Design of Compact Antenna in Package for 2.4 GHz Band Applications

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***Abstract*— Antenna-in-package is an interested topic that has been the focus of much research in recent years. To face the development of the communication technology and the significant demands of wireless communication systems, the aim of this work is to develop a compact antenna-in-package printed on an FR4 multilayer structure, based on an ordinary patch antenna with a single layer substrate. The different issues encountered during the size optimization, bandwidth-increasing and the overall system design procedure are described herein. The final designed antenna has a very small size of 6x6x6mm^3 on a three layers FR4 substrate with a Cooper thickness of 50µm. Performance parameters like bandwidth and reflexion coefficient have been evaluated and compared with the patch antenna with a single layer substrate. With more advantage, the proposed AiP is suitable to cover also several standards of communication as Wi-Fi (IEEE 802.11b), Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4), WIMAX (IEEE 802.16), ISM band and WLAN (802.11b,g). The new AiP is simulated using the commercial electromagnetic CST Microwave Studio software. Results show a good performance.**

Index Terms*—Microstrip antennas, wireless communication systems, Packaging technology, layers.Microstrip antenna, RF systems.

I. INTRODUCTION

Rapid progress in wireless communication systems lead to a fast evolution in the antenna design to take up the challenges in size and performance. Each type of antenna is good in its own properties and usage. Nowadays, microstrip antennas have been applied in WiMAX and WLAN according to standard of IEEE 802.11 b/g/a/h and IEEE 802.16 d. Microstrip patch antenna consists of a dielectric substrate, with a ground plane on the other side. Due to its advantages such as low weight, low profile planar configuration, low fabrication costs and capability to integrated with microwave integrated circuits technology, the microstrip patch antenna is very well suited for applications such as wireless communications system, cellular phones, pagers, radar systems, and satellite communications Systems . This results in a demand for similar reductions in antenna size. Therefore, it is challenging to design and miniature microstrip antennas to have better radiating properties with a compact size. The antenna on the substrate with high dielectric constants is nearly a factor of $\sqrt{\varepsilon r}$. Smaller than the antennas designed on the air substrate, in which is the dielectric constant of the substrate [1]. However, this technique not only raised the cost of the antenna, but also not applicable to integrated communication systems whose substrate dielectric constant is always small. In the literature concerning the miniaturization of the size of patch antennas, authors use several techniques. Some of them consist on insertion of: shorting posts and pin [2], short circuit [3] and cutting slots in radiating patch [4-5]. The optimization is obtained also by partially filled high permittivity substrate [8], using fractal microstrip patch configuration [6] and increasing the electrical length of the antenna by optimizing the shape [7] and ching periodical slow wave structures on the ground plane [8]. Not that, the maximum percentage of size reduction using these techniques is about 65% [9].

The size of a conventional microstrip antenna is somewhat large when designed at lower microwave frequency spectrum. Size of antenna is the major factor in the new technology of communications systems, particularly for integration in the RF (SiP) Systems in package. RF system in package (SiP) technology has rapidly developed in wireless application. The RF system successfully integrated the balance/unbalance (balun) transformer, the power amplifier (PA), the antenna switch, the filter, and the low noise amplifier (LNA) into a single package. The various communication products must be reduced in physical size and weight in order to facilitate the growth of these markets and satisfy the end users requirement of low cost and multi-function system solutions. Packaging technology is becoming more and more popular for producing complex multilayer modules and antennas because of its flexibility in realizing a variable number of laminated layers. With development of Systems-in-Package with integration technology, size reduction of antennas is becoming an important design consideration for practical applications. As the demands of the integration increase, it is inevitable to integrate the antenna into the same RF package to achieve total RF system in single package. Thus, the antenna in package (AiP) technology becomes a hot topic.

