to achieve the required characteristics and to cover multiband operation. However, there are many limitations, such as complex structures and large size of designs. Interestingly, in terms of miniaturization and bandwidth, the patch antenna proposed in this study has improved performance over the reference antennas. Furthermore, the performance of the proposed antenna is comparable to those of the reference antennas in terms of return loss and gain. Moreover, the simplicity and ease of fabrication of the structure make it a suitable candidate for mobile applications requiring miniature and multi-band structures that can be easily integrated into modern telecommunication systems.

Table 5. Comparison between the proposed patch antenna and antennas from previous works.

Ref	Freq. (GHz)	$S_{11}(dB)$	BW (MHz)	Gain (dB)	Technology	Size (mm^3)
[4]	2.4	-27	197	2.017	DGS planar patch antenna	$34 \times 30 \times 1.6$
	3.5	-17	118	2.994		
	5.8	-15	90	3.362		
[5]	1.8	-16	140.2	2.34	F-shaped planar patch antenna	$60 \times 50 \times 1.6$
	3.5	-17	180.1	5.2		
	5.4	-19	200.2	1.42		
[6]	1.9	-24.56	130	4.1	Spiral-shaped planar patch antenna	$50 \times 56 \times 1.6$
	2.45	-27.21	290	4.25		
	3.19	-22.46	160	4.74		
This work	**3.4/3.45**	**-21/-19.9**	**300/190**	**0.7**	DGS planar patch antenna	$\mathbf{16 \times 20 \times 1.6}$
	5.7/5.6	**-24/-30.2**	**400/450**	**1.76**		
	6.7/7	**-17.2/-16.5**	**800/900**	**2.93**		

4. CONCLUSION

A tri-band miniature planar rectangular patch antenna structure for wireless mobile applications has been proposed. The miniaturization, tri-band functionality and high performance of the proposed design are achieved by optimizing the structure parameters and the position of a rectangular slot with T-shaped heads on the edges in the ground plane by a genetic algorithm (GA). The antenna performance simulations were performed using an interface between the Antenna Toolbox in MATLAB 2020a and CST studio suite 2019.The proposed tri-band patch antenna's frequency response is well matched to three frequency bands, such that the reflection coefficients are equal to -21dB, -24dB and -17.2dB for the resonance frequencies centered at 3.4 GHz, 5.7 GHz and 6.7 GHz, respectively, with improved bandwidths, a typical radiation pattern and a significant gain. A prototype of the studied antenna is manufactured to validate the optimized structure. The simulated and measured results are almost identical and demonstrate the good performance and tri-band functionality while keeping the simple and compact geometry.

REFERENCES

[1] M. Zavvari, R. Ebadzadeh and M. Mohammadifar, "Localized Surface Plasmons of a Corrugated Metal–insulator–metal Ring Resonator for Enhanced Multiband Antenna," Electronics Letters, vol. 54, no. 3, pp. 120–122, DOI: 10.1049/el.2017.2456, 2018.

[2] T. Dabas, B. K. Kanaujia, D. Gangwar, A. K. Gautam and K. Rambabu, "Design of Multiband Multipolarized Single Feed Patch Antenna," IET Microwaves, Antennas & Propagation, vol. 12, no. 15, pp. 2372–2378, DOI: 10.1049/iet-map.2018.5401, 2018.

[3] Y. F. Cao, S. W. Cheung and T. I. Yuk, "A Multiband Slot Antenna for GPS/WiMAX/WLAN Systems," IEEE Transactions on Antennas and Propagation, vol. 63, no. 3, pp. 952–958, DOI: 10.1109/TAP,2389219, 2015.

[4] A. Ibrahim, N. Arina Fazil and R. Dewan, "Triple-band Antenna with Defected Ground Structure (DGS) for WLAN/WiMAX Applications," J. Phys.: Conf. Ser., vol. 1432, no. 1, p. 012071, DOI: 10.1088/1742-6596/1432/1/012071, Jan. 2020.

[5] A. S. Elkorany et al., "Implementation of a Miniaturized Planar Tri-band Microstrip Patch Antenna for Wireless Sensors in Mobile Applications," Sensors, vol. 22, no. 2, Art. no. 2, DOI: 10.3390/s22020667, Jan. 2022.

[6] N. R. Kumar, P. D. Sathya, S. K. A. Rahim, M. Z. M. Nor, A. Alomainy and A. A. Eteng, "Compact Tri-band Microstrip Patch Antenna Using Complementary Split Ring Resonator Structure," The Applied Computational Electromagnetics Society Journal (ACES), vol. 36, no. 3, pp. 346–353, Mar. 2021.

