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Research Paper

Genetic Algorithm Based Approach for Frequency Switchable Dual-Band Patch Antenna

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Abstract: In this paper, a frequency switchable antenna design using genetic algorithms (GAs) for dual band WiMAX (3.5GHz) and WLAN (5.2GHz) applications is proposed. The area of the radiating patch element is divided into 2 mm square cells, with each cell assigned a conducting or non-conducting characteristic. To realize frequency reconfiguration, switches are incorporated into appropriate locations to activate/deactivate corresponding cells. The on/off states of the switches are represented by the presence or absence of conductor, respectively. Hence, the proposed approach allows the antenna to operate as mono-band or dual-band radiator according to the desired application. Further, measurements and simulations are carried out and a reasonable agreement is achieved.

Keywords: Genetic Algorithm, Dual-Band Antenna, Switchable Frequency Band.

1 Introduction

NOWADAYS, multiband antennas are very popular because of their suitability for compactness, integration and allowing several services on single radio terminal. The literature is rich of antennas able to cover wide range of the available spectrum with different operation bands [1-9]. Antenna frequency reconfiguration is one of the key elements in this challenge [10-12].

The principle idea of reconfiguration is based on the ability to redistribute the surface current-flow on the radiating element. In conventional designs, several methods were adopted to achieve this purpose, such as: introducing slots in the ground plane of the antenna [10] or on the radiator [13] in order to create resonances. In [14, 15], another way for reconfigurability based on metamaterial cells was presented. Stub loaded resonators were also exploited as in [16]. Further, reconfigurability is achieved through moving between different states; hence various switching circuits were used such as PIN Diodes [10], RF-MEMS [17], optical switches, etc. Besides, ideal switches can be used, as well, for proof of concept [14, 18].

The primary challenge in frequency reconfigurable antenna design is the optimization of such structures, which has become an important research area for antenna designers. Further, automatic and straightforward optimization method is highly requested unlike conventional techniques which are widely reported in the literature. Genetic algorithm (GA) is one the most interesting tools providing optimized structures in order to achieve better performances than what regular shapes usually allow. Hence, several antenna designs based on GA have been proposed with advanced features [19-21].

In this paper, it is proposed to explore the possibility to apply GA to design frequency-reconfigurable antennas. In this perspective, a GA-based frequency reconfigurable patch antenna is presented. It consists of a dual-band rectangular patch antenna exhibiting full frequency reconfiguration between the frequency bands corresponding to WiMAX (3.5GHz) and WLAN (5.1GHz) standards. The antenna can be operated at any of these two bands or at both of them.

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2 Antenna Configuration and GA Process

The basic geometry of the proposed antenna is shown in Fig. 1. The structure consists of 18x14 mm^2 rectangular patch fed by a 50 Ω microstrip line over 1.6 mm height FR-4 substrate with dielectric constant of 4.3 and loss tangent of 0.02.

In order to apply GA, as indicated in Fig. 1, the radiating element (patch) region is divided into 2 mm square cells, with each cell having either a conducting or non-conducting feature, the binary coding is always utilized because each cell can only have two values, hence 'on' (1)/'off' (0) states of the switches are represented by the presence or absence of conductor, respectively. Consequently, the resulting structure is composed of 63 fragment cells which correspond to a matrix of 9×7 over which a GA optimization can be run to achieve judicious arrangement allowing frequency reconfiguration ability.

The GA code is first developed in visual basic script (VBS) environment. It sets the shape of the radiating element by affecting the value “1” to the conducting pixels (cells containing conductor) and “0” to the non-conducting ones. Then, a constraint function based on S11-parameter for targeted bands is calculated as follows:

$$L(f)=\begin{cases}|S11(f)|\text{dB}, & -10\text{dB}\le|S11(f)|\text{dB}<-5\text{dB}\\ -10, & |S11(f)|\text{dB}<-10\text{dB}\\ 0, & |S11(f)|\text{dB}\ge-5\text{dB}\end{cases} \tag{1}$$

where, i and j correspond, respectively, to the targeted operating frequencies and the targeted suppressed frequencies.