For this reasons, Antennas in package are investigated vastly due to their properties, such as small size, high-speed, highly functional, low profile, low cost, conformability and ease of integration with active devices [11]. In this work, a new compact antenna for 2.4 GHz wireless communication systems is proposed for the packaging technology. The size of the antenna is of (6x6x4.8) mm^3, printed on multilayered structure. The detailed process of the antenna optimization has been based on following techniques. In the first step, the study has been focused on the determination of the geometrical parameters of the conventional patch antenna, and then the optimization process has also been considered to allow the antenna to operate in the WIFI frequency band at 2.4 GHz. In the second step, the main objective has been focused to design a novel antenna-in-package with a reduced size operating in the same frequency band that the conventional patch antenna designed in the first step. The specifications and implementation of this antenna are discussed in detail. The choice of feed line and all components location has been deeply studied. Parametrical study in CST Microwave Studio simulator has been taken into account to optimize the antenna properties. Finally the new compact and the conventional antenna are compared in terms of radiation characteristics. Results demonstrate in addition to being small in size, the novel antenna provides a large operating bandwidth covering the 2.4 GHz band.

II. CONVENTIONAL 2.4 GHZ PATCH ANTENNA

The conventional microstrip antenna designed to operate at *2.4 GHz* is presented in Fig. 1, the dimensional parameters for the radiating element are respectively the width *W=30 mm* and the length *L=38* mm, with the dielectric permittivity $\varepsilon_r = 4$ and thickness of *1.5 mm*. The feed line dimensions are $L_f=15$ *mm* and $W_f=3$ *mm* respectively. The effective permittivity of the microstrip structure ε_{eff} at the required resonant frequency can be designed as follows [10], using the formulas given in.

$$W = \frac{c}{2f_r}\left[\frac{\varepsilon_r+1}{2}\right]^{-\frac{1}{2}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1} \tag{2}$$

$$L_{eff} = L + 2\Delta L = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = 0.412h\left(\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right)\frac{(W/h)+0.264}{(W/h)+0.8} \tag{4}$$

The length of the patch is $L=L_{eff}-2\Delta L$, where c and f_r are respectively the speed of light in vacuum and the resonance frequency. Based on the previous equations, the width and the length of the feed line are done by.

$$L_f = \frac{\lambda_g}{4} = \frac{c}{4f_r\sqrt{\varepsilon_{eff}}} \tag{5}$$

$$W_f = \frac{120\pi h}{Z_0\sqrt{\varepsilon_{eff}}} = \frac{120\pi h}{Z_0 c}\times 2f_r L_f \tag{6}$$

With $Z_0 = 50\ \Omega$ is the impedance of the microstrip line.

After a detailed study of critical parameters on the antenna radiation, in Fig. 2 we can observe clearly that the reflection coefficient is centered perfectly at *2.4 GHz*. We note, that good radiation properties for the antenna under study are obtained, Furthermore, future antenna requirement in modern communication networks must have antenna size reduction to be conformed to the shape of the supporting miniaturized structures. All these vital requirements impose significant challenges on the current technology and illustrate the need for new designs and advanced techniques to optimize the size obtaining good performance of the antennas in term of radiations properties. For this raison the antenna in package (AiP) technology becomes a hot topic.

