Design and Optimization of a CPW-Fed Tri-Band Patch Antenna Using Genetic Algorithms

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Abstract **─** This paper investigates a compact tri-band patch antenna fed by a coplanar waveguide (CPW) line for the applications of WiFi, WiMAX and HiperLAN. The dimensions of the proposed antenna are optimized using genetic algorithms (GAs). The antenna is designed to function at three different resonant frequencies which are 2.46 GHz, 3.56 GHz and 5.5 GHz. Numerical results for the return loss, radiation pattern and gain of the antenna are presented. The antenna structure was fabricated, and the measured results have a good agreement with the full-wave simulated ones.

Index Terms **─** Coplanar waveguide (CPW), genetic algorithms (GAs), patch antenna, tri-band.

I. INTRODUCTION

In recent years, multiple service technology is broadly developed, especially in the radio frequency (RF) devices of the modern wireless communication systems such as high-speed wireless fidelity (WiFi), Bluetooth, worldwide interoperability for microwave access (WiMAX) and high performance radio local area network (HiperLAN) systems operating at frequencies between 2 GHz and 6 GHz. In order to accommodate this multi-band RF signal transmission and reception into a single RF transceiver, dual or more bands devices are required to incorporate circuits working in different bands into a single unit so that size, cost and device number can be reduced. To meet this demand, several multi-band antennas with a variety of services have been carried out [1]-[4]. However, it is still a big challenge to design this type of antenna with suitably compact circuit size, high gain and more design feasibility.

In this paper, we propose a novel compact tri-band patch antenna fed by a coplanar waveguide (CPW) line for WiFi at 2.46 GHz, WiMAX at 3.56 GHz and HiperLAN at 5.5 GHz. The antenna structure is simple, compact and has controllable topology where its dimensions are optimized using internal genetic algorithms (GAs). The substrate material used for the design is an epoxy glass type with a thickness of 1.6 mm and a relative permittivity of 4.4. Two different electromagnetic (EM) simulators and measurements are used to validate the results obtained for the return loss response. The simulation results show a good agreement to the measurement ones.

II. THE PROPOSED ANTENNA GEOMETRY

The geometry and parameters of the proposed antenna fed by a CPW line is shown in Fig. 1. The patch antenna is printed on a dielectric substrate of a height equal to 1.6 mm and a relative permittivity of 4.4. The width of the 50 Ω microstrip fed line is 3 mm. The choice of the radiating element shape depends on diverse factors such as radiated power, polarization type, multi-band operation, gain and bandwidth of the radiator. The parameters for optimal antenna design which are selected to achieve the compact dimensions and possible best features such as high radiation efficiency, etc., are presented in the next section. The antenna was simulated and its prototype was fabricated

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and measured.

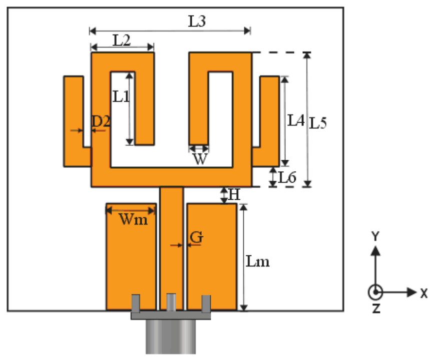


Fig. 1. The proposed antenna.

III. OPTIMIZATION AND SIMULATION: RESULTS AND DISCUSSIONS

The optimization objective of the proposed structure consists of finding the best values of geometrical parameters which are close to the objective function of GAs. The literature has reported some works about the application of GAs for general electromagnetic (EM) problems [5]-[9] and particularly for the design and optimization of antennas arrays [10]-[11]. The GAs are a class of search techniques that employ the mechanics of natural selection and genetics to conduct a global search of a solution space. The search objective is to find a good solution to the given problem. To start the optimization, the GA selects a set of designs, almost always at random. This set is called the population, just as in biology. The GA evaluates the performance of each member of the population using a simulator or analytic expression, and then applies a cost function. This function compares individual performance to the desired or ideal performance. It then returns a single number as a measure of its fitness to the GA. Table 1 illustrates the variation intervals of the antenna geometrical parameters.