The next step is minimizing the following cost function:

$$Cost=\frac{1}{N_b}\sum_{nb=1}^{N_b}\left(\frac{\sum_{i=1}^{M}L_{nb}(f_i)}{M}\right)-\frac{1}{N_a}\sum_{na=1}^{Na}\left(\frac{\sum_{j=1}^{P}L_{na}(f_j)}{P}\right) \tag{2}$$

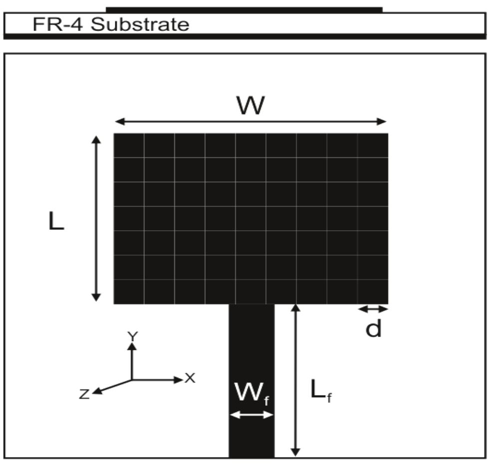


Fig. 1 Subdivided patch area with geometrical parameters.

Nb and *Na* are the number of desired and suppressed frequency bands, where the integers *M* and *P* represent the number of frequency points in the desired and suppressed bands, respectively. In this work *M* is chosen to be equal to 100 samples in desired bands and *P* equal to 150 samples in suppressed bands.

The minimization of cost function is the targeted study which allows obtaining good impedance matching (|*S*11|< -10 dB) in the desired frequency band and impedance mismatch (|*S*11|> -5 dB) in the undesirable band. The convergence of the GA is then performed by the choice of the values -10 dB and -5 dB Similarly, to lower the number of iterations (convergence time) that correspond to all feasible combination forms and over which the GA is run, the percentage of conductor and no-conductor subdivisions is set to be 90% and 10%, respectively.

In all designs, the population size is made up of 20 chromosomes every generation. Individuals with higher fitness value are selected to support the next generation. The crossover probability from the individual’s selection is 100%, and the single point crossover method was utilized with a mutation probability of 0.1 %, a new generation is generated from the present one. This work employs a total of 30 generations.

The next step in the design process consists in introducing frequency reconfiguration through selection of three radiating element shapes providing three operating possibilities: WiMAX only, WLAN only and both of them simultaneously (dual-band). Among different shapes that fulfill the desired frequency band selection, only those requiring minimum number of switches are adopted.

The last step consists in proposing a more realistic switch shape (optimized switch) by using 0.5 mm strips instead of the whole pixel metallization without making any changes in the simulation results.

3 Results and Discussion

The three antenna designs obtained by G.A optimization are shown in Fig. 2, while simulated S11 parameter for each configuration is depicted in Fig. 3. The full-wave EM simulator CST microwave studio suite is used for simulations process.

As shown in Fig. 3, the first antenna configuration (see Fig. 2(a)) resonates clearly at two distinct frequencies: 3.53 GHz and 5.2 GHz corresponding to WiMAX and WLAN bands, respectively. In the second configuration (see Fig. 2(b)), only one resonant frequency is obtained at 3.5 GHz corresponding to WiMAX band. Similar result is obtained by the third configuration (see Fig. 2(c)) operating in WLAN band (5.2 GHz). We note that in all configurations, excellent impedance matching is achieved as the S11-parameter is much less than -10 dB.

To more explain the operating antenna mechanism and clarify the return loss performance of the proposed

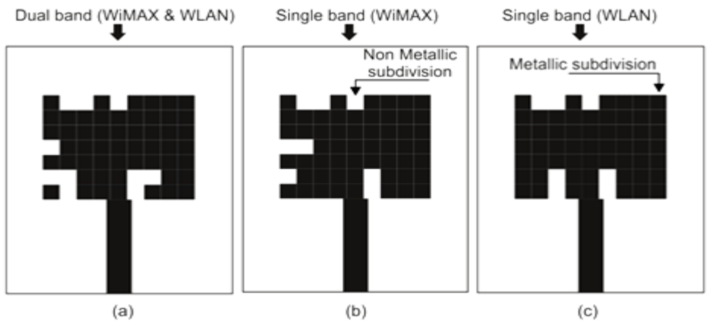


Fig. 2 Configurations of three antennas optimized by GA; a) First configuration, b) Second configuration, and c) Third configuration.