[7] A. Abed, J. Mandeep and M. Islam, "Compact-size Fractal Antenna with Stable Radiation Properties for Wi-Fi and WiMAX Communications," KSII Transactions on Internet and Information Systems, vol. 12, pp. 2743–2747, DOI: 10.3837/tiis.2018.06.016, Jun. 2018.

[8] K.-C. Lee and J.-Y. Jhang, "Application of Particle Swarm Algorithm to the Optimization of Unequally

Spaced Antenna Arrays," Journal of Electromagnetic Waves and Applications, vol. 20, no. 14, pp. 2001–2012, DOI: 10.1163/156939306779322747, Jan. 2006.

[9] 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, DOI: 10.1109/LAWP.2002.805128, 2002.

[10] P. Soontornpipit, C. M. Furse and Y. C. Chung, "Miniaturized Biocompatible Microstrip Antenna Using Genetic Algorithm," IEEE Transactions on Antennas and Propagation, vol. 53, no. 6, pp. 1939–1945, DOI: 10.1109/TAP.2005.848461, Jun. 2005.

[11] Constantine A. Balanis, Antenna Theory: Analysis and Design, 2nd Edition, ISBN: 0000471592684, [Online], Available: https://www.amazon.com/Antenna-Theory-Analysis-Design-2nd/dp/0471592684.

[12] M. Ramesh and K. B. Yip, "Design Formula for Inset Fed Microstrip Patch Antenna," Microwaves and RF, vol. 3, pp. 5–10, Dec. 2003.

[13] M. Kumar and V. Nath, "Analysis of Low Mutual Coupling Compact Multi-band Microstrip Patch Antenna and Its Array Using Defected Ground Structure," J. Engineering Science and Technology, vol. 19, no. 2, pp. 866–874, DOI: 10.1016/j.jestch.2015.12.003, Jun. 2016.

[14] Ashwini K. Arya, M. V. Kartikeyan and A. Patnaik, "Defected Ground Structure in the Perspective of Microstrip Antennas: A Review," Frequenz, vol. 64, no. 5–6, pp. 79–84, DOI: 10.1515/FREQ.2010.64.5-6.79, Jun. 2010.

[15] A. Arya, A. Patnaik and K. Machavaram, "Microstrip Patch Antenna with Skew-F Shaped DGS for Dual Band Operation," Progress in Electromagnetics Research M, vol. 19, DOI: 10.2528/PIERM11052305, Jan. 2011.

[16] I. Bouchachi, K. Hamdi-Cherif, K. Ferroudji et al., "A Comparison of Genetic Algorithm and Practical Swarm Optimization for the Design of Waveguide Filters," Proc. of the Int. Telecommunications Conf., vol. 504, pp. 89-98, [Online], Available: https://link.springer.com/chapter/10.1007/978-981-13-0408-8_8 , 2022.

[17] R. L. Haupt and S. E. Haupt, Practical Genetic Algorithms, 2nd Ed. Hoboken, N. J.: John Wiley, 2004.

ملخص البحث:

تقدّم هذه الورقة طريقةً لتصميم هوائي صغير مسطّح مستطيل ثلاثي النّطاقات للتّطبيقات المتنقّلة اللاسلكية. وقد تم تحقيق التّشغيل ثلاثي النّطاقات مع الحفاظ على حجم صغير للهوائي عبر تشويه بنية الأساس من أجل التّحكم بتوزيع تيار السّطح. وقد تمّ تحديد الأبعاد الهندسية للرّقعة بالإضافة الى تحديد الموضع المثالي لتشويه بنية الأساس بواسطة خوارزميّة جينيّة بهدف الحصول على أداء مثالي للهوائي باستخدام تصميم بسيط وصغير بحجم بلغ (16×20×1.6) ملم^3؛ أي بنسبة أقلّ من حجم الهوائي أحادي النّطاق مقدارها 82%.

لقد حقّق الهوائي المقترح تشغيلاً ثلاثي النّطاقات (3.2 - 3.5) جيجا هيرتز؛ (5.5 - 5.9) جيجا هيرتز؛ (6.3 - 7.1) جيجا هيرتز عند $|S11| < 6$ ديسيبل. وبلغت قيم كَسْب الهوائي عند الترددات المركزية (3.4 و 5.7 و 6.7) جيجا هيرتز (0.7 و 1.76 و 2.93) ديسيبل على الترتيب. وقد تمّ وضع الهوائي المصمّم بصورة مثالية على طبقة أساس (FR-4). وبينت نتائج المحاكاة ونتائج القياسات اتّفاقاً جيداً، وهذا يجعل البِنية المقترحة مرشحةً للتّطبيقات اللاسلكية المتنقّلة التي تتطلب أجهزة اتّصالات صغيرة ومتعددة الوظائف.