Table 1: Geometrical parameters interval of the antenna

Parameters (mm)	Interval
W	[1 5]
Wm	[1 15]
Lm	[5 20]
H	[0.5 5]
G	[0.2 1]
L1	[0.1 15]
L2	[2 15]
L3	[5 30]
L4	[0 15]
L5	[5 20]
L6	[0 10]
D2	[0 5]

The aim of this part is to minimize the average value of the S_{11} module (in dB) in the three bands of ([2.4 2.48] GHz, [3.5 3.7] GHz, [5.15 5.8] GHz) frequencies which correspond to WiFi, WiMAX and HiperLAN standards respectively. The cost function is computed for each individual as the sum of return losses at desired frequencies, given by Eq. (1), and the fitness is to minimize the cost:

$$\cos t = \frac{1}{N_b} \sum_{n_b=1}^{N_b} \left(\frac{\sum_{n_i=1}^{N_i} \left| S_{11}(n_i) \right|_{dB}}{N_i} \right), \tag{1}$$

where $\left|S_{11}(n_i)\right|_{dB}$ is the magnitude of the reflection coefficient, N_i is the number of desired frequency band and N_b is the number of frequency points in the desired frequency band.

In this case, the multi-objective optimization function of the reflection coefficient must meet the following requirements:

$S_{11} \leq$ -15 dB for 2.4 GHz $\leq f \leq$ 2.48 GHz,
$S_{11} \leq$ -15 dB for 3.5 GHz $\leq f \leq$ 3.7 GHz,
$S_{11} \leq$ -15 dB for 5.15 GHz $\leq f \leq$ 5.8 GHz,

and the GA, used in the optimization, has the following properties:

- Number of population members: 60,
- Number of generations: 30,
- Mutation rate: 0.01.

The optimization time for the antenna optimization took 2 days 03 hours and 21 minutes with HP I5 CPU 2.5 GHz and RAM = 6 Go.

The results obtained by a GA optimization are illustrated in Table 2, whereas the reflection coefficient simulation versus frequency of the proposed antenna is shown in Fig. 2. Figure 2 shows the presence of three diverse resonant frequencies which are 2.46 GHz, 3.56 GHz and 5.5 GHz, in which a good matching is satisfied.

Table 2: Optimized dimensions of the antenna

Parameters (mm)	Optimized Value
W	2.43
Wm	6.26
Lm	13.33
H	2.06
G	0.476
L1	9.19
L2	7.91
L3	20.22
L4	11.29
L5	16.83
L6	2.55
D2	1.01

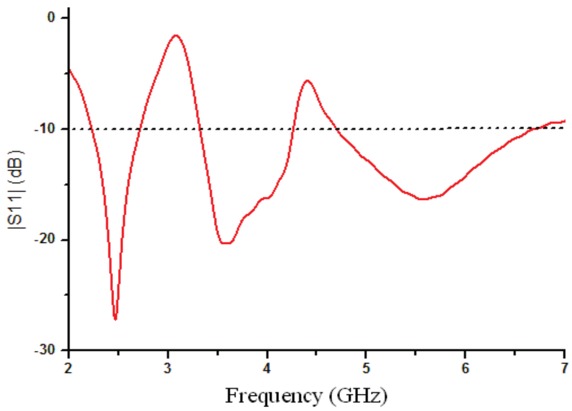
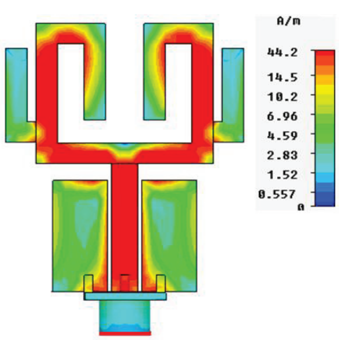


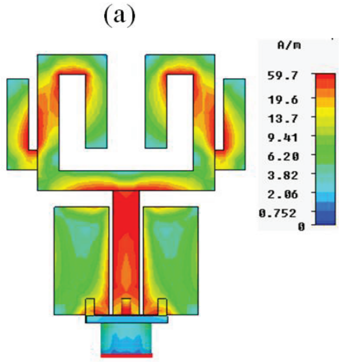
Fig. 2. The input reflection coefficient versus frequency.

The current distribution of the structure is shown in Fig. 3 for diverse resonant frequencies values. It is clear the current circulation is concentrated on the feeding line and in diverse regions of the radiated element.