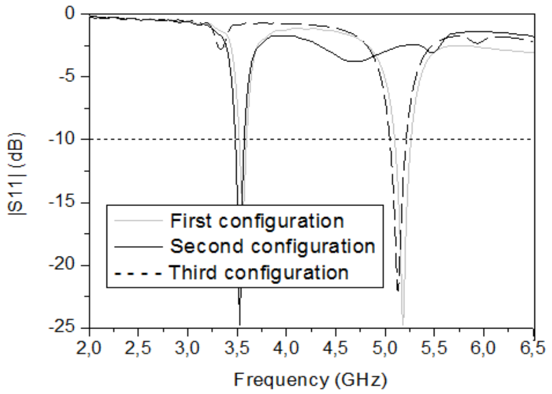
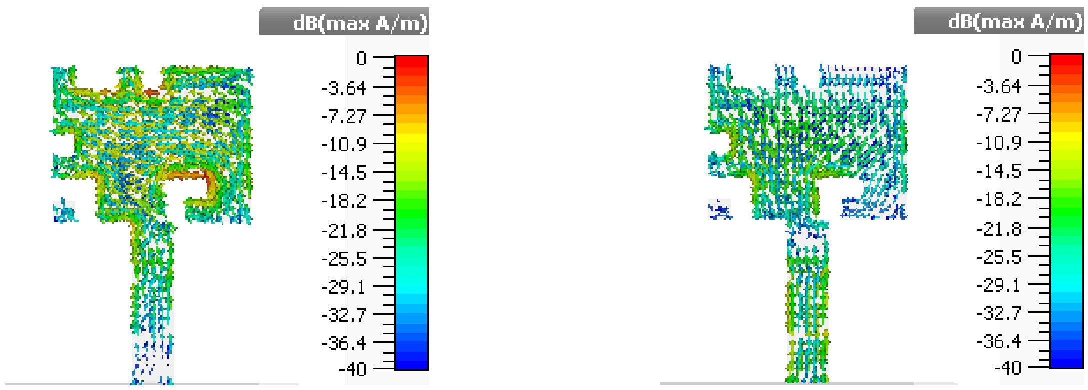


Fig. 3 Simulated *S*11-Parameter for three antenna configurations optimized with GA.



(a) (b)

Fig. 4 Current density distribution for the dual band antenna a) at 3.5 GHz and b) at 5.1 GHz.

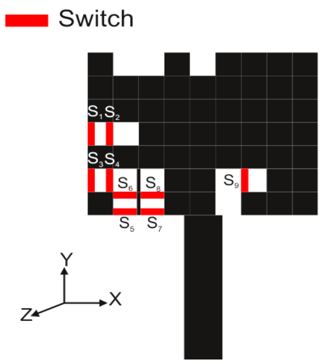


Fig. 5 Proposed antenna with integration of ideal switches.

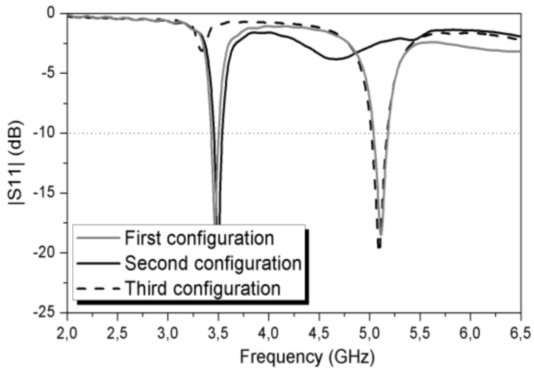


Fig. 6 Simulated *S*11 of the optimized antenna.

antenna structure, the current distributions is simulated at the first configuration (dual band antenna) for *F*1 = 3.5 GHz and *F*2 =5.1 GHz as depicted in Fig. 4, it is observed that the current density is distributed in all area of the patch and is more concentrated in the first frequency compared to the second frequency band, specifically around the etched pixels boundary, which prove the effectiveness of the proposed method.

In order to achieve frequency reconfigurable printed antenna, the three previous configurations (shown in Fig. 2) are merged together to obtain one reconfigurable antenna as seen in Fig. 5. In this new shape, non-common subdivisions in the previous configurations are replaced by nine ideal switches labeled Si (i = 1 to 9), where the 'on' (1)/'off' (0) states are represented by the presence/ absence of conductor, respectively.

Therefore, through this new arrangement, one can achieve any desired operating band by properly activating or deactivating the switches.

Table 1 illustrates the switches configuration for different modes. Furthermore, the simulated *S*11 obtained with those switches demonstrates that effectively the proposed antenna can achieve three operating modes in WiMAX, WLAN and both frequency bands as shown in Fig. 6.