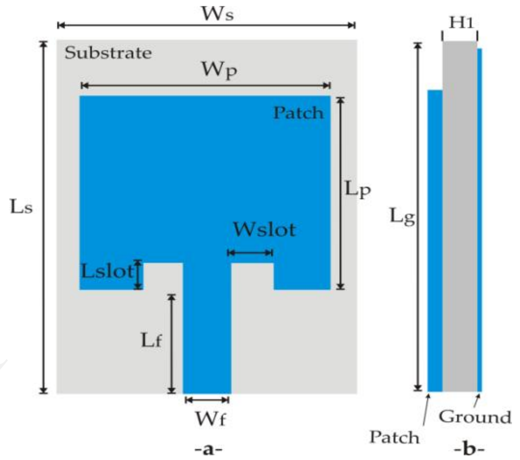

Fig. 1. Geometry of the conventional patch antenna

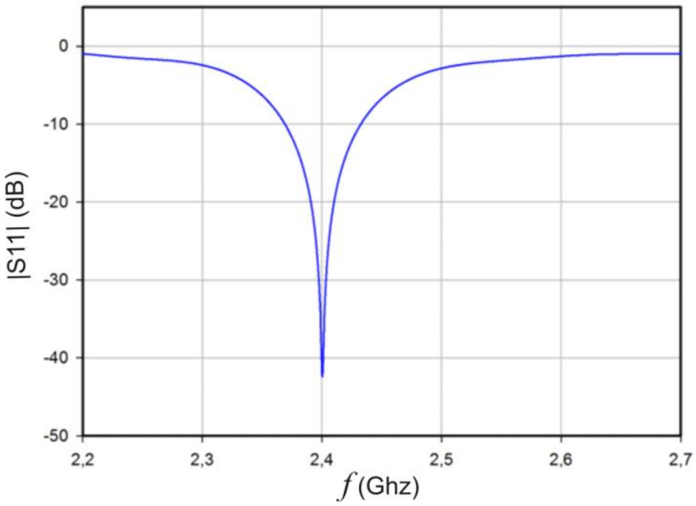

Fig. 2. Return Loss for of the conventional 2.4 GHz patch antenna.

The next section presents a detailed study of the proposed antenna structure for 2.4 GHz standards. The design and specifications will be discussed and optimized.

III. PROPOSED 2.4 GHZ ANTENNA-IN-PACKAGE

A. Antenna in Package

In wireless communication systems, the compact multifunctional package is driven by the advances of the technologies and the great requirement from users. Antenna-in-Package (AiP) Design offers an elegant antenna solution radio frequency system. To suit AiP of highly integrated wireless transceivers, a number of antennas have been developed [11-15] in the past few years.

In Fig. 3 an example of antenna-in-package (AiP) is presented, via holes are used to connect the antenna with the ground. The location of the ground has an influence on the performance of the AiP. Generaly, the AiP is composed by multi-layers substrates and mlti-conductor. In this paper, similar miniaturized AiP will be proposed for the frequency band of *2.4 GHz* applications.

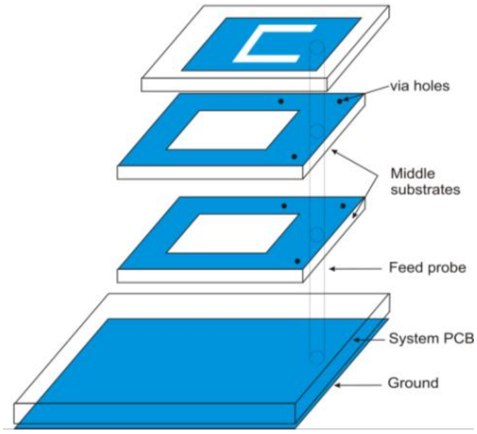

Fig. 3. Geometry of Antenna in Package

B. *Geometry of the Basic Antenna-in-Package of 2.4 GHz*

In the past few years, several authors have been worked on antenna in-package and different structures for highly integrated wireless systems have been developed [11-12], In this way, our objective in this paper is to design a novel very small antenna for *2GHz a*pplications with the same improvement response characteristics as shown in Fig.1, to be adaptable to the new packaging systems. Fig.4 presents an optimized design of the antenna in package proposed in this paper.