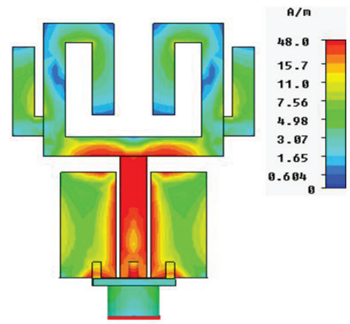
Figure 4 shows the 3D radiation patterns variation for various resonant frequencies values, whereas Fig. 5 shows the 2D radiation patterns at three distinct frequencies in the plans: (a) θ = 90°, (b) φ = 90°, and (c) φ = 0°. In the E-plane (φ = 90°) and H-plane (φ = 0°), Fig. 5 (b and c), the radiation pattern is bidirectional oriented towards the angles θ = 0° and θ = 180° for the three resonant frequencies. Consequently, the proposed antenna pattern looks like to that of a dipole.



(a)

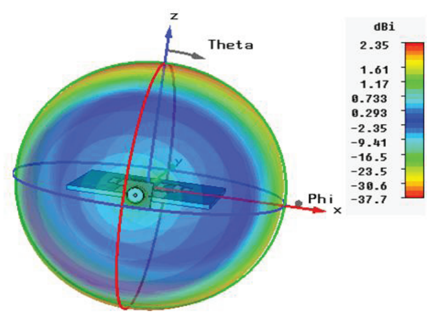


(b)

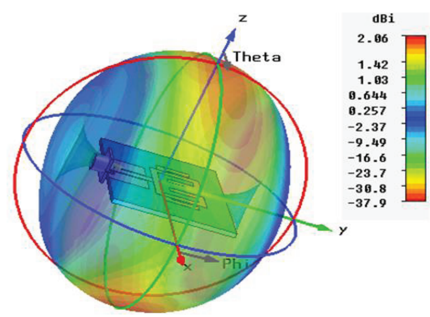


(c)

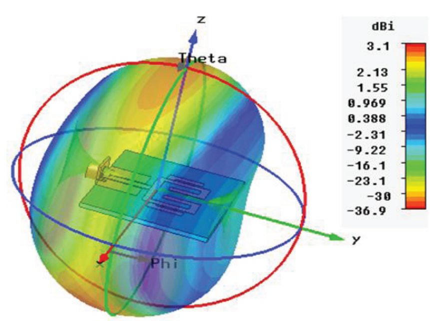
Fig. 3. Current distribution at three distinct frequencies: (a) f = 2.46 GHz, (b) f = 3.56 GHz, and (c) f = 5.5 GHz.



(a)



(b)



(c)

Fig. 4. 3-D radiation patterns at three distinct frequencies: (a) f = 2.46 GHz, (b) f = 3.56 GHz, and (c) f = 5.5 GHz.

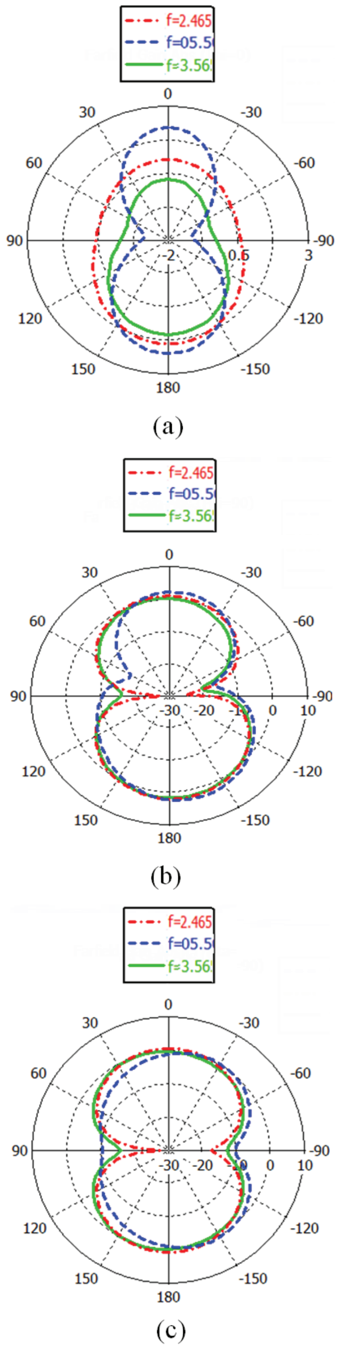


Fig. 5. 2-D radiation patterns at three distinct frequencies in the plans: (a) θ = 90°, (b) φ = 90°, and (c) φ = 0°.

For the frequency 2.46 GHz, the maximum gain is around 2.15 dBi in the direction φ = 90° and θ = 180° with a -3 dB aperture of 83.6°. For the frequency 3.56 GHz, the maximum gain is approximately 1.7 dBi in the direction φ = 90° and θ = 179° with a -3 dB aperture of 80.6°. For the frequency 5.5 GHz, the maximum gain is approximately 2.8 dBi in the direction φ = 90° and θ = -165° with a -3 dB aperture of 68.9°.

Figure 6 shows the simulated maximum gain of the proposed antenna in the three bands. It is shown that this antenna has a good gain, varies between 2.1 dBi and 2.3 dBi inside the first frequency band, between 1.4 dBi and 2.4 dBi inside the second frequency band, and between 2.6 dBi and 3.4 dBi inside the third frequency band.

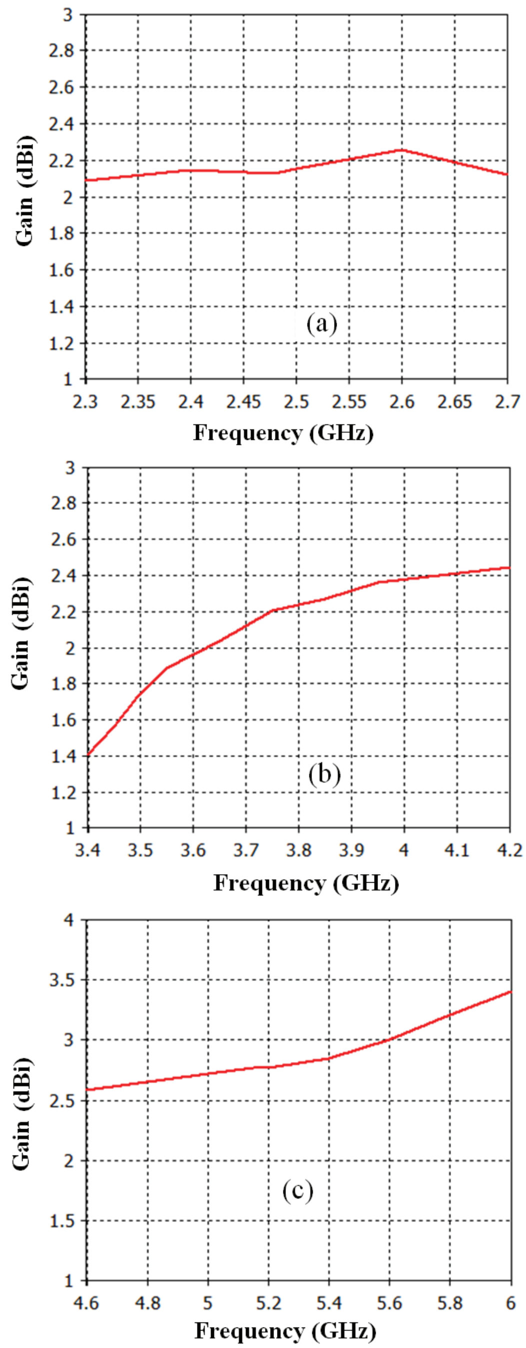


Fig. 6. Maximum gains versus frequency in the three bands.

IV. IMPLEMENTATION AND MEASUREMENT

The proposed antenna with small in size of 27.1x32.22 mm^2 is fabricated as shown in Fig. 7.

From Fig. 8, an acceptable agreement between the measured and simulated return losses is achieved. Moreover, these results show three diverse resonant frequencies with a small shifting toward high frequencies. The small deviations between the simulated and measured results may most probably be caused by the usual connectors and manufacturing errors. Moreover, the limitation of the EM simulator's may lead to discrepancy between the simulated and measured results. Usually, such discrepancies may be attributed to the dielectric material that should be characterized before realization since its properties deviates from those set in the software simulator.

The measured results are compared with some of the efficient and related antennas existing in literature and summarized in Table 3. The measured results indicate that the proposed antenna can meet the bandwidth requirements of WiFi/WiMAX/HiperLAN standards. It provides good performance in terms of better matching, larger bandwidth and smaller in size than those published works.

Figure 8 shows the measured and simulated input reflection coefficient. The antenna characteristics were measured with an HP8719ES VNA.

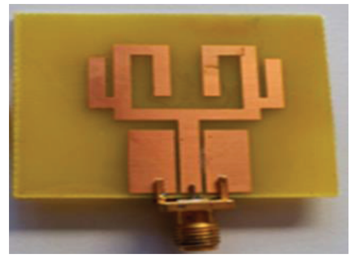


Fig. 7. Photograph of the fabricated compact tri-band antenna.

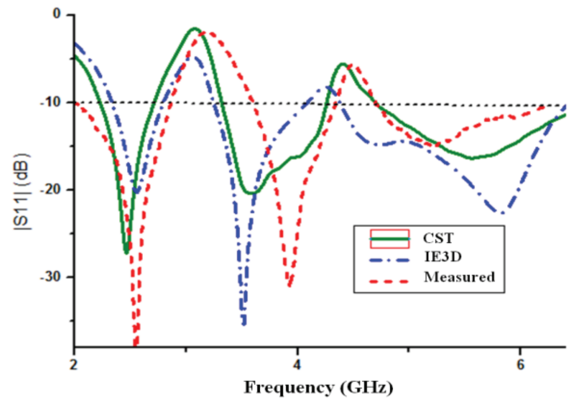


Fig. 8. Comparison between simulation and measurements of the input reflection coefficient.

Table 3: Comparison of the proposed CPW-fed tri-band antenna with other reported antennas

	Substrate Material (ε_r/h)	Size (mm^2)	Resonant Frequencies (GHz)	Max $\lvert S_{11}\rvert$ (dB)	Measured Impedance Bandwidths (GHz)	Max Gain (dB)
Ref. [2]	4.4/1.6	30x42	2.50/3.50/5.50	-26/-16/-14	0.41/0.44/1.00	< 2
Ref. [3]	2.2/1.588	36.56x43.42	2.40/3.50/5.70	-32/-17/-22	0.12/0.15/0.20	-
This work	4.4/1.6	27.1x32.22	2.46/3.56/5.50	-40/-32/-15	0.94/0.82/1.60	2.15/1.7/2.8

V. CONCLUSION

In this paper, a novel compact tri-band antenna fed by a CPW line for WiFi, WiMAX and HiperLAN has been introduced and investigated. The proposed antenna dimensions have been optimized using genetic algorithms (GAs). The obtained results by this algorithm are acceptable and show the importance of using a GA in the field of antennas synthesis. The results achieved by simulation as well as measurement show tri-bands behavior with a good matching for all resonant frequencies.

REFERENCES

[1] M. Pokorný, J. Horák, and Z. Raida, "Planar tri-band antenna design," *Radioengineering*, vol. 17, pp. 28-36, 2008.

[2] J. Chen, S. T. Fan, W. Hu, and C. H. Liang, "Design of tri-band printed monopole antenna for WLAN and WIMAX applications," *Progress In Electromagnetics Research C*, vol. 23, pp. 265-275, 2011.

[3] G. Sami, M. Mohanna, and M. L. Rabeh, "Tri-band microstrip antenna design for wireless communication applications," *NRIAG Journal of Astronomy and Geophysics*, vol. 2, pp. 39-44, 2013.

[4] S. B. Chen, Y. C. Jiao, W. Wang, and F. S. Zhang, "Modified T-shaped planar monopole antennas for multiband operation," *IEEE Trans. Mi-crow. Theory Tech.*, vol. 54, no. 8, pp. 3267-3270, 2006.

[5] Y. R. Samii and E. Michielssen, *Electromagnetic Optimization by Genetic Algorithms*, John Wiley & Sons, Inc., 1999.

[6] R. L. Haupt and S. E. Haupt, *Practical Genetic Algorithm*, Second edition, John Wiley & Sons, Inc., 2004.

[7] D. A. Coley, *An Introduction to Genetic*

Algorithms for Scientists and Engineers, World Scientific, 1999.

[8] C. A. Balanis, *Antenna Theory: Analysis and Design*, Third edition, John Wiley & Sons, Inc., 2005.

[9] D. S. Weile and E. Michielssen, "Genetic algorithm optimization applied to electromagnetics: a review," *IEEE Trans. Antennas Propag*., vol. 45, no. 3, Mar. 1997.

[10] F. J. Ares-Pena, J. A. Rodrigues-Gonzalez, E. Villanueva-Lopez, and S. R. Rengarajan, "Genetic algorithms in the design and optimization of antenna array patterns," *IEEE Antennas and Propag. Mag.*, vol. 47, no. 3, pp. 506-510, Mar. 1999.

[11] D. Marcano and F. Duran, "Synthesis of antenna arrays using genetic algorithms," *IEEE Antennas and Propag. Mag*., vol. 42, pp. 12-20, Jun. 2000.

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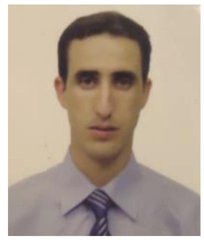

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