Fig. 7 depict the simulated gain of the first configuration (dual-band antenna) against frequency, the two maximum gain values of 2.6 dB and 4.1 dB

Table1 Switches configuration for the three operating modes.

Configuration	*S*1	*S*2	*S*3	*S*4	*S*5
First	on	on	on	on	on
Second	off	off	off	on	on
Third	off	on	off	off	off
Configuration	*S*6	*S*7	*S*8	*S*9	
First	on	off	off	on	
Second	on	on	on	on	
Third	off	on	on	off	

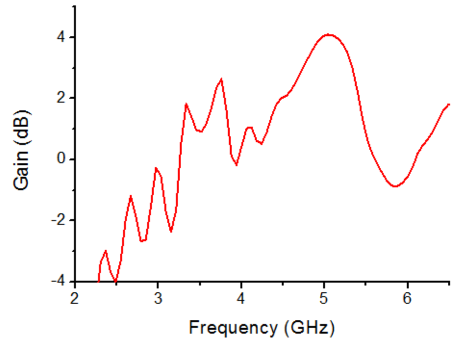


Fig. 7 Simulated gain of dual band antenna versus frequency.

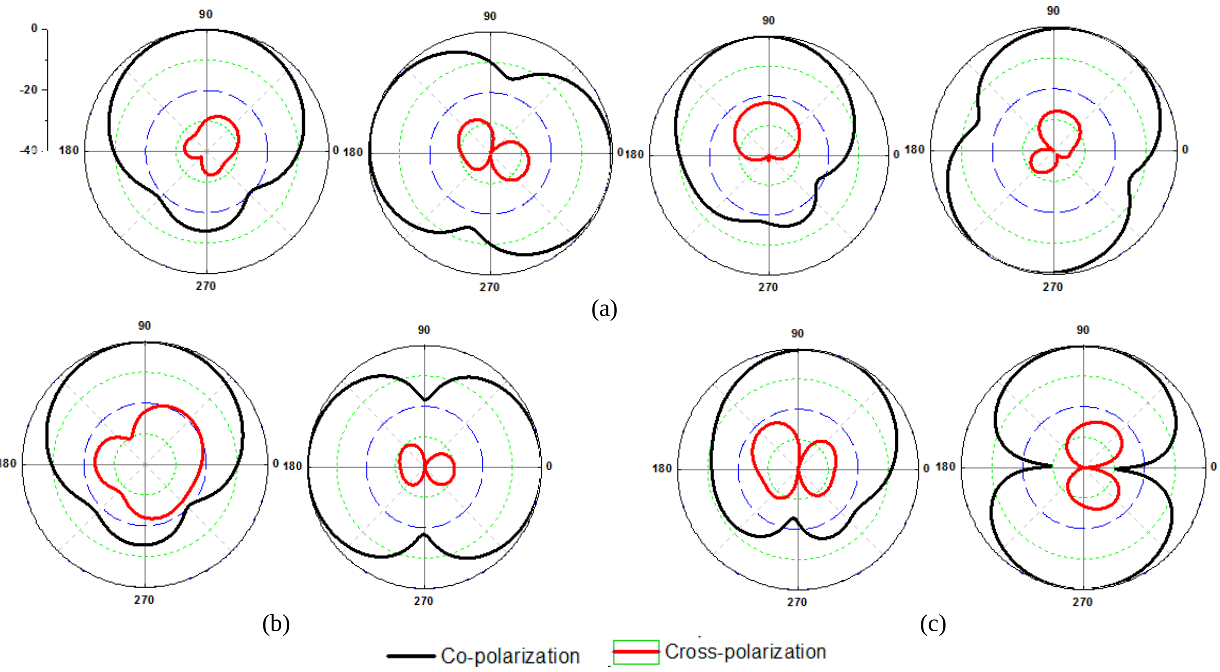


Fig. 8 Normalized radiation pattern for three configurations of proposed antenna: a) from left to right hand side E and H plane patterns at F1 and F2 respectively for the first configuration, b) E and H plane patterns at *f* = 3.5GHz for the second configuration, and c) E and H plane patterns at *f* = 5.1GHz for the third configuration.

corresponding, respectively to the central frequencies of dual-band antenna.