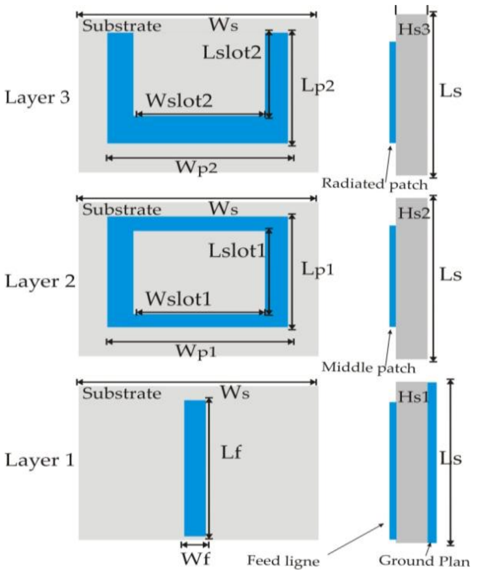

Fig..4. Geometry of the proposed multi-layer antenna

To achieve the new antenna design for the required band, a step by step study of all critical antenna parameters has been taken into account. The proposed antenna-in-package is implemented in *FR4* substrate having a relative permittivity of *4.4* and thickness of *1.5mm*. The ground plane dimensions are $W_g \times L_g = 6\ mm \times 6mm$. The antenna is feeding by a proximity feed line with width of $W_g = 1mm$ and length of $L_f = 5\ mm$. The feed line and the radiating patch are made of copper with a thickness of $H_c = 0.05mm$. The hole antenna dimensions are Ws*xLs= 6mmx6mm*. Note that, the novel proposed AiP is designed for wireless communication systems of *2.4GHz*, including WiFi, Bluetooth, Zigbee, WiMAX, etc. The antenna presented is based in multi-layers techniques on the FR4 substrate. Introducing slots in radiating patch with different geometry allow big performance and important improvement in size dimensions. Fig.4 presents a detailed initial design of 2.4GHz proposed antenna-in-Package.

The rest of parameters of the designed antenna are: L_{s11}=3.6mm,$W_{s11}=3.6mm$,$L_{s12}=3mm$, $W_{s12}=3mm$, $L_{p1}=5mm$, $W_{p1}=5mm$,$L_{p2}=5mm$,$W_{p2}=5mm$ *and* tree layers of antenna having fixed values of *Ws x Ls x Hs = 6mm x 6mm x 1.5mm*. By comparing the structure of Fig.4 with the conventional antenna of Fig.1, we conclude that, 80% reduction in size enhancement is obtained. In the next step, more detailed parametric study will be introduced to optimize more and more the operability of the proposed antenna, in term of bandwidth and Return Loss.

C. *Parameters study of the 2.4 GHz Antenna-in-Package*

After a deep study, the optimized geometry parameters of the antenna are fixed in the following values: $Ws=Ls=Wg=6mm$, $H_{s1}=H_{s2}=H_{s3}=1.5\ mm$, $H_c=0.05mm$, $L_{p1}=W_{p1}=L_{p2}=W_{p2}=5\ mm$. Note that, for all substrate layers the materiel used is FR4.

As can be shown below, a critical study of the antenna parameters can demonstrate clearly, the effect of these geometrical parameters on the desired responses.

1) *Effect of the Ground Plane*

The metallic ground is considered among the parameters that have a big influence on the response of radiation. In Fig. 5. we plot the return loss response for different dimensions of the metallic ground plane. Effectively, we conclude that the dimension of the ground plane have an important effect on the radiation, resonance frequency and bandwidth. The optimized value of this parameter is $L_g=6mm$. The same issues and other parametric study will be discussed in detail in the next subsections.

2) *Effect of the feed line length L_f*

The effect of the feed line length on the Antenna-in-package radiation properties is presented in this section. The width of the feed line is $W_f=1mm$. The return loss of the proposed new antenna-in-package for different values of L_f is presented in Fig.6. We can observe that, L_f parameter affect the bandwidth and the resonance frequency of antenna, the important radiation is presented using the L_f =5.8mm. It is clear that the length of the feed line is responsible for the shifting of the frequency band. Consequently, the antenna under study could be used for several recent technologies operated in 2.4 GHz: Bluetooth and WLAN, scientific and medical (ISM) band (frequency range 2.4–2.5 GHz), unlicensed national information infrastructure (U-NII) band used in WLAN, Bluetooth and Wi-Fi operation.