The simulated results co-and cross-polar far-field E-plane and H-plane radiation patterns of the proposed antenna for the three configurations are presented in Fig. 8. It is seen that these patterns show that the designed antenna provides linear polarization with a cross polarization level of about 25 dB lower than the co-polarization level in the E- and H-planes. The cross-polarization levels in the other directions are significantly small, indicating excellent polarization purity.

4 Implementation and Measurement

To validate experimentally the proposed approach using genetic algorithm optimization, the antenna prototype is manufactured and measured. Fig. 9 show the photograph of the fabricated design in case of all switches are turned off.

*S*11 measurements are depicted in Fig. 10 for three operating modes. Those modes are obtained by activating appropriate switches according to Table 1. From Fig. 10, it seen that the measured results show clearly that the antenna is able to work either in dual-band mode (3.55 GHz and 5.25 GHz) or in one of the two bands with good impedance matching. Moreover, very reasonable agreement between measured (Fig. 10) and simulated (Fig. 6) results is obtained.

It is worthwhile to point out that the proof of concept is demonstrated through the use of ideal switches, since real ones require advanced soldering technology of very small SMD PIN diodes [22] which is possible in modern factories or the use of MEMS switches [17].

5 Comparative Study

Table 2 summarizes the comparative study conducted between the proposed approach and previous relevant works published in the literature. It can be noticed that our work allows automatic location of switches providing flexible choice to mono-band or dual-band

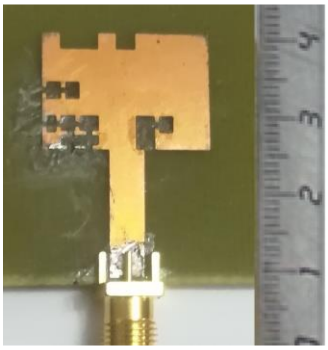


Fig. 9 Photograph of the fabricated antenna.

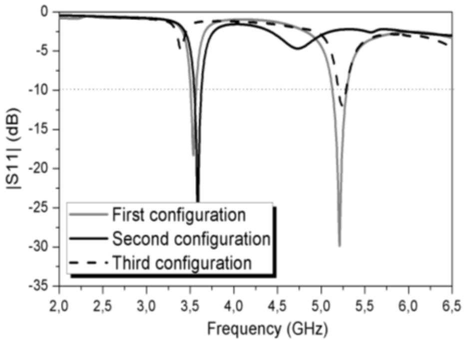


Fig. 10 Measured S11 of the fabricated prototype.

Table 2 Comparison study.

Ref.	Size [mm^2]	Switches location	Method	Reconfigurability freedom	Resonance frequencies [GHz]	Number of switches	Gain [dB]
[18]	80×30	Studied	Conventional	Slots in ground plane	2.4, 3.5, 5.2	4	5.4, 4, 4.1
[22]	50×50	Concluded	Conventional	Parasitic stubs	1.88to 2.55	2	4.54, 5.16
[23]	450×500	Studied	Conventional	Slot-ring	1.76, 5.71	16	0.1, 4.2
[24]	59.4×59.8	Studied	Conventional	Cross slot	1.65 to2.5	4 varactors	2.1-2.8
[25]	144×75	Studied	Conventional	Symmetrical three coupled-line structure	2.03	4	5.8
[26]	70×70	Studied	Conventional	CSRR	2.42	8	6
This work	18×14	Automatic	GAO	Free from constraints	3.5, 5.2	9	2.6, 4.1

frequency reconfiguration with compact design and good performances (matching). Moreover, the outlining technique allows canceling unwanted bands without adding any extra-structures.

6 Conclusion

A new concept of printed frequency reconfigurable antenna design using genetic algorithm (GAs) for WiMAX and WLAN standards has been presented in this paper. The proposed antenna can operate at either of the bands, 3.5 GHz and 5.1 GHz, or at both of them. The obtained results are very satisfactory and show the advantages of using a GA in the design of frequency reconfigurable antennas. The proposed prototype has been validated experimentally where a very reasonable agreement between measured and simulated results has been achieved.

Intellectual Property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property.

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CRediT Authorship Contribution Statement

K. Fertas: Conceptualization, Methodology, Software, Formal analysis, Writing - Original draft. **F. Fertas:** Supervision. **S. Tebache:** Investigation. **A. Mansoul:** Data curation. **R. Aksas:** Writing - Review and editing, Investigation.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to “Iranian Journal of Electrical and Electronic Engineering”.

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