3) *Effect of the feed line width W_f*

In this section, we present the effect study of feed line dimension on the antenna responses. For this purpose, the value of L_f is *5.8mm* and the results are plotted in Fig .7. As can be shown, the W_f value of *1.2mm* offers a good response with return loss of about -50 dB. Finally, we conclude, that the length and the width of the feed line are critical parameters that that have a big effect on the radiation properties of the antenna. Therefore, they are essential parameters that can be optimized to deal with an efficient the antenna proposed

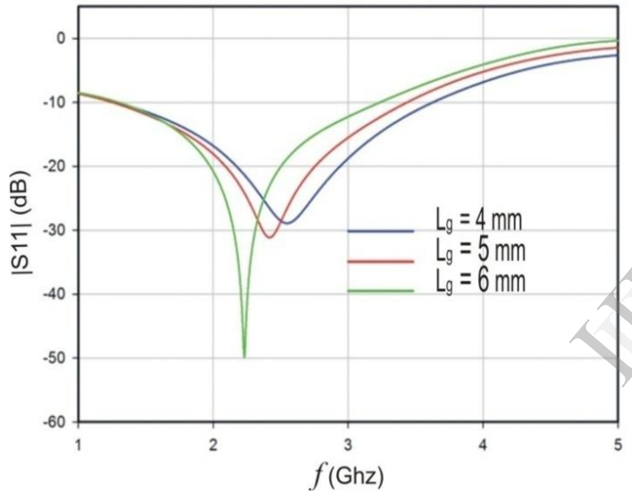

Fig..5. Return loss of the proposed antenna with for different ground plane length Lg

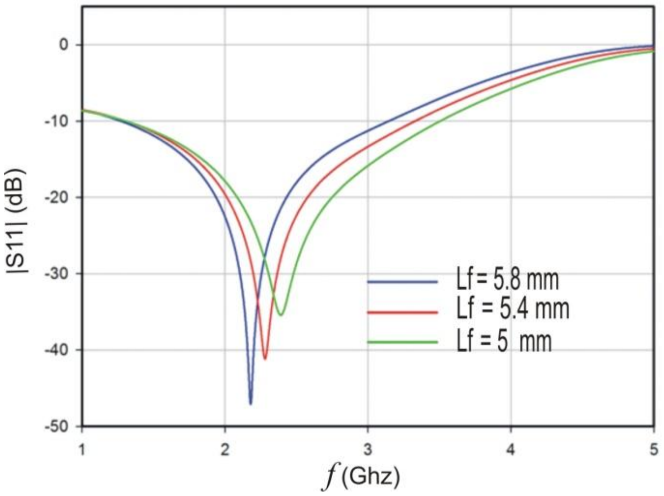

Fig..6. Return loss of the proposed antenna with for several values of feed line length Lf

4) *Effect of the slot in the middle patch*

As mentioned previously, our principal purpose is focused on the development of a new Antenna-in-Package structure with a tree layers dielectric substrate. In this section, we prove that the implementation of an aperture in the middle patch affects the radiated element (Upper patch) presented in Fig.8.

Fig.9. shows the simulated return loss of the proposed antenna-in-package using different values of the diameter of the slot in the middle patch. After a detailed study, we consider that, the localization of the slot in the middle patch is one of the parameters that have a big influence on the antenna responses. Therefore, the radiation of this antenna is highly influenced by the diameter of the slot for the middle patch. We conclude that the dimension of the slot for the middle patch have a big effect on the resonance frequency and radiation properties. Consequently, this parameter is important for optimizing the proposed antenna.

5) *Effect of the radiated patch geometry*

In this section, we will present some modifications for the upper layer of the designed antenna. Particularly, our

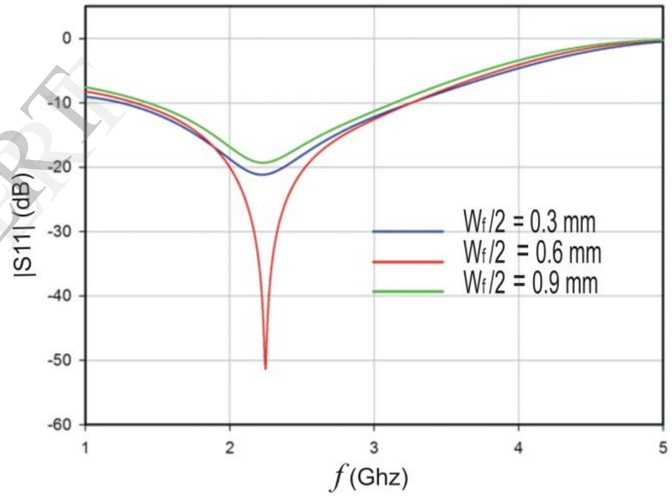

Fig. 7. Return loss of the proposed antenna with for several values of feed line width *Wf*.

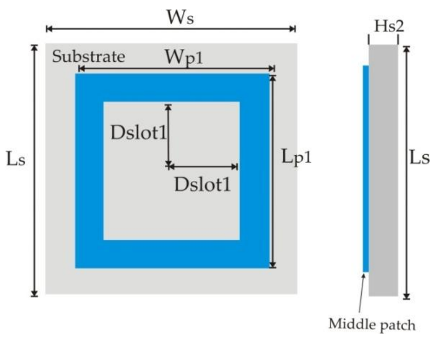

Fig.8. Configuration of the middle layer.

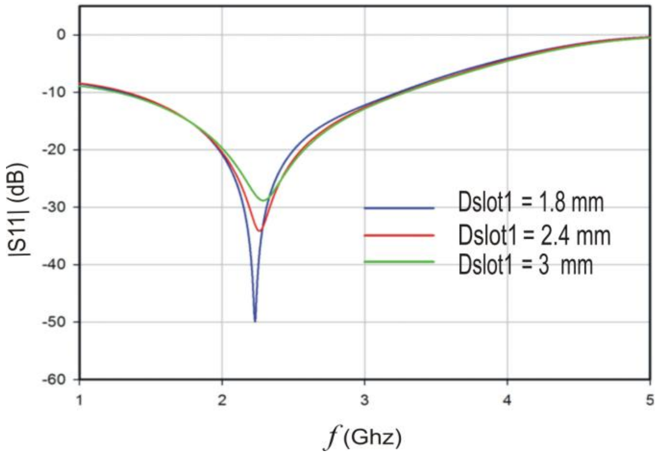

Fig..9. Return loss of the proposed antenna for several values of Dslot1

investigation has been focused on the effect of the radiating element geometry on the behavior of the results. In our case, the radiating element is U-shaped, for a good simulation of the response of our antenna was proposed to study the variation of the open U in X-direction (Wslot1) and the Y-direction (Lslot2).

The value of Wslot1 is fixed on *3mm*; the return loss of the proposed antenna-in-package for different values of Lslot2 is presented in Fig. 11. It can be shown that the length of the slot in radiating element has an important effect on the radiation efficiency, and affect also the bandwidth and the resonance frequency. In the same way, different values of Dslot2 are presented in Fig.12 using Lslot2=*3mm*.

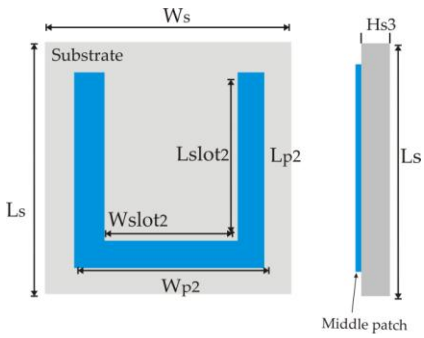

Fig..10. Configuration of the radiating patch

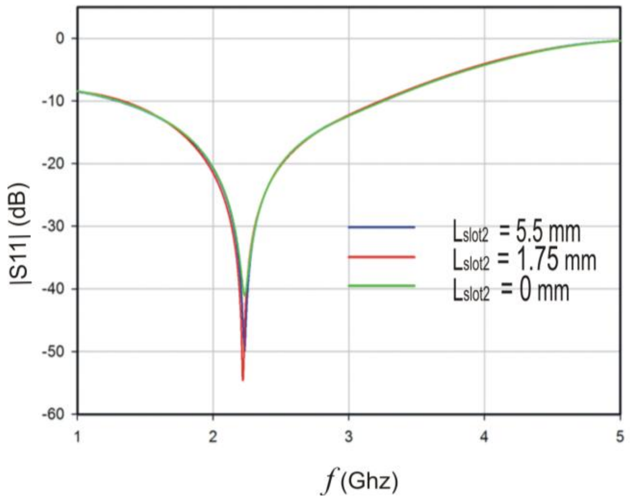

Fig..11. Return loss of the proposed antenna with for different values of Lslot2

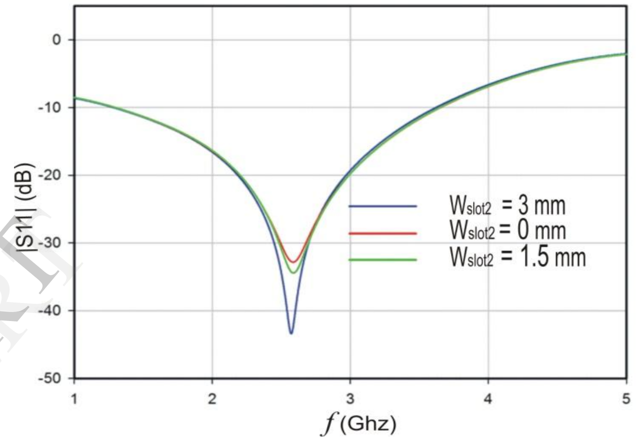

Fig..12. Return loss of the proposed antenna with for several values of Wslot2

IV. OPTIMIZED ESIGN OF THE PROPSED ANTENNA

Table 1 shows the final design parameters of the proposed antenna. They are obtained using the parameters optimization described previously. Fig.13 presents, the return loss of the optimized antenna in package developed in this paper compared to the conventional antenna of Fig. 1. It's clearly observed that a very small size is achieved with better response in term of return loss and bandwidth.

TABLE I. FINAL PARAMETER VALUES OF THE PROPOSED ANTENNA

Parameters	**Values**
Lg	4.7mm
Ws,Ls,Wg	6mm
Hs1,Hs2,Hs3 Hc	1.5mm 0.05mm
Wf	1mm
Lf	5.1mm
Wslot1	3.6mm
Lslot1 Wslot2 Lslot2	3.6mm 3mm 3mm
Wp1,Wp2,Lp1,Lp2	3mm

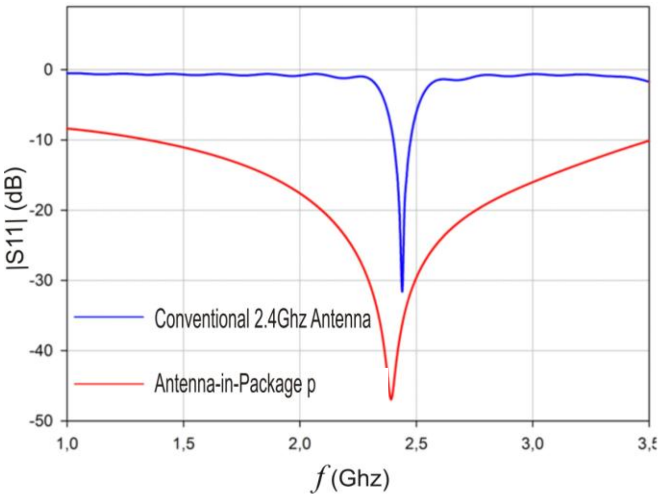

Fig..13. Return loss of the proposed antenna compared to the conventional antenna

V. CONCLUSION

In this paper a very small antenna in package for the 2.4 GHz frequency band technologies is presented. Multi-layer substrate using FR4 and slots are introduced. The effect of critical parameters on the antenna response is detailed in order to achieve the desired antenna responses. In comparison with the classical patch antenna for *2.4GHz*, our resulting antenna offers an improvement of bandwidth with better return loss and decreasing in size of order of 80% compared with the conventional antenna. Based on the configuration of the proposed antenna and it performances in term of return loss bandwidth and miniaturized size, it can be considered as a good candidate for systems in packages